PROGRESS REPORT

PROJECT TITLE: Precision irrigation and nitrogen management for enhancing water-nitrogen use efficiency
PROJECT NUMBER: 6104-23DD
REPORTING PERIOD: April 2023-March 2024
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1.) PROJECT ACTIVITIES COMPLETED DURING THE REPORTING PERIOD. (*Describe project progress specific to goals, objectives, and deliverables identified in the project workplan.*)

Background:

Two critical challenges face Minnesota's agricultural watersheds: (1) nitrate leaching into groundwater supplies, and (2) competition over a limited groundwater resource. These issues are predominant in the Central Sands region of Minnesota. Irrigation makes row-crop agriculture in the Central Sands region highly productive due to the soil's naturally low water holding capacity and rapid drainage rate. At the same time, most communities depend on groundwater as their sole drinking water supply. Precision water management has the potential to strike a balance between groundwater use for irrigation and as a drinking water source. However, production-scale research on advanced precision irrigation and nitrogen (N) management techniques, such as variable rate irrigation (VRI) and variable rate N (VRN), has been lacking in Minnesota. In this project, we conducted a field study to quantify and evaluate the impact of VRI and VRN management in comparison to both conventional uniform rate irrigation (URI) and uniform rate N (URN) management. Specifically, we quantified the effect of VRI and VRN on nitrate leaching, corn plant growth and development, grain yield, evapotranspiration, and N and water use efficiencies. An economic analysis of VRI and VRN management will be conducted to assess the economic feasibility of the system for greater adoption. The project will also focus on extension and engagement through field days, student mentoring, and conversations with farmers to disseminate the research results, promote VRN and VRI technologies among growers, and develop actionable strategies for adoption.

Project goals:

- Improve nitrogen (N) and irrigation.

- management for corn at a farm level using innovative, practical, reliable, and profitable technology of the remote sensing calibration strip-based precision nitrogen management (PNM) integrated with precision irrigation management.
- Assess agronomic, economic, and environmental benefits of the variable-rate nitrogen and irrigation technologies (VRN x VRI) to promote wider adoption by corn farmers.

Our overarching objective is to refine nitrogen (N) and irrigation management for corn at the farm scale, harnessing the power of remote sensing. In this endeavor, we gathered remote sensing data from six UAV flights throughout the growing season. This data was captured using the SENTERA 6X thermal sensor, boasting an impressive 8 cm spatial resolution, and a multispectral sensor with a spatial resolution of 5 cm. With our data collection, we've also developed an algorithm dedicated to calculating nitrate leaching.

We calculate the Crop Water Stress Index (CWSI) (Figure 3) and other vegetation indices from Remote sensing (figure 4, 5 and 6) for further analysis of Nutrient and water management.

In addition, we looked at the impact of VRI and URI on nitrate leaching. We only installed the lysimeters are few locations in the field so for the nitrate leaching data we will compare URI and VRI only at 30% FNR +VRN treatment.

Field Trial Overview:

Trial area:21 ac
Preplant N applied: 05/05/2023
Planted: 05/05/2023
Sidedress N applied: 06/19/2023
Harvested: 11/1/2023
Previous crop (2021): Corn
Irrigated: Yes
Farmer's N rate (FNR):

- FNR 220 lb N/ac

N and Irrigation strategies:

- 20% FNR + VRN | URI (20% FNR before or at pre-plant + Sidedress N rate determined by calibration strip | Uniform rate irrigation)
- 20% FNR + VRN | VRI (20% FNR before or at pre-plant + Sidedress N rate determined by calibration strip | Variable rate irrigation)
- 30% FNR + VRN | URI (30% FNR before or at pre-plant + Sidedress N rate determined by calibration strip | Uniform rate irrigation)
- 30% FNR + VRN | VRI (30% FNR before or at pre-plant + Sidedress N rate determined by calibration strip | Variable rate irrigation)
- 40% FNR + VRN | URI (40% FNR before or at pre-plant + Sidedress N rate determined by calibration strip | Uniform rate irrigation)
- 40% FNR + VRN | VRI (40% FNR before or at pre-plant + Sidedress N rate determined by calibration strip | Variable rate irrigation)
- 50% FNR + 50% FNR | URI (50% FNR before or at pre-plant + 50% FNR for side-dress | Uniform rate irrigation)
- 50% FNR + 50% FNR | VRI (50% FNR before or at pre-plant + 50% FNR for side-dress | Variable rate irrigation)

