Effect of variable rate irrigation and nitrogen fertilizer rates on crop productivity and water quality

2022 Annual Report—Second Year of a three Year Project (2021 corn growing season)

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Summary

Under reduced irrigation rates, nitrogen (N) fertilizer must be correspondingly adjusted to optimize economic crop production. However, in Minnesota, the combined effects of irrigation and N management on corn yield and nitrate leaching have not been extensively investigated. As one example, the current N recommendations in Minnesota are based on 100% irrigation or rainfed conditions. However, with increasing pressure on water resources and declining water quality, deficit/limited irrigation management practices are being promoted and used, which alters the N uptake by the crop. Will reduction in irrigation rates (using deficit irrigation management) reduce the N fertilizer requirement and thus nitrate leaching? What is the best irrigation and nitrogen management combination practice that will maintain optimum crop yields while reducing nitrate leaching? These are the questions that irrigators and key agricultural stakeholders have and we do not have the answers to. So our goal is to develop research-based irrigation and N management data, information and fundamental relationships that will help farmers to make better on-farm management decisions, government agencies to develop policy/rules, and researchers to advance the sensor-based (proximal and remote sensing) irrigation and N management research. This report discussed the results from the first growing season of this study.

Background

In Minnesota, the interest in deficit/limited and variable rate irrigation management, to address/reduce water quality and quantity problems, has been increasing amongst farmers, agricultural professionals and key stakeholders. However, it's challenging to understand, how much reduction in irrigation rate as compared to full irrigation and what amount of nitrogen (N) fertilizer is optimum, under that reduced irrigation rate, for sustainable crop production. Consequently, when farmers use deficit irrigation amounts in combination with recommended N rates that are developed under well-watered conditions, plants cannot utilize all the N applied and thus the remaining can be lost in the environment.

Water quality and quantity issues in irrigated regions of the state have led to scrutiny of groundwater by the government, leading to the development of new regulatory approaches and groundwater policies. One such regulation is the Groundwater Protection Rule developed by the Minnesota Department of Agriculture (MDA) that would regulate the N fertilizer use in the areas that are vulnerable to groundwater contamination. Such rules are important in order to reduce the impact of agriculture on the environment but at the same time, requires robust and evolving research based scientific knowledge, specifically in the fields like irrigation that has not been explored much in Minnesota. An innovative research, that integrates N fertilizer and irrigation or crop water use, needs to be developed to back up these programs and rules with scientific research based knowledge and also help growers in efficient farm management.

Several researches have investigated the combined effect of irrigation and N on crop production, nitrate leaching and water use efficiency, and found that N and water are codependent management factors that cannot be evaluated independently (Al-Kaisi and Yin, 2003; Pandey et al., 2000a; Pang et al. 1997). In these studies researchers found that crop water productivity (yield/water use) vary with varying rates of N and irrigation and that under deficit irrigation, N must be correspondingly adjusted to optimize economic crop production. However, most of this knowledge is based on research conducted in more arid regions where precipitation and the water balance of cropping systems are substantially different from those in Minnesota. To the best of our knowledge, very limited research has been done to investigate the N and irrigation interaction effect on nitrate leaching in corn cropping systems in Minnesota. One such research is Maharjan et al. (2014) who compared the effects of different N treatments for fully irrigated and minimum-irrigated corn in Becker, MN. They found greater yield-based nitrate leaching and lower grain yields in minimum-irrigated plots than fully irrigated plots. However, in their study, they used only one N rate (180 kg N/ha) under two irrigation levels with different types and timing of N fertilization.

Our overarching goal is to build capacity to provide government agencies, stakeholders and producers with scientific research-based irrigation and N management data, and information on fundamental relationships that help develop policy/rules, make better on-farm management decisions, and help advancing the sensor-based (proximal and remote sensing) irrigation and N management research. Since corn is one of the principle crops irrigated in Minnesota, our research will focus on continuous-corn cropping systems under sprinkler irrigation.

Major objectives of this study are to: 1) evaluate variable irrigation and N rate interaction effects on corn yield, nitrate-N leaching, crop evapotranspiration, crop water productivity, and water- and N-use efficiency; 2) develop corn evapotranspiration crop coefficient (Kc) curves for efficient irrigation management, and, 3) develop proximal and UAV remote sensing-based non-destructive in-season corn water and N status diagnosis methods and in-season variable rate N and irrigation management strategies.

