INNOVATION GRANT FINAL REPORT

PROJECT TITLE: On-farm Evaluation of the Potential Benefits of Variable Rate Nitrogen Application in Corn Fields Applied with Manure
REPORTING PERIOD: January 1, 2025
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1.) PROJECT ACTIVITIES COMPLETED DURING THE REPORTING PERIOD. (*Describe project progress specific to goals, objectives, and deliverables identified in your project proposal.*)

In 2024, on-farm experiments were conducted on three fields (F1: 365 acres, corn-corn; F21: 240 acres, corn-corn; F22: 130 acres, soybean-corn), all receiving liquid swine manure in fall 2023.

UMN Dr. Miao's group designed the on-farm experiments for each of the three fields (Figure 1). In each of these fields, experimental blocks were established with varying rates of pre-plant N. Rate structure varied by field, depending on manure application rate and manure source. Estimated manure N availability ranged from 90 to 100 pounds N/acre. Across the three fields, total applied N (manure N + supplemental N) rates ranged from roughly 60 pounds less to 30 pounds more per acre compared to the farm's normal N application rate for the rotation. To facilitate data collection at harvest, variable rate N application maps were created to align with pre-established planter and combine guidance lines.

Variable rate N trials:

A randomized complete block design trial without sidedress N applications was conducted in F22 North to determine within-field variability in optimal N rates in manure-applied fields.

- Farmer's Practice (FP): 160 lb N/ac (60 lb N/ac UAN32 + 100 lb N/ac manure N credit)
- Five N treatments were as follows:
  - 0: 0 lb N/ac preplant + 100 lb N/ac manure
  - 30: 30 lb N/ac preplant + 100 lb N/ac manure
  - 60 (FP): 60 lb N/ac preplant + 100 lb N/ac manure
  - 90: 90 lb N/ac preplant + 100 lb N/ac manure
  - 0+VRN: 0 lb N/ac preplant + sidedress N rate (calibration strip-based) + 100 lb N/ac manure

In-season site-specific precision N management trials:

F1 Trial

- Farmer's Practice (FP): 200 lb N/ac (110 lb N/ac preplant + 90 lb N/ac manure N credit)

- N-Rich Strips: 85PPN + 50SN (85 lb N/ac preplant + 50 lb N/ac side-dress, with 90 lb N/ac manure N credit)
- In-Season Management Strips:
  - 60 + VRN: 60 lb N/ac preplant + side-dress N rate (calibration strip-based), with 90 lb N/ac manure N credit
  - 85 + VRN: 85 lb N/ac preplant + side-dress N rate (calibration strip-based), with 90 lb N/ac manure N credit

F21 Trial

- Farmer's Practice (FP): 210 lb N/ac (110 lb N/ac preplant + 100 lb N/ac manure N credit)
- N-Rich Strips: 135PPN (135 lb N/ac preplant, with 100 lb N/ac manure N credit)
- In-Season Management Strips:
  - 60 + VRN: 60 lb N/ac preplant + side-dress N rate (calibration strip-based), with 100 lb N/ac manure N credit
  - 85 + VRN: 85 lb N/ac preplant + side-dress N rate (calibration strip-based), with 100 lb N/ac manure N credit

F22 South

- Farmer's Practice (FP): 160 lb N/ac (60 lb N/ac UAN32 + 100 lb N/ac manure N credit)
- In-Season Management Strips:
  - 0+VRN: 0 lb N/ac preplant + sidedress N rate (calibration strip-based) + 100 lb N/ac manure
  - 30+VRN: 30 lb N/ac preplant + sidedress N rate (calibration strip-based) + 100 lb N/ac manure

PlanetScope satellite NDVI maps were used to create prescriptions for in-season supplemental N applications at the V8-V9 stage (Figure 2). All four field trials (F1, F21, and F22 North and South) were successfully applied and harvested from October 11–18, 2024, with complete yield and N fertilizer management data collected. To ensure data reliability, the combine harvester's yield monitor was recalibrated, and Yield Editor (Version 2.0.7, USDA-ARS, 2019) was used for data processing. Yield quality was assessed, and outliers were removed. Except for areas affected by flooding, no harvest data was missing. The UMN team analyzed all trials, and the results have been summarized.

