Urea Fertilizer Reduces N_2O Emissions by 50% Compared with Anhydrous Ammonia in Corn and Corn/Soybean Systems in Minnesota

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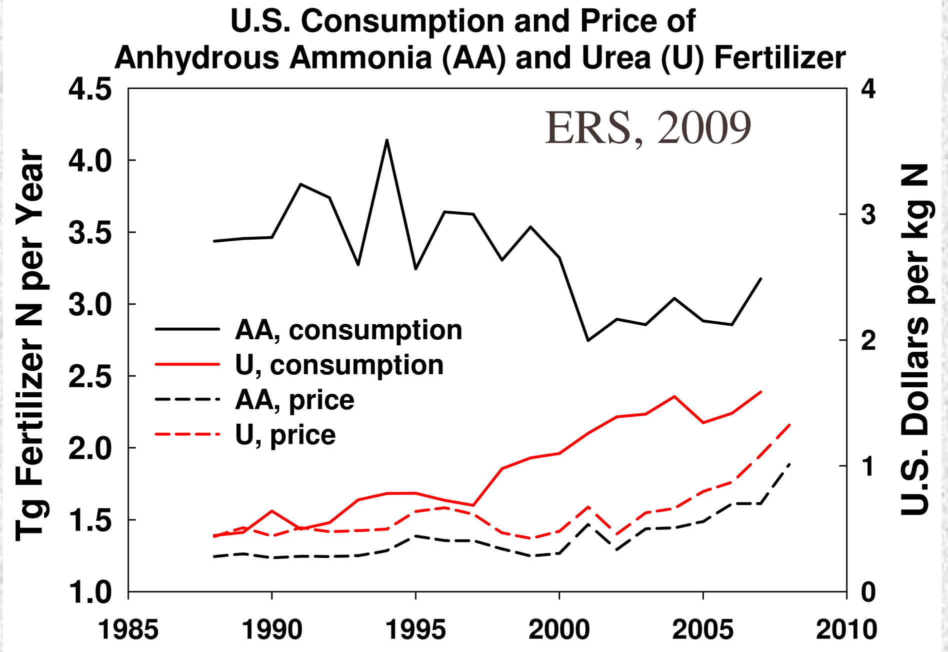
Introduction

Corn and soybean production together account for nearly half of all land used for crops in the U.S. and comprise about 8% of total area of the contiguous U.S. Quantifying soil emissions of N_2O associated with production of these crops is essential to developing accurate greenhouse gas (GHG) inventories for agriculture.

Anhydrous ammonia (AA) and urea (U) are two of the most commonly used fertilizers in the U.S. and the world. Use of AA in the U.S. has generally declined over the past 3 decades, while U use has increased (see graphic below). If N_2O emissions following AA and U application differ substantially, these trends in fertilizer use may substantially alter N_2O emissions at national and global scales. However, there are few systematic studies comparing N_2O emissions following AA and U application within the same cropping system.



Objectives

This three-year study had three main objectives:

1. To compare growing season N_2O emissions and grain yields in a continuous corn (Cc) cropping system to that in a corn/soybean system during both the corn (Cc) and soybean (Sc) phases of the rotation; and
2. To examine the effects of anhydrous ammonia (AA) versus urea (U) on growing season N_2O emissions and grain yields in the Cc system, which was fertilized annually, and during the corn phase of the corn/soybean system (Cs, fertilized biennially).
3. To apply a new technique for calculating chamber-based gas flux which adjusts for the effects of chamber deployment.

Methods

Site: At Univ. of Minnesota Research Park in Rosemount, MN (44º 45' N, 93º 04' W). Site was planted to alfalfa prior to 1987, and corn during 1987-1989. Current cropping systems were established in 1990.

Soil: Waukegan silt loam with clay content of 22%, organic carbon of 2.6-3% and pH 5.5–6.5 in upper 20 cm.

Crop Treatments: In 1990, continuous corn and corn/soybean treatments were established in a randomized complete block design with 3 replicates of each crop, and with each phase of the rotation present each year (9 plots).

