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

2023 Annual Report—Third Year of a five-Year Project (2022 corn growing season results)

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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 discusses the results from the third 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 is 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 to reduce the impact of agriculture on the environment but at the same time, require robust and evolving research based scientific knowledge, specifically in the fields like irrigation that have not been explored much in Minnesota. 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 research 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 principal 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 were 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. A 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) and irrigation water use efficiency (IWUE) which is the ratio of (yield – rainfed yield)/irrigation water applied 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.

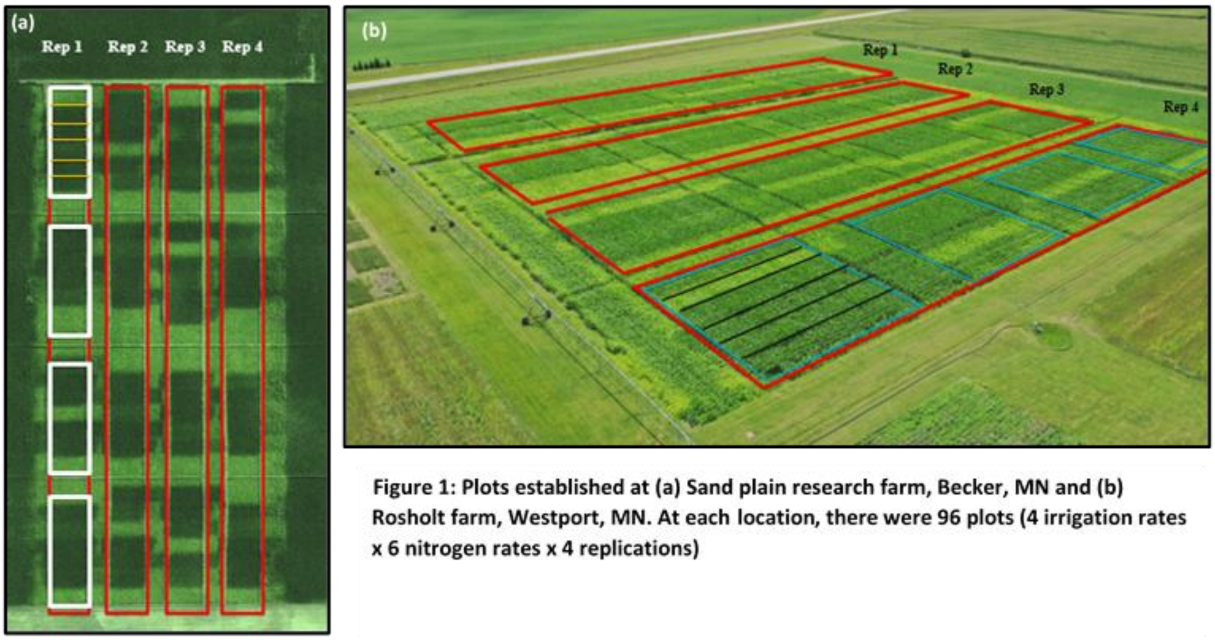


Figure 1: Plots established at (a) Sand plain research farm, Becker, MN and (b) Rosholt farm, Westport, MN. At each location, there were 96 plots (4 irrigation rates x 6 nitrogen rates x 4 replications)