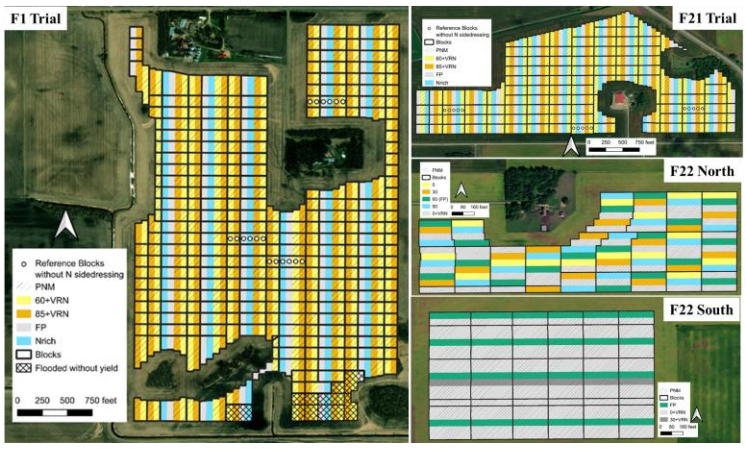

Figure 1. on-farm N trial design map of F1, F21, F22 North and South

Figure 2. Advanced Precision Nitrogen Management Based on Satellite Imagery: From Prescription Maps to In-Field Corn Application).

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

Variable rate N trials:

F22 North

- Total N application rates, yield, N use efficiency (yield lb/applied N lb), and profit for the F22 North site are presented in Figure 3. On average (Table 1), the farmer N practices (FP, 60 lb/ac, all applied before and at planting) ranked as 2nd economically among four preplant N rates in terms of profits ($932/ac) and yield (207 bu/ac) with good N use efficiency (NUE, obtained 196 lb yield from 1 lb N/ac input). The 90 lb N /ac treatment, on average, performed the best agronomically and economically in terms of profits (962 $/ac), NUE (136 lb/lb N), and yield (217 bu/ac).
- The proportion of field areas where each treatment achieved the best yield performance was 90 (50%), 60 (FP, 31%), 30 (7%), and 0 (6%). The proportion of field areas where each treatment achieved the best economic performance was 90 (56%), 60 (FP, 31%), 30 (13%), and 0 (6%). This field with manure application, no single rate dominated the field, indicating that the optimum N rate was quite variable across the field (Table 2).
- Variable-rate N application at site-specific optimal N rates (0+VRN) would obtain an 8% (=16

bu/ac) higher yield, 9% (=18 lb/N lb) better NUE, and 8% (= $79/ac) more profit, with 14% (=8 lb N/ac) less N rate compared to the uniform farmer N practice. Additionally, 0+VRN reduced nitrogen use by 27% (=19 lb N/ac) and increased yield, NUE, and profit by 1% (=2 bu/ac), 10% (=19 lb/N lb), and 2% (=$20/ac), respectively, compared to the potential of preplant EONR (Table 1).

