



Precision Fall Urea Fertilizer Applications: Timing impact on Carbon dioxide, Ammonia Volatilization and Nitrous Oxide Emissions

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Abstract. *To minimize ammonia (NH_3) volatilization and nitrous oxide (N_2O) emissions from fall applied fertilizer, it is generally recommended to not apply the fertilizer until the soil temperature decreases below 10 C. However, this recommendation is not based on detailed measurements of NH_3 and N_2O emissions. The objective of this study was to determine the influence of fertilizer application timing on nitrous oxide, carbon dioxide, and ammonia volatilization emissions. Nitrogen fertilizer was applied at two rates (0 and 224 kg urea-N ha^{-1}) to two soil moisture treatments (natural rainfall and natural + supplemental water) in mid-September, mid-October, and the beginning of November. Soil temperatures at fertilizer application were approximately 27 C, 16 C, and 5 C, in September, October, and November, respectively. Gas flux rates of N_2O , CO_2 , and NH_3 were monitored every 4 hours for 3 weeks following application. As the season progressed from September to November, CO_2 and N_2O emissions decreased. However, for ammonia, different results were observed and rates increased from September to October, however, emissions decreased thereafter. At the end of the November application, CO_2 , N_2O , and NH_3 emissions were very low. These findings suggest that minimizing NH_3 and N_2O losses requires a better understanding of the loss mechanisms.*

Keywords. *Fertilizer, Greenhouse gas, Application timing*

Introduction

The world population continues to increase and agricultural producers are faced with the challenge of meeting growing market and social demands. To achieve this challenge, producers apply increasing amounts of synthetic nitrogen fertilizers to achieve higher yields. However, escalating fertilizer rates raise concerns about their impact on the environment. The Intergovernmental Panel on Climate Change (IPCC) estimated N₂O-N emissions at 1.25% of total N application (IPCC, 1997). This conversion factor does not account for local conditions affecting losses. For example, research shows that split N applications can increase soil temperature, and moisture and fertilizer application timing can impact emissions. However, little research has been performed to see how weather events affect N₂O, CO₂ and NH₃ emissions. It has generally been noted that warmer soils results in increased N₂O emissions due to the increased biological activity (Chang et al., 2016). Also, some have suggested that increased soil moisture content increases N₂O emissions but the extent to the increase in emissions is not fully understood (Chang et al., 2016). This increase is attributed to reduced aerobic respiration and increased anaerobic respiration (Linn and Doran, 1984). Results reported by Linn and Doran (1984) suggest that ammonification has a maximum activity at 60% water filled capacity, and denitrification has maximum activity when the water content is greater than 60% water filled porosity.

Nitrous oxide emissions occur during ammonia nitrification and denitrification. Nitrification, the process by which microbes (*Nitrosomonas* bacteria) oxidize ammonium (NH₄) fertilizers to nitrite (NO₂), produces small amounts of N₂O gas as a byproduct. Nitrite (NO₂) is further oxidized to nitrate (NO₃) by *Nitrobacter* bacteria. This nitrification process converts NH₄, a positively charged, immobile ion bound to the soil and organic matter, to free negatively charged NO₃ and NO₂ ions, which are readily lost from the rooting zones by water movement. In the absence of oxygen, some soil bacteria have the capacity to conduct anaerobic respiration, where nitrate is converted to N₂O or N₂.

Soil temperatures effects microbial activity and nitrification, with rates greatly reduced below 10 Celsius, and low pH (<5.5). Corn roots assimilate N from soils in either the NH₄ or NO₃ forms, but nitrification occurs quickly in warm soils in the spring, and ammonium (NH₄) does not remain in the stable form after soil temperatures increase in the spring. Because of this, most corn plants assimilate the bulk of applied N fertilizers as NO₃. However, with rainfall, the nitrate can be leached with percolating water or converted to N₂O through denitrification (Chang et al., 2016).