Fertilizer treatments: In spring 2005, each plot was sub-divided into two subplots. Each spring in 2005, 2006, and 2007, the two subplots in the Corn following corn (Cc) and Corn following soybean (Cs) treatments received 146 kg N ha^{-1} applied 1–2 wks prior to planting either as (i) AA which was knife-injected 0.15–0.20 m below the surface, or (ii) U, which was surface broadcast and then incorporated by disking to a depth of 0.15 m. The Soybean following corn (Sc) treatment did not receive fertilizer.

Measurements: Soil N_2O and CO_2 fluxes were measured twice per wk in Apr. through Oct. of each growing season using chamber methods in two locations within each subplot (row and inter-row). Chamber tops were secured to bases, samples were collected after 0, 0.5, and 1 hr, and analyzed within 1 wk of collection by GC. Soil temp. and moisture were measured during each flux measurement period. Soil samples were collected for analysis of soluble organic carbon (SOC), pH, inorganic N, and bulk density.

Flux calculations: Gas fluxes were calculated using two different flux calculation schemes, i.e., linear regression, and the quadratic model of Wagner et al. (1997). Fluxes were also adjusted to account for the so-called "chamber effect" resulting from suppression of the concentration gradient at the soil-atmosphere interface. Adjusted fluxes were calculated using measurements of soil moisture content and bulk density as described by Venterea (2010).