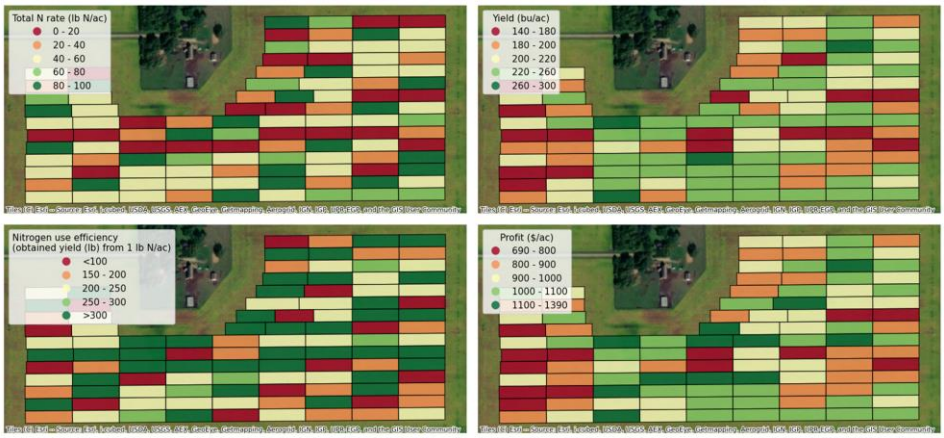

Figure 3. Maps of total nitrogen applied rate (lb N/ac), yield (bu/ac), nitrogen use efficiency (obtained yield (lb) with 1 lb N/ac), and profit ($/ac) in F22 North in 2024.

Table 1. Summary table of information related to F22 North field, management, and results for different N treatments in 2024.

Treatment		Area (ac)	N applied rates (lb/ac)			Yield (bu/ac)	N use efficiency (Yield_lb/AppiedN_lb)	Benefit ($/ac)			
			Pre-plant N	Side-dress N	Total N			N fertilizer Output	Yield income	Profit	Profit grain/loss compared to FP
VRN	**0**	6	0	0	0	**184±22**	-	0	857±103	857±103	**-75**
	30	6	30±1	0	30±1	**196±19**	369±32	17	913±87	897±87	**-35**
	60 (FP)	7	59±2	0	59±2	**207±22**	196±20	32±1	965±102	932±102	-
	90	7	90±2	0	90±2	**217±22**	136±15	50±1	1011±101	962±102	**+30**
	The potential	-	70±25	0	70±25	**221±21**	195±93	39±14	1030±97	991±100	**+59**
PNM	**0+VRN**	11	0±2	51±25	51±25	**223±26**	214±28	28±14	1039±122	1011±114	**+79**

1. Prices for corn and fertilizers were used for the whole on-farm trials for comparison purposes: Corn price: $4.66/bu; Urea + Urease inhibitor cost: $0.58/lb N and UAN32 + Urease inhibitor: $0.55/lb N.
2. Manure applications (N credit) are 100 lb N/ac. PFP is the NUE of inorganic N fertilizer applied.
3. Note that the symbol ± represents the standard deviation of the statistics.
4. [Acronyms] FP: farmer's N practice; PNM: precision N management system; VRN: calibration-strip and remote sensing-based side-dress prescription. The potential refers to the benefits of applying Preplant N with optimal VRN treatment for each block, maximizing economic outcomes across the entire field.

Table 2. Areas within the field where each preplant N treatment performed the best agronomically and economically.

Optimal Treatment	Area Within Field	
	Agronomically(%)	Economically(%)
0	6	6
30	7	13
60 (FP)	31	31
90	56	50
Total	100	

In-season site-specific precision N management trials:

F1

- Total N application rates, yield, N use efficiency (yield lb/applied N lb), and profit for the F1 trial are presented in Figure 4.
- Across all nitrogen (N) management strategies, the P0507Q hybrid consistently produced higher yields than the B06Y18Q hybrid. Under the high N treatment (Nrich), for example, P0507Q increased yield by approximately 285 bu/ac compared to B06Y18Q (256 bu/ac). Additionally, yield response trends observed after sidedress N application closely aligned with NDRE response patterns (Figure 5).
- On average (Table 3), the farmer N practice (110PPN) performed the least among all treatments in terms of profits ($ 1024/ac) and yield (233 bu/ac) with fair N use efficiency (NUE, obtained 119 lb yield per1 lb N/ac input).
- Overall (Table 3), PNM reduced N use by 13 lb N/ac, but increased yield, NUE and profit by 6 bu/ac, 31 lb/N lb and $35 /ac compared to the farmer N practice (110PPN), respectively. Applying 85 lb N/ac before and at planting with variable rate side-dress N application (85+VRN) performed the best economically, increasing yield by 4% (=9 bu/ac) and profit by 5% (= $48 /ac).
- The most economical precision nitrogen strategies used Nrich (85PPN+50SN) in higher elevation areas and PNM (85+VRN and 60+VRN) in low to mid-elevation areas (Figure 6).

