EFFECTS OF NITROGEN MANAGEMENT ON MAIZE YIELD AND NITRATE LEACHING ON IRRIGATED SANDY SOILS

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Abstract

Irrigated sands are some of the most productive and environmentally sensitive areas in Minnesota. Reducing nitrate leaching is critical for corn (*Zea mays* L.) production as ground water is a major source of drinking water in these soils. The objective of this study was to evaluate agricultural technologies that may improve nitrogen (N) management for profitable corn production and mitigate negative effects in groundwater. A randomized complete block design with four replications was established in Dakota County, MN with continuous corn (C-C) and in Pope County, MN with corn after soybeans (C-S), soybean after corn (S-C) and C-C with urea broadcast at rates of 0, 45, 90, 135, 180, 225, 270, and 315 kg N ha^{-1} as a split applications, half of the rate at pre-plant and half at V4 development stage. Two additional N sources: Super U at 180 kgN ha^{-1} and ESN at 180 and 225 kg N ha^{-1} were applied at planting. Crop canopy was sensed with SPAD meter, GreenSeeker, and Crop Circle technologies. Whole plant dry biomass and N concentrations were measured at the V8 and V12 development stages. Grain N content and yield were determined at harvest. Soil water below the root zone was collected from suction cup lysimeters weekly throughout the growing season for nitrate (NO_3-N) analysis. Yield was effectively predicted (R^2 between 0.59 and 0.89) with the use of SPAD meter and Crop Circle. The Maximum Return to N (MTRN) rate ranged from 240 to 270 kg N ha^{-1} between the two locations. In Pope County in 2013 season-long mean water NO_3-N concentrations in mg L^{-1} and load (between parenthesis in kg N ha^{-1}) were 36.7 (52) for C-S, 16.6 (27) for S-C, and 23.8 (32) for C-C. In C-C increasing N rate from 135 to 270 kg N ha^{-1} increased NO3-N load from 29 to 33 kg N ha^{-1} while yield increased from 11.9 to 12.9 Mg ha^{-1}. No concentration or load differences occurred with different N sources.

Introduction

Minnesota has a large portion of its agricultural production in irrigated sandy soils, approximately 202,500 ha. These soils are formed from glacial outwash, and are characterized by their coarse texture and high capacity for leaching. At least half of these hectares are in corn production each year. Nitrogen is of large importance for corn grown on these soils because it is often the most limiting nutrient for the crop and because of the risks associated with groundwater contamination. Nitrate contamination of groundwater is widespread, and much of the population in the Upper Midwest depends on ground water for its drinking water supply (Gehl et al., 2005). Nitrate in drinking water possess potential human health concerns. The drinking water standard for water nitrate concentration is 10 ppm (US EPA, 2012). Young children and infants who ingest water containing nitrate levels above the drinking water standard may suffer shortness of breath and methemoglobinemia, also known as Blue Baby Syndrome, which can be fatal (US EPA, 2012).

Further, because sandy soils have high infiltration rates and low water holding capacities, corn grown on this soil type is commonly irrigated. Supplemental irrigation has potential to greatly increase corn grain yield (Wienhold et al., 1995), but also has the potential to move nitrate-N though the soil profile and below the rooting zone (Smika et al., 1977). Once nitrate is moved below the rooting zone, it cannot be taken up by the crop before it enters the groundwater. To ensure a safe drinking water supply, best management practices should be identified and followed (Klocke et al., 1999). For this reason, the objective of this study is to evaluate agricultural technologies that may improve N management for profitable corn production in sandy irrigated fields and mitigate negative effects in groundwater.

Materials and Methods

Field trials were conducted in 2013 and 2014 in two counties in Minnesota. In Dakota County the study was established on a Sparta loamy fine sand (sandy, mixed, mesic, Entic Hapludolls) in 2013 and on a Waukegan silt loam (fine-silty over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls) in 2014. In Pope County the study was conducted in the same field on an Estherville Loam (sandy, mixed, mesic, Typic Hapludolls) with a sandy/ gravelly outwash parent material. The slope at both sites is between 0 and 2%. All locations were sprinkler irrigated.