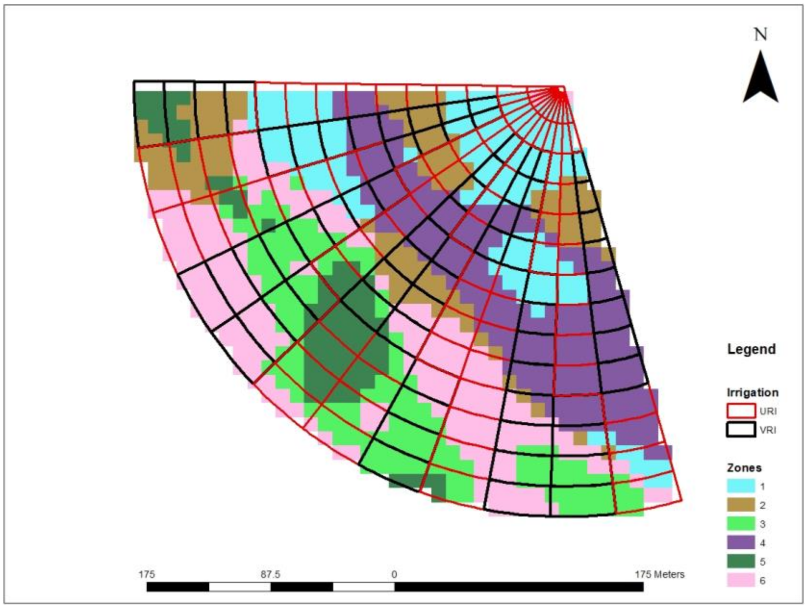

Figure 1: Research field showing 6 irrigation management zones and irrigation treatments (VRI and URI). We combined zone 6 and 1, and both got 100% irrigation (Blue and pink zone)

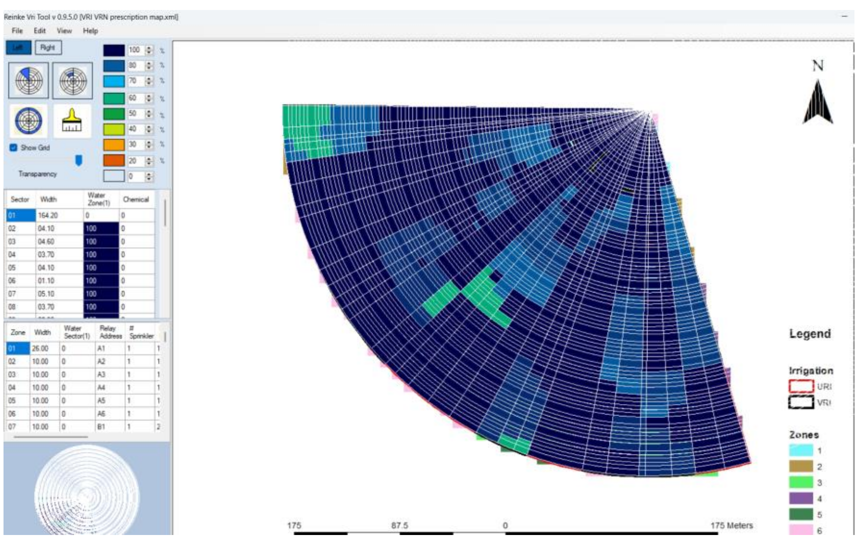

Figure 2: Irrigation prescription map created using Reinke VRI tool. The uniform rate irrigation (URI) plots will get 100% uniform irrigation. The VRI plots will get irrigation based on the management zones. Zone 1: 100% irrigation, Zone 2: 80% irrigation, Zone 3: 95% irrigation, Zone 4: 89% irrigation, Zone 5: 60% irrigation and Zone 6: 100% irrigation.