Figure 4. Maps of total nitrogen applied rate (lb N/ac), yield (bu/ac), nitrogen use efficiency (obtained yield (lb) with 1 lb N/ac), and profit ($/ac) in F1 in 2024.

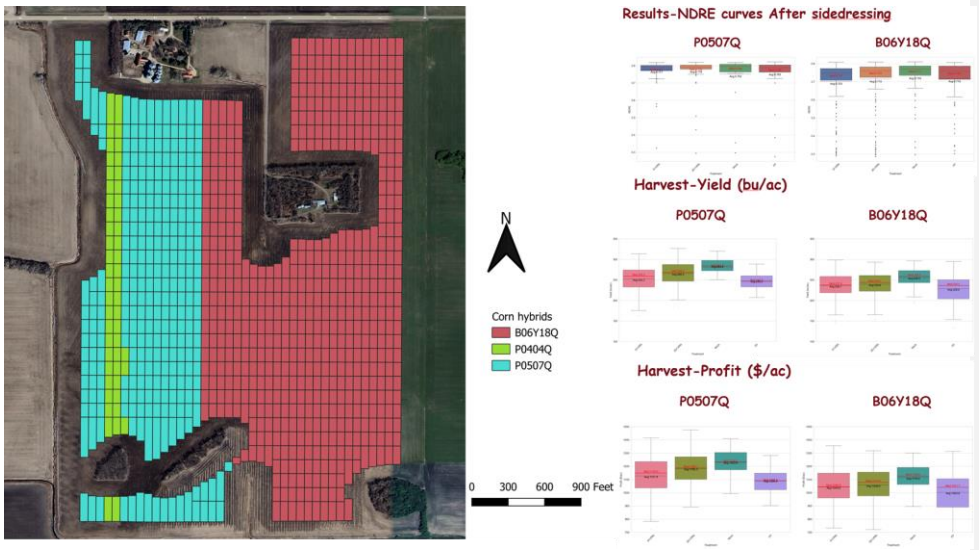

Figure 5. Map of hybrid distribution (left) and comparisons of NDRE, yield, and profit for two hybrids P0507Q and B06Y18Q (right).

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Table 3. Summary table of information related to F1 field, management, and results for different N treatments in 2024.

Treatment	Area (ac)	N applied rates (lb/ac)			Yield (bu/ac)	N use efficiency (Yield_lb/Applied N_lb)	Benefit ($/ac)			
		Pre-plant N	Side-dress N	Total N			N fertilizer Output	Yield income	Profit	Profit grain/loss compared to 100%FNR
FP	35	109±2	0	109±2	233±40	119±21	62±1	1086±186	1024±186	–
Nrich	31	85±1	59±7	144±7	259±24	101±11	81±4	1207±114	1126±115	**102**
60+VRN	73	60	32±28	92±28	236±42	157±57	53±15	1100±197	1047±194	+23
85+VRN	73	85±1	14±23	99±23	242±44	142±37	56±13	1128±206	1072±204	+48
PNM	146	73±5	23±23	96±22	239±42	150±41	54±12	1114±195	1059±193	**+35**

1. Prices for corn and fertilizers were used for the whole on-farm trials for comparison purposes: Corn price: $4.66/bu; Urea + Urease inhibitor cost: $0.58/lb N and UAN32 + Urease inhibitor: $0.55/lb N.
2. Manure applications (N credit) are 90 lb N/ac. PFP is the NUE of inorganic N fertilizer applied.
3. Note that the symbol ± represents the standard deviation of the statistics.
4. [Acronyms] FP: farmer's N practice; PNM: precision N management system; VRN: calibration-strip and remote sensing-based side-dress prescription.

