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Direct whole-farm greenhouse gas flux measurements for a beef cattle operation

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ABSTRACT

Landscape-scale measurements of greenhouse gas exchange from whole farms can bracket the magnitude of fluxes, identify sources and sinks, and provide data for model development and validation. Greenhouse gas fluxes were measured for an annual cycle on a 123-ha beef-cattle farm in southwestern Manitoba, Canada. Carbon dioxide and methane fluxes were measured from a central eddy covariance flux tower. These measurements were supplemented by a secondary flux tower, and by static chambers that measured carbon dioxide, methane and nitrous oxide fluxes. The farm had 104 backgrounding steers and an additional 160 cow-calf pairs occupied the farm for part of the period. Cattle occupied a winter bale-grazing field, a confined feeding paddock, a summer pasture, and a cereal-crop swath-grazing field in sequence. Cattle within the flux footprint exhibited large respiration and methane fluxes, and the cattle respiration was separated from the land CO_2 exchange. The largest fluxes of nitrous oxide from cattle excreta (urine, manure) were emitted from the confined feeding paddock and from the location of the winter-feed bales, but only the confined feeding paddock had a net emission of methane from excreta. Despite challenges with cattle movements and scaling in space and time, a greenhouse gas budget was estimated: over the annual cycle, cattle respiration dominated the budget with an emission of 20 t CO_2 equivalent ha^{-1} y^{-1}; CO_2 from the plant/soil system was a net emission of 10 t CO_2 equivalent ha^{-1} y^{-1}; enteric methane was 11 t CO_2 equivalent ha^{-1} y^{-1}; methane from soil/excreta was 0.06 t CO_2 equivalent ha^{-1} y^{-1}; and nitrous oxide from soil/excreta/fertilizer was 4 t CO_2 equivalent ha^{-1} y^{-1}. The farm was a net greenhouse gas source of 46 t CO_2 equivalent ha^{-1} y^{-1} and the plant/soil system was a contributing source in this year, partly because of respiration of imported feed.

1. Introduction

In Canada, agriculture contributes about 8% of anthropogenic greenhouse gas emissions (Environment Canada, 2015). Methane (CH_4) from cattle production and nitrous oxide (N_2O) from cropping systems are the largest agricultural contributors. Carbon dioxide (CO_2) exchange is also important but the source/sink dynamics on any land area are complex and this is often not included in national greenhouse gas emission inventories unless there has been a change in land management. Agriculture includes a wide range of enterprises, such as dedicated cropping systems (annual, perennial), dedicated animal systems (e.g. cattle, swine, poultry), and a mixture of these. However, some of these enterprises have very specific processes for greenhouse gas exchange. For example, application of nitrogen fertilizers to crops generates N_2O, cattle emit enteric CH_4, and the plant/soil system has an annual cycle of CO_2 exchange in temperate climates.

The beef-cattle production system incorporates many diverse components of greenhouse gas dynamics. Beauchemin et al. (2010) estimated that in Canadian beef production, 63% of emissions (as CO_2 equivalents) were from enteric methane, 28% were from manure (mostly as N_2O) and 4% were N_2O from cropping systems for feed. These were based on a whole-farm model, which helps to understand the relative components and dynamics of greenhouse gases on complex production systems (e.g., White et al., 2010; Rotz et al., 2011; Foley et al., 2011). Models have advantages to integrate and test hypotheses more easily than setting up specific field experiments. However, direct measurements at different scales help to develop parameters for models and provide data sets for validation and continued model improvement. Several studies have directly measured greenhouse gas fluxes from parts of farms. Often these have measured a single gas, such as methane from individual animals (e.g., Boadi et al., 2002; Beauchemin and McGinn 2005), roaming cattle herds (McGinn et al., 2015), or from

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confined areas with a high cattle density (e.g., Laubach et al., 2008; McGinn et al., 2009). Similarly, whole-field N_2O emissions (e.g., Wagner-Riddle et al., 2007; Maas et al., 2013) and CO_2 exchange (e.g., Hollinger et al., 2005; Taylor et al., 2013), or all three gases (Bavin et al., 2009; Merbold et al., 2014) have been measured from feed crops.

Micrometeorological techniques, such as eddy covariance or backwards trajectory calculations, are used at scales from meters to kilometers, whereas chambers measure at the sub-meter scale. However, there are challenges using these methods to measure at the whole-farm scale. Most farms have tremendous spatial variability with operations taking place in specific parts of the landscape. Recently Felber et al. (2015) measured CH_4 fluxes from dairy cattle using eddy covariance and described many of the challenges associated with moving point sources on a farm. They further separated net ecosystem exchange of CO_2 into cattle-generated and land-controlled components (Felber et al., 2016a,b), but their system was relatively well constrained in size and animal movements, unlike many large-scale beef cattle operations. Aside from their recent study and measurements over a confined feedlot (Prajapati and Santos, 2017), there have been very few attempts to integrate measurements of multiple greenhouse gas fluxes for a whole farm.