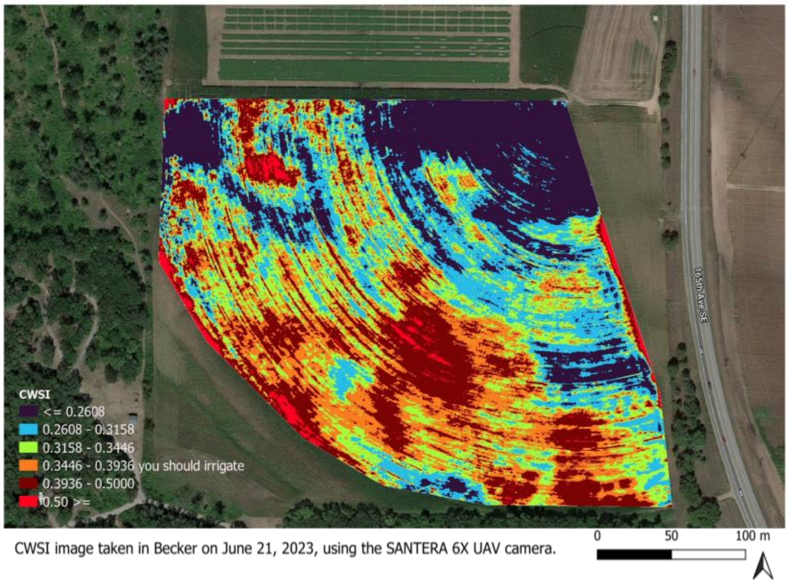

Figure 3. CWSI Map Ranging from 0 (No Stress) to 1 (Severe Stress) calculated from thermal data taken in Becker on June 21, 2023

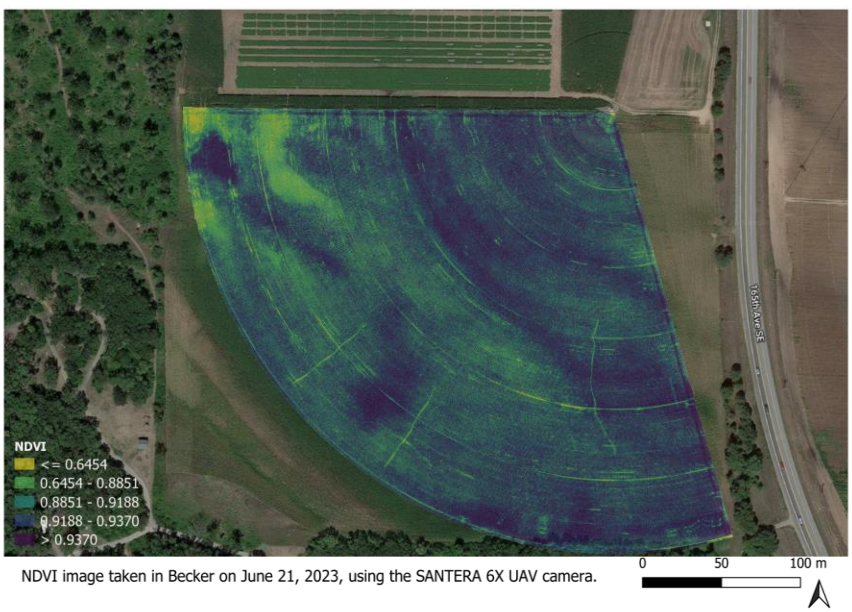

Figure 4. NDVI Map calculated from Multispectral data taken in Becker on June 21, 2023

Figure 5. NDRE Map calculated from Multispectral data in becker on June 21, 2023

2.) IDENTIFY ANY SIGNIFICANT FINDINGS AND RESULTS OF THE PROJECT TO DATE.

Figures 1 and 2 indicates different irrigation and pre-plant N treatments along with the irrigation management zones.

Findings from 2023 season:

Summary of Findings

- Similar to last year (2022 growing season), the treatment applying **30%FNR** before or at planting with variable rate sidedress nitrogen application and uniform rate irrigation (**30% FNR + VRN | URI)** resulted in the highest economic profits among all treatments in 2023 (Table 1).
- The VRI management had higher yield than URI under 20% FNR + VRN treatment and 50% FNR + 50% sidedress N treatment where as slightly lower corn yield compared with URI in other two N treatments. On average of four N treatments VRI yield was only 0.5% (1 bu/ac) lower than URI. The water savings with VRI technology were 10% as compared to URI. The irrigation water productivity was greater in VRI treatment as compared to URI at all levels of N treatment (Figure 6 and 7 and Table 1).
- On average, nitrate leaching (load) under VRI was reduced by 34% as compared to URI at 30% 30% FNR + VRN **treatment (Figure 10).**