Denitrification is the major pathway of N loss and N₂O emissions from most fine-textured soils in warm and wet areas of the U.S. Midwest. Denitrification rates are highest in warmer soils (above 16°C) with higher pH values (>7); with little denitrification occurring in low pH (<5) cool soils (below 4°C). An alternative loss mechanism is ammonia volatilization. Following the application of urea to soil, the enzyme urease converts urea to ammonia, which can be volatilized (Clay et al., 1990a, 1990b; Chang et al., 2016, 2017). Volatilization can be reduced by using urease inhibitors (Clay et al., 1990a). In past research, most research projects focused on nitrous oxide emissions or ammonia volatilization, not both. The ability to evaluate the impacts of N fertilizer

management on N₂O and NH₃ emissions on a near continuous basis, has been made possible by hardware and software capable of collecting and analyzing data from targeted experiments. The objective of this study was to determine the influence of fall fertilizer application timings on nitrous oxide emissions and ammonia volatilization.

Materials and Methods

Gas Sampling Protocol

A field study was conducted at the Aurora Research Farm near Aurora, South Dakota. The soil series was a Brandt silty clay loam managed under a conservation tillage program. Additional information on this soil is available in Kim et al. (2008). The total area of the experiment was approximately ten square meters in which all of the chambers were placed. The chamber base was a 203 mm diameter PVC ring. Eight long term chambers (LI-COR 8100-104, LI-COR, Lincoln, NE, USA) were installed, according to LI-COR protocol. The chambers were placed on flat, barren soil with no vegetation or residue present in a random pattern (Fig. 1). Each treatment was replicated twice and the treatments were randomly located in the field. The chambers sampled one at a time, in a designated sequence. Individual chambers were analyzed every four hours for a total of six readings conducted every day per chamber. Gas samples were collected and subsampled using a LI-COR LI-8100 Automated Soil CO₂ Flux System (LI-COR, Lincoln, NE, USA), and transferred through a sampling harness to the Picarro Cavity Ringdown Spectrometer model G2508 (Picarro) (Picarro Inc., Santa Clara, CA, USA). The Picarro determined the concentration of N₂O, CO₂, and NH₃ in the chambers. On a regular interval, the calibration of the Picarro was checked with standards. Nitrous oxide and carbon dioxide were measured at parts per million (ppm) and ammonia was measured at parts per billion (ppb). Soil moisture was measured using LI-COR 8100-204 Soil Moisture Probes (LI-COR, Lincoln, NE, USA). Temperature was measured using LI-COR 8150-203 Soil Temperature Thermistor probes (LI-COR, Lincoln, NE, USA). The soil moisture and temperature probes were inserted into the soil approximately sixty mm and attached to the chambers.

Calculation of Flux

Calculations of flux were performed according to LI-COR protocols. Corrections were applied for individual long term chamber offsets as called for by LI-COR protocols. Flux was calculated using LI-COR SoilFluxPro™ software (ver. 4.0.1) (LI-COR, Lincoln, NE, USA). Calculations were slightly different for the different gases. For N₂O and NH₃, gas flux was calculated from 45 seconds to 900 seconds after closing the chamber, whereas for CO₂, flux was calculated from 45 seconds to 165 seconds after closing the chamber. Anova and Fisher LSD were used for statistical analysis.

Treatments

The experiment was repeated three times during the fall of 2017. The treatments were applied on September 20, 2017 (September), October 11, 2017 (October), and November 1 (November). Air temperatures at fertilizer application were approximately 17 C, 2 C, and 0 C, in

September, October, and November, respectively. For each application, the chambers were moved less than 5 m (Fig 1).

The four treatments were two N rates (0 and 224 kg urea-N/ha) and two soil moisture regimes (natural rainfall and natural rainfall + supplemental water). The supplemental water treatment was used to increase the soil water content to > 60% water filled porosity. Each treatment was replicated twice.



Fig. 1. Setup and configuration of Picarro Spectrometer and LI-COR chamber units at the Aurora Research Farm, Fall 2017. Picarro and LI-COR analysis equipment was housed in white weatherproof trailer in background.

Results and discussion

Carbon dioxide emissions from the control decreased as the season progress from September to November (Fig. 2). This decrease was attributed to decreasing activity with decreasing temperature. Others have reported similar results (Chang et al., 2016. 2017).