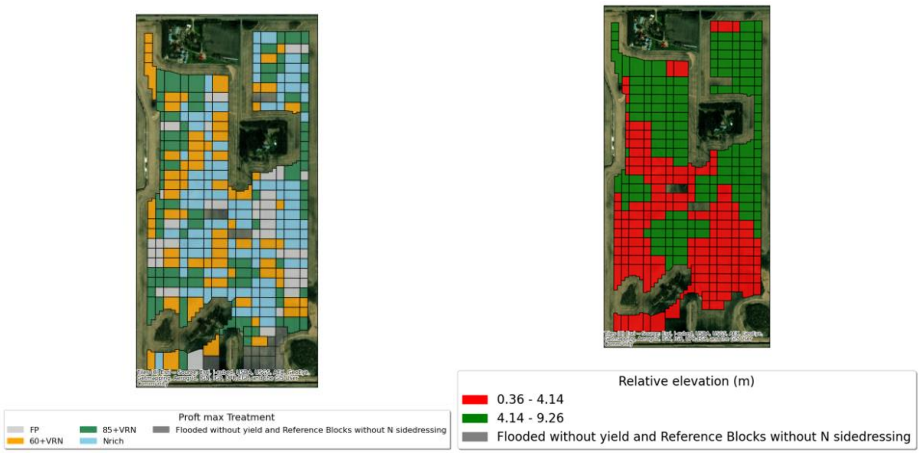

Figure 6. Spatial distribution of the treatment with the maximum profit and relative elevation.

F21

- Total N application rates, yield, N use efficiency (yield lb/applied N lb), and profit for the F21 trial are presented in Figure 7.
- On average (Table 4), the farmer N practice (110PPN) performed the least among all treatments in terms of profits ($ 898/ac) and yield (206 bu/ac) with fair N use efficiency (NUE, obtained 105 lb yield per lb N/ac input).
- Overall (Table 4), the precision N management (PNM) strategy slightly increased N by 5% (=5 lb N/ac), increased yield by 11% (=22 bu/ac) and NUE by 12%, and increased profit by 11% (=$98 /ac) over the traditional farmer N practice (FP) in the WET year of 2024. Applying 60 lb N/ac before and at planting with variable rate side-dress N application (60+VRN) performed the best economically, increasing yield by 11% (=22 bu/ac) and profit by 11% (= $101 /ac).
- The most cost-effective precision nitrogen strategies were employed with PNM (60PPN+VRN) in most areas, while 85+VRN, Nrich, and FP were applied in specific higher-elevation regions (Figure 8).
- The Nrich treatment at field F21 was applied entirely before and at planting. This contrasts with field F1, where the Nrich treatment included 60 lb N/A applied at sidedress. The differences between the Nrich treatments in these two fields should be considered when making inferences from the data in 2024, when very high June rainfall led to considerable pre-sidedress N losses.

