Minnesota Department of Agriculture
Pesticide & Fertilizer Management
FINAL REPORT
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PROJECT NUMBER:	R2023-12, SWIFT Agreement #226046, MDA P.O. #3000045291, University of Minnesota Award #CON000000102908
PROJECT DESCRIPTION:	Advancing Continuous Corn with Mid-Season Application of Nitrogen and Sulfur
REPORT DUE DATE:	April 30, 2024
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1) GOALS AND OBJECTIVES OBTAINED

   a) ***Collect 0- to 6-inch soil samples and analyze for organic matter, pH, phosphorus, potassium, and sulfate-sulfur.*** Soil samples were collected from both locations in the spring prior to field operations and were analyzed.

      Prior to preplant fertilization, collect 0- to 24-inch soil samples and analyze for nitrate-nitrogen. Soil samples were collected from both locations in the spring prior to field operations and were analyzed.

   b) ***Apply preplant fertilizers.*** Preplant fertilizers were applied at both locations.

   c) ***Plant corn and apply herbicides.*** At both locations, corn was planted, followed by preemergence and postemergence herbicide applications.

   d) ***Measure corn plant population.*** Corn plant population was measured from all plots at both locations.

   e) ***At V14 prior to the V14 fertilizer applications, collect corn leaf samples, dry and grind them, and then analyze them for nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, iron, boron, copper, manganese, and zinc.*** Corn leaf samples were collected at the V14 corn stage from both locations just prior to the V14 fertilizer applications. The samples were then dried, ground, and submitted to a commercial lab for analysis of nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, iron, boron, copper, manganese, and zinc.

f) ***Apply V14 fertilizer treatments.*** The V14 fertilizer treatments were applied at Lamberton, MN on July 18, 2023 and at Waseca, MN on July 17, 2023.

g) ***After corn has reached physiological maturity, collect whole-plant samples of corn, separate them into grain, cob, and stover fractions, and dry and weigh them.*** This objective was fully completed in late September at Lamberton, MN and in early October at Waseca, MN.

h) ***Harvest plots with a combine to measure grain yield and grain moisture content.*** This objective was fully completed in late October at both locations.

i) ***Analyze the corn grain, cob, and stover samples that were collected at physiological maturity for nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, iron, boron, copper, manganese, and zinc.*** This objective was fully completed. The samples were analyzed in March 2024.

j) ***Calculate corn whole-plant dry matter yield and uptake of nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, iron, boron, copper, manganese, and zinc.*** This objective was fully completed. The results are shared below in this report.

k) ***Measure dry kernel weight and calculate kernels per square foot.*** This objective was fully completed. The results are shared below in this report.

l) ***Calculate corn recovery efficiency, physiological use efficiency, and agronomic use efficiency of nitrogen and sulfur fertilizers.*** This objective was fully completed. The results are shared below in this report.

m) ***Conduct an economic analysis that includes cost, revenue, and net return for the different treatments.*** This objective was fully completed. The results are shared below in this report.

n) ***Share results from this project with farmers and agricultural professionals through Extension activities.*** This objective was fully completed. The results from this project were shared with farmers and agricultural professionals through presentations at the University of Minnesota Extension Institute for Agricultural Professionals Research Update Meetings at Owatonna, MN on January 3, 2024, at Willmar, MN on January 4, 2024, and at the virtual edition of these meetings on February 9, 2024, at the University of Minnesota Southern Research and Outreach Center Winter Crops Day on January 11, 2024, and at the University of Minnesota Extension Nutrient Management Conference at Mankato, MN on February 20, 2024.

2) ACTIVITIES PERFORMED

This project involved field experiments on Normania loam soil at the University of Minnesota Southwest Research and Outreach Center near Lamberton, MN and on Nicollet clay loam soil at the University of Minnesota Southern Research and Outreach Center near Waseca, MN. The previous crop at both locations was corn, which had been stalk chopped and disk-ripped in the fall.

The experiment at each location contained 30 treatments (three corn hybrids × two planting rates × five fertilizer treatments) in a randomized complete block design with four replications (Table 1). The plots were four rows (30-inch) wide by 30 feet long. The three corn hybrids were

DKC50-87RIB, DKC54-64RIB, and DKC58-64RIB, with relative maturity (RM) ratings of 100, 104, and 108, respectively. These hybrids reflect the range of hybrid RM that local farmers use, and they have tolerance to herbicides and resistance to above-and below-ground insect pests. The two planting rates were 34,000 and 38,000 seeds/acre, which represent low and high planting rates for high-yield environments. The five fertilizer treatments included different strategies for managing nitrogen (N) and sulfur (S), along with non-N- and non-S-fertilized controls to enable calculation of corn recovery efficiency, physiological use efficiency, and agronomic use efficiency of N and S fertilizers. The five fertilizer treatments were:

1. Preplant N and S: 240 lb N/acre + 25 lb S/acre preplant
2. Split N and preplant S: 200 lb N/acre + 25 lb S/acre preplant, and 40 lb N/acre at V14
3. Split N, preplant S, and additional S: 200 lb N/acre + 25 lb S/acre preplant, and 40 lb N/acre + 10 lb S /acre at V14
4. Preplant N and no S: 240 lb N/acre preplant
5. No N and preplant S: 25 lb S/acre preplant

The total N rate of 240 lb N/acre and the base rate of 25 lb S/acre represent standard farmer practices.

Table 1. Description of the 30 treatments in the field experiments at Lamberton, MN and Waseca, MN.

Treatment	Hybrid	Planting rate (seeds/acre)	Nitrogen (N) and sulfur (S) fertilization
1	DKC50-87RIB	34,000	Preplant N and S
2	DKC50-87RIB	34,000	Split N and preplant S
3	DKC50-87RIB	34,000	Split N, preplant S, and additional S
4	DKC50-87RIB	34,000	Preplant N and no S
5	DKC50-87RIB	34,000	No N and preplant S
6	DKC50-87RIB	38,000	Preplant N and S
7	DKC50-87RIB	38,000	Split N and preplant S
8	DKC50-87RIB	38,000	Split N, preplant S, and additional S
9	DKC50-87RIB	38,000	Preplant N and no S
10	DKC50-87RIB	38,000	No N and preplant S
11	DKC54-64RIB	34,000	Preplant N and S
12	DKC54-64RIB	34,000	Split N and preplant S
13	DKC54-64RIB	34,000	Split N, preplant S, and additional S
14	DKC54-64RIB	34,000	Preplant N and no S
15	DKC54-64RIB	34,000	No N and preplant S
16	DKC54-64RIB	38,000	Preplant N and S

17	DKC54-64RIB	38,000	Split N and preplant S
18	DKC54-64RIB	38,000	