The Dakota County location is in a continuous corn (C-C) rotation both growing seasons. At the Pope County location there was a corn-soybean (C-S), soybean-corn (S-C), and C-C crop rotation. Nitrogen fertilizer treatments were applied in the same plots each year of the experiment except when soybean was grown, in which case the residual N effect from the previous application to corn was measured.

All plots were 4.56 meters (six-76 cm row spacing) by 12.2 meters. The same 12 fertilizer treatments are applied in all site-years as a broadcast application. Eight treatments included urea (46-0-0) at 45 kg N ha^{-1} rate increments from 45 to 315 kg N ha^{-1} and a check plot with no N applied. Each of these rates was split-applied with half the rate pre-plant and the other half at V4 development stage. Four additional treatments were applied at pre-plant: 180 and 225 kg N ha^{-1} as polymer-coated urea (ESN) (44-0-0), 180 kg N ha^{-1} as Super U (46-0-0), and a blend of 90 kg N ha^{-1} as urea and 90 kg N ha^{-1} as ESN. Treatments were arranged in a randomized, complete block with four replications.

Primary tillage is done with a chisel plow in the fall and with a field cultivator in the spring at both locations. In Dakota County corn hybrid Pioneer P0533AMI was planted on 10 May 2013 and 7 May 2014. In Pope County corn hybrid Dekalb DKC 50-77 RIB was planted on 20 May 2013 and on 15 May 2014. Pests were controlled using farmer practices. Irrigation at each location was scheduled based on rainfall, plant water use, and soil conditions.

After emergence of corn plants, stand counts were taken by counting the number of plants emerged in 12.2 meters of row. At the V8 and V12 corn development stages, and at physiological maturity (Abendroth et al., 2011), six plants were collected by cutting the plants at the soil surface, passing through a chipper with a 0.5 cm screen, dried at 60°C, and weighed. Samples were then mixed, subsampled, and ground with a Thomas Wiley mill with a 2mm-sized screen.

At the Pope County location soybeans were sampled at the R6 development stage by cutting at the soil surface all plants in a 1.8 meters of row. The plants were then processes in a similar way as corn.

All ground whole plant samples are analyzed at the University of Minnesota Research Analytic Laboratory for total N.

Corn plants are sensed with Greenseeker (Trimble Navigation Limited, Sunnyvale, CA) and Crop Circle (Holland Scientific, Inc., Lincoln, NE) canopy sensors at the V8 and V12 development stages by holding each device approximately 40 cm above the crop canopy on top of the row and walking the length of the two center harvest-rows in each plot to avoid border effects. Within these rows the leaf opposite and below the ear of 30 randomly selected plants is sampled with a SPAD chlorophyll meter (Konica Minolta, Inc., Tokyo, JP).

Suction tube lysimeters were installed permanently at the Pope County location in 2011 and just for the growing season at the Dakota County location for nitrate-N leachate sampling at selected treatments including the control, 135-270 kg N ha^{-1} as urea, and the SuperU, ESN, and ESN/urea blend each at 180 kg N ha^{-1}. Each plot contained three lysimeters in order to improve accuracy of nitrate concentration data of the extracted soil water. The body of each suction tube lysimeter consists of a polyvinylchloride pipe 3.8 cm in diameter. The suction cup lysimeters are buried at depths between 1.2 m and 1.8 meters below the soil surface. Tubes used for water extraction and pressurizing are encased in additional polyvinylchloride piping in order to protect them from damage. At the soil surface, the flexible tubes are folded shut, and are accessible by removing a sleeve of protective PVC piping.

The suction tube lysimeters are placed under a vacuum pressure in order to draw water from the soil into the tube bodies (Weihermuller et al., 2007). Water sampling is performed weekly for the entire growing season. In order to measure the amount of nitrate that leached past the root zone, a measure of the depth of water which drained through the soil profile was taken by the use of six passive capillary lysimeters, marketed as Drain Gauges (Decagon Devices, Inc., Pullman, WA). The passive capillary lysimeters were permanently installed during the previous 2011 growing season and at the Pope County location.

