Monitoring nitrous oxide emissions from manure-fertilized alfalfa and corn cropland in the Northeastern US

Marina Molodovskaya[A], Olga Singurindy[A], Brian K. Richards[A], Jon S. Warland[B] and Tammo S. Steenhuis[A]

[A]Department of Biological & Environmental Engineering, Cornell University, Ithaca, NY 14853 USA Email bkr2@cornell.edu
[B]Department of Land Resource Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1 Email jwarland@uoguelph.ca

Abstract

Elevated nitrogen (N) loadings in modern agriculture have led to enhanced denitrification losses and resultant increases of atmospheric nitrous oxide (N_2O). Continuous monitoring of N_2O emissions from corn (*Zea mays*) and alfalfa (*Medicago sativa*) fields fertilized with dairy manure was carried out with an eddy covariance (EC) system from 2006 to 2008, with a short comparative chamber campaign in the summer of 2008. Manure N loading was the most important factor controlling N_2O emissions, with fluxes reaching maxima during or immediately following manure spreading. Emissions peaks during the growing season were promoted by strong rainfall and warmer temperatures, whereas winter/early spring peaks followed snowpack thaw events. Cumulative emissions were 3.2 kg N_2O-N/ha (alfalfa 2006 growing season), 9.7 kg N_2O-N/ha (corn 2007), and 3.6 kg N_2O-N/ha (split alfalfa/corn field 2008). Emission factors ranged from 0.62 to 1.1% of applied manure N, the greatest factor resulting from summer 2006 manure spreading on alfalfa. The EC system was run concurrently with a 4-day campaign of 28 chambers placed in a transect across the split corn/alfalfa field in 2008. Both EC and chamber methods revealed similar mean emissions and day-to-day trends, showing that concurrent field-scale EC and small-scale chamber measurements can cross-validate emission determinations.

Key Words

N_2O, emission factor, micrometeorology, dairy manure, soil chambers.

Introduction

Agricultural practices related to N fertilization and manure management are believed to be the greatest anthropogenic contributor to the steady increase in atmospheric N_2O (Kroeze *et al.* 1999) which is of concern given its persistence, its role in ozone depletion and its high CO_2 equivalence (310 CO_2 eq.). The dairy industry is the largest agricultural activity in the Northeast US, and significant levels of regional feed N importation can resulted in high rates of manure N fertilization of croplands, creating potential for elevated environmental losses. Boyer *et al.* (2002) found that riverine exports represent only a fraction of net N imports for 16 major watersheds in the Northeast US, implying large gaseous emissions. Whereas the majority of manure N losses occur as ammonia volatilization, there is a potential for significant denitrification and N_2O formation, since many soils in the region are underlain by dense glacial tills that promote shallow seasonal perched water tables and elevated soil moisture contents that promote denitrification (Singurindy *et al.* 2009).

Researchers report large variability and uncertainty of N_2O fluxes for crops commonly associated with dairy farming, with literature values of annual N_2O emissions of 0.6–8.7 kg N_2O-N/ha for corn and 0.7–6.3 kg N_2O-N/ha for alfalfa; manure applications substantially increased the level of N_2O emissions from any crops. Difficulties in quantification of N_2O fluxes from agricultural soils and the detection of any regular emission patterns arise from both the large diversity of combined climatic and land conditions affecting flux formation as well as the highly variable and instantaneous ‘spike-like' nature of N_2O fluxes. Most N_2O flux responses to environmental changes or anthropogenic factors can occur on the time scales of several hours to several days (Teepe *et al.* 2001), making continuous long-term monitoring of N_2O field emissions an important component of understanding temporal emission patterns. However, long-term field scale monitoring offers little insight into spatial variability of flux generation due to soil heterogeneity, including in-field moisture soil gradients. Since chambers are the only tool currently available for estimating spatial variability of N_2O emissions at the field scale, parallel measurements with both techniques can be a useful tool to cross-validate both methods and identify the local sources of N_2O emissions, especially where heterogeneities of crops, soil conditions and/or other treatments may be present in the contributing area (Pattey *et al.* 2007). This paper presents a brief overview of our work (Molodovskaya *et al.* 2009ab, Singurindy *et al.* 2009) to date.