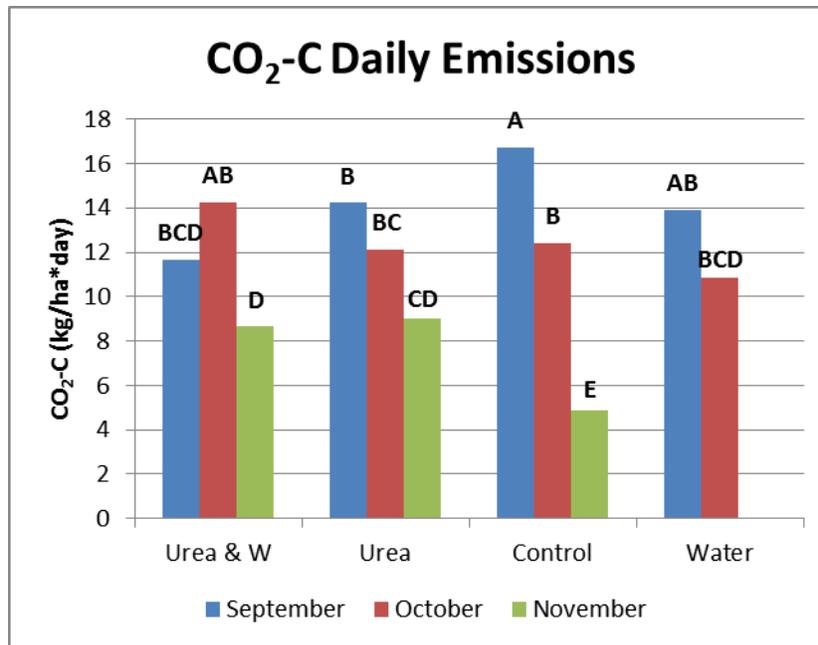


Fig. 2. CO₂-C daily emission rates indicating a decrease soil microbial activity rate as temperatures cooled throughout the fall. These rates also corresponded to decreasing nitrous oxide daily emission rates. Application dates were September 20, October 11, and November 1.

The application of urea increased N₂O and NH₃ emissions (Fig. 3, 4). In the fertilized treatments, N₂O emissions were highest at the first application date. As the season progressed, N₂O emission decreased. Different results were observed for the ammonia, where emissions increased from September application to October (Fig. 4). These results suggest that interactions between the biological and chemical processes impacted N₂O and NH₃ emissions. In the urea treatment, when CO₂ emissions were high, nitrous oxide emissions were high. Associated with the high CO₂ and N₂O emissions were relatively low ammonia volatilization losses. In the urea treatment, as the season progress from September to October, CO₂ and N₂O emissions decreased. However, associated with this decrease was associated with a stable amount of ammonia volatilization. All emissions in November were relatively low as soil temperature was near or below 0 Celsius.