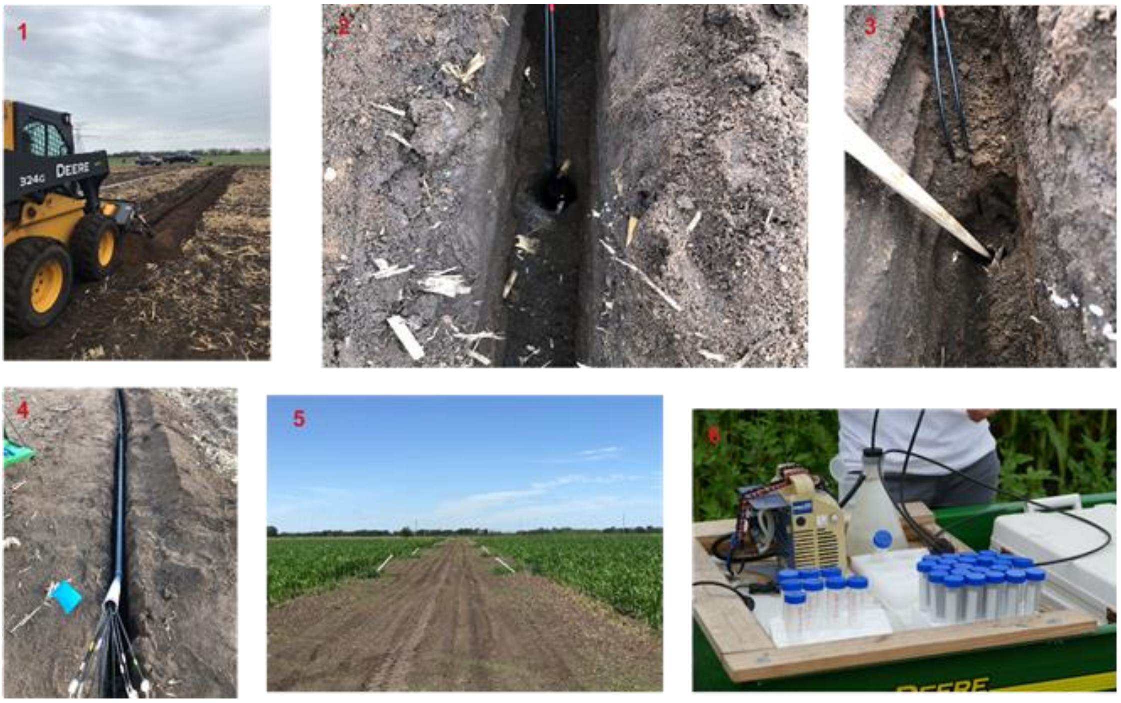


Figure 2: Permanent suction cup lysimeter installation. 1. Digging 2 feet deep trenches, 2. Dug a 2 feet deep hole inside the trench so that the bottom of the lysimeter is at 4 feet and then lowered the lysimeter in, 3. Packed the soil around the lysimeter so that there is no preferential flow, 4. Connected 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 third year of the study

The average growing season precipitation in 2022 was 13 inches and 11 inches at SPRF and Westport sites, respectively. The average growing season (planting to harvesting) temperature was 17.7ºC at SPRF whereas at Westport, the average temperature was 17.5ºC. The 100% irrigation applied was 6 inches at SPRF and 4 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 2022 growing season at SPRF and Westport, MN are presented in table 1. The maximum grain yield result obtained at SPRF was 223 bu/ac under the 100% irrigation at 280 lb N/ac treatment. The lowest grain yield was observed under rainfed conditions. At Rosholt farm, maximum grain yield of 229 bu/ac was observed under 75% irrigation at 350 lb N/ac and lowest yield was observed under rainfed treatment. In 2022, we observed a significant irrigation and nitrogen interaction effect on grain yield at both sites. At Becker, under 100% irrigation 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, and figures 3 and 4). At the same site, under 75% and 50% irrigation treatments yield flattens after 70 lb N/ac treatment. At Westport, grain yields under 100% and 75% irrigation grain yield significantly increased with an increase in nitrogen application up to 140 lb N/ac and then plateaus at higher N rates whereas under 50% irrigation, the yield plateau occurs are 70 lb N/ac. At both sites, grain yield was not significantly different between 210, 280 and 350 lb N/ac treatments at all levels of irrigation. There was no significant yield difference between 100% and 75% irrigation at all levels of N rate at both sites except for 280lb N/ac treatment at Becker where 100% irrigation treatment grain yield was significantly higher than 75% irrigation. At both sites, grain yield under 50% irrigation treatment at 210, 280 and 350 lb N/ac treatment was significantly lower than 100% irrigation at same N rates. At N rate of 0-140 lb N/ac, the grain yield was not significantly different between 100% and 50% irrigation with the exception of 70 lb N/ac at Becker (Table 1). At both sites, no significant grain yield difference was observed between 75% and 50% irrigation treatments under all N rates, with the exception of 70 lb N/ac at Becker and 350 lb N/ac at

Westport. The results indicate that even in the dry years like 2022, there is a potential in using limited irrigation such as 75% irrigation as irrigation management strategy to save water while producing comparable yield.

Figures 3 and 4 show 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.

