EMISSIONS OF AMMONIA AND GREENHOUSE GASSES FROM DAIRY PRODUCTION FACILITIES IN SOUTHERN IDAHO

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ABSTRACT

Idaho is one of the top three milk producing states in the United States. While this commodity group is a very valuable part of the economy, there is concern over the impact of these production facilities on the generation of ammonia (NH_3) and greenhouse gases (methane, CH_4 and nitrous oxide, N_2O) which are linked to air quality degradation and global warming. To gain a better understanding of the on-farm emissions from these production facilities, we monitored both cattle housing and manure management systems on dairies in southern Idaho. Emissions estimates were determined utilizing inverse dispersion modeling. Emissions from animal housing on a per cow per day basis ranged from 0.03 to 0.25 kg NH_3, 0.10 to 0.93 kg CH_4, and 0 to 46 g N_2O. Emissions from wastewater ponds on a square meter per day basis ranged from 0.25 to 9.4 g NH_3, 19.4 to 231 g CH_4, and 0 to 1.28 g N_2O. Emissions from composting dairy manure on a square meter per day basis ranged from 0.34 to 3.45 g NH_3, 2.6 to 35.2 g CH_4, and 0.12 to 2.67 g N_2O. Emissions of NH_3 and CH_4 had strong diurnal trends with emissions tending to be lower in the evening and early morning and then increasing throughout the day, while N_2O emissions tended to be somewhat consistent. In the cattle housing area, NH_3 emissions tended to be lower in the winter and greater in spring and fall, while CH_4 emissions tended to be the greatest in the winter and spring. In the manure storage areas, NH_3 emissions tended to be consistent over the measured periods, while CH_4 emissions tended to increase from spring to fall as average temperatures increased. Emissions of N_2O from all sectors seemed to be limited and did not demonstrate any clear seasonal trend. This dataset elucidates the importance of accounting for daily and seasonal variation in on-farm emissions as well as providing baseline emission factors for these dairy production facilities.

INTRODUCTION

The state of Idaho has experienced rapid growth of the dairy industry in the past decade with the number of milk cows increasing approximately 73% and milk production increasing 88% (USDA NASS, 2011). In 2009, there were 529,366 milking cows in Idaho with 71% of these being located in the Magic Valley region of southern Idaho (UDI, 2011). While this region has benefited economically from the growth of the dairy industry, there is concern regarding the impact of concentrated dairy production facilities on the environment, particularly emissions of ammonia (NH_3), methane (CH_4), and nitrous oxide (N_2O). In the atmosphere, NH_3 primarily reacts to form ammonium sulfate and ammonium nitrate aerosols which contribute to $PM_{2.5}$ (particulates with an aerodynamic diameter < 2.5 μm) formation. The emissions of $PM_{2.5}$ are regulated as part of the U.S. EPA National Ambient Air Quality Standards, as they are considered to be a human health concern. Because NH_3 is highly correlated with $PM_{2.5}$ formation, it is anticipated that NH_3 emissions from confined animal feeding operations (CAFOs) in the U.S. may be regulated in the near future. Under the Emergency Planning and Community Right-to-Know Act, CAFOs are required to report NH_3 emissions if they emit more than 45 kg NH_3 day^{-1} (U.S. EPA, 2009b). Additionally, the U.S. EPA Climate Change Division of the Office of Atmospheric Programs has recently adopted a rule for mandatory reporting of greenhouse gases (U.S. EPA, 2009a). This rule will require that livestock facilities with manure management systems that emit 25,000 metric tons of carbon dioxide equivalents (CO_2e) report the annual aggregate CH_4 and N_2O emissions from their manure management system. The implementation of air quality regulations in livestock-producing states increases the need for accurate on-farm determination of emission rates that reflect the range of animal production facilities and climatic conditions that exist in the U.S.

The development of accurate on-farm emissions factors will have to take into account both diurnal and seasonal variations in emissions under different production scenarios and climatic regions. Additionally, comprehensive datasets that determine the emissions of all trace gases will be valuable particularly when we begin to change management practices that may positively affect the emissions of one gas but may negatively affect another. Therefore, the objective of these studies was to determine the emission rates of NH_3, CH_4, and N_2O over various seasons from different farm source areas (open-lots, free-stall barns, wastewater pond, compost) on three dairies located in southern Idaho.

