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Methane emissions from dairy lagoons in the western United States

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ABSTRACT

Methane generation from dairy liquid storage systems is a major source of agricultural greenhouse gas emissions. However, little on-farm research has been conducted to estimate and determine the factors that may affect these emissions. Six lagoons in south-central Idaho were monitored for 1 yr, with CH_4 emissions estimated by inverse dispersion modeling. Lagoon characteristics thought to contribute to CH_4 emissions were also monitored over this time period. Average emissions from the lagoons ranged from 30 to 126 kg/ha per day or 22 to 517 kg/d. Whereas we found a general trend for greater emissions during the summer, when temperatures were greater, events such as pumping, rainfall, freeze or thaw of lagoon surfaces, and wind significantly increased CH_4 emissions irrespective of temperature. Lagoon physicochemical characteristics, such as total solids, chemical oxygen demand, and volatile solids, were highly correlated with emission. Methane prediction models were developed using volatile solids, wind speed, air temperature, and pH as independent variables. The US Environmental Protection Agency methodology for estimating CH_4 emissions from manure storage was used for comparison of on-farm CH_4 emissions from 1 of the lagoon systems. The US Environmental Protection Agency method underestimated CH_4 emissions by 48%. An alternative methodology, using volatile solids degradation factor, provided a more accurate estimate of annual emissions from the lagoon system and may hold promise for applicability across a range of dairy lagoon systems in the United States.
Key words: emission, methane, manure, inverse dispersion

INTRODUCTION

The latest US Environmental Protection Agency (**USEPA**) greenhouse gas (**GHG**) inventory (USEPA, 2016b) estimates that agriculture accounts for 9% of total GHG emissions in the United States. The percentage of agricultural GHG emissions from enteric CH_4 production and manure management are 28.6 and 13.7%, respectively. The majority of enteric CH_4 produced is estimated to be from beef cattle (71%), whereas dairy cattle contributed 26%; however, CH_4 production from dairy manure management is estimated to be the largest fraction of CH_4 produced from manure at 53%, followed by swine at 37%. The majority of these manure emissions are generated from the storage of liquid manures in anaerobic lagoons.

A large body of work exists related to estimation of enteric CH_4 production by cattle and potential mitigation strategies (e.g., Kebreab et al., 2008; Sejian et al., 2011; Powers et al., 2014); however, CH_4 production from manure storage is not well studied and there may be large discrepancies between inventory estimates and actual on-farm emissions. Some research indicates that the USEPA and Intergovernmental Panel on Climate Change methodologies may be underestimating CH_4 contributions from liquid dairy manure storage by up to 130% (Lory et al., 2010; Baldé et al., 2016). One of the reasons for these large discrepancies is that the emission factors developed for inventory purposes were based on limited data that may not represent the variety of manure storage conditions found on US dairies (Bryant et al., 1976; Morris 1976; Mangino et al., 2001).

Approximately 17 on-farm studies (21 lagoons) have been published related to CH_4 production from dairy liquid manure storage (Table 1). Only 8 of these studies were conducted on dairies located in the United States, and another 4 were on Canadian dairies, which could represent both weather characteristics and management practices in certain regions of US dairy production. Approximately half of the studies have provided an annual average CH_4 emission factor, whereas the remaining studies only looked at emissions during shorter intervals. The emission rates reported in the literature vary widely, with a range of 12 to 2,030 kg of CH_4/ha per day and 4.7 to 1,028 g/head per day. This range in values indicates the diversity of the different manure-management systems that can be found in dairy

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production and originates from factors such as fraction of manure stored as a liquid, effects of enhanced solid separation, length of storage, temperature, agitation, and crust formation. In addition, the influence of cattle diets, the addition of materials such as spilled feed, milk, and cleaning agents that are washed into storage areas, and the amount of inoculum remaining in storage may have an effect.