		Becker			Westport		
Irrigation	Nitrogen	Irrigation amount	Grain yield	IWUE	Irrigation amount	Grain yield	IWUE
	lb N/ac	Inches	bu/ac	bu/ac-in	Inches	bu/ac	bu/ac-in
100%	0	5.6	90.4 a	7.6	3.8	73.0 ab	4.0
	70	5.6	173.1 bc	27.8	3.8	135.8 cd	10.2
	140	5.6	207.0 def	34.0	3.8	181.7 efg	18.5
	210	5.6	211.7 de	34.9	3.8	207.8 hij	21.3
	280	5.6	223.3 e	38.3	3.8	208.3 hij	26.2
	350	5.6	221.0 e	36.5	3.8	213.3 hi	24.3
75%	0	4.2	73.3 a	6.0	2.85	79.5 ab	7.6
	70	4.2	157.3 bf	33.3	2.85	133.1 cdl	12.6
	140	4.2	187.7 cf	40.8	2.85	185.5 efgj	26.0
	210	4.2	190.6 cdf	41.6	2.85	205.3 hfij	27.6
	280	4.2	196.7 df	44.7	2.85	193.4 hfgj	29.6
	350	4.2	200.8 def	43.8	2.85	228.6 i	37.8
50%	0	2.8	75.6 a	9.9	1.9	76.8 ab	9.9
	70	2.8	129.6 g	40.1	1.9	147.8 ck	26.7
	140	2.8	146.9 fg	46.6	1.9	161.6 ek	26.4
	210	2.8	151.7 bfg	48.5	1.9	181.7 efg	29.0
	280	2.8	157.3 bf	53.0	1.9	173.8 eg	34.2
	350	2.8	158.5 bf	50.6	1.9	191.2 efgj	37.0
Rainfed	0	0	48.0 l		0	57.9 adl	
	70	0	17.3 j		0	97.2 mdl	
	140	0	16.5 j		0	111.6 mdl	
	210	0	16.1 j		0	126.7 cl	
	280	0	8.9 j		0	108.9 mb	
	350	0	16.8 j		0	120.9 m	

The responses of grain yield to irrigation (irrigation production function and irrigation water use efficiency (IWUE)) for different nitrogen treatments are presented table 1 and figure 5 for SPRF and Westport. Under all irrigation rates, maximum IWUE was observed at 280 lb N/ac except for 50% I at Westport where maximum IWUE was observed under 350 lb N/ac. On average, IWUE increases with decrease in irrigation. A quadratic relationship of irrigation and grain yield 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 0.1 N price/Corn price ratio (black solid points on figures 3 and 4). Similar results were obtained at both sites with maximum yield at EONR at 100% irrigation. At SPRF, the minimum EONR was obtained at 50% irrigation which was 5 lb N/ac lower than 100% irrigation treatment, however, the yield at EONR at 50% irrigation was 64 bu/ac lower than 100% irrigation treatment. A similar EONR was estimated for 100% and 75% irrigation with yield reduction of 20 bu/ac under 75% as compared to 100%. We combined the 3 years data (2020, 2021 and 2022) to better understand the effect of water (irrigation and precipitation) on EONR and found that, on average, EONR increase with increase in water application to crop-soil system but after a certain water level EONR decreased, potentially due higher leaching losses and reduced yield and profit with more water in the system (figure 6).

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

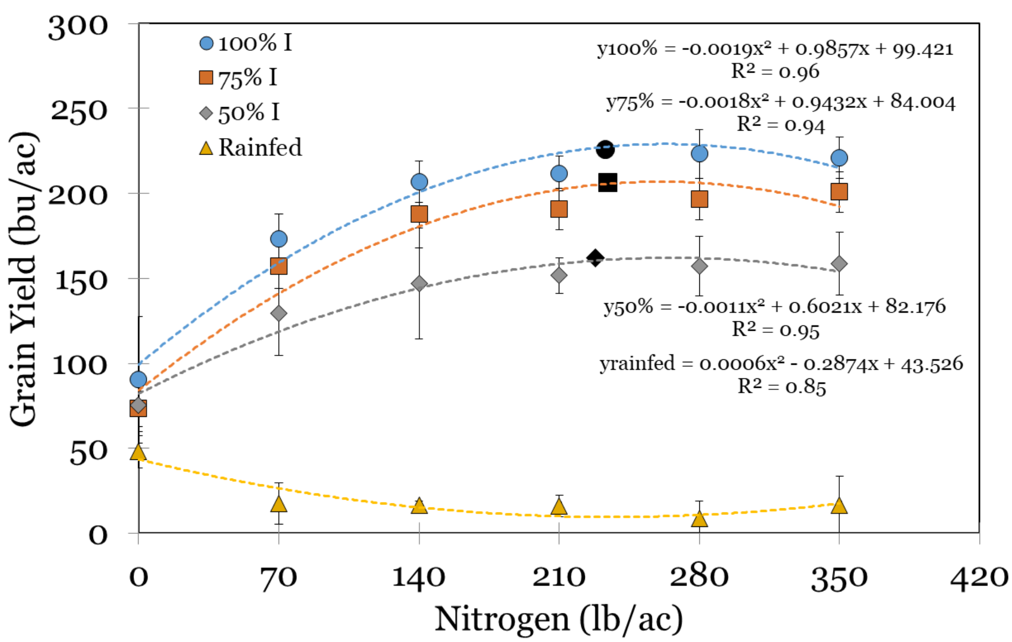


Figure 3. Grain yield response to nitrogen application under different irrigation treatments at SPRF, MN. Black points on each irrigation line indicate economic optimum nitrogen rate (EONR) and corresponding yield at EONR.