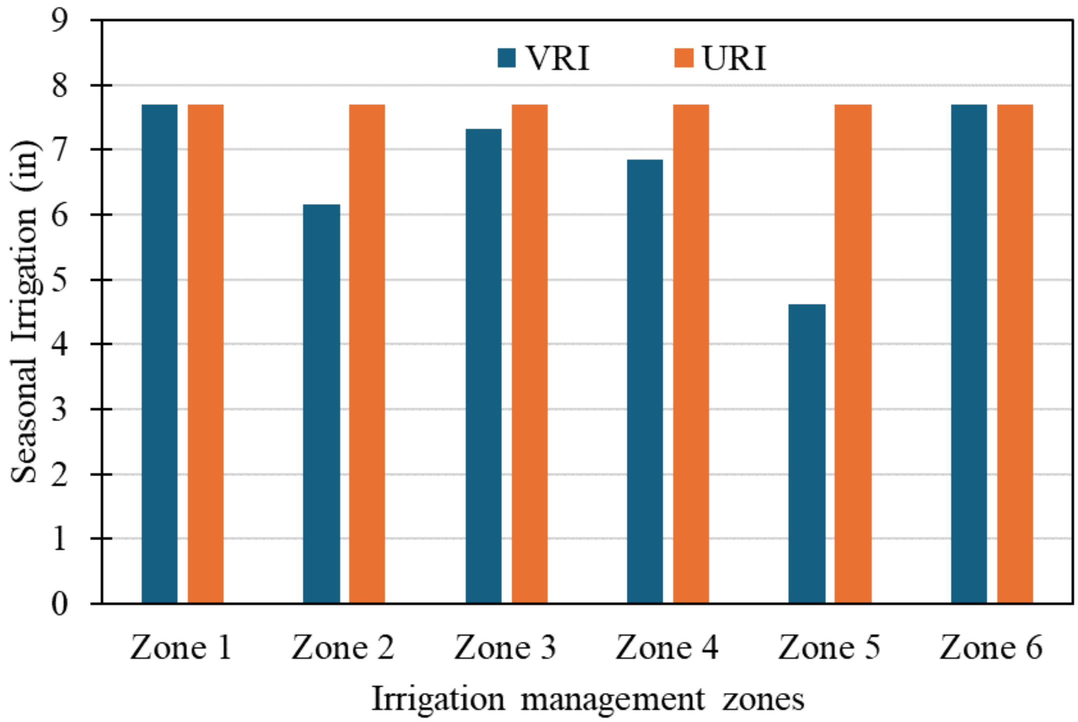

Figure 6. Irrigation amount in each zone under VRI and URI treatments in 2023.

