Herd-scale enteric methane emission from cattle measured using eddy covariance and the CH_4:CO_2 ratio method

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Introduction

Methane is a powerful greenhouse gas that is naturally produced during the digestive process of ruminants (Hill et al., 2016). Most of this enteric methane is emitted by cattle grazing on pasture, but measurement of mobile point sources of CH_4 is challenging. Felber et al. (2015) used eddy covariance coupled with two-dimensional footprint analysis to measure CH_4 emissions from a grazing dairy herd. Ratio methods using SF_6 as a tracer gas are well established (Grainger et al., 2007; Hill et al., 2016). Less common is the use of CO_2 as a tracer, where the method is typically applied to individual animals (Madsen et al., 2010; Haque et al. 2014, 2017). The ratio method has not been scaled up to measure CH_4 emissions from a grazing cattle herd.

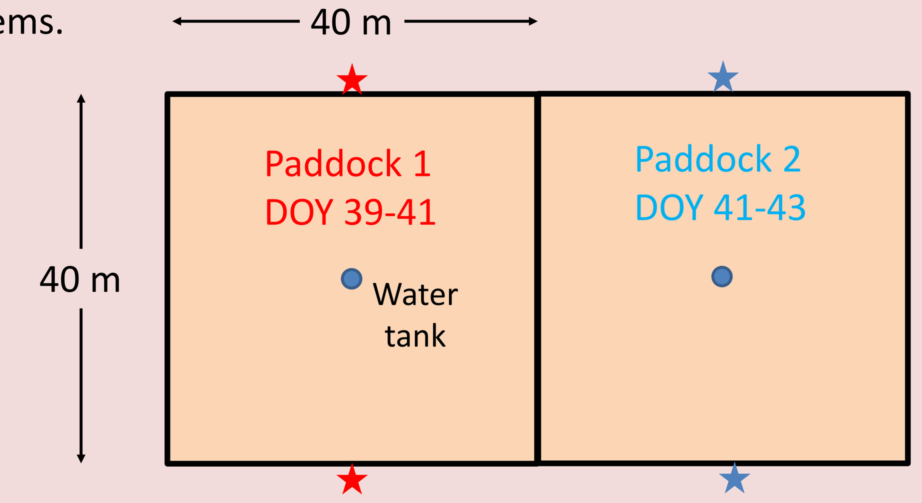
Where Madsen et al. (2010) used the ratio of concentrations of CH_4 and CO_2, we modified the method to use the ratio of *mass fluxes* of the gases, measured using eddy covariance (EC). The method is based on the idea that the ratio of measured enteric CH_4 to measured respired CO_2 equals the ratio of the actual enteric emission to the actual respired CO_2. We applied the method to a small herd of cows grazing on dormant tallgrass prairie in 40-m x 40-m paddocks. **Our objectives were 1) to test the feasibility of the ratio method using eddy covariance fluxes of CH_4 and CO_2, and 2) to calculate the herd-scale daily enteric CH_4 emissions.**

Materials and Methods

Experimental Description

- Conducted during winter 2017, Day of Year (DOY) 39-43
- Dormant tallgrass prairie pasture, central Oklahoma
- Twelve cows, mean 575 kg body weight (BW), sequentially grazed two 40-m by 40-m paddocks
- Cattle offered 1.36 kg d^{-1} cow^{-1} 37% soybean meal protein supplement
- Individual cow locations tracked every 5 minutes using GPS locators

Figure 1. Experimental layout. Stars indicate positions of EC systems. Cattle were moved from Paddock 1 to Paddock 2 on DOY 41 between 0730 and 1000 h.



Ratio Method

$$\frac{Enteric\ CH_4}{Respired\ CO_2} = \frac{EC\ Measured\ CH_4}{EC\ Measured\ CO_2} \Longrightarrow Enteric\ CH4 = \frac{EC\ Measured\ CH_4}{EC\ Measured\ CO_2}\ Respired\ CO_2$$

- Respired CO2 was assumed constant at 7 kg d^{-1} cow^{-1}
- Upwind fluxes subtracted from downwind fluxes to remove pasture soil as source or sink of CH_4 or CO_2

CO_2 and CH_4 Fluxes

- Two eddy covariance systems located upwind and downwind of a paddock; each included:
  - CO_2: closed path infrared gas analyzer (Licor LI7200)
  - CH_4: open path laser (Licor LI7700)
  - Turbulence: 3-axis sonic anemometer (Gill Windmaster Pro)
- Fluxes calculated on 15-min time steps using EddyPro v.6.0.0