Methods

Field plot experiments were conducted at the Sand Plain Research Farm (SPRF) in Becker, MN (45º 20' N, 93º 51' W) and Herman Rosholt farm (45° 42′ 49.07″ N; 95° 10′ 29.39″ W), in Westport, Minnesota (both sites are in vulnerable groundwater areas). Four (4) irrigation treatments and six (6) N rate treatments were evaluated, and replicated four (4) times (Figure 1). The irrigation treatments were: full irrigation (FI), i.e., imposing no water stress on the crop, 75% of FI, 50% of FI and rainfed conditions. The N application rates were 0, 70, 140, 210, 280 and 350 lb/ac. Irrigation was applied using a GPS guided variable rate linear move irrigation system at both locations. Urea- N fertilizer was applied to the plots in two splits, with 30% at V2, and 70% at V9 growth stages. The experimental design was a split-plot design with irrigation treatments as the main plot and N-rates as the sub-plot.

Above-ground plant biomass and N uptake were measured by taking plant samples from each plot at V8, R1 and R6 development stages to evaluate the effect of irrigation levels on N uptake under different nitrogen rates. Grain yield and grain N content were measured for total N balance and N use efficiency calculations by combine-harvesting the middle two rows of each plot.

Weekly nitrate-N concentrations below the root zone at 1.2 m depth was monitored with two lysimeters in each plot. We have installed 192 permanent suction cup lysimeters at each location (Figure 2).

A neutron moisture gauge was used to monitor soil moisture status for each plot in 1 ft intervals down to 4 ft soil depth to estimate crop evapotranspiration and drainage at different N rates under full irrigation, limited irrigations and rainfed conditions. General soil water balance approach followed by FAO-56 was used to calculate crop evapotranspiration (ETa) and drainage. Crop water use efficiency (CWUE), which is the ratio of yield (Y, kg/m2) to crop water use (ETa, mm) was estimated for each treatment.

Economic optimum N rate (EONR) was calculated using the regional N rate guideline approach with an N fertilizer to corn price ratio reflecting mean market prices.

Analysis of variance (ANOVA) was conducted using Proc Mixed in SAS. Fisher's Protected Least Significant Difference Test at a 95% confidence interval will be used to identify significant differences among mean grain yield and ETa of different treatments. The regression procedure will be used to test the heterogeneity of regression slopes of Irrigation and ETa on N fertilizer rates. The coefficient of determination (R^2) and standard deviation (SD) will also be used to assess potential treatment differences.

Crop coefficient (Kc) values are the ratio of soil water balance determined ETa and ETref from the Penman-Monteith equation: $\mathrm{K_c} = \frac{\mathrm{ET_a}}{\mathrm{ET_{ref}}}$. Since we do not have the complete dataset for three years, we have not developed these relationships yet. ETa will be calculated for each treatment as described in Task 1C. Daily reference evapotranspiration (ETref) will be calculated using the Penman-Monteith equation. The weather variable for calculating ETref will be obtained from the weather station at the research sites. Crop coefficients will be calculated for each treatment on a weekly basis. Crop coefficient curves as a function of cumulative growing degree days (GDD) will be developed for each irrigation and nitrogen combination treatments.

Sensing data was collected from each plot and related to soil moisture measured using neutron probe. The Crop Circle Phenom proximal sensor has three spectral bands and sensing capability to measure air temperature, crop canopy temperature, humidity, and LAI, relative chlorophyll content and photosynthetically active radiation (PAR) etc. This instrument was used to collect weekly measurements until V12. A UAV remote sensing system with an optical camera of 6 wavebands and FLIR thermal camera was used to monitor corn N and water status across the growing season. These data will be used together with ground truthing data to develop non-destructive N and water status diagnosis methods.