METHODS

Three dairies were selected to represent a range in size and production management which would be typical of western US dairy production. Farm 1 was an open-lot dairy that housed approximately 700 milking cows. Lots were harrowed daily with manure stockpiled in lots until clean out which occurred twice a year. Manure from the feed alleys was vacuumed and placed into the compost yard. Parlor wash water and lot runoff went into a settling cell and then into the wastewater storage pond. Measurements were made during 2005 across the pens and lagoon during the four seasons (January, March, June, and September) using open-path Fourier Transform Infrared Spectrometry. Farm 2 was an open-lot dairy that housed approximately 10,000 milking cows with 800 additional cows housed in the lot area. Lots were harrowed daily with manure stockpiled in lots until clean out which occurred twice a year. Manure from the lots was composted in windrows on the north side of the lots. Parlor wash water and lot runoff went through a solid separator and then into the wastewater storage pond. Measurements were made during 2008-2009 at the center of the pens, center of the compost yard and at the wastewater pond. Photoacoustic field gas monitors were used from March to November, and then open-path Ultra Violet Differential Optical Absorption Spectroscopy was used in January and February to measure NH_3 concentrations. Farm 3 was an open free-stall dairy that housed approximately 10,000 milking cows. Barns were flushed approximately 3 times a day with re-circulated waste water. Approximately one third of the parlor wash water and lane flush water then go through a solid separator and into an anaerobic digester. The remaining water goes through a solid separator and then into the wastewater ponds along with the water from the anaerobic digester. Measurements were made with photoacoustic field gas monitors during 2009-2010 at the center of the barns, downwind of the barns, and at the wastewater pond.

Weather data and wind statistics were measured utilizing three-dimensional sonic anemometers and a weather station. Emissions estimates were determined utilizing inverse dispersion modeling (i.e. WindTrax). Monitoring occurred for 2-7 days at each location and emissions estimates were derived from as many sets of 24 h (1 hr average) intervals of data as possible. For additional information on monitoring and modeling please see Bjorneberg et al. (2009) and Leytem et al. (2010).

RSEULTS AND DISCUSSION

There were strong diurnal trends in emissions of both NH_3 and CH_4 at all locations throughout all measurement periods. Emissions were lowest at night and early morning and then increased throughout the day as temperatures, wind speed, and animal activity increased. There were no strong diurnal trends in N_2O emissions, as these emissions were very low and variable throughout the day. These diurnal trends are very important to consider when making emissions estimates. Data covering a full 24 h period should be used in order to capture these trends and produce more reliable emissions estimates.

Open-Lot Dairies

Open Lots. Average NH_3 emissions from the lots tended to be the lowest in the winter, greatest in the spring and then moderate throughout the rest of the year. The annual average NH_3 emissions rates were 0.15 and 0.13 kg cow^{-1} d^{-1} at the 700 and 10,000 milking cow dairies, respectively. Similar trends were seen with CH_4 emissions from the lots which tended to be the greatest during early spring. The annual average CH_4 emissions rates were 0.32 and 0.49 kg cow^{-1} d^{-1} at the 700 and 10,000 milking cow dairies, respectively. Emissions of N_2O were low and variable throughout the year. The concentrations measured at the 700 milking cow dairy were not different than background concentrations, therefore there were no emissions estimates made at that dairy. At the 10,000 cow dairy it appears as if the N_2O emissions increased and peaked in May and then decreased, but as the data were very variable, this trend is not necessarily real. The average annual N_2O emission rate was 0.01 kg N_2O cow^{-1} d^{-1} at the 10,000 milking cow dairy.

