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Nitric oxide soil emissions from tilled and untilled cornfields

Kevin L. Civerolo[1], Russell R. Dickerson*

Department of Meteorology, University of Maryland, College Park, MD 20742, USA

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Abstract

Results from the eddy covariance nitric oxide flux measurements made at a site on the Eastern Shore of Maryland during July 25–30, 1995 are reported. The mean (and median) NO flux measured along the dividing line between two fertilized cornfields, one conventionally-tilled and one untilled, was 7.5 (and 7.6) ng N m^{-2} s^{-1}. Average NO emission rates from the untilled field, 1.2 (0.1–3.3) ng N m^{-2} s^{-1}, were significantly lower than from the tilled field, 8.6 (2.5–15.5) ng N m^{-2} s^{-1}, where the ranges in parentheses cover the central 90% of the data. This finding suggests that no-till agriculture might reduce NO emission from soils during the summer months. © 1998 Elsevier Science B.V.

1. Introduction

Nitric oxide (NO) is produced in soils as a result of microbial activity (e.g. Lipschultz et al., 1981; Johansson and Galbally, 1984), through the processes of nitrification and denitrification. Soil emissions from agricultural lands are enhanced by the application of nitrogen (N)-based fertilizers (e.g. Johansson, 1984; Slemr and Seiler, 1984, 1991; Harrison et al., 1995). In rural regions with intense agriculture, soil emissions of NO may be comparable to the local anthropogenic input. While only about 4% of the land area in the United States is used to grow corn, this area accounts for about 40% of the yearly soil emissions (Williams et al., 1992).

Values of NO fluxes from soils reported in the literature are scattered over several orders of magnitude (e.g. Galbally and Roy, 1978; Johansson and Granat, 1984; Slemr and Seiler, 1984; Anderson and Levine, 1987; Parrish et al., 1987; Williams et al., 1988; Williams and Fehsenfeld, 1991; Thornton and Valente, 1996) and depend on many variables including soil temperature and moisture, time of year, rate of N-based fertilizer application, plant canopy type, distribution of soil microbes and soil type. Eddy covariance is a direct micrometeorological technique for measuring the surface fluxes, but to date relatively few such measurements of nitrogen oxides have been published (e.g. Wesely et al., 1982; Delany et al., 1986; Hicks et al., 1986; Wesely et al., 1989; Stocker et al., 1993). The purpose of this paper is to present NO flux measurements during late July 1995 on Maryland's Eastern Shore above a fertilized corn canopy.

2. Measurement site

Nitric oxide flux measurements were made during the summer of 1995 at the Wye Research and Educa-

*Corresponding author. Fax: 1 301 314-9482.

[1]Present address: New York Department of Health, Wadsworth Centre, Albany, New York 12201-0509, USA.

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tion Center in Queenstown, MD (38°55′ N, 76°09′ W), along the dividing line between a conventionally-tilled and an untilled cornfield. This dividing line runs from southeast to northwest, with the tilled field to the west and the untilled field to the east. The study area is an agricultural experiment station, with the nearest urban centers being Baltimore, MD (~60 km to the northwest) and Washington D.C. (~70 km to the west). The Wye River, a tributary of the Chesapeake Bay, is less than 1 km from the measurement site. Trees ~30 m tall are less than 400 m from the sampling tower.

The Wye site is generally flat (<3% grade) and is about 5 m above sea level. The soil in these fields is silty, moderately well-drained and slightly acidic (pH ~6.5–7.0) (Staver and Brinsfield, 1990). Chisel plowing was used on the tilled field to cut rows and remove cover vegetation and weeds. The herbicide Paraquat was applied to both fields, with an additional treatment to the untilled field to further control weed and cover grass growth within a week of seeding.

The cornfields were fertilized twice in 1995 with the following mixture by weight: 42.2% NH_4NO_3, 32.8% urea, 25% water and 0.1% NH_4OH. On May 16, an application of 34 kg N ha^{-1} was injected 5 cm into the soil and a treatment of 125 kg N ha^{-1} was applied to the soil surface from June 15 to 16. By the end of July the 3 m corn canopy had reached senescence.

3. Experimental methods

Fluxes of nitric oxide were made using the eddy covariance method. All flux measurements were made at a height of 6 m on a sampling tower. Assuming a displacement height of 80% of the corn canopy height of 3 m, the zero-plane displacement was 3.6 m. Three dimensional wind speed and temperature measurements were made with an Applied Technologies (Boulder, CO) sonic anemometer/thermometer probe, mounted on a boom on the tower. To keep flow distortion to a minimum, only the sample inlet was placed on the tower. Air was sampled through nearly 8 m of 0.31 cm o.d. black Teflon tubing which introduced a delay in the NO signal with respect to the wind speed signal. This delay time was removed before calculating half-hour average fluxes.