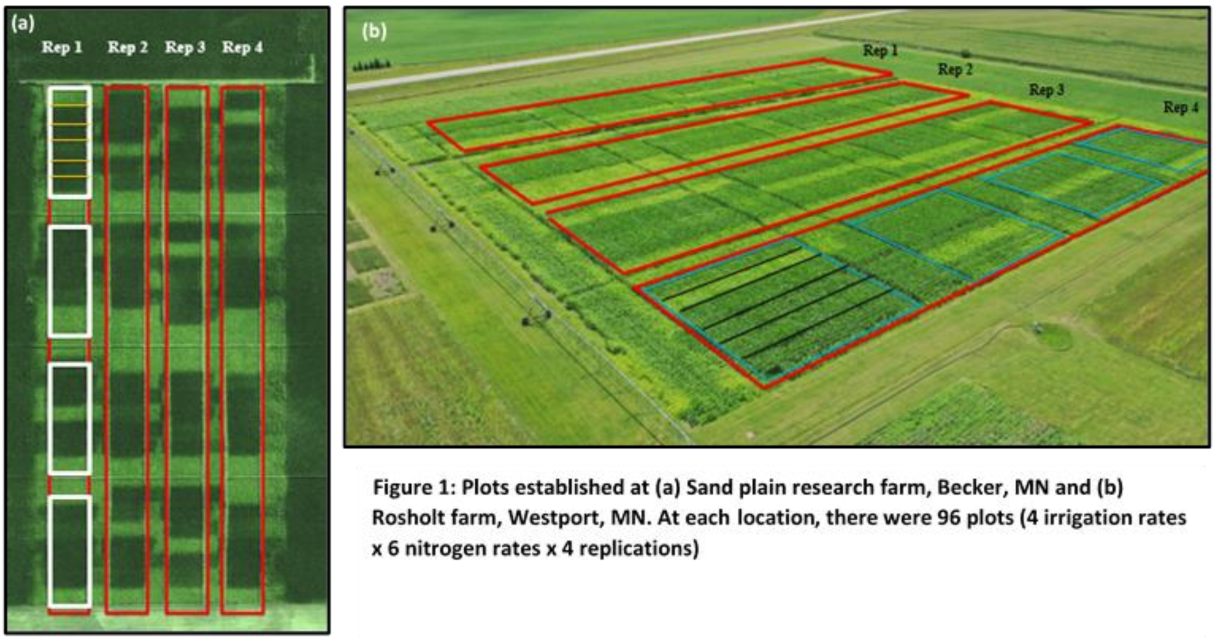

Figure 1: Plots established at (a) Sand plain research farm, Becker, MN and (b) Rosholt farm, Westport, MN. At each location, there were 96 plots (4 irrigation rates x 6 nitrogen rates x 4 replications)