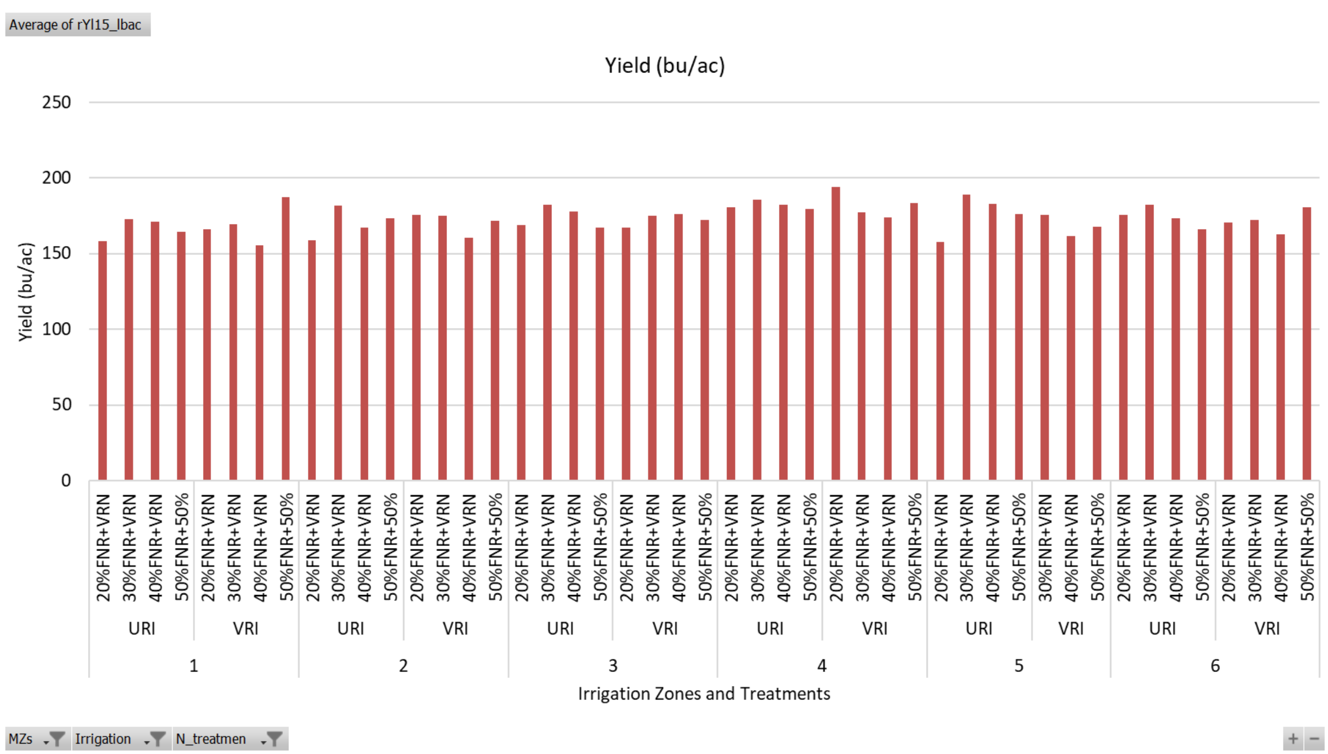

Figure 7. Yield under each management zone and treatment

Table 1. Summary table of information related to field, management, and results from precision nitrogen and irrigation management on-farm trial by different treatments (lb N/ac) at the Becker field trial in 2023.

Treatment	Avg. Preplant N Rate (B)	Avg Sidedress N Rate (C)	Total N (D = B+C)	Avg Irrigated Water (E)	Avg Yield (F)	Avg Applied N cost (G=D*price)	Irrigation cost (H = E *Price)	Total Cost (I = G+H)	Yield income (J = F *Price)	Profit (K = J-I)	Profit gain/loss compared to 60%+40% FNR	Nitrogen Use Efficiency	Irrigation Water Productivity
	(lb N/ac)	(lb N/ac)	(lb N/ac)	(inches)	(bu/ac)	($/ac)	($/ac)	($/ac)	($/ac)	($/ac)	($/ac)	(Yield bu /Applied N lb)	(bu/ac-in)
20%FNR+VRN|URI	44.2	108.0	152.2	7.7	168.4	103.5	77.0	180.5	926.1	745.6	36.3	1.1	21.9
30%FNR+VRN|URI	65.8	112.1	177.9	7.7	182.5	121.0	77.0	198.0	1003.6	805.6	96.3	1.0	23.7
40%FNR+VRN|URI	87.9	114.4	202.2	7.7	175.6	137.5	77.0	214.5	965.9	751.4	42.1	0.9	22.8
50%FNR+50%|URI	109.9	109.9	219.9	7.7	170.1	149.5	77.0	226.5	935.8	709.3	0.0	0.8	22.1
20%FNR+VRN|VRI	44.2	101.2	145.4	7.2	175.3	98.9	71.8	170.6	964.3	793.7	38.5	1.2	24.6
30%FNR+VRN|VRI	65.8	114.8	180.5	6.9	174.7	122.8	69.0	191.8	960.9	769.2	14.0	1.0	25.8
40%FNR+VRN|VRI	87.9	114.9	202.7	6.8	166.1	137.9	68.3	206.2	913.7	707.5	-47.7	0.8	24.9
50%FNR+50%|VRI	109.9	109.9	219.9	6.7	176.7	149.5	67.2	216.7	971.9	755.2	0.0	0.8	27.0

Q. Which N and irrigation management strategies worked best in this field in 2023?

- The treatment 30%FNR + VRN|URI on average performed the best, resulting in the **highest yield (182.5 bu/ac) and highest profit ($806/ac)**, which was $**96/ac** higher than farmer's normal practice (50% FNR + 50% FNR|URI). Among all N treatments under URI, 30%FNR + VRN|URI has the highest irrigation water productivity.
- Among all treatments, highest N use efficiency was found under 20%FNR+VRN|VRI treatment (Table 1)
- The treatment 50% FNR + 50% FNR | VRI strategy achieved the highest water use efficiency (27.0 bu/ac-in). The second highest water use efficiency of 25.8 bu/ac-in was obtained in treatments 30% FNR + VRN| VRI
- Under all N treatments, VRI treatment had greater irrigation water productivity or water use efficiency than URI.
- On average, the irrigation water application was 10% reduced using VRI technology (~ 1 inch lower irrigation).
- VRI worked better agronomically and economically than URI when applying 20%FNR before or at planting with UMN variable rate sidedress N (20% FNR + VRN).

