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Sensor-based variable-rate N on corn reduced nitrous oxide emissions

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Abstract. *More nitrogen fertilizer is applied to corn than to all other U.S. crops combined, contributing to atmospheric heat trapping when nitrous oxide is produced. Higher nitrogen rate is well known to increase nitrous oxide emissions, and earlier N application time may increase the window during which nitrous oxide can form. An experiment was initiated in 2012 comparing nitrogen management and drainage effects on corn yield and nitrous oxide emissions. Two nitrogen treatments were used: 140 lb N/acre applied before planting, and N applied variably when corn was knee-high with N rate guided by canopy sensors. Little nitrous oxide was released in 2012, a drought year. In 2013, in-season N application reduced nitrous oxide emissions by 75% compared to pre-plant N application; in 2014 the reduction was 40%. In both years, in-season N application increased corn yield by nearly 20 bushels/acre relative to pre-plant application. Nitrate concentration in drainage water was also reduced.*

Keywords. *Denitrification, carbon footprint, heat trapping potential, canopy sensor, reflectance sensor, variable-rate nitrogen, economically optimal nitrogen rate (EONR).*

Introduction

In the U.S., nitrous oxide (N_2O) impairment of the atmosphere is dominated by agriculture, and specifically by nitrogen fertilizer (Aneja et al., 2009). Approximately 7 million tons of N are applied to cropland in the Mississippi River basin each year. Corn receives more of this N fertilizer than all other crops put together.

Nitrous oxide is an atmospheric impairment mainly due to its ability to capture infrared radiation that would otherwise leave the Earth. Elevated levels of nitrous oxide in the atmosphere will contribute to elevated heat capture and global warming. In the U.S., the global warming contribution of nitrous oxide from agriculture is dwarfed by carbon dioxide from fossil fuel combustion; however, **nitrous oxide remains the largest global warming contribution originating from U.S. agriculture**—greater than fuel burned in agriculture.

Nitrous oxide is produced mainly by biological processes in soil. It can be produced during both nitrate reduction (denitrification) and ammonia oxidation (nitrification), but evidence is good that denitrification is the dominant process (Ostrom et al., 2010; Zhu et al., 2013). Denitrification is rapid when soils are wet and warm.

When the N fertilizer rate exceeds crop needs, nitrous oxide emissions may go up non-linearly (Hoben et al., 2011). Later N applications may also result in lower N_2O emissions (Sainz Rojas et al., 2001). Relative to the dominant Corn Belt practice of applying all N fertilizer before planting at a uniform and generous rate, **sensor-based sidedress has the potential to reduce N_2O emissions through both improved rate and improved timing**.

Methods

This experiment was initiated in 2012 at the Bradford Research Center near Columbia, Missouri, U.S.A. Cropping system is continuous no-till corn (maize). The soil is a Vertic Epiaqualf. A high-clay (>50%) argillic horizon is found at about 16-18 inch depth.

Treatments are nitrogen management and drainage in an incomplete factorial design. Plot dimensions are 40 feet by 200 feet (Figure 1), large enough to manage spatial variability within plots (undrained plots are 50 feet wide). Only nitrogen management treatments will be reported in this paper. There were two nitrogen management treatments:

1) 140 lb N ac-1 applied pre-plant, and

2) sensor-based N rate at stage V7 (about 18-20 inch height).

In addition, a high-N reference area was established adjacent to the experiment using broadcast ammonium nitrate as the N source at a rate of 200 lb N ac^{-1}.

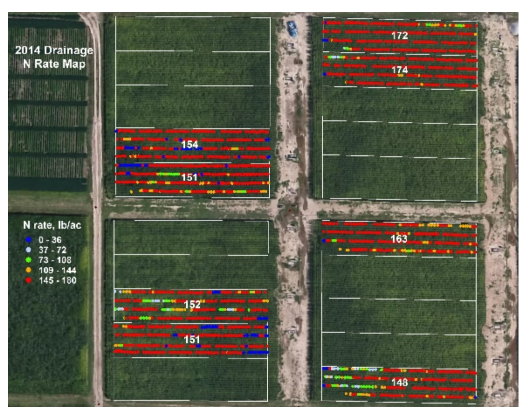

Figure 1. Aerial photo of the experiment with plot boundaries overlaid. N rates based on canopy sensors in 2014 are shown.

Both treatments were applied as urea-ammonium nitrate solution injected to a depth of about 2 inches. The sensor-based N treatment was applied as a real-time variable-rate N application with N rate based on the stream of sensor data. Three Crop Circle ACS-210 sensors were positioned about 20 inches above the canopy. Measurements were taken from the high-N reference area to get the reference reflectance for use in calculating N rate. Custom software averaged the readings from the three sensors each second and calculated N rate using the equation of Scharf et al. (2011). N rates from this software were used to control a Capstan pulse-width-modulation valve system. Rates applied in 2014 are shown in Fig. 1.

Figure 2. Water flow measurement and sampling installation.

Drainage tile is installed at an average depth of 16 inches at a spacing of 20 feet. Shallow placement and close spacing was an attempt to overcome the low saturated hydraulic conductivity of the subsoil at this site.

Each drained plot has two 3-inch diameter tile laterals emptying into a sub-main of 4-inch diameter. Controlled-drainage treatments have a control structure installed in this submain. Water from each sub-main empties into a collection barrel placed in a subsurface concrete box at the end of each plot (Figure 2). The barrel has a float which triggers an electric pump when the barrel is nearly full. A flow meter measures the volume of water pumped out of the barrel, and a passive splitter takes about 0.1% of the flow to a covered bucket. During periods of drain flow, the flow meter value is recorded each 1 to 2 weeks. At the same time, a water sample is taken from the bucket and the bucket is emptied. Water samples are analysed for nitrate concentration on an autoanalyzer using Cd reduction and the Griess-Ilosvay colorimetric reaction.