Results

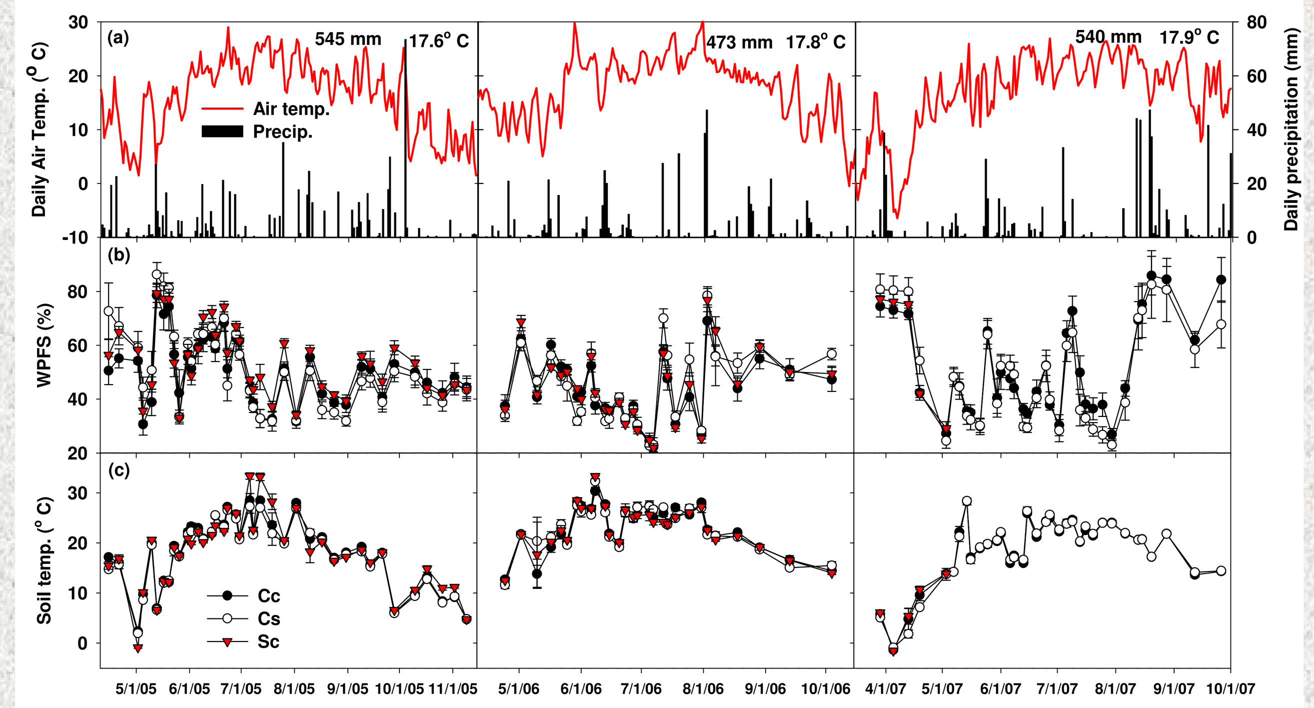


Figure 1. (a)Air temperature and precipitation, (b) water-filled pore space (WFPS), and (c) soil temperature in corn after corn (Cc), corn after soybeans (Cs), and soybeans after corn (Sc) during each growing season. Values in (a) are average daily temperature and total precipitation for the period 1 April through 1 October.

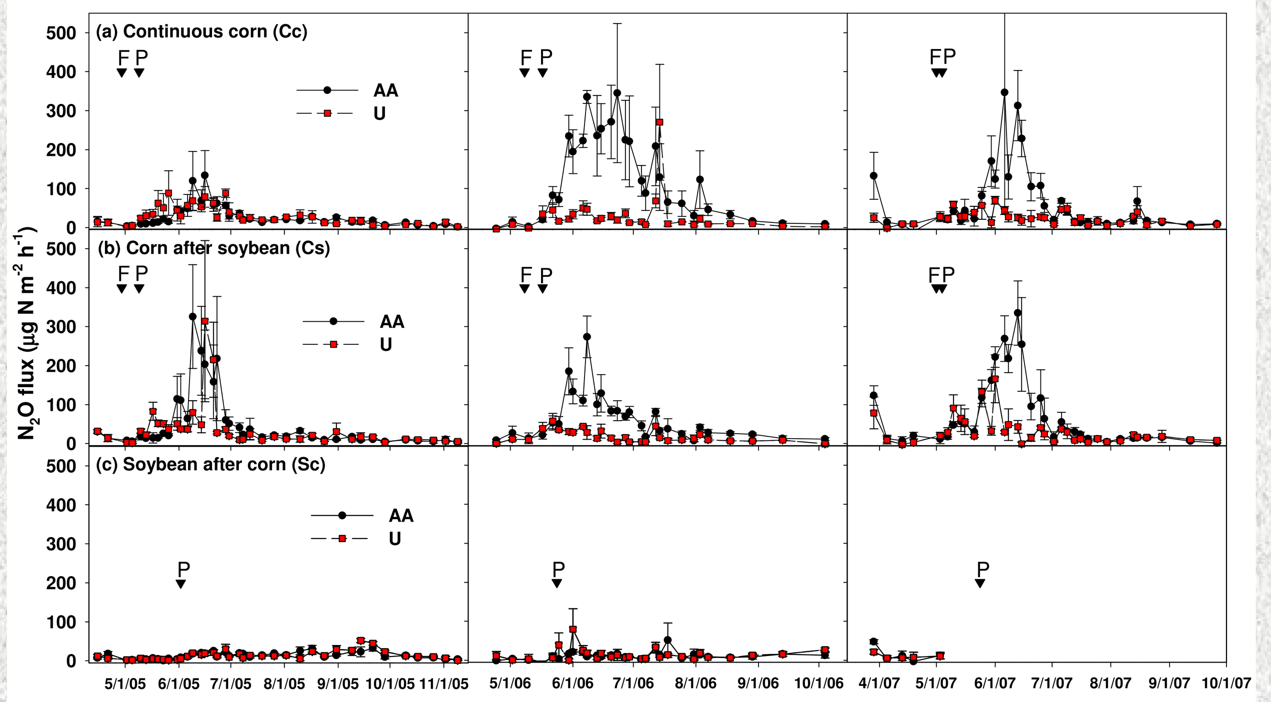


Figure 2. N_2O fluxes during each growing season; Cc and Cs were fertilized with anhydrous ammonia (AA) or urea (U). For Sc, AA and U designations apply to previous season. Inverted triangles indicate dates of fertilizer application (F) and planting (P). Fluxes were calculated using the quadratic model and corrected for chamber effects.