Wastewater Ponds. Ammonia emissions from the wastewater ponds tended to be the lowest in winter and early spring and then increased as temperatures increased throughout the year. The average NH_3 emission rates were 9 and 20 kg ha^{-1} d^{-1} at the 700 and 10,000 milking cow dairies, respectively. Average CH_4 emissions from the wastewater ponds followed similar trends as the NH_3 emissions with lower rates in the winter and early spring and then increasing as temperature increased with greatest emissions in late summer and early fall. The average CH_4 emissions rates were 24 and 1,028 kg ha^{-1} d^{-1} at the 700 and 10,000 milking cow dairies, respectively. Emissions of N_2O tended to be greater in early spring and then lower during the summer months at the 10,000 milking cow dairy. As measured N_2O concentrations at the 700 cow dairy were similar to background, no emissions estimates were made at that dairy. The average annual N_2O emission rate from the wastewater pond at the 10,000 cow dairy was 0.49 kg N_2O ha^{-1} d^{-1}.

Compost Yard. The 10,000 cow open-lot dairy composted their solid manure from the lots in windrows north of the facility. Emission rates at the compost yard were fairly consistent over the year with the largest fluctuations resulting from compost management. During June, when emissions were the greatest, the windrows were being turned frequently and new manure was brought into the compost yard. The average emissions over the monitoring period were as follows: NH_3 emissions – 16.4 kg ha^{-1} d^{-1}, CH_4 emissions – 135 kg ha^{-1} d^{-1}, N_2O emissions – 9 kg ha^{-1} d^{-1}

Contribution of Source Areas to Total Farm Emissions on Farm 2. Table 1 shows the average combined emission rates of NH_3, CH_4, and N_2O measured from the three source areas on the 10,000 milking cow open-lot dairy. The open-lot areas had the greatest contribution to emissions of NH_3 and N_2O with averages of 78 and 57% of the total farm emissions, respectively (calculated for months when there were values for all three sources). The wastewater pond contributed 12 and 15% of the total farm emissions for NH_3 and N_2O, respectively. The compost area contributed 10 and 27% of the total farm emissions for NH_3 and N_2O, respectively. As the lot is approximately 6-fold greater in area than the wastewater pond and compost areas, these numbers are not surprising. In addition, as much of the ammonia loss occurs from evaporating urine patches, the majority of NH_3 would be expected to be released from the area with the greatest urine deposition, which in this management system is the lot area. The methane emissions, however, had the greatest contribution from the lots in April (74% of total emissions), but then once temperatures began to increase the wastewater pond became the largest source of CH_4 emissions averaging 55% of total emissions for the remainder of the year. The compost area contributed an average of 7% of total CH_4 emissions over the year.

Table 1. Average combined emission rates of NH_3, CH_4, and N_2O measured from the open-lot, wastewater pond, and compost areas of a 10,000 milking cow open-lot dairy over four seasons.

	Emissions Rates		
	NH_3	CH_4	N_2O
	----------------- kg day^{-1} -------------------		
Month			
Spring (March-May)	1,699	14,495	231
Summer (June-August)	1,581	13,080	270
Fall (September-November)	1,748	26,834	76
Winter (December-February)	1,474	(5,760) †	(50) †
Average total emission (kg day^{-1})	1,625	15,042	186
Average emission cow^{-1} day^{-1} ‡	0.15	1.39	0.02
Average emission kg $milk^{-1}$ day^{-1} §	0.005	0.044	<0.001

†values substituted from March 2008, ‡Average based on the 10,800 cows in the lot area, §Average based on the milk produced from the 10,000 milking cows in the lot area

Open Free-Stall Dairy

Work on this dairy began in 2010 and will continue through spring of 2011, therefore limited data are available at this time to look at seasonal trends.

Free-stall Barns. Average NH_3 and CH_4 emissions from the free-stall barns were fairly consistent over the monitoring period with an average of 0.11 and 0.43 kg cow^{-1} d^{-1}, respectively. Emissions of N_2O were somewhat variable over the monitoring period and averaged 0.03 kg cow^{-1} d^{-1}.

Wastewater Pond. Average NH_3 emissions at the wastewater pond were somewhat variable over the course of the monitoring periods and averaged approximately 97 kg ha^{-1} d^{-1}. Average

CH_4 and N_2O emissions increased from spring to late summer with an average of approximately 303 and 7.5 kg ha^{-1} d^{-1}, respectively.