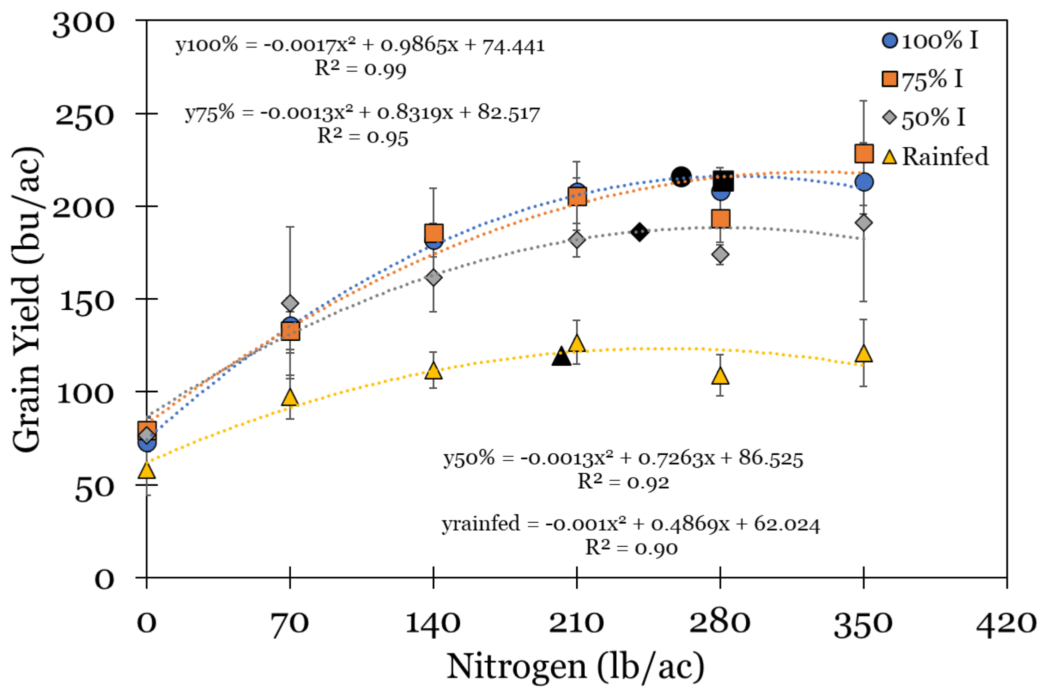
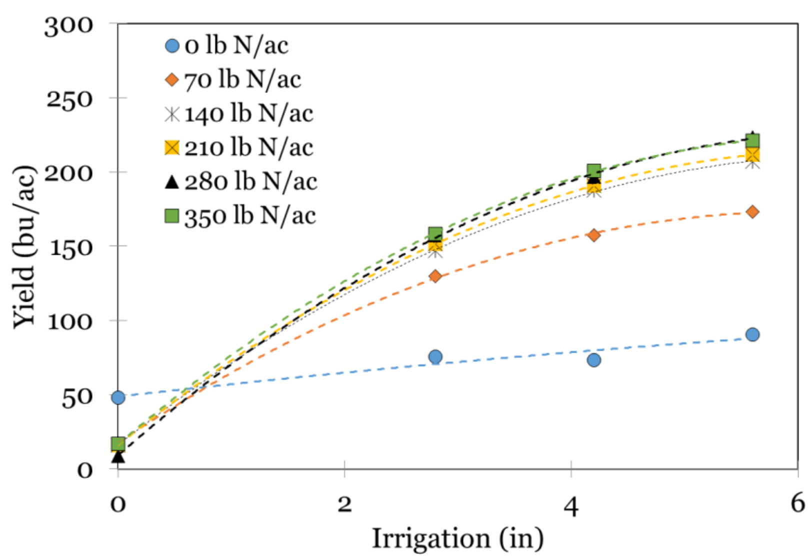


Figure 4. Grain yield response to nitrogen application under different irrigation treatments at Westport, MN. Black points on each irrigation line indicate economic optimum nitrogen rate (EONR) and corresponding yield at EONR.