Methods

Test fields

N_2O flux observations were carried out on two fields at Cornell University's Animal Science Teaching and Research (T&R) Center in Harford, NY, USA (42°26'N, 76°15'W). With over 500 ha of cropland in corn and alfalfa and ~750 head of dairy cattle, the T&R Center represents a large dairy farm with typical regional cropping practices. Monitored fields (selected to ensure a minimum 100:1 fetch:sampling height ratio) were slightly rolling to level at an elevation of 375-380 m, on well-drained Howard gravelly loam (loamy-skeletal, mixed, active, mesic Glossic Hapludalfs). The first was an existing alfalfa stand monitored during growing season of 2006. In 2007, the experimental system was moved to the second field prior to corn planting. Monitoring continued at the same site in 2008, when approximately a half of the field area was rotated to alfalfa whereas the balance remained in corn. Fields were moldboard (corn) or chisel plowed (alfalfa) followed by disc harrowing before planting in early spring. Fields received fresh semi-solid and/or liquid dairy manure annually, with application determined by farm manure management needs (which, due to lack of on-farm storage led to widely-varying application patterns and rates, sometimes exceeding crop needs; Table 1). Manure was surface broadcasted for up to 12 weeks each year without immediate incorporation.

Table 1. Monitored field areas and manure loading summary.

Monitored site	Field (ha)	Observation period	Manure application period	Total N applied (kg/ha)	NH_3-N applied (kg/ha)
Alfalfa-2006	25	20-Apr – 10-Oct-06	09-Jun-06 – 30-Sep-06	291	147
Corn-2007	30	1-Dec-06 – 31-Dec-07	22-Dec-06 – 15-Mar-07	1296	585
Split -2008 alfalfa	14	1-Jan-08 – 31-Dec-08	18-Jan-08 – 10-Apr-08	750	340
corn	16	1-Jan-08 – 31-Dec-08	30-Apr-08 – 14-May-08	125	70

Equipment

The micrometeorological EC system described in detail by Molodovskaya *et al.* (2009a) consisted of a 3-D sonic anemometer (CSAT3) and TDLAS trace gas analyzer (TGA100A; both Campbell Scientific, Inc.) to measure wind speed and N_2O concentration, respectively. High-frequency (10Hz) N_2O concentration and wind data was collected using a model CR5000 data logger. Quality control was performed on the half-hour data prior to the covariance calculations. Covariances were rotated to a natural coordinate system. Data with friction wind velocity ≤ 0.1 m/s and horizontal wind speed ≤ 1.5 m/s were discarded to exclude periods when turbulent mixing was not sufficient. To remove potential disturbances to the wind, data associated with wind directions ≥ 120° and ≤ -120° from the sonic anemometer pointing axis were also discarded. Fluxes were averaged over half-hour and daily periods. Source area contribution to the integrated flux was estimated as described by Schuepp *et al.* (1990) and Laville *et al.* (1999); footprint analysis showed that 40% of the flux originated within 75m of the system mast, and 75% of the flux originated within 150m of the mast. Other measurements included volumetric soil moisture content (two CS616 Water Content Reflectometer sensors installed 10 cm below the surface), soil temperature (4 replicated thermocouples 10cm deep), air temperature and humidity (Vaisala HMP45A/D), and precipitation (tipping bucket gauge).

The 4-day comparative chamber campaign (Molodovskaya *et al.* 2009b) was conducted June 30-July 3, 2008, with three deployments per day using 28 static closed chambers installed in replicate pairs on a transect (10m spacings) across the split alfalfa/corn fields. Chambers (0.07 m^2 coverage area, 0.017 m^3 enclosed volume) consisted of a cylindrical collar installed in the soil, and a removable cover fitted with sampling and vent ports, installed on the collars only during 30 min sampling runs to minimize potential artifacts. Air samples were withdrawn by syringe and placed in evacuated vials for analysis (Agilent 6890N GC/ECD). The N_2O flux measured by static chambers was calculated from rate of change of N_2O concentration during 30 min cover deployment (Rochette and Bertrand 2007). Daily mean fluxes were calculated for each chamber from three deployments per day. EC and chamber fluxes were tested for normality with the K-S test (P=0.05), and corn/alfalfa and chamber/EC differences were analyzed with parametric unpaired t-test or non-parametric Mann-Whitney rank sum test. Descriptive statistical parameters for EC and chamber fluxes were calculated and compared for the chamber campaign.

Results

Long-term EC system monitoring

Growing season (April-October) rainfall in 2006 was 700 mm, in contrast to 481 mm (895 mm annual) in

2007 and 438 mm (833 mm annual) in 2008. Average growing season temperatures for the research site were 16.7 (2006), 14.3 (2007) and 13.9ºC (2008), compared to the area 10-year average (15.0ºC). Despite elevated manure N loadings (typical N loading rates being ≤200 kg N/ha), fluxes observed by the EC system (Figure 1) were comparable to other literature EC flux measurements, which generally exceed those of chamber studies due in part to the continuity of sampling which diminishes the risk of missing peaks that can account up to 50% of annual emissions. Average monthly N_2O-N fluxes for all three years of monitoring ranged from -0.4 to 108.4 g N_2O-N/ha/d.