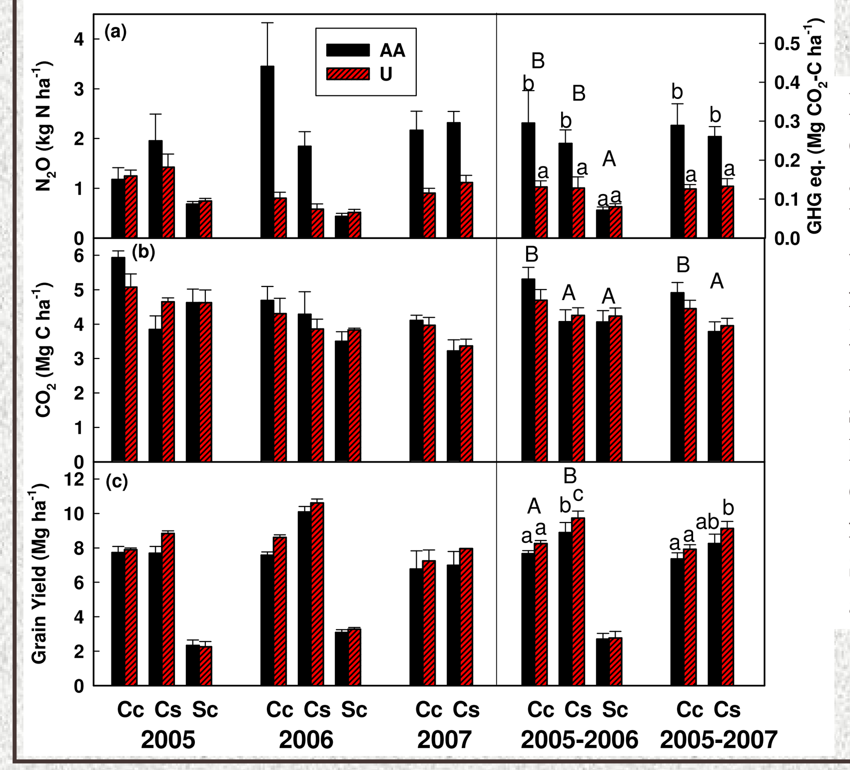


Figure 3. Total growing season soil emissions of (a) N_2O, and (b) CO_2, and (c) grain yields. Emissions are based on fluxes calculated using the quadratic model and corrected for chamber effects. For 2005-2006 and 2005-2007, bars having the same lower case letters are not significantly different. Upper case letters indicate significant differences by crop across both fertilizer treatments ($P < 0.05$). Statistical grain yield comparisons are shown for corn only.