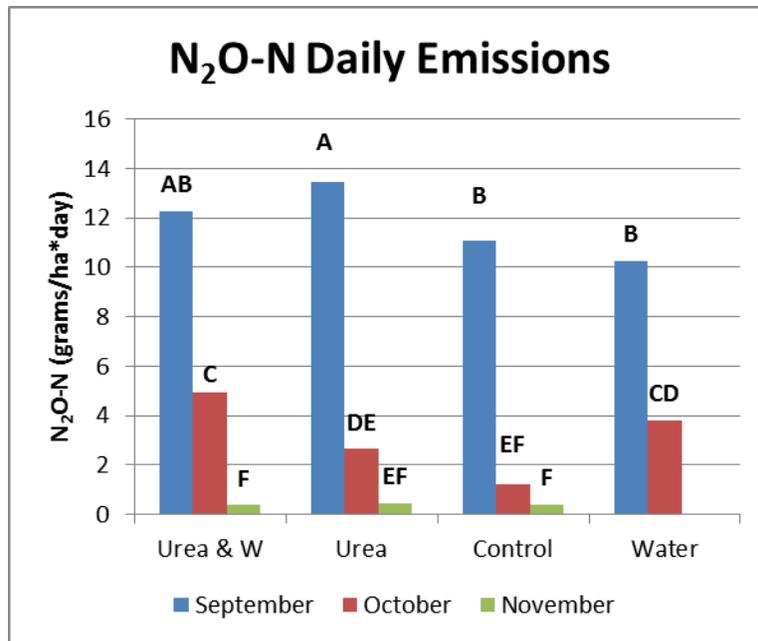


Fig. 3. Daily N₂O-N emissions in a month by month basis indicating a decrease in emissions when N was applied at later dates. Application dates were September 20, October 11, and November 1.

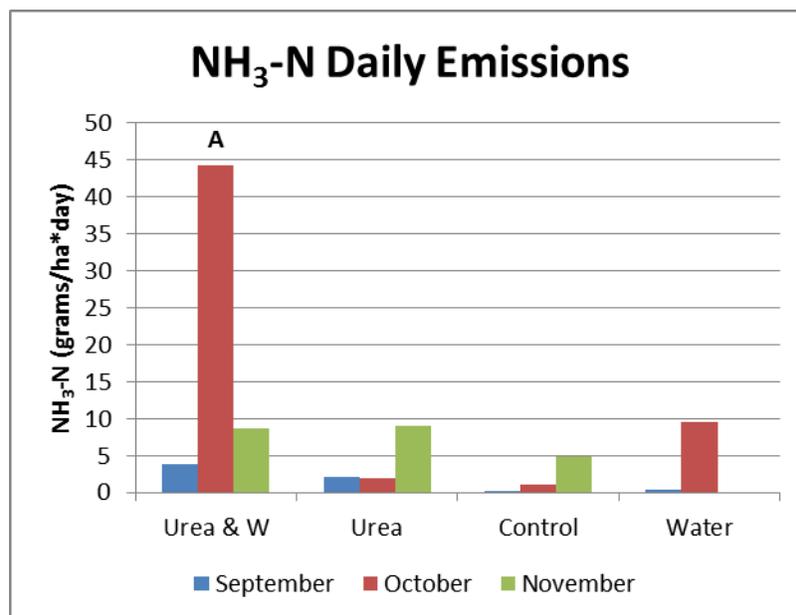


Fig. 4. Daily NH₃-N emissions in a month by month basis indicating an increase in emissions as the temperatures cooled down throughout the fall. Application dates were September 20, October 11, and November 1.

These findings suggest that when respiration was high in the urea treatment, N₂O emissions were high and NH₃ emissions were low. Decreasing the temperature, from September to October reduced N₂O and CO₂, but did not influence NH₃ emissions.

The water treatments did not directly follow the conceptual model proposed by Linn and Doran (1984). Differences between the Linn and Doran (1984) conceptual model and the observed results are attributed to spatial variability, that impacted water and oxygen movement in the soil.

Conclusions

N₂O-N daily emissions decreased as the monthly air and soil temperatures decreased (Fig. 2). September had the highest N₂O-N emission rate in grams/ha×day in all four treatments. Air temperature in September at the time of fertilizer application was 17 C, followed by 2 C and 0 C in October and November, respectively. N₂O-N daily emissions appeared to decrease by month as temperatures decreased.

NH₃-N daily emissions increased as air temperatures cooled, with the urea plus water treatment demonstrating a jump in emissions from September to October (Fig. 4). The urea and control treatments demonstrated increases in NH₃-N daily emissions between the first two months and November, indicating a shift from biological loss to chemical loss and emissions as microbial activity slows down in the cooling soils.

CO₂ daily emissions demonstrated a general trend of decreasing biological activity as the air temperatures cooled over the three months of sampling (Fig. 2). As microbial respiration decreased over the months, microbial denitrification slowed down and N₂O-N emissions decreased accordingly. These findings demonstrate that to reduce N losses, the entire system must be understood. Recent technology improvements provide an opportunity to quantitatively measure the impact of management on multiple loss mechanisms.

Citations

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