The mass of nitrate leached past the rooting zone can be calculated using the amount of water that moves past the root zone and the concentration of nitrate in the water (Smika et al., 1977). Data was collected from the passive capillary lysimeters at 21 dates during the 2013 growing season.

The mass of nitrate leached through the soil is calculated by multiplying the mean nitrate concentration value on a mass/mass basis by the mass of water leached past the root zone (Gehl et al., 2005).

$$N = C \times q$$

With N equaling the mass of nitrate-N lost through leaching, C is the nitrate-N concentration in the leachate, and q is the quantity of water leached. The mass of nitrate leached per day is calculated by dividing the total nitrate loss in each drainage gauge sampling time period by the total amount of days in that period. The annual nitrate mass loss is calculated by summing the loss from the 21 individual passive capillary lysimeter sampling dates.

The soil was sampled at each site in the fall following harvest using a vehicle-mounted hydraulic soil probe. Soil samples are collected from each corn plot and no soybean plots. In each plot, two soil cores are taken. At the Dakota County location, the cores are taken to a depth of 120 cm. These cores are divided into depths of 0-30, 30-60, 60-90, and 90-120 cm. Because the subsoil at the Pope County site is gravelly, soil cores were only taken at depths of 0-30 and 30-60 cm. The samples from each depth are then mixed to make one representative sample. The samples were dried in an oven at 35 degrees Celsius. The samples were then analyzed for nitrate-N.

All statistics were calculated in R.

Results

The data reported represents only the 2013 growing season as the proceedings paper was written before all the 2014 data were compiled. Thus, the discussion in this report can be considered only preliminary.

Nitrate leaching

In 2013 there were 21 sampling dates from the lysimeters to collect NO3-N leachate at the Pope County location and 13 sampling dates at the Dakota County location. Throughout the collection there were some days where no sample could be retrieved from certain lysimeters because of very low soil moisture. These values were left blank when calculating statistics. We are unable to calculate nitrate load in kg ha $^{-1}$ for Dakota County because of the missing drainage gauge value, the average concentration of this site was 15.11 (mg/L) with no significant difference between treatments. Variability in nitrate concentrations were great, with many plots having been fertilized in smaller amounts having greater nitrate leachate concentrations (Figure 1, 2, and 3).

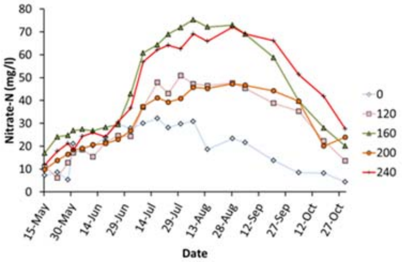

Figure 1: Corn after soybean nitrate concentrations through the 2013 growing season in Pope County.

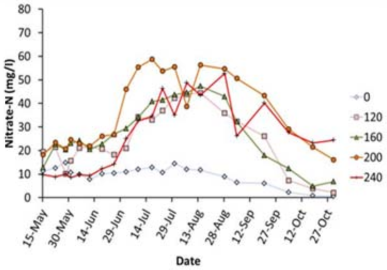

Figure 2: Continuous corn nitrate concentrations through the 2013 growing season in Pope County.

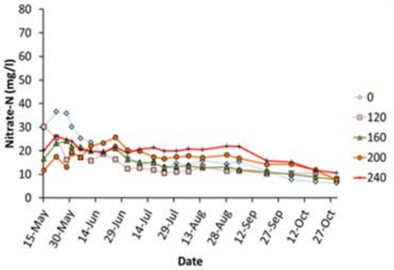

Figure 3: Soybean after corn nitrate concentrations through the 2013 growing season in Pope County.

As seen above there is a decrease in NO_3-N concentrations around mid-August even though the crop is still growing at that point. We believe this is because there is less precipitation and higher evapotranspiration during this time so less water is moving through the soil profile.

Using the drainage gauge values from Pope County we were able to determine the load in kg/ha^{-1} lost. This was calculated by the equation below.