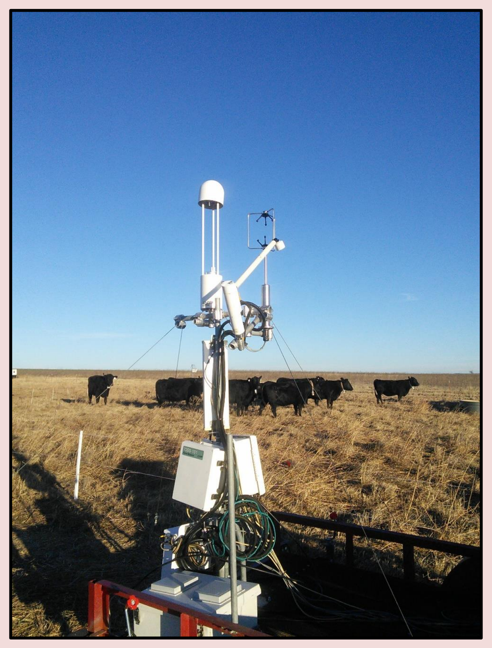


Figure 2. Instrumentation and cattle.

a. Cows with GPS collars. b. EC system mounted on solar trailer. c. Cows grazing closer to EC system. d. Cows grazing farther from EC system. e. Resting period during daytime.

Results and Discussion

Figure 3
Upwind/Downwind Fluxes

When a tower was upwind of a paddock, CH_4 fluxes were near zero, indicating that soil was a very weak source/sink for methane; upwind CO_2 fluxes were small and represented fluxes into and out of upwind soils. The source of downwind fluxes were enteric CH_4 and respiratory CO_2 from cattle. The magnitude of fluxes depended on the location of cattle, wind direction and tower location, with greater fluxes measured when cattle were more directly upwind of a tower.

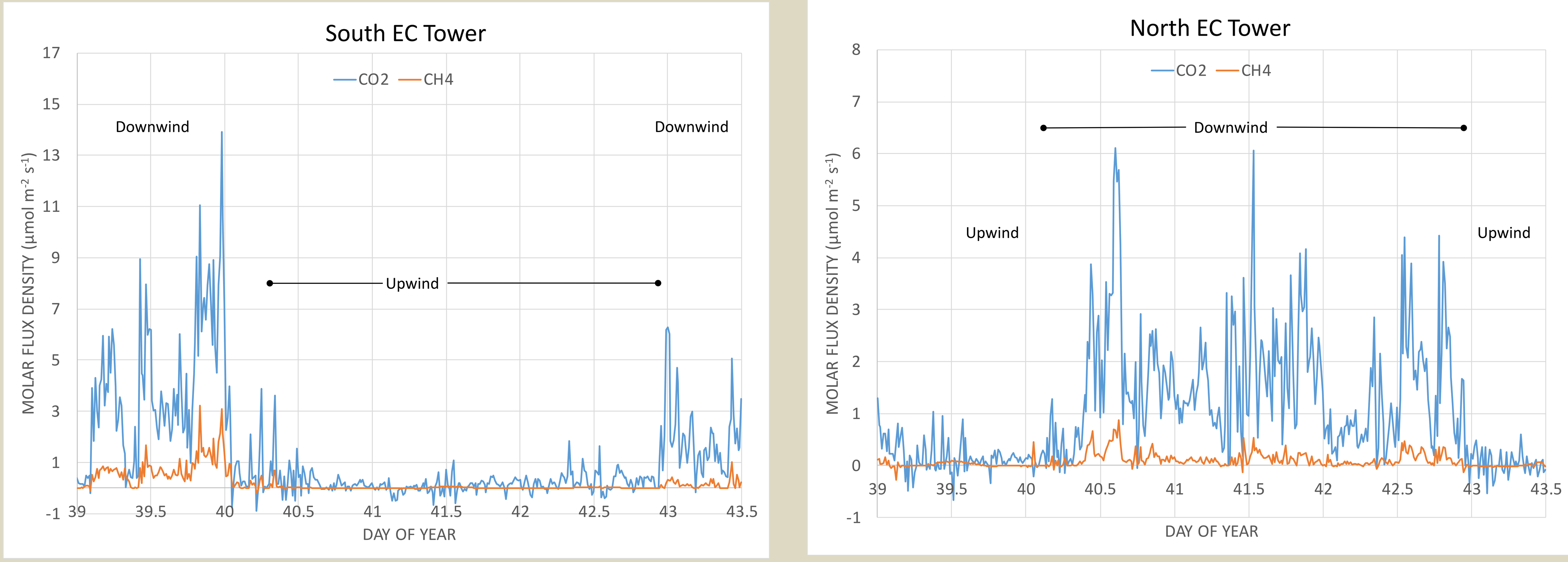


Figure 4
CH_4:CO_2 Ratio

Cattle behavior followed a predictable pattern. A midnight grazing bout began an hour either side of midnight and lasted from 2 to 5 hours. Late morning grazing began between 0800 and 0900 and lasted from 4.5 to 6.5 hours. Late afternoon grazing began about 1800 h and lasted for 3-4 hours. Enteric CH_4 emissions were expected to vary during the day in response to feeding bouts, but the diel variability we observed was confounded with the use of a constant value for respired CO_2.