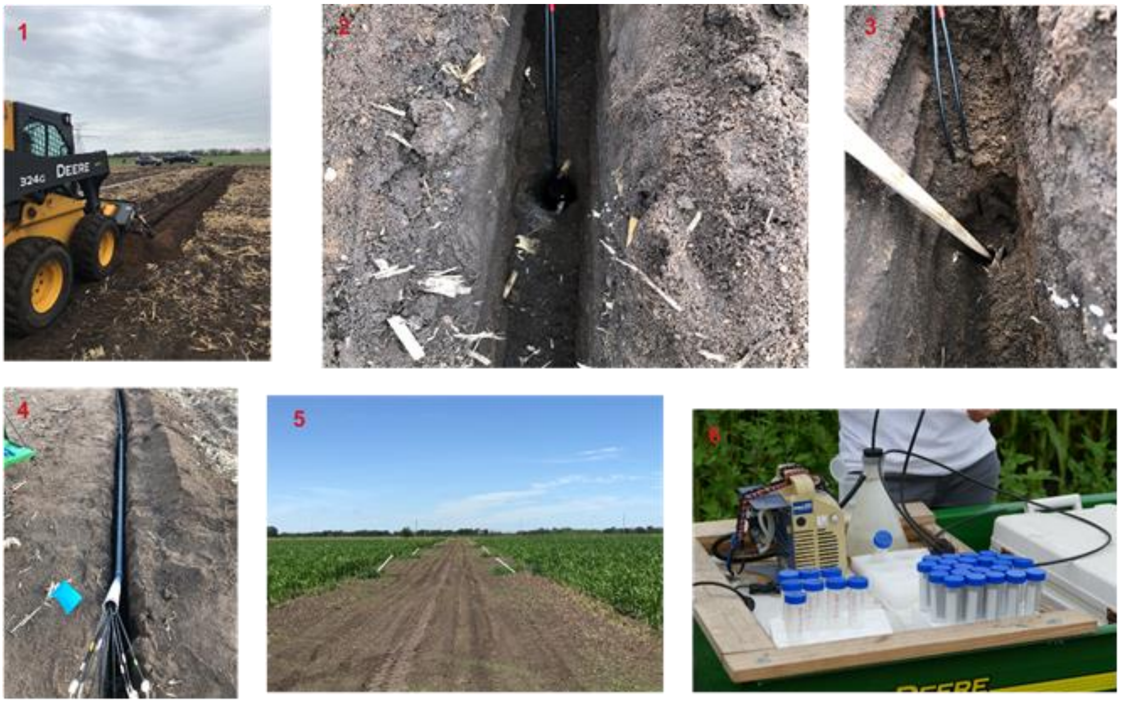

Figure 2: Permanent suction cup lysimeter installation. 1. Digging 2 feet deep trenches, 2. Dug a 2 feet deep hole inside the trench so that the bottom of the lysimeter is at 4 feet and then lowered the lysimeter in, 3. Packed the soil around the lysimeter so that there is no preferential flow, 4. Connected 6 lysimeters together and brought them out from one outlet, 5. Final picture of lysimeter outlets, 6. Intern collecting the water samples from the lysimeters.

Results from the second year of the study

The average growing season precipitation in 2021 was 12 inches and 18 inches at SPRF and Westport sites, respectively. The average growing season (planting to harvesting) temperature was 19ºC at SPRF whereas at Westport, average temperature was 18ºC. The 100% irrigation applied was 13 inches at SPRF and 8 inches at the Westport site.

The grain yields that were measured for all N treatments under 100% irrigation, 75% irrigation, 50% irrigation, and rainfed conditions for the 2021 growing season at SPRF and Westport, MN are presented in table 1. The maximum grain yield result obtained at SPRF was 226 bu/ac under the 75% irrigation and 280 lb N/ac treatment. The lowest grain yield was observed under rainfed condition. At Rosholt farm, maximum grain yield was observed under 100% irrigation at 210 lb N/ac and lowest yield was observed under rainfed treatment. In 2021, we observed a significant irrigation and nitrogen interaction effect on grain yield at SPRF. At all levels of irrigation except rainfed treatment, grain yield significantly increased with an increase in nitrogen application up to 140 lb N/ac and then plateaus at higher N rates (table 1). At both sites, grain yield was not significantly different between 210, 280 and 350 lb N/ac treatments at all levels of irrigation. Comparing irrigation treatments, a significant difference existed in grain yield between irrigation treatments at all levels of nitrogen except 0 and 70 lb N/ac. At Rosholt farm, irrigation and nitrogen interaction effect was significant, however, at all N rates, there was no significant difference between 100%, 75% and 50% grain yield. This indicates that even in the drought year like 2021, reducing the irrigation amount up to 50% could have a potential in reducing water applications for irrigation without significantly impacting the grain yield. Since only one of the study sites indicated this trend, it can be suggested that soil type and climate has an effect on the yield response to irrigation. At Westport site, the total seasonal rainfall was higher than SPRF which might have resulted in mild water stress that did not impact grain yield even at lower irrigation rates.

Figures 3 and 4 shows the grain yield response to nitrogen application under different irrigation treatments. A quadratic relationship was observed between grain yield and N application amounts for all irrigation levels at both sites.

Table 1. Grain yield, and irrigation water use efficiency (IWUE) for 0, 70, 140, 210, 280 and 350 lb N/ac treatments under 100% irrigation, 75% irrigation, 50% irrigation and rainfed settings for the 2021 growing season at SPRF, MN and Rosholt Farm, Westport, MN.