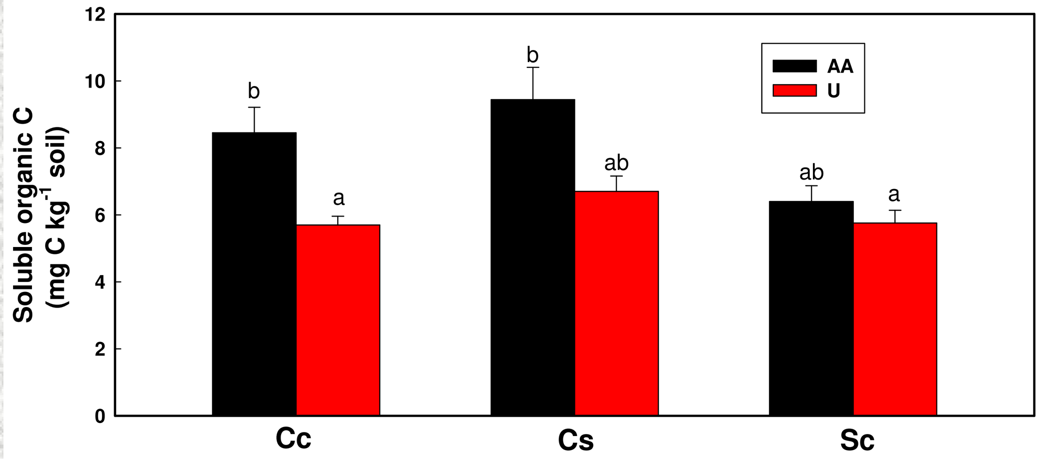


Figure 4. Mean soluble organic carbon concentrations in samples from the 0.1 to 0.2-m depth, in plots fertilized with anhydrous ammonia (AA) or urea (U). For Sc, fertilizer designations apply to previous season. Bars represent means across all years and sample collections.

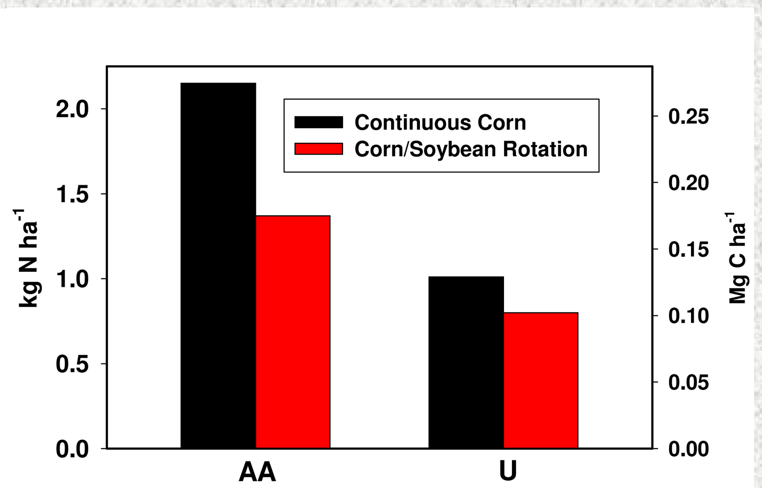


Figure 5. Mean growing season N_2O emissions and CO_2 equivalents for 2-yr Corn/Soybean rotation compared with Continuous Corn, using anhydrous ammonia (AA) or Urea (U) as fertilizer sources.

Major Findings and Conclusions

In both corn following corn (Cc), and corn following soybean (Cs), N_2O emissions with AA were twice the emissions with U. After accounting for N_2O emissions during the soybean phase (Sc), it was estimated that a shift from a Corn/Soybean rotation to Continuous Corn would result in an increase in growing season emissions of 0.78 kg N ha^{-1} when AA was used, compared to only 0.21 kg N ha^{-1} with U. In CO_2 equivalents, these changes in emissions equate to 0.11 and 0.03 Mg CO_2-C ha^{-1} for AA and U, respectively. In light of trends toward increased use of U, these results suggest that fertilizer-induced soil N_2O emissions may decline in the future, at least per unit of applied N. A complete GHG life cycle analysis would need to account for the lower energy requirements associated with the manufacture and transport of AA compared to U (Snyder et al. 2007).

Higher N_2O emissions from AA compared to U have been previously observed (Thornton et al. 1997), but a recent study showed no differences (Burton et al. 2008). Further study is needed in different soils and cropping systems. Venterea and Rolston (2000) attributed elevated N_2O fluxes under AA to chemo-denitrification. The relatively low WFPS values observed during high-flux periods in the current study are consistent with this explanation. Higher SOC levels with AA may have contributed to the higher N_2O fluxes.

Soil CO_2 emissions were 20% higher under Cc compared to Cs. However, crop residue from the prior year did not affect soil inorganic N or SOC during the subsequent season. N_2O fluxes during winter and early spring were not measured, so it is possible that crop residues may have affected N_2O fluxes during these periods.

We also compared different flux-calculation schemes, including a new method that adjusts for chamber-induced errors. Adjusted N_2O emissions estimates were up to 35% higher than estimates based on non-adjusted linear regression.

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