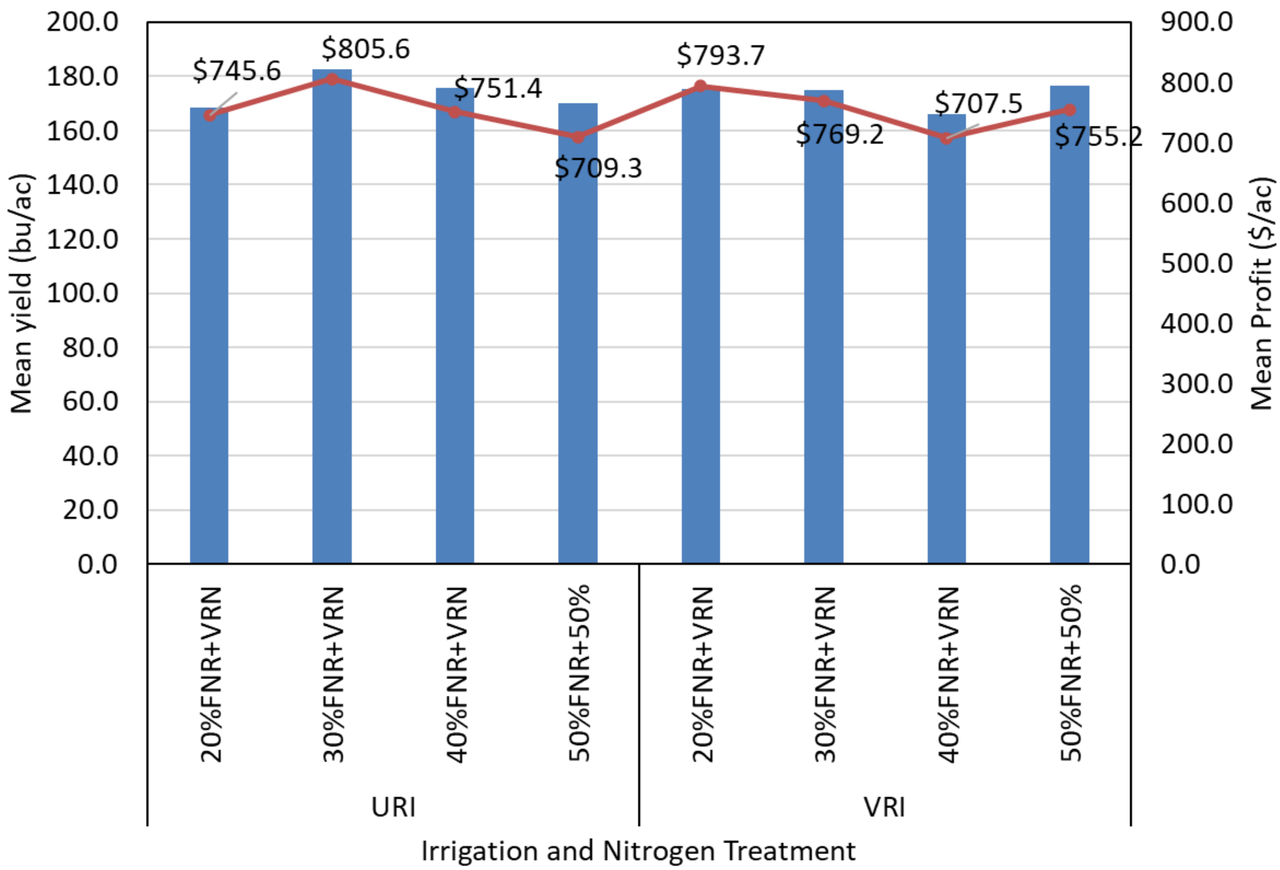

Figure 8. Average yield and profit of each Irrigation and Nitrogen rate

Q. What were other key factors affecting yield and profit in this field?

- We used machine learning to detect key variables affecting the economic optimum Nitrogen rate (EONR).
- The SHAP waterfall plot illustrates that relative elevation and slope are the principal variables influencing the EOSR.
  - In this plot, points with red colors and negative SHAP value signify High values, indicating variables that decrease the EONR—specifically, temperature.
  - On the other hand, variables that positively impact the EONR include relative elevation .