Because the NO detector measures mixing ratio rather than concentration and since past investigators have generally reported negligible temperature corrections to the fluxes of reactive nitrogen and ozone (e.g. Munger et al., 1996), no corrections were made to the reported fluxes (Webb et al., 1980). We estimate the run-to-run variability of our flux estimates to be on the order of 30–50%, due in part to the NO detector not having adequate spectral response at high frequencies. Cospectrum analysis shows that the uncorrelated sensor noise at frequencies >1–2 Hz does not contribute to the flux, but does contribute to the flux measurement precision.

4. Results

4.1. Observations

Nitric oxide eddy covariance flux measurements were made during late July and early August of 1995 and a summary of the results from July 25–30 is presented in this section. The mean (and median) of 113 half-hour average fluxes was 7.5 (and 7.6)$\times 10^{-9}$ g as nitrogen per square meter per second (ng N m^{-2} s^{-1}), with a standard deviation of 5.1 ng N m^{-2} s^{-1}. Ninety percent of the data ranged between 0.4 and 14.7 ng N m^{-2} s^{-1}. Only two of the observed fluxes were negative (-12.3 ng N m^{-2} s^{-1} and -1.2 ng N m^{-2} s^{-1}), denoting periods of deposition. Ninety-six of the fluxes corresponded to times when the local winds passed over the tilled cornfield to the sample inlet and the mean (and central 90% range) NO flux during these times was 8.6 (and 2.5–15.5) ng N m^{-2} s^{-1}, which includes the two negative fluxes. The remaining 17 values occurred when the local winds passed over the untilled side to the sample inlet and the corresponding mean (and central 90% range) was 1.2 (and 0.1–3.3) ng N m^{-2} s^{-1}.

A histogram of half-hour flux values is shown in Fig. 1. The shaded region corresponds to times when the surface wind passed over the untilled field, while the unshaded region corresponded to times when the wind passed over the tilled field. The distribution passed a Chi-squared (9 degrees of freedom, α=0.05) 'goodness-of-fit' test for a normal distribution, reasonable to expect since the fluxes were measured under various atmospheric and environmental conditions.

The flux time series is shown in Fig. 2. On two of the days (July 26 and 27) there was a maximum NO

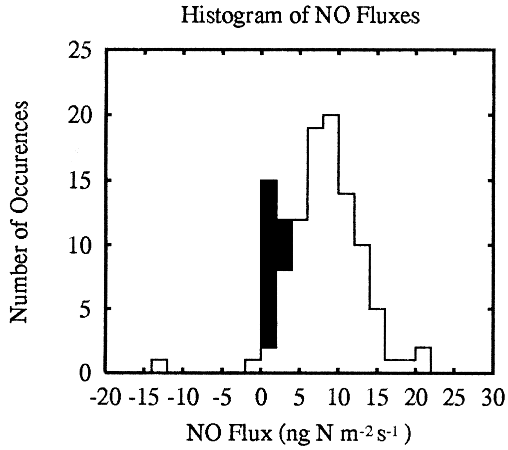

Fig. 1. Histogram of half-hour average NO fluxes (n=113), in increments of 2 ng N m^{-2} s^{-1}, from July 25–30 at the Wye site. The unshaded region corresponds to times when the wind passed over the tilled field and the shaded region corresponds to times when the wind passed over the untilled field.

flux around late morning to early afternoon. There was also a large nighttime flux on July 28–29. With such a short, discontinuous time series it is difficult to determine an average daily variation in NO flux typical of the summer season in general.

The variance in NO flux can depend on many factors. Table 1 shows the correlation coefficients for the regression between NO flux and various measured parameters – wind speed, friction velocity, air temperature, heat flux, stability (z/L, where L is the Monin–Obukhov length) and UV radiation. To test the

Table 1
Correlation coefficients (r) between NO flux and various near-surface parameters

Parameter	All data	Tilled field data	Untilled field data
Wind Speed	0.22	0.37	0.03
Friction velocity	0.23	0.28	0.08
Air temperature	−0.04	0.06	−0.46
Heat flux	−0.06	0.01	0.48
Stability (z/L)	0.02	−0.15	−0.31
UV radiation	0.15	0.15	–

[a] There are no UV radiation data corresponding to data from the tilled field.

significance of these coefficients, a Student's t-test (10 degrees of freedom, α=0.05) was performed. None of the correlation coefficients are statistically significant at the 95% significance level and given the fact that the surface elements within a 200 m radius of the tower are similar, the data suggest that these variables may not be as important for controlling NO fluxes as tillage practice and the various soil parameters which were not measured.