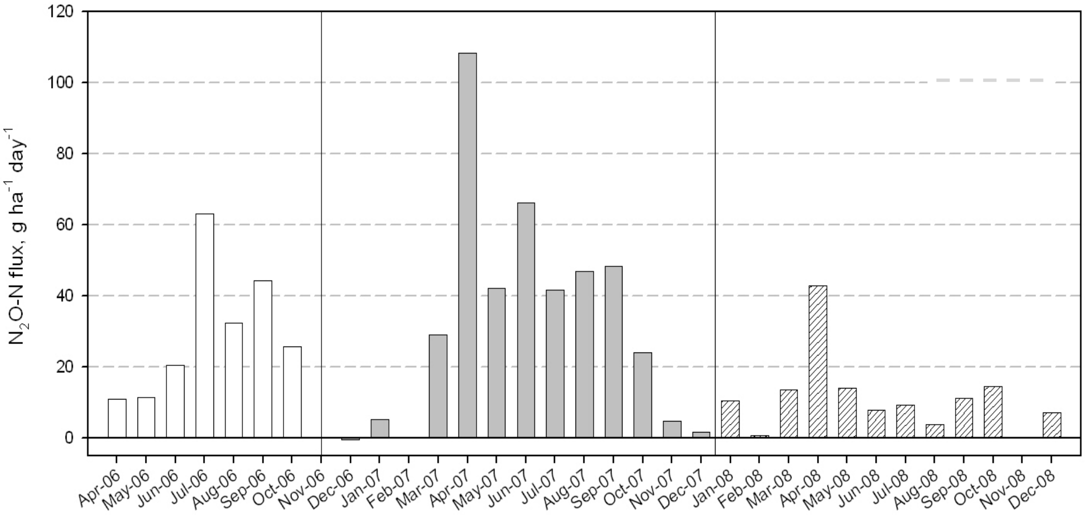

Figure 1. Mean monthly emissions from alfalfa (2006), corn (2007) and split corn/alfalfa (2008) fields.

Cumulative measured emissions were 3.2 kg N_2O-N/ha from alfalfa (growing season only) in 2006; 9.7 N_2O-N/ha for corn in 2007 (9.1 kg/ha for growing season); and 3.6 kg N_2O-N/ha the split field in 2008 (2.3 kg/ha for growing season).Source area analysis for the 2008 split alfalfa/corn field (based on wind direction calculations) showed that cumulative N_2O-N emissions from the alfalfa field were 3.0 kg/ha vs. only 0.6 kg/ha from corn. The alfalfa field also produced 89% of total daily fluxes over 100 g/ha/d. Daily means varied widely, with coefficients of variance (CV) of 160% (2006), 238% (2007) and 328% (2008). N_2O-N fluxes reached maxima during or immediately after manure fertilization events combined with seasonal weather changes. For both 2007 and 2008, winter manure applications were followed by spring thaws that resulted in emission peaks in April of each year. The magnitude of each annual maximum (63 g N_2O-N/ha/d in July 2006 (alfalfa), 108 g/ha/d in April 2007 (corn), and 43 g/ha/d in April 2008 for alfalfa/corn) exceeded the next highest monthly average of any given year by at least 30%. Emission factors (EF) for all three years of observations were calculated using the updated IPCC methodology which includes manure N and crop N residue inputs. Emission factors were 1.11% (2006), 0.75% (2007) and 0.62% (2008), as compared to the IPCC default factor of 1% for non-organic soils.