		SPRF			Rosholt Farm		
Irrigation	Nitrogen (lb/ac)	Irrigation amount (inches)	Grain yield (bu/ac)	IWUE (bu/ac/in)	Irrigation amount (inches)	Grain yield (bu/ac)	IWUE (bu/ac/in)
100%	0	12.9	80.7i	5.9	7.7	84.3hg	3.8
	70	12.9	157.9ed	13.2	7.7	182.7ed	11.0
	140	12.9	190.9b	15.8	7.7	203.6bc	14.3
	210	12.9	214.6a	18.3	7.7	235.7a	18.7
	280	12.9	225.5a	19.0	7.7	234.3a	19.7
	350	12.9	211.2a	17.7	7.7	230.1ab	18.5
75%	0	9.2	62.4i	6.8	6	85.0hg	14.2
	70	9.2	149.2edf	16.2	6	158.3ef	26.4
	140	9.2	165.3cd	18.0	6	207.9abc	34.7
	210	9.2	177.2cb	19.3	6	222.8abc	37.1
	280	9.2	164.2cd	17.9	6	229.0abc	38.2
	350	9.2	179.8cb	19.6	6	233.4a	38.9
50%	0	6.6	63.7i	9.6	4.3	83.6hg	19.4
	70	6.6	111.6h	16.9	4.3	139.4f	32.4
	140	6.6	128.3hg	19.4	4.3	178.1cd	41.4
	210	6.6	130.8gf	19.8	4.3	222.7abc	51.8
	280	6.6	131.6gf	19.9	4.3	220.2abc	51.2
	350	6.6	141.7egf	21.5	4.3	230.5ab	53.6
Rainfed	0	1.35	12.1j		0.9	58.3h	
	70	1.35	5.4j		0.9	108.0g	
	140	1.35	8.6j		0.9	106.5g	
	210	1.35	2.8j		0.9	108.5g	
	280	1.35	6.6j		0.9	100.2g	
	350	1.35	6.6j		0.9	104.1g	

The responses of grain yield to irrigation (irrigation production function) for different nitrogen treatments are presented in figure 5 for SPRF and Rosholt farm. A quadratic relationship was observed for all nitrogen treatments. Higher N treatments typically experienced a greater increase in grain yield with increasing irrigation water than lower N treatments. At both sites, grain yield increased significantly with an increase in irrigation however plateaus or starts decreasing at higher levels of irrigation. As expected, the lower N treatments imposed N deficiency on the crop resulting in greater variability in grain yield vs. irrigation amount relationship. However, at higher N rates, there was no N deficiency on the crop, therefore the grain yield vs irrigation amount relationships were stronger.

We also calculated the EONR for each irrigation treatment at both sites at 0.15 N price/Corn price ratio. Similar results were obtained at both sites with maximum yield at EONR at 100% irrigation (Table 2). At SPRF, the minimum EONR was obtained at 75% irrigation which was 16 lb N/ac lower than 100% irrigation treatment, however, the yield at EONR at 75% irrigation was 39 bu/ac lower than 100% irrigation treatment. Considering the current corn and nitrogen price, 16 lb N/ac costs around $16 (16 lb N x $1) and 39 bu/ac corn costs $234 (39 bu/ac X $6) which indicates that 100% irrigation treatment is more profitable. If we consider the water saving under 75% irrigation, 75% irrigation used 4 inches less water as compared to 100%. Though the monetary benefits of water savings in MN are low as growers do not have to pay for the water except the energy cost, the environmental benefits could be big.

The detailed results, nitrogen leaching and uptake data and analysis and remote sensing analysis will be presented in the final report.