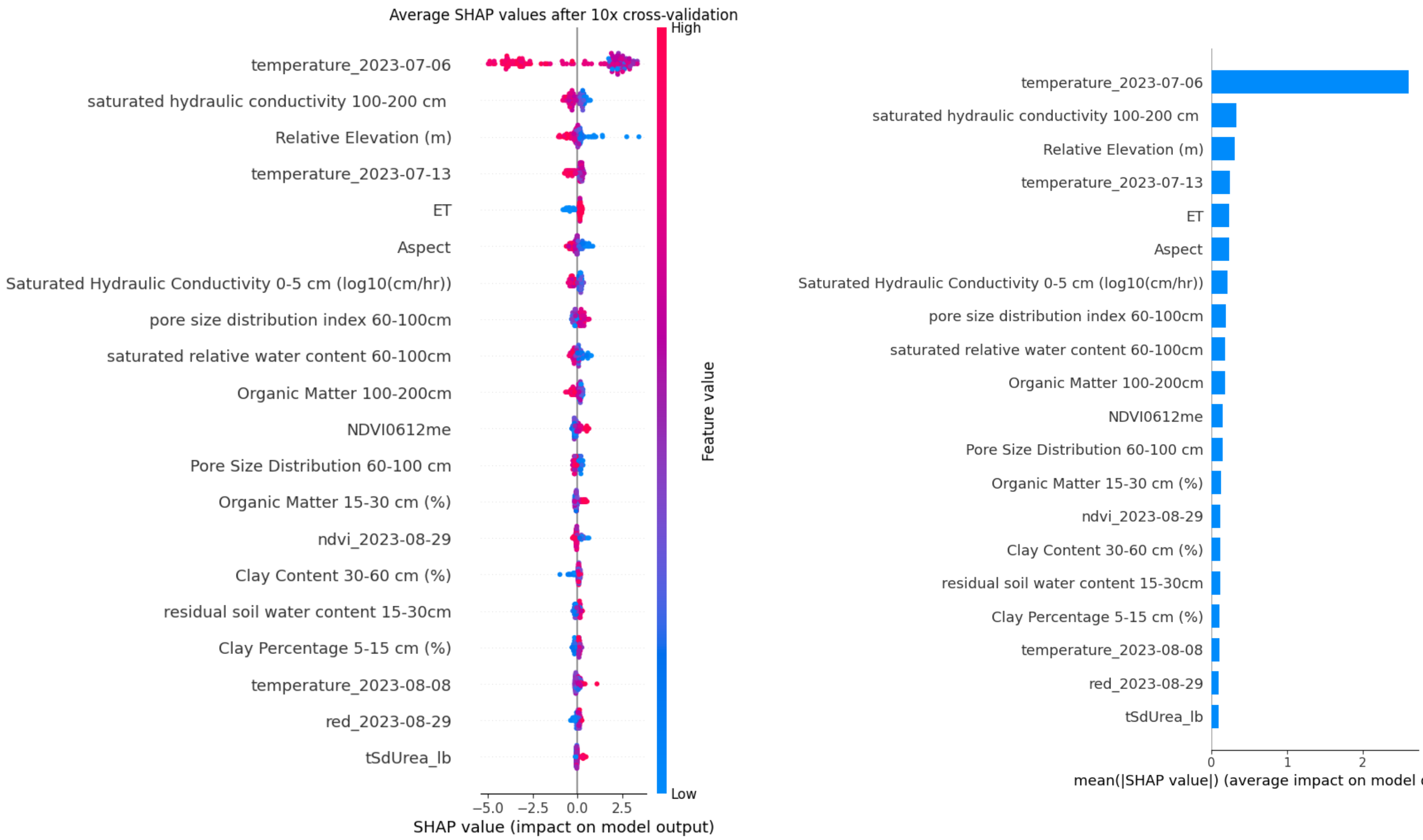

Figure 9. Soil and landscape variables influencing EOSR level identified using machine learning