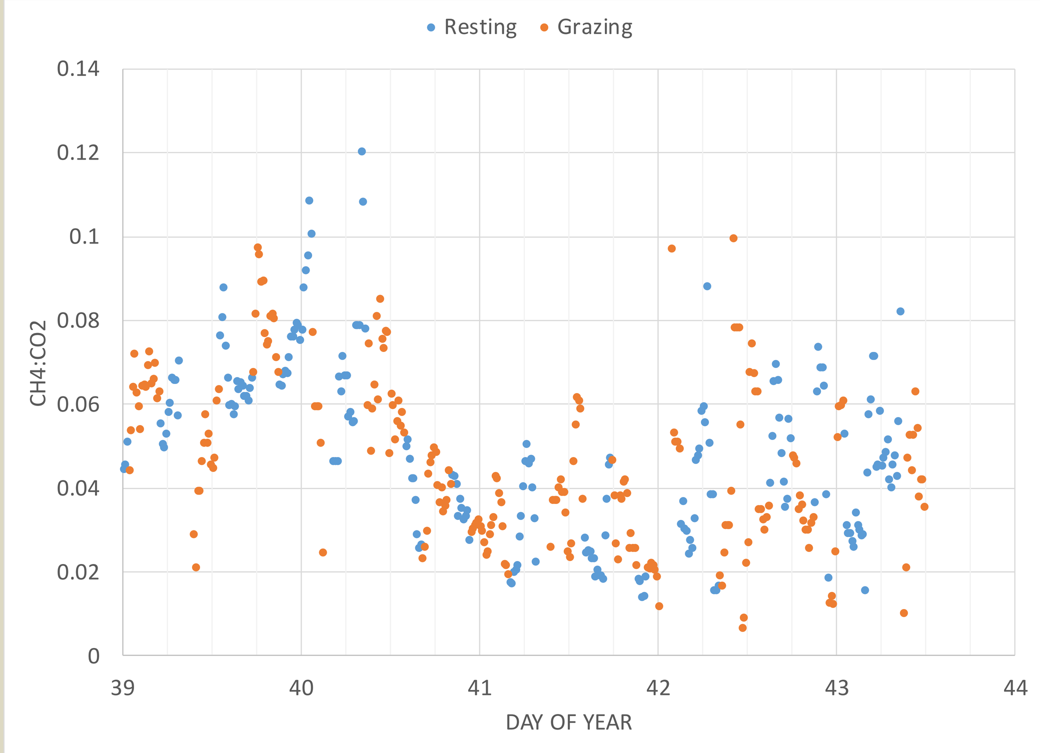


Table 1
Summary Emissions

Data gaps usually occurred when wind direction was unuseable (easterly, westerly or highly variable) or when CH_4 flux was very small. The mean daily mass **ratio of enteric CH_4 to respired CO_2** varied from 0.031 to 0.065 and averaged **0.048**. Pesta et al. (2016) reported that ratios of cattle on finishing diets ranged from 0.04 to 0.05. Lassen et al. (2016) showed differences in dairy cow breed, with Jersey cow ratios averaging 0.05 and Holstein cow ratios averaging 0.065.

DOY	Data coverage	CH_4:CO_2 Mass flux ratio	Enteric CH_4
	%		kg d^{-1} cow^{-1}
39	83	0.065	0.45
40	70	0.053	0.37
41	84	0.031	0.22
42	70	0.043	0.30
43	41	0.043	0.33
Composite mean		**0.048**	**0.34**

Assuming a respired CO_2 emission rate of 7 kg d^{-1} cow^{-1} yielded **daily enteric CH_4 emissions** that ranged from 0.22 to 0.45 kg d^{-1} cow^{-1} and averaged **0.34 kg d^{-1} cow^{-1}**. An IPCC Tier 2 estimate (based on dry matter intake = 2.5% of BW, forage gross energy = 18 MJ kg^{-1} and Y_m = 7.5%) was **0.35 kg d^{-1} cow^{-1}**. Emission during early summer grazing in the same pasture in 2014 averaged **0.32 kg d^{-1} cow^{-1}** (Todd et al., 2016).

Conclusions

- The ratio method, at this scale of grazing, was able to provide reasonable herd-integrated enteric CH_4 emission rates.
- Respired CO_2 values with a finer time step would improve estimates and better resolve diel variability.
- The method is especially suited when vegetation is dormant and background fluxes are small.
- GPS-located cattle positions are not needed, but could provide additional detail to explain observed fluxes.

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