Nitrous oxide flux is measured weekly from all plots during and slightly before and after the growing season, except following fertilization and saturating rain events, when flux is measured twice weekly if possible. An aluminium anchor measuring 30 x 10 inches is installed in each plot, with the long dimension running from one corn row to the next (Figure 3). The anchor protrudes from the soil about half an inch and is uncovered except during flux measurements. To measure flux, a gutter around the top of the anchor is filled with water, creating a seal when the lid is set down on the anchor. A LumaSense Technologies photoacoustic spectrometer is connected to the interior of the flux chamber through two small ports with fine tubing. For 14 minutes, chamber gas is pumped out through the spectrometer and back into the chamber, with nitrous oxide concentration measurements occurring every two minutes. Nitrous oxide flux rate is calculated from the time course of nitrous oxide concentration inside the chamber.

Figure 3. Nitrous oxide concentration measurements are made for 14 minutes under a chamber that spans from one row to the next using a photoacoustic spectrometer. The measurement area is uncovered except during flux measurements.

Results

A severe season-long drought in 2012 limited yields to below 30 bushels acre^{-1}. No drainage was recorded, and nitrous oxide emissions were minimal until an early-September rainfall from the aftermath of hurricane Isaac, which resulted in substantial emissions from a single plot.

Under dry conditions, differences in reflectance between the high-N reference area and the plots to be fertilized were relatively small, leading to low average N rate (102 lb N acre^{-1}) based on sensors.

In 2013 and 2014, early-season rainfall was plentiful or excessive, leading to some loss of preplant N. Yields were average for our climate and this soil. In both years, average sensor-based N rate exceeded the preplant N rate by about 10%. I interpret this to mean that sensors were detecting the loss of soil-derived N and compensating for it. Yields with sensor-based N also exceeded yields with preplant N by about 10%.

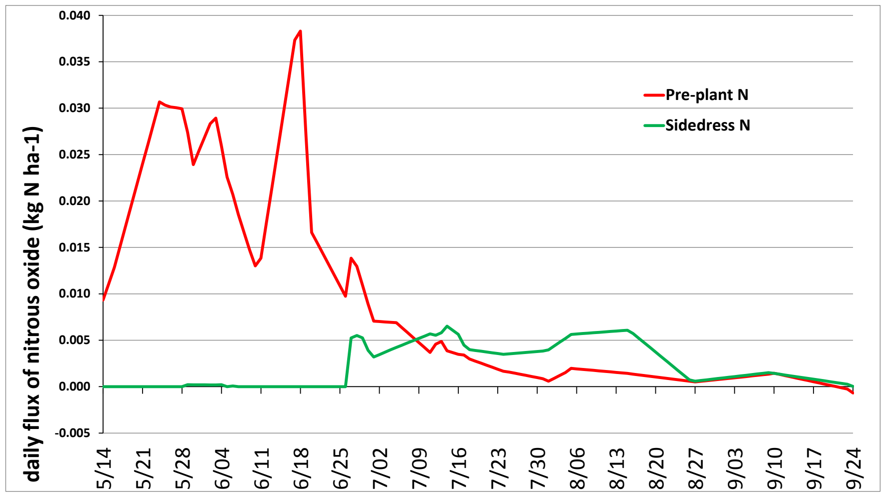

Figure 4. Interpolated flux of nitrous oxide under the two different nitrogen management treatments in 2013. Relative to preplant N application, variable-rate sidedress N application reduced season-long flux by 75%, from 1.2 kg N ha^{-1} to 0.3 kg N ha^{-1}. Flux from sidedress plots prior to N application was low, and was subtracted from both treatments as representing nitrous oxide evolution from non-fertilizer N.

Nitrous oxide flux was significantly lower in both 2013 and 2014 with sensor-based variable-rate N than with preplant N, despite slightly higher rates of N application. This appeared to be mainly an effect of N timing. Substantial nitrous oxide was evolved from plots receiving preplant N before any N was applied to the sidedress treatments (which received zero N until the sidedress N application) (Figure 4). Nitrous oxide emissions after the sidedress N application were modest in 2013 because rainfall was sparse and soil moisture was low. Season-long emissions were 75% lower with variable-rate sidedress N than with preplant N ($p = 0.0007$).

In contrast, emissions after sidedress application were higher in 2014 due to abundant rainfall in the two weeks after sidedress. The large difference in emissions prior to the application of sidedress N was similar to 2013, but emissions from both N treatments were high and similar after sidedress N was applied. The emissions reduction was thus smaller than in 2013, with 40% less N_2O ($p = 0.08$) released from plots receiving variable-rate sidedress N than from plots receiving preplant N.

Conclusion or Summary

When averaged over the 3-year period, the two N management systems used almost exactly the same total amount of N, but sensor-based management produced higher yield. It also resulted in a substantial (60%) reduction in nitrous oxide emissions in the two years where emissions were observed, and a modest (23%) reduction in flow-weighted nitrate concentration in drainage water.

Table 1. Yield, N rate, nitrous oxide emissions, and drainage water nitrate concentration for two N management systems over three years.

Year(s)	N management system	Yield (bu ac^{-1})	N rate (lb N ac^{-1})	N_2O emitted (lb N ac^{-1})	Flow-weighted nitrate conc. (ppm)
2012	140 lb N ac^{-1} preplant	30	140	0.0	--
	Sensor-based at knee high	31	102	0.2	--
2013	140 lb N ac^{-1} preplant	125	140	1.2	18
	Sensor-based at knee high	142	155	0.3	13
2014	140 lb N ac^{-1} preplant	132	140	1.0	13
	Sensor-based at knee high	151	158	0.6	11

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