The goal of the current study was to add to the body of knowledge related to CH_4 emissions from storage of liquid manure on dairy production facilities in the western United States. In particular, we aimed to study seasonal trends in emissions, relate emissions measured on the farm with lagoon liquid characteristics, and compare these emissions with estimates derived with current inventory methodology.

MATERIALS AND METHODS

Farm Descriptions

During September 2010 to November 2015, 6 dairy lagoons were selected for monitoring of CH_4 emissions (Table 2). These farms were selected to represent manure-handling techniques typically found on a western US dairy and based on farm layout and the ability to separate the lagoon emissions from the rest of the farm. They were also situated in areas where no other upwind CH_4 sources could contribute to measured CH_4 concentrations. This enabled us to select lagoons that would not have any interference from internal or external CH_4 sources. In addition, farms were selected to represent a variety of sizes, ranging from less than 1,000 cows to greater than 5,000 cows. Five of the dairies were dry lot dairies where cows were housed in pens and the majority of manure was stored as a solid. In these systems, manure from the milking parlor and holding areas flowed into a lagoon system, which typically consisted of 1 or more settling basins to separate out some of the solids followed by a larger lagoon. These lagoons were typically pumped out in the spring and fall onto the surrounding cropland; however, the sludge remaining in the ponds was typically not removed. The settling basins were cleaned out on an infrequent basis, but in many cases they were not cleaned out more than once a year at the most. One dairy was a freestall dairy where the lactating cows were housed in naturally ventilated barns and the manure from the barns was cleaned out by flushing the alleyways behind the freestalls. The wash water from the milking parlor and holding area on this dairy also flowed into the lagoon system. The dairy manure-handling systems varied by farm and are described below.

- D1: A dry lot dairy with manure storage comprised of 3 settling basins and a main lagoon. The main lagoon was monitored.
- D2: A dry lot dairy with manure storage comprised of 4 settling basins and a main lagoon. The main lagoon was monitored.
- D3: A dry lot dairy that was recently converted to a heifer operation; however, during the last quarter of the study lactating animals were on the farm. The lagoon system consisted of 5 settling basins and a main lagoon. The main lagoon and settling basins were monitored.
- D4: A freestall dairy utilizing a flush system with the manure-storage system consisting of a screen separator, 3 settling basins, 3 main lagoons, and a satellite lagoon. The satellite lagoon was monitored.
- D5: A dry lot dairy composed of a concrete settling cell and 3 lagoons. The final lagoon in the series was monitored.
- D6: A dry lot dairy comprised of 1 settling basin and a main lagoon. The main lagoon and settling basin were monitored.

Methane Concentration and Wind Measurements

Initially, lagoons were monitored seasonally (D1 and D2), but as more resources became available monitoring times were increased to better capture annual variations in emissions (D3–D6). The concentration of CH_4 was measured using open-path Fourier transform infrared spectrometry (**OP/FTIR**; Griffiths et al., 2009; Shao et al., 2010). One OP/FTIR (Air Sentry, Cerex Monitoring Solutions, Atlanta, GA, or ABB-Bomem MB-100, MDA, Atlanta, GA) was located either across the downwind edge/corner (D1, D3, D4) or on the downwind bank (D2, D5, D6) of the lagoon, with a sensor height at 1.7 m and path lengths ranging from 130 to 240 m. On D3 and D6, the position of the OP/FTIR enabled monitoring of either the settling basins or the lagoons depending on wind direction. Spectra were acquired continuously and averaged over 5-min intervals. Background concentrations were measured at each dairy for several days at the onset of the study as well as at a remote (nonagricultural affected) location for comparison. Experiments performed with the OP/FTIR units demonstrated that background concentrations were very stable and did not fluctuate daily (CV = 4% over a 4-d period with 1,049 measurements and a change in background concentration of ≤0.3 ppm). In addition, the on-farm concentration data at each location was filtered for wind directions to isolate times when no upwind source of CH_4 was present to verify