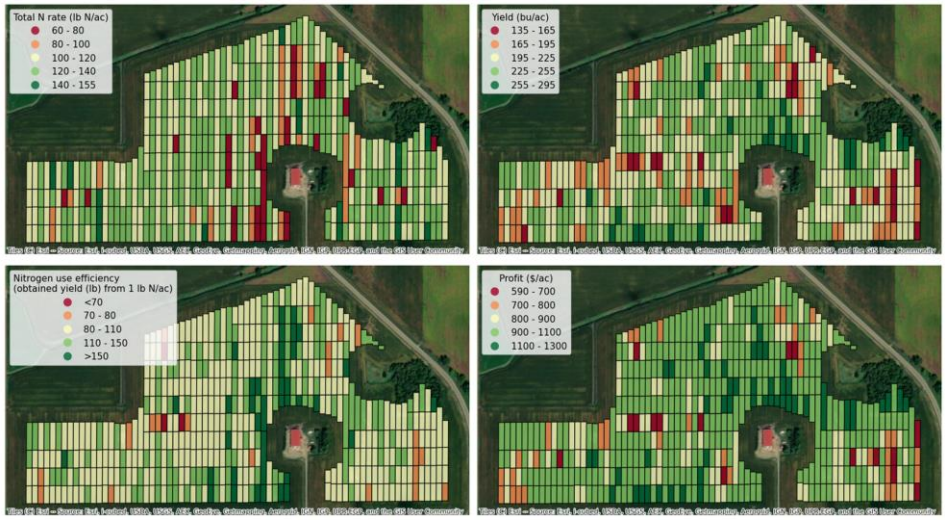

Figure 7. Maps of total nitrogen applied rate (lb N/ac), yield (bu/ac), nitrogen use efficiency (obtained yield (lb) with 1 lb N/ac), and profit ($/ac) in F21 in 2024.

Table 4. Summary table of information related to F21 field, management, and results for different N treatments in 2024.

Treatment	Area (ac)	N applied rates (lb/ac)			Yield (bu/ac)	N use efficiency (Yield_lb/Appied N_lb)	Benefit ($/ac)			
		Pre-plant N	Side-dress N	Total N			N fertilizer Output	Yield income	Profit	Profit grain/loss compared to 100%FNR
FP	33	110±1	0	110±1	206±26	105±13	62	960±119	898±119	–
Nrich	30	134±2	0	134±2	217±25	91±10	76±1	1011±116	936±116	38
60+VRN	47	60	53±23	113±23	228±21	120±37	64±12	1062±97	999±96	101
85+VRN	20	85	34±25	119±25	227±20	113±30	67±14	1058±94	991±96	93
PNM	67	67	47±17	115±17	228±18	118±24	65±9	1061±83	996±83	**98**

1. Prices for corn and fertilizers were used for the whole on-farm trials for comparison purposes: Corn price: $4.66/bu; Urea + Urease inhibitor cost: $0.58/lb N and UAN32 + Urease inhibitor: $0.55/lb N.
2. Manure applications (N credit) are 100 lb N/ac. PFP is the NUE of inorganic N fertilizer applied.
3. Note that the symbol ± represents the standard deviation of the statistics.
4. [Acronyms] FP: farmer's N practice; PNM: precision N management system; VRN: calibration-strip and remote sensing-based side-dress prescription.

Figure 8. Spatial distribution of the treatment with the maximum profit and relative elevation.

F22 South

- Total N application rates, yield, N use efficiency (yield lb/applied N lb), and profit for the F22 South are presented in Figure 9.
- On average (Table 5), the farmer N practice (60PPN) performed the least among all treatments in terms of profits ($ 998/ac) and yield (221 bu/ac) with fair N use efficiency (NUE, obtained 216 lb yield per1 lb N/ac input).
- Overall (Table 5), the precision N management (PNM) strategy decreased N by 31% (=18 lb N/ac), increased yield by 13% (=29 bu/ac) and increased profit by 15% (=$145/ac) over the traditional farmer N practice (FP) in the WET year of 2024. Applying 0 lb N/ac before and at planting with variable rate side-dress N application (0+VRN) performed the best economically, in terms of profits ($1148 /ac) and yield (251 bu/ac) with higher N use efficiency (218 lb/N lb). The most cost-effective precision nitrogen strategies were employed with PNM (0+VRN) in most areas.