Our main objective was to measure the annual cycle of greenhouse gas fluxes (CO_2, CH_4, and N_2O) over a whole farm. Further, we selected a farm operation that raised beef cattle so that we could test our ability to incorporate animal and crop dynamics within a single operation. With this choice, we aimed to determine if the CO_2 flux for the land (soil and plants) system could potentially offset the emissions of CH_4 from cattle and N_2O from soil. As such, we measured individual components at the flux-tower scale (100s m): CO_2 flux that included cattle and land, and CH_4 flux that included enteric emissions from cattle as the main component but also included manure and soil exchange. These flux tower data were supported by chamber measurements to help identify landscape features and practices that controlled the exchange of CO_2, CH_4, and N_2O from soil including animal bedding and excreta (urine, manure).

2. Methods

2.1. Site description and experimental design

The measurements were conducted on a research farm operated by Agriculture and Agri-Food Canada (Johnson Farm) at Brandon, MB, Canada (49.87528° N, 99.90611°W, 396 m.a.s.l.) on Class 3, low water-holding capacity agricultural land (Manitoba Soils Survey, 1974). It is located within the Aspen Parkland ecoregion and the Stockton District, characterized by undulating glaciolacustrine sand and hummocky landforms with short slopes of gradients of 6–15% (Smith et al., 1998). The soil is a Black Chernozem (Udic Boroll), Marringhurst coarse sandy loam soil on coarse sand and gravelly outwash along the Assiniboine River, and is well- to excessively-drained due to the high porosity of its parent material (Ehrlich et al., 1956). Our site had little overall slope but had land undulations of the order of 2 m. Brandon, MB, has a mean annual temperature of 1.9 °C and mean annual precipitation of 472 mm, of which 24% is snowfall (Environment Canada, 2014).

The farm has been used for agricultural and livestock research for more than a decade (e.g., Kopp et al., 2004; Legesse et al., 2012). Our study ran from October 2012 to October 2013, encompassing an annual cycle in feed crop and beef cattle production at this location. As in many farms, management practices can be quite complex. During this timeframe, 104 yearling steers were

Table 1
Livestock and crop management practices. The fields are identified in Fig. 1.

Date	Field	Event	Value
Apr 30, 2012	NE	Pre-seed herbicide spray (Round-Up^{TM})	Recommended rate
May 10–14, 2012	NE	Barley (vs. AC Desperado) seeded with Conserva Pak seeder (19 cm row spacing, 2.5 cm depth)	150 kg ha^{-1}
May 10–14, 2012	NE	Oats (Souris) seeded with Conserva Pak seeder	140 kg ha^{-1}
May 26, 2012	NE	Liquid fertilizer applied (28-0-0)	56 kg N ha^{-1}
Jun 15–19, 2012	NE	In-crop herbicide (Refine SG & Agril)	Recommended rate
July 3, 2012	NE	Early barley paddocks swathed	10 cm height
July 5, 2012	NE	Early oats swathed	10 cm height
July 20, 2012	NE	Late barley & oats swathed	10 cm height
Oct 4, 2012		Steers weighed	104 yearling steers (mean B.W. 225 kg)
Oct 15, 2012		Main, central micrometeorological tower installation completed	8 m high
Nov 13, 2012	SW	Bales set up in field	279 bales total
Nov 16, 2012	SW	Steers moved from corral to bale-grazing	104 yearling steers
Feb 22, 2013	NE	First bale field feed consumed, bales added to second pasture	50 bales
Mar 21, 2013	Corral	Bale grazing snowed in, steers confined to water corral	
May 3, 2013	SW	Static-vented chambers installed in field	64 circular chambers
May 8, 2013		Pre-pasture grazing weight	104 yearling steers (mean B.W. 317 kg)
May 13–15, 2013	NE	Barley (vs. AC Desperado) seeded with John Deere 750 seed driller (19 cm row spacing, 2.5 cm depth)	150 kg ha^{-1}
May 13–15, 2013	NE	Oats (vs. Souris) seeded with John Deere 750 seed driller	140 kg ha^{-1}
May 13–15, 2013	NE	Fertilizer application, mid-row banded (46-0-0)	56 kg N ha^{-1}
May 17, 2013	NE	Static-vented chambers installed in field	21 rect. chambers
June 3, 2013		Secondary micrometeorological tower installed on east side of farm	3 m high
June 7, 2013	SE	Steers moved from water corral to pasture	104 yearling steers (mean B.W. 342 kg)
June 7, 2013	Corral	One-time sampling with static-vented chambers	33 circular chambers
June 12, 2013	NE	In-crop herbicide (Refine SG & Agril)	Recommended rate
June 26, 2013	NW	Cow-calf pairs access to water & secondary pasture	160 cow-calf pairs
July 4, 2013	NE	Early barley & early oats swathed	10 cm height
July 24, 2013	NE	Late barley & late oats swathed.	10 cm height
July 31, 2013		Calves weaned from heifers	160 calves (mean B.W. 201 kg)
Aug 12, 2013	NE	Chambers removed from the field	
Aug 13, 2013	NE	Weaned calves moved to swath grazing	10 calves/paddock (mean B.W. 194 kg)
Aug 19, 2013	NW	Heifers removed from the site	160 heifers
Aug 26, 2013	SW	Chambers removed from the pasture	
Sept 9, 2013	SE	All steers moved off site	104 yearling steers (mean B.W. 409 kg)
Oct 10, 2013	NE	Calves moved off site	160 calves (mean B.W. 209 kg)