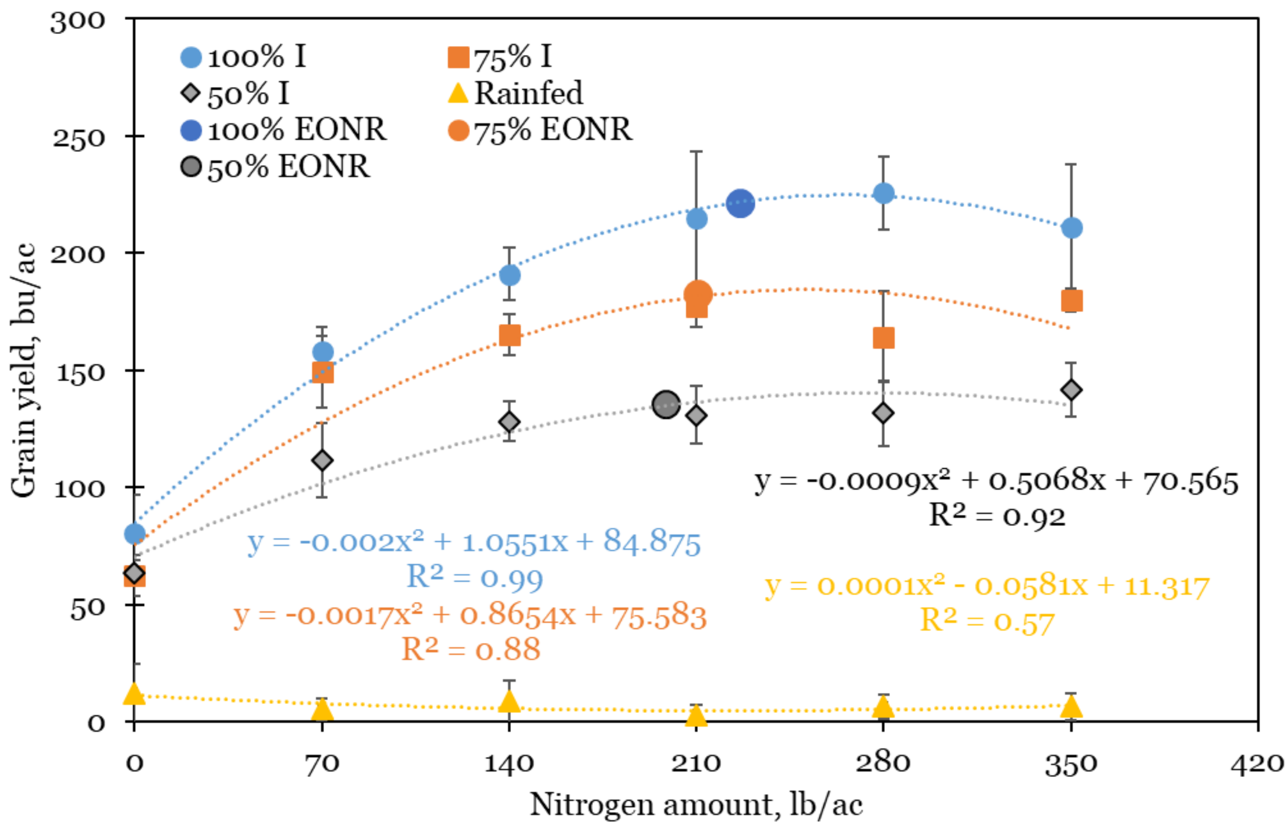

Figure 3. Grain yield response to nitrogen application under different irrigation treatments at SPRF, MN