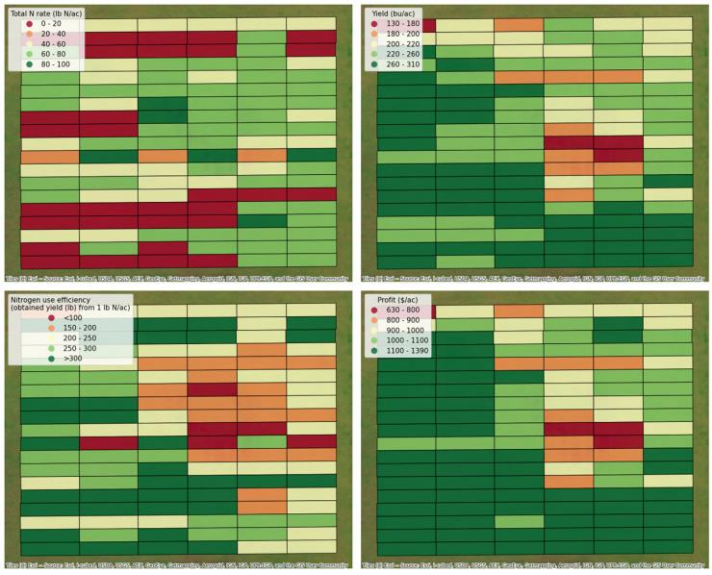

Figure 9. Maps of total nitrogen applied rate (lb N/ac), yield (bu/ac), nitrogen use efficiency (obtained yield (lb) with 1 lb N/ac), and profit ($/ac) in F22 South in 2024.

Table 5. Summary table of information related to F22 South, management, and results for different N treatments in 2024.

Treatment	Area (ac)	N applied rates (lb/ac)			Yield (bu/ac)	N use efficiency (Yield_lb/Appied N_lb)	Benefit ($/ac)			
		Pre-plant N	Side-dress N	Total N			N fertilizer Output	Yield income	Profit	Profit grain/loss compared to 100%FNR
FP	10	58±4	0	58±4	221±44	216±39	32±2	1030±203	998±202	–
0+VRN	29	0	39±33	39±33	251±31	218±40	21±18	1170±145	1148±145	150
30+VRN	2	30	24±33	54±33	215±43	284±145	30±18	1002±200	972±192	-26
PNM	31	2	38±28	40±29	250±33	222±42	22±16	1165±154	1143±149	**145**

1. Prices for corn and fertilizers were used for the whole on-farm trials for comparison purposes: Corn price: $4.66/bu; Urea + Urease inhibitor cost: $0.58/lb N and UAN32 + Urease inhibitor: $0.55/lb N.
2. Manure applications (N credit) are 100 lb N/ac. PFP is the NUE of inorganic N fertilizer applied.
3. Note that the symbol ± represents the standard deviation of the statistics.
4. [Acronyms] FP: farmer's N practice; PNM: precision N management system; VRN: calibration-strip and remote sensing-based side-dress prescription.

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

Nitrogen Management and In-Season Adjustments: Heavy rainfall in 2024 led to significant nitrogen losses, especially between June 21-28. Nitrogen recommendations may need to incorporate imagery closer to the in-season application date (e.g., July 1) for more accurate decision-making. However, acquiring suitable imagery within a short time frame for precision management remains a challenge.

Uncertainty in Nitrogen Response and Economic Benefits: Nitrogen response varies significantly based on field drainage conditions and soil organic matter history. Well drained fields experience greater nitrate-nitrogen losses, whereas poorly drained fields retain more nitrogen but are at risk of waterlogging and losses of NOx to the atmosphere. Operational factors, such as tractor compaction, also have a notable impact on yield. Furthermore, NDVI and nitrogen response differ across corn hybrids, necessitating further optimization of nitrogen application strategies based on hybrid-specific responses.

Extreme Weather Events: Heavy rains in May and June caused waterlogging in some cornfields. In low-lying areas, this resulted in significant corn mortality, leading to yield reduction and economic losses.

4.) EDUCATION AND OUTREACH ACTIVITES. *(Describe any opportunities to engage with farmers, influencers or the media about your project.)*

The UMN team shared the progress of this project as oral presentations at the 2024 ASABE Regional Meeting in Brookings and 2024 International Conference on Precision Agriculture in Manhattan in KS.

UMN organized an on-farm research summary meeting in Feb. 2025 and the results from this project were shared at this event.