4.2. Discussion

Tilling agricultural fields increases the amount of exposed soil and allows for easier exchange of NO into the boundary layer, while no-till agriculture keeps the cover grass root mass in the soil. Our results indicate that NO emissions may be reduced significantly by not tilling the soil, that NO emission rates are dependent

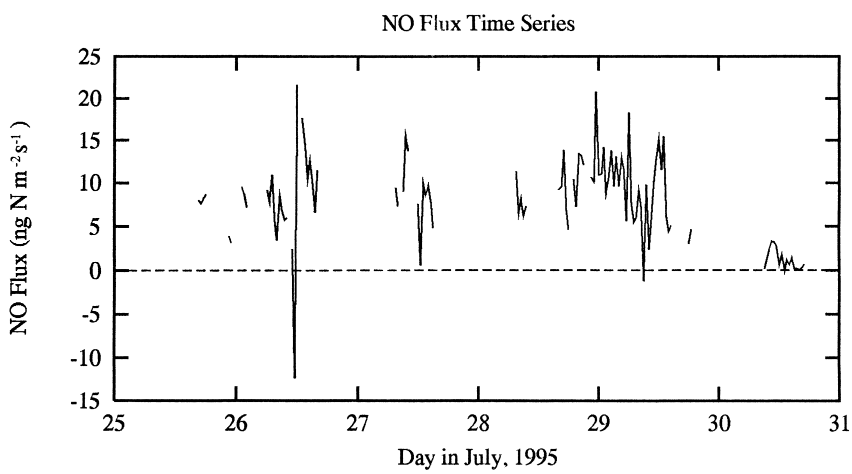

Fig. 2. Time series of NO fluxes, in ng N m^{-2} s^{-1}, from July 25–30, 1995 at the Wye site, with zero flux shown as a dashed line.

on physical transfer out of the soil, in addition to rates of nitrification. By not tilling, farmers also have the potential for increased profitability. No-till agriculture has the advantages of drastically reduced surface runoff and lower fuel consumption, since large tilling machines are not used (Mathson et al., 1998).

Differences in the NO emission from the two fields may result from differences in soil moisture, temperature and nitrogen levels – parameters not monitored during the project. Both fields received the same amount of rainfall, 0.4 cm during the project and only 6.7 cm for the entire month of July. Both fields received the same fertilizer application, so that differences more than two months after fertilization should not account for the observed differences in flux from the two fields. Finally, the same crop was grown on both fields, with planting only a few days apart. With both fields having nearly identical canopies and receiving the same amount of sunlight, it is unlikely that the soil temperatures in the two fields were markedly different either.

Some of the observed difference in NO emission between the two cornfields may be attributed to the fact that the site had less than ideal surface roughness. Although the fields had very similar surface roughness within a 200 m radius of the sampling tower, there were trees and roads within 400 m which may have perturbed the eddies, causing spurious NO fluxes. Horst and Weil (1994) showed that for the observed flux to be within 10–20% of the actual flux, the fetch needs to be as much as 100–1000 times the displacement height.

Finally, the sonic anemometer was oriented such that it faced the tilled field, since the prevailing flow during the summer at the Wye site is southwesterly. Therefore, fluxes measured when the surface wind passed over the untilled field may have been contaminated by the tower and anemometer. These errors may contribute an additional 20– 30% to the difference in the NO emission from the two fields (R. Valigura, personal communication).

5. Conclusions

Nitric oxide fluxes measured during six days in the summer of 1995 at a site on Maryland's Eastern Shore presented in this paper averaged 7.5 ng N m^{-2} s^{-1}. The NO flux when the surface wind passed over the tilled field was 8.6 ng N m^{-2} s^{-1} and 1.2 ng N m^{-2} s^{-1} when the surface wind passed over the untilled field, a substantial difference. Despite the uncertainty in our results caused by the relatively few data points (especially when the wind passed over the untilled field to the sample inlet) and the lack of important ancillary measurements (soil moisture, nutrient levels and temperature), it is unlikely that this uncertainty approaches the seven-fold difference in the NO flux. This substantial difference between the fluxes from the tilled and untilled fields should be further investigated and quantified over the course of a full growing season.

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