Comparative study

Daily mean EC and chamber N_2O fluxes are shown in Figure 2. Chamber fluxes from both alfalfa and corn transects were normally distributed, with the overall mean flux from the alfalfa field almost twofold of that from the corn field, again reflecting the greater N loadings. Chamber N_2O fluxes were -1.1 to +5.6 μg N_2O-N/m^2/min (alfalfa) and -2.4 to +6.1 μg N_2O-N/m^2/min (corn), reflecting heterogeneity of soil N_2O formation including, in places, net N_2O consumption. Concurrent EC fluxes varied from -10.5 to +40.0 μg N_2O-N/m^2/min and strongly depended on contributing footprint. The wind direction and footprint analysis showed that approximately 75% of the integrated daily EC flux was primarily constituted by emissions from the area under alfalfa treatment, which was confirmed by the similar daily EC and alfalfa chamber means. Corn chamber data were more variable than alfalfa, both spatially and temporally. Overall chamber and EC fluxes showed a continuous decrease for the period over four days of observations both on alfalfa and corn sites, which was likely related to the steadily diminishing soil moisture content. The four-day mean EC flux was approximately four times greater than corn and two times greater than alfalfa overall chamber means. However daily chamber fluxes along the transect between the two fields were not significantly different from the daily mean EC flux, likely due to the high variability of the data.

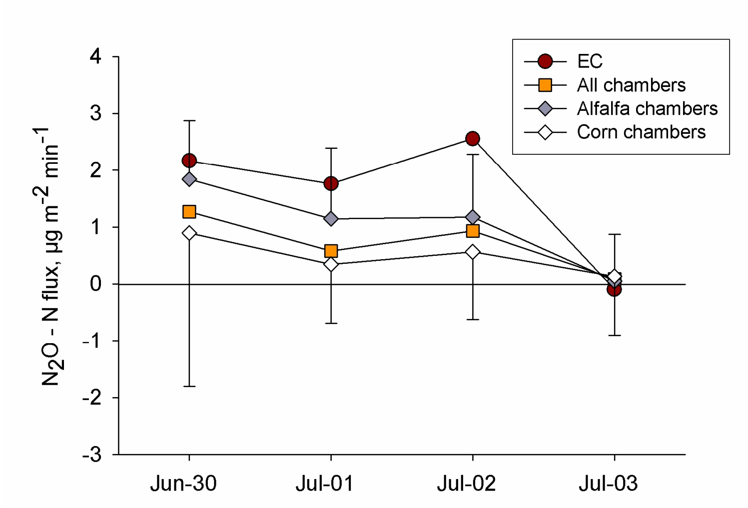

Figure 2. Comparative results of 4-day EC system and chamber campaign (Molodovskaya *et al.* 2009b).

Conclusion

Despite widely ranging loadings, emission factors determined by continuous EC monitoring ranged from 0.62 to 1.1% of applied manure N. Concurrent field-scale EC and small-scale chamber measurements can cross-validate emission determinations.

References

Boyer EW, Goodale CL, Jaworsk NA, Howarth RW (2002) Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA. *Biogeochemistry* **57,** 137-169.

Kroeze C, Mosier A, Bouwman L (1999) Closing the global warming budget: a retrospective analysis 1500-1994. *Global Biogeochem. Cycles* **13**, 1-8.

Laville P, Jambert C, Cellier P, Delmas R (1999) Nitrous oxide fluxes from a fertilised maize crop using micrometeorological and chamber methods *Agric. Forest Met.* **96,** 19:38

Molodovskaya M, Singurindy O, Richards BK, Warland J, Steenhuis TS (2009a) Continuous eddy covariance monitoring of nitrous oxide emissions from manure-fertilized alfalfa and corn cropland in New York State. Under review, *Agric. Ecosyst. Environ.* AGEE5233

Molodovskaya M, Warland J, Richards BK,Steenhuis TS (2009b) Measurements of agricultural nitrous oxide emissions: a comparative study of static chamber and eddy covariance fluxes. Under review, *Atmos. Environ.*

Pattey E, Edwards GC, Desjardins RL, Pennock DJ, Smith W, Grant B, MacPherson JI (2007) Tools for quantifying N2O emissions from agroecosystems *Agric. For. Meteorol.* **142,** 103–119

Rochette P, Bertrand N (2007) Soil-surface gas emissions. In: MRCarter and EG Gregorich, Eds, *Soil sampling and methods of analysis*, 2nd ed., Canadian Society of Soil Science, CRC Press, pp.851-861.

Schuepp PH, Leclerc MY, MacPherson JI, Desjardins RL (1990) Footprint prediction of scalar fluxes from analytical solutions of the diffusion equation. *Boundary-Layer Meteorol.* **50,** 355-373.

Singurindy O, Molodovskaya M, Richards BK, Steenhuis TS (2009) Nitrous oxide emission at low temperatures from manure-amended soils under corn (*Zea mays* L.). *Agric. Ecosyst. Environ.* **132,** 74-81.

Teepe R, Brumme R, Beese F (2001) Nitrous oxide emissions from soil during freezing and thawing periods. *Soil Biol. Biochem.* **33,** 1269-1275