> NO3-N (lb/ac) lost = (Drainage in inches)*27154 (gal/ac in)*8 (lb/gal))*(Nitrate Concentration/1000000)

With our best management practice recommendation of 179 kg ha^{-1} split application we looked at four treatments at 179 kg ha^{-1}. We have found that in 2013 there was no significant difference between any of the treatments in NO_3-N concentration or load lost (Table 1). We also compared the concentration and load for each cropping system at Pope County finding only difference was in the corn after soybean system (Table 2).

Table 1: Sources of nitrogen comparing NO3-N (mg/L) of leachate and NO3-N (kg/ha^{-1}) load lost in Pope County 2013.

Source at 179 (kg ha^{-1})(2013)	NO_3-N (mg/l)	NO_3-N (kg ha^{-1})
Urea	21.9 a	30.1 a
ESN	29.2 a	39.2 a
ESN/Urea	29.3 a	42.0 a
SuperU	30.3 a	36.2 a

Table 2: Season average load and concentration comparison at Pope County in 2013.

	Load vs Concentration in Pope County 2013		
	C-S	S-C	C-C
NO3-N (mg/L)	36.7 a	16.6 b	23.8 b
NO3-N (kg ha^{-1})	51.5 a	26.9 b	32.3 b

We believe there that the reason we are not seeing significant data results for the Dakota County site is because the suction sup lysimeters are taken out each year and put back in in the spring. This means that the soil is being disturbed every year which would not be representative of a normal field situation. On the other hand the Pope County site lysimeters were installed in 2011 and have not been disturbed since, this may be why the data is more significant at that site versus Dakota County.

Sensing

Three different optical sensors were used to measure greenness of the crop in this study. It was found that the SPAD meter accurately predicted yield with an R2 of 0.68 at V8 and 0.89 at V12 (Figure 4). The Crop Circle predicted yield with an R2 of 0.59 at V8 and 0.49 at V12 (Figure 5). However the Green Seeker did not accurately predict yield at V12 with an R2 of 0.38 (Figure 6). This may be because the sensor is not sensitive enough to detect differences at this growth stage of the tassels have already emerged and the color of the tassels is what the sensor is picking up.

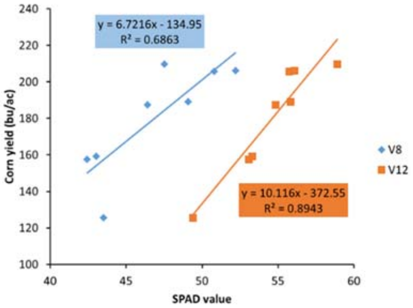

Figure 4: SPAD meter correlation between V8 and V12 growth stages on the continuous corn rotation in Pope County 2013.

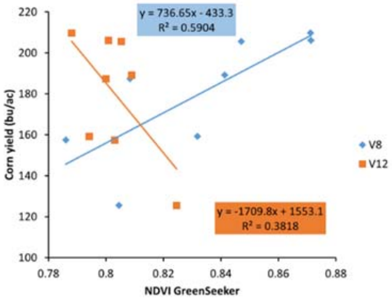

Figure 5: GreenSeeker correlation between V8 and V12 growth stages on the continuous corn rotation in Pope County 2013.

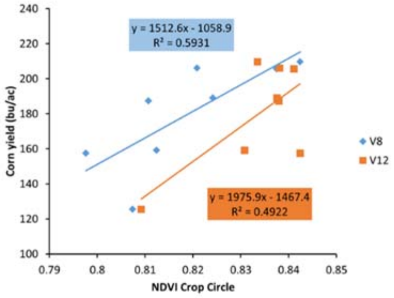

Figure 6: Crop Circle correlation between V8 and V12 growth stages on the continuous corn rotation in Pope County 2013.

Yield

Grain yield increased with increasing N rate in all plots with corn. Only the soybeans had no significant increase with increasing N rate. Dakota County had a Economic Optimum Nitrogen Rate (EONR) of 247.7 pounds N per acre (277 kg ha^{-1}) with a EONR yield of 204 bushels per acre (228.48 kg ha^{-1}). Pope County in the continous corn had a EONR of 248 pounds N per acre (277.76 kg ha^{-1}) and a yield of 207 bushels per acre (231 kg ha^{-1}) (Figure 7). The corn after soybean rotation had a EONR of 236 pounds N per acre (264.32 kg ha^{-1}) and a yield of 207 bushels per acre (231 kg ha^{-1}) (Figure 8). We can see that for each location and cropping system there is not a large difference between yield and econimic optimum nitrgoen rate applied.