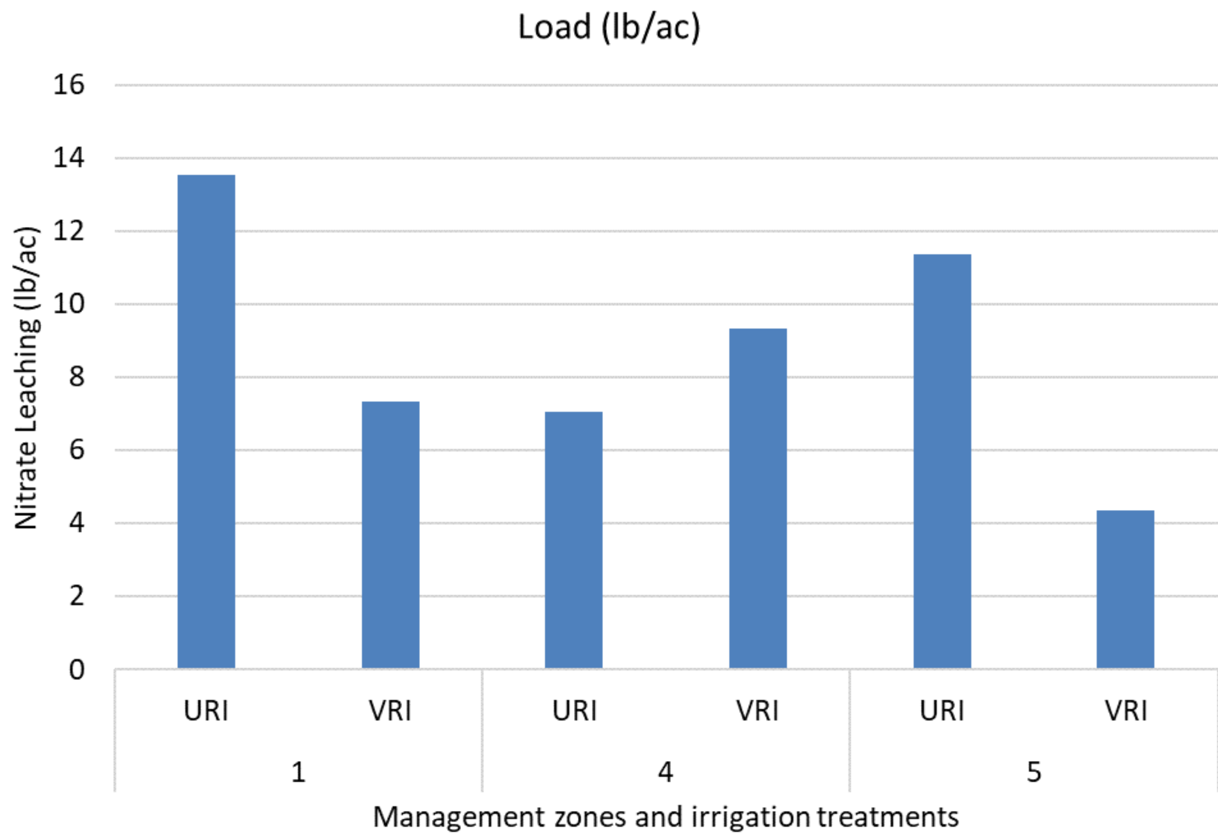

Figure 10. Nitrate leaching in management zones 1, 4, and 5 under VRI and URI at 30%% FNR + VRN

3.) CHALLENGES ENCOUNTERED. (Describe any challenges that you encountered related to project progress specific to goals, objectives, and deliverables identified in the project workplan.)

None

4.) FINANCIAL INFORMATION (*Describe any budget challenges and provide specific reasons for deviations from the projected project spending.*)

See SPA invoice

5.) EDUCATION AND OUTREACH ACTIVITES. *(Describe any conferences, workshops, field days, etc attended, number of contacts at each event, and/or publications developed to disseminate project results.)*

At the Field Day event organized by UMN Extension on August 10, 2023, in Becker, MN, Dr. Vasudha Sharma presented the latest developments of this project to an audience comprising farmers, industry professionals, government employees, fellow researchers, and graduate students. The presentation is entitled as:

- Sharma, V., Miao, Y., Mizuta, K., Kechchour, A., Taylor B., (2023). Precision Irrigation and Nitrogen Management Strategies in continuous corn for improved water and nitrogen use efficiencies. Field Day, UMN Extension, August 10, 2023. Becker, MN

Figure 11: Field Day event organized by UMN Extension on August 10, 2023 in Becker, MN.