Implications for Regulations and Reporting Requirements

To put these emission estimates into context with regards to regulations and reporting requirements, we utilized the information from Farm 2 as we had the greatest seasonal data from this facility. If the value of 0.14 kg NH_3 cow^{-1} d^{-1} is utilized to represent an open-lot dairy in this region, then according to the EPA limit of 45.5 kg NH_3 d^{-1}, any farm over 325 cows would have to report NH_3 emissions under the Emergency Planning and Community Right-to-Know Act (U.S. EPA, 2009b). The state of Idaho has a requirement that any farm emitting more than 90,909 kg NH_3 $year^{-1}$, adopt a certain number of best management practices to reduce NH_3 emissions. This would mean that any farm over 1,779 cows would be over the state threshold and be required to reduce NH_3 emissions.

Emissions of greenhouse gases are expressed in equivalent terms, normalized to carbon dioxide using global warming potentials, and are referred to as carbon dioxide equivalents (CO_2e). The generation of CO_2e from CH_4 production at the open-lots, which should represent mainly enteric fermentation (with some additional contribution from the manure stockpiles), was approximately 10.8 kg CO_2e cow^{-1} d^{-1}. Comparatively, the USDA GHG inventory reports an estimate of 5.9 kg CO_2e cow^{-1} d^{-1} while the IPCC Tier 1 estimate is 8.1 kg CO_2e cow^{-1} d^{-1}, both of which are lower than the value determined in the present study. As EPA does not consider CO_2 production from manure storage systems to be anthropogenic, it would not fall under the proposed rule for mandatory reporting of greenhouse gasses. However, both the CH_4 and N_2O generated from the lots (excluding enteric fermentation), wastewater pond, and compost would fall under the proposed reporting rule.

As it is difficult to discern the CH_4 emissions from the manure stockpiles in the lots (due to the presence of the cattle) and previous studies have shown little CH_4 generation from fresh manure, we did not consider this as a separate source in our subsequent calculation. The combined manure management (wastewater pond and compost) CO_2e generation for the year at this facility would be approximately 67,690 metric tons of CO_2e. Even though N_2O is considered a more potent greenhouse gas and has a CO_2e value of 310, compared to only 21 for CH_4, the contribution from N_2O was only 14% of the CO_2e generated on farm. If all cows on the facility are included (13,000 cows, including dry cows and replacement heifers as they all contribute to the manure volume), this would be approximately 5.2 metric tons of CO_2e per cow per year. The EPA reporting threshold value is 25,000 metric tons of CO_2e per year (U.S. EPA, 2009a) which would equate to 4,808 cows based on the information from this dairy. The final EPA rule has determined that the average annual animal population (head) under which facilities are not required to report emissions is 3,200 for dairy (mature dairy cows), which is less than our estimated threshold number.

One thing that needs to be considered when making decisions regarding regulation of dairy facilities is the productivity of these facilities. Although the kg CO_2e cow^{-1} d^{-1} from enteric fermentation on this open-lot dairy is 10.8, the average milk cow at this facilities generate 34 kg milk cow^{-1} d^{-1}, which translates to a value of 0.31 CO_2e kg $milk^{-1}$ produced. Other production systems, particularly pasture based systems, not only generate less milk per cow, but also generate higher CH_4 due to the high intake of lower quality forage. In these systems, the CO_2e kg $milk^{-1}$ can be as high as 0.74 CO_2e kg $milk^{-1}$ (Ulyatt et al., 2002). Therefore it is imperative for emissions regulations to be based on unit of production instead of on an animal basis as is typically used by U.S. EPA. Related to this is the issue of scale. As air quality is a regional issue, large producers are being penalized by reporting requirements or adoption of BMPs to control NH_3 emissions, when on an airshed basis the total number of cows is likely more important. This is an issue that needs to be discussed by regulators in order to more fairly assess the burden of emissions reductions throughout an airshed.

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PROCEEDINGS

OF THE

WESTERN NUTRIENT

MANAGEMENT CONFERENCE

Volume 9

MARCH 3-4, 2011
RENO, NEVADA

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