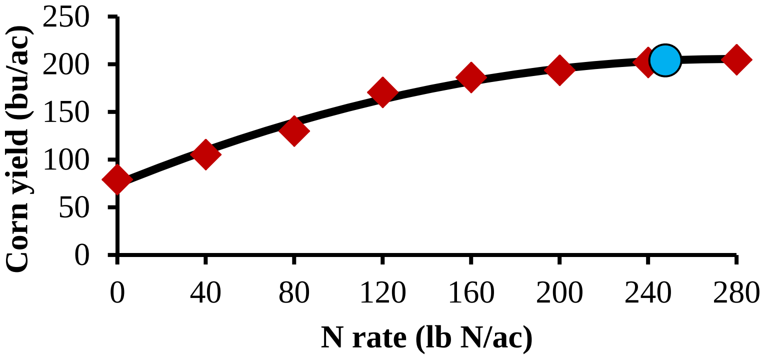

Figure 7: Continuous corn yield in bushels per acre by nitrogen applied in pounds per acre, with predicted yield and EONR yield for Pope County in 2013

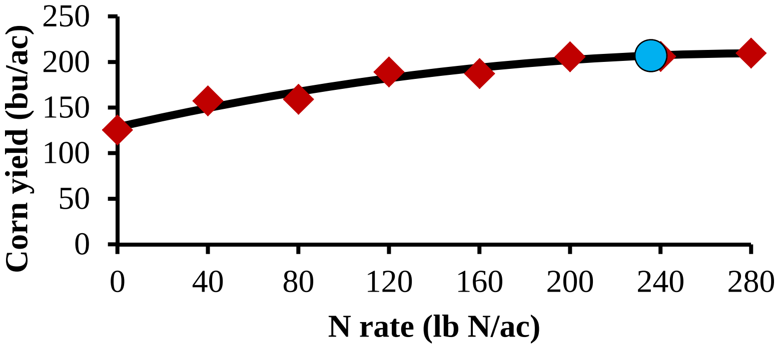

Figure 8: Corn after soybean yield in bushels per acre by nitrogen applied in pounds per acre, with predicted yield and EONR yield for Pope County in 2013.

Soil N

After the growing season is finished, residual soil nitrate (RSN) remains in the soil because the crop did not demand it or was unable to uptake it. Increased applied N rates in the spring will often result in increased RSN in the fall post-harvest (Wortmann et al., 2011). All plots fertilized at N rates of 0, 134, 179, 224, and 314 kg ha-1 were sampled for RSN. The concentration of

RSN was generally greater when larger N rates were applied. Due to variation in the data and a relatively weak relationship between N rate and RSN, there was no significant difference between treatments. One reason for the lack of a significant relationship between N rate and RSN is that on sandy soil, much of the soil nitrate is able be lost though leaching during the growing season, which will result in lower RSN values in the fall (Gehl et al., 2006).

Conclusion

Irrigated sandy soils in Minnesota have the potential to be highly productive. These soils have less organic matter than heavier-textured soils, and they respond to applied N for a variety of measurements including N uptake and grain yield. NO_3-N leaching had no significant difference between cropping systems or with the use of different N products at the same rate, which leads us towards sticking with our best management practice recommendation of applying 179 kg of N per hectare with a split application at pre plant and at the V4 growth stage. This data shows that even with decreasing N application the amount of leaching is similar while the yield decreases. Unlike N uptake a, NDVI measurements often did not have a significant relationship to N rate. Leaf chlorophyll data had a strong response to applied N rate and was significant at each location for both the V8 and V12 growth stages. It is a useful tool for in-season crop measurements, and proved to be superior in comparison with the more easily acquired NDVI values. RSN tended to increase with increasing N rate but in comparison to the control treatment there was no significant difference between treatments, leaving small amounts left in the soil at the end of the growing season. The current 2014 growing season is coming to an end which will hopefully give us a greater trend to look at to help improve our recommendations.

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