Agricultural and Forest Meteorology 213 (2015) 102–113

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Methane and carbon dioxide emissions from manure storage facilities at two free-stall dairies

Richard H. Grant*, Matthew T. Boehm, Bill W. Bogan

Purdue University, West Lafayette, IN, USA

ARTICLE INFO

Article history:
Received 19 September 2014
Received in revised form 11 June 2015
Accepted 12 June 2015
Available online 9 July 2015

Keywords:
Carbon dioxide
Methane
Dairy
Waste
Emissions
Inverse Lagrangian

ABSTRACT

Manure management by dairies is estimated to account for 6% of the greenhouse gas warming potential of all agricultural emissions in the USA. Emissions methane (CH_4) and carbon dioxide (CO_2) were measured from manure storage facilities at two Midwestern dairies (an Indiana lagoon and two Wisconsin basins). The CH_4 concentrations were measured using photoacoustic infrared absorption spectroscopy and flame ionization gas chromatography. The CO_2 concentrations were measured using photoacoustic infrared absorption spectroscopy and non-dispersive infrared spectroscopy. Emissions were estimated using a backward Lagrangian Stochastic model with on-site turbulence measurements.

The WI basins emitted more CH_4 and CO_2 than the waste lagoon in IN on an animal basis. Peak emissions were episodic. Mean daily CH_4 emissions during the fall (October) from the WI basins and IN lagoon were 295 g hd^{-1} d^{-1} (374 g AU^{-1} d^{-1}) and 47 g hd^{-1} d^{-1} (59 g AU^{-1} d^{-1}), respectively. Mean CO_2 emissions during the fall were 575 g hd^{-1} d^{-1} (374 g AU^{-1} d^{-1}) from the WI basins (October) and 107 g hd^{-1} d^{-1} (135 g AU^{-1} d^{-1}) from the IN lagoon (September). Emissions were not resolvable (approximately emissions MDL) when the storage area surface was frozen. Methane emissions contributed eight–ten times the radiative warming potential of CO_2 (animal basis) at both dairies. Mean daily CO_2-equivalent emissions from the WI basins (IN lagoon) ranged from highs of 7.9 kg CO_2-e hd^{-1} d^{-1} in October (2.6 kg CO_2-e hd^{-1} d^{-1} in September) to lows of 1.6 kg CO_2-e hd^{-1} d^{-1} (0.4 kg CO_2-e hd^{-1} d^{-1}) in December through January. Air temperature was correlated with CH_4 and CO_2 emissions at the WI basin but not the IN lagoon. Wind speed was weakly correlated with CH_4 emissions (but not CO_2 emissions) at both dairies. While weather conditions were similar, the separation of solids prior to storage contributed to lower CH_4 and CO_2 emissions and lower greenhouse warming potential per animal. Cooler climatic conditions decreased CH_4 and CO_2 emissions as well as decreasing the mass ratio of CH_4–CO_2 emissions.

1. Introduction

Agriculture contributes approximately 8% of the greenhouse gas (GHG) warming potential of emissions in the United State of America (USA) while the management of manure accounts for 13% of that warming potential (EPA, 2014). Methane (CH_4) and nitrous oxide (N_2O) are the reported GHG for the agricultural sector. Carbon dioxide (CO_2) is a small component of agricultural greenhouse gas emissions that does not contribute to the greenhouse gas potential for the sector since the carbon in the animal feed was originally fixed by photosynthesis from the atmosphere. Although dairies contribute almost 47% of the manure management equivalent CO_2 emissions of agricultural sources in the USA (EPA, 2014), there are only a few studies to support these emission estimates.

Methane is biologically produced during anaerobic decomposition of organic matter (Casey et al., 2006). Since these solids are largely in the bottom of the lagoon or basin, most of the CH_4 is produced at the bottom of the storage facility. The optimum temperature range for methanogenic archaea is around 35–45 °C (similar to the core temperature of a cow), with a decrease in CH_4 production of approximately an order of magnitude as the temperature decreases to 15 °C (Zeikus and Winfrey, 1976). Since methane has a low solubility in water (NIST, 2012), as the production of CH_4 increases, the CH_4 produced exceeds the capacity to be dissolved in water and forms bubbles attached to the solid surfaces where the production occurs. Consequently, this results in the concentration of CH_4 in the bubbles to be much higher than that of the liquid (Ni et al., 2009). As the bubbles rise through the lagoon or basin, they either 'boil' at the open liquid surface or burst at

* Corresponding author. Fax: +1 765 496 2926.
E-mail address: rgrant@purdue.edu (R.H. Grant).

http://dx.doi.org/10.1016/j.agrformet.2015.06.008
0168-1923/

the bottom of the crust layer enhancing the gas concentration in the crust. Reported CH_4 emissions from waste storage facilities vary widely. Emissions from the wastewater pond of one Idaho open-lot dairy during 13 days of measurements across six months ranged from 152 g d^{-1} hd^{-1} (hd = head) to 1774 g d^{-1} hd^{-1} with the highest emissions not corresponding to the warmest conditions (Leytem et al., 2010). In a second study, wastewater pond CH_4 emissions from another Idaho open-lot dairy over five days across four months ranged from 15 g d^{-1} hd^{-1} to 41 g d^{-1} hd^{-1} with the highest emissions corresponding to the warmest conditions (Bjorneberg et al., 2009). Emissions from a batch-filled shallow waste storage tank in an Ontario dairy ranged from 9 g d^{-1} hd^{-1} to 41 g d^{-1} hd^{-1} from half-hourly measurements from January through mid-July (VanderZaag et al., 2011). A deep, long term storage tank in Ontario had a mean CH_4 emission based on daily sampling near noon from mid-June to mid-November of 833 g d^{-1} hd^{-1} (Kaharabata et al., 1998).