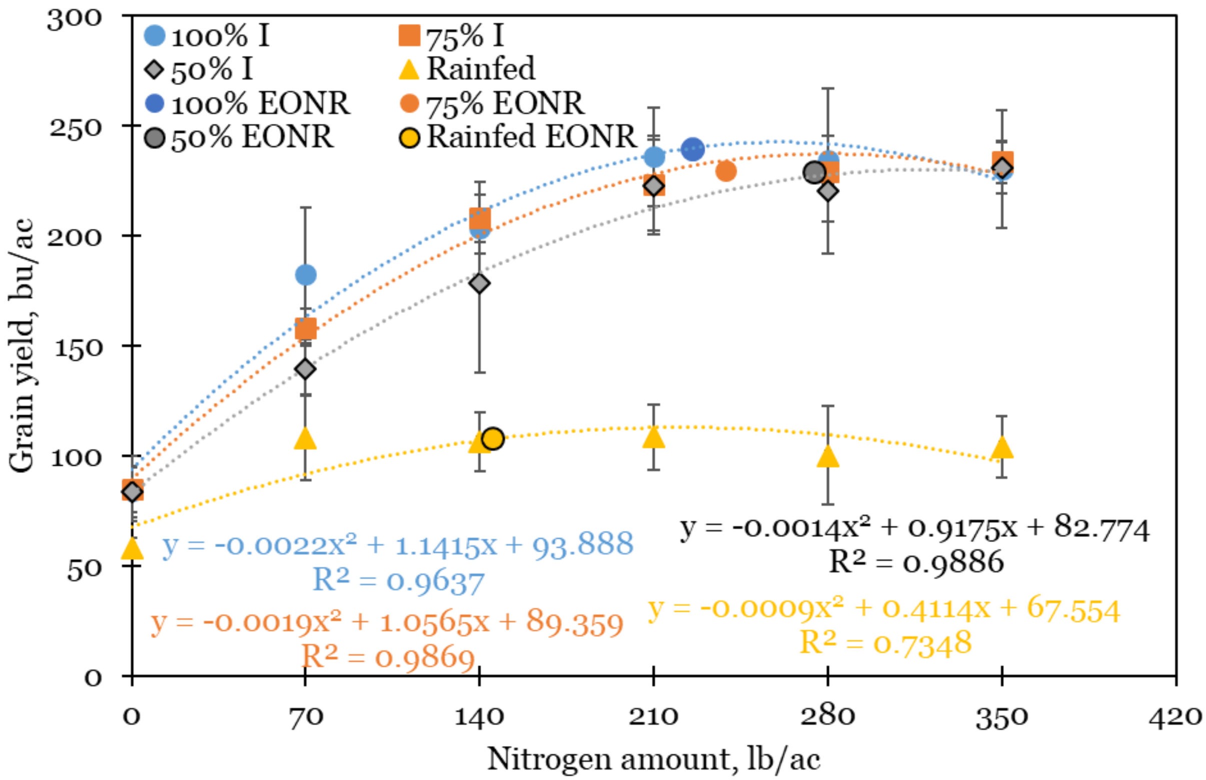

Figure 4. Grain yield response to nitrogen application under different irrigation treatments at Westport, MN

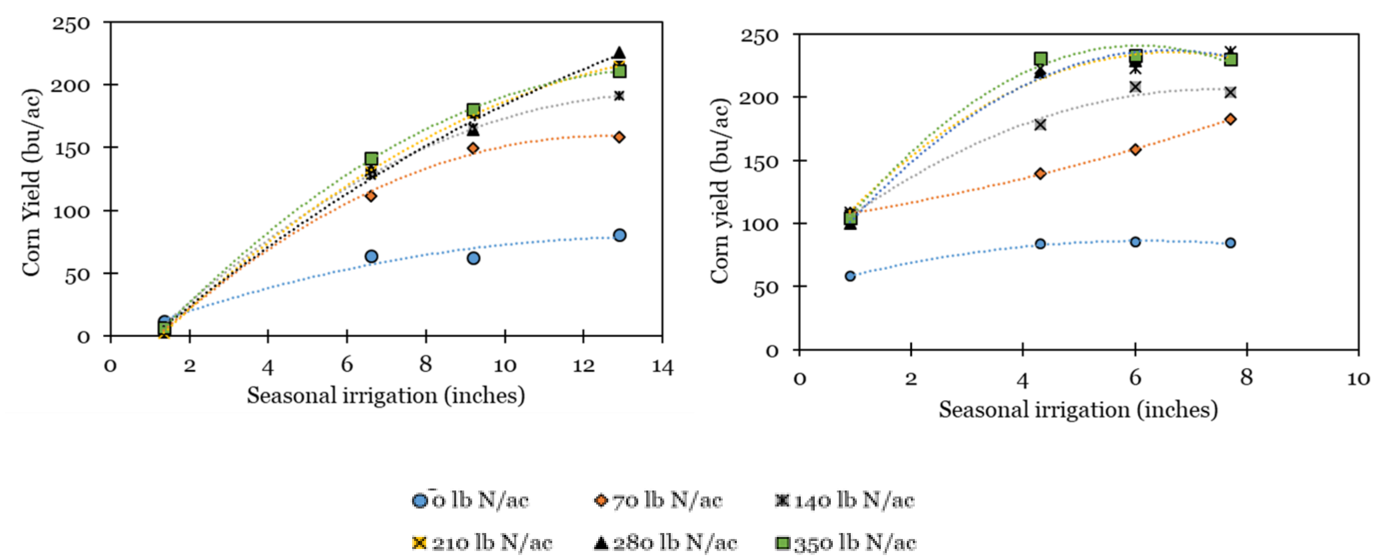

Figure 5. Grain yield response to irrigation at different nitrogen rates (left-SPRF and right-Rosholt farm)

Table 2. Economic optimum N rate (EONR) of corn as affected by irrigation level in 2021 at SPRF and Westport farm sites. N fertilizer/price grain ration (0.15)

Site	Irrigation	Irrigation (in)	R^2	EONR (lb N/ac)	Yield at EONR	AE at EONR (bu grain/lb N applied))

Becker	Rainfed	1.35	0.57	1041	59	0.04
	50%	6.6	0.92	198	136	0.33
	75%	9.2	0.88	210	182	0.51
	100%	12.9	0.99	226	221	0.60
Westport	Rainfed	0.9	0.73	145	108	0.28
	50%	4.3	0.99	274	229	0.53
	75%	6	0.99	239	229	0.60
	100%	7.7	0.96	225	239	0.64