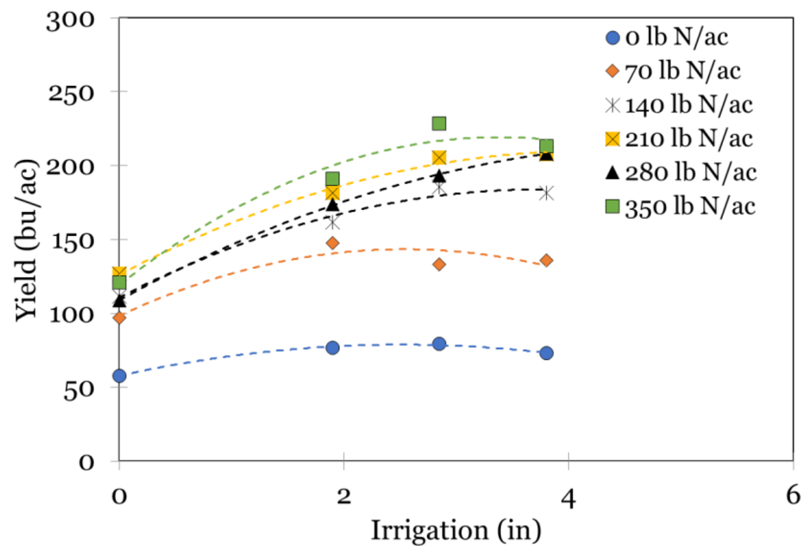


Figure 5. Grain yield response to irrigation at different nitrogen rates (top-SPRF and bottom-Rosholt farm)

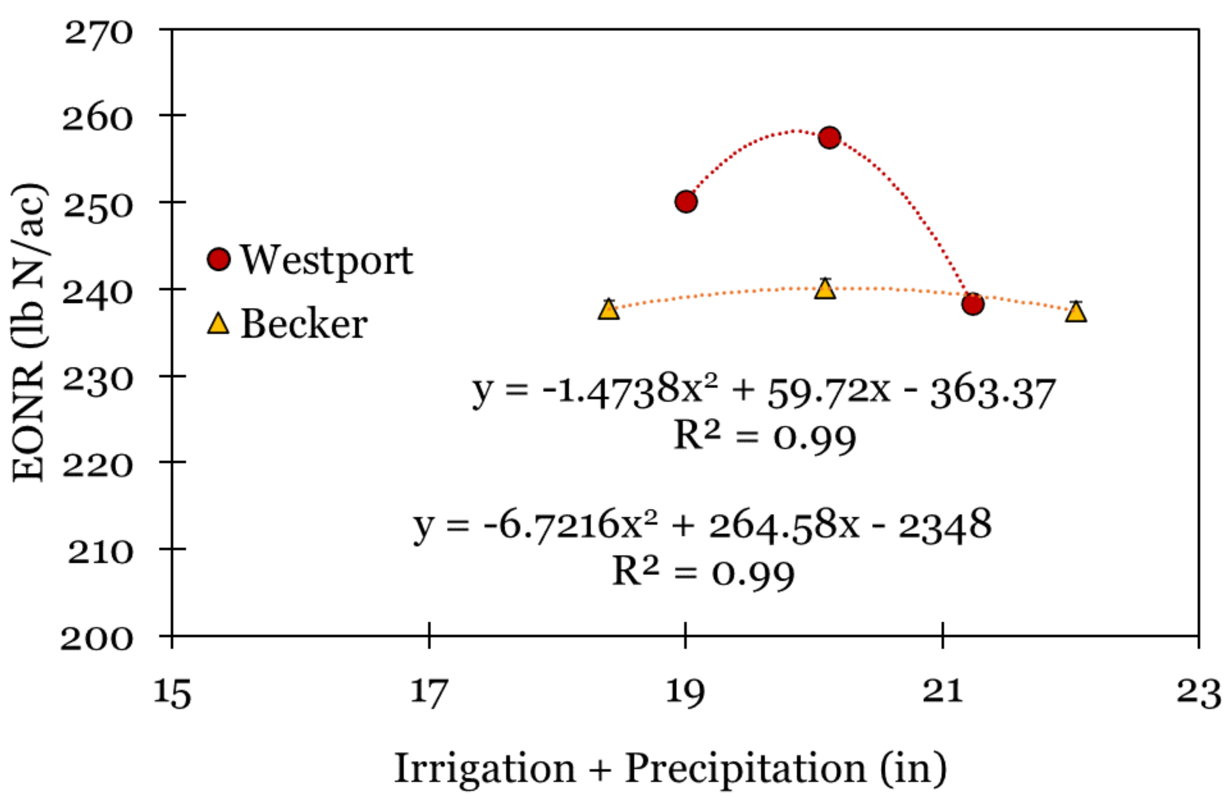


Figure 6. Economic optimum nitrogen rate (EONR) relationship with total water (irrigation + precipitation).