Carbon dioxide (CO_2) is biologically produced in the aerobic zone of the lagoon and in the crust overlying the lagoon or basin through the oxidation of the available carbon stock of the manure, including CH_4 rising from the anaerobic regions of the lagoon or basin. It is also produced anaerobically in the waste through acetoclastic methanogenesis by archaea (Demirel and Scherer, 2008). Bacterial carbon oxidation is temperature sensitive (Novak, 1974). The high solubility of CO_2 in water (NIST, 2015) suggests that CO_2 emissions can be described as a diffusion process across the air:liquid interface described by a two-film equilibrium (Denmead and Freney, 1992). Concentration of CO_2 within the pore spaces of a crust might be expected to be greater than the dissolved concentration at the surface as the turbulent mass transfer will be greater for the liquid surface than from within the crusted surface. Carbon dioxide emissions from the wastewater pond of one Idaho open-lot dairy over 13 days over six months ranged from 2224 g d^{-1} hd^{-1} to 6575 g d^{-1} hd^{-1} with no trend of emissions relative to air temperature (Leytem et al., 2010).

The management systems used by dairies are quite diverse within the USA. Understanding the temporal variability in emissions of both CH_4 and CO_2 under differing management systems, and the processes controlling these emissions, are needed to properly inventory the emissions from farms using differing manure management practices. Here, we look at the emissions associated with two different manure management practices within the Midwestern USA: long term storage with prior solids separation in a lagoon in Indiana (IN) that is maintained to facilitate anaerobic decomposition and shorter term storage in a series of holding basins with limited solids separation in Wisconsin (WI) in which there is little effort at maintaining anaerobic processes.

2. Methods

Gaseous emissions of CH_4 and CO_2 were measured around an anaerobic waste lagoon at an IN free stall dairy and around two waste basins at a WI free stall dairy.

2.1. Farm description

The WI free stall dairy consisted of five barns for lactating cows, a special needs barn, a feed storage area, and a milking parlor (Fig. 1; Grant and Boehm, 2010a). The three measured manure storage basins received wastewater from the flush of two barns, the holding area, and the milking parlor. Waste from the two barns was transferred into a solids separator and then pumped into the northernmost of the three basins. The solids separator often failed during the study. Waste from the milking parlor was transferred directly into the middle basin without solids separation. The third (southernmost) basin filled when the other two basins exceeded capacity and rarely had any manure in it. Emissions from this third basin were not measured. At maximum capacity, the liquid depth was 3 m, with a combined volume of 23,400 m^3 and surface area of 9986 m^2 for all 3 basins. The measured basins had a volume of 16,980 m^3 and a surface area of 7091 m^2. Liquid manure was removed from the basins approximately every 12 weeks with the solids removed twice a year. Since there were additional lactating cows moving through the milking parlor than just those from the two barns flushing into the basins, a time-weighted population was determined for the loading of the basins. The facility had an average population of 1509 lactating cows and an effective population loading the basins of 559 lactating cows. Given the average mass of cow, the equivalent animal units (1 AU = 500 kg) was 440 AU.

Fig. 1. Configuration of the WI dairy. Manure in the measured basins (1 and 2) came from barns 1 and 2 and the parlor and holding area illustrated in a *GoogleEarth*® image. Solids are separated at the separator and liquids pumped to inlet on the east side of the 1st basin.

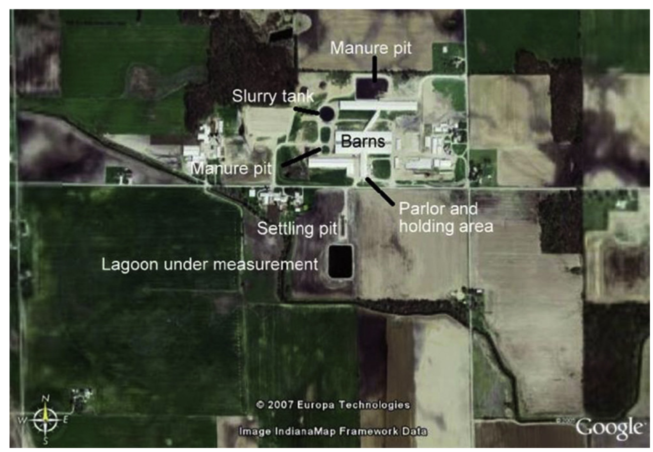

Fig. 2. Configuration of the IN dairy. Locations of non-barn manure emission sources are indicated in a *GoogleEarth*® image. Manure in the measured lagoon comes from the parlor and holding area only. Solids are deposited from the parlor and holding area in the settling pit. Liquids are gravity fed to inlets on the north side of the lagoon.

The IN free stall dairy consisted of three barns for lactating cows, a feed storage area, a special needs barn, and a milking parlor (Fig. 2; Grant and Boehm, 2010b). The measured anaerobic lagoon received wastewater (flush) from the holding area and milking parlor. All waste was first transferred into a rectangular solids settling pit north of the lagoon, with a weir limiting the solids transferred into the lagoon. Liquid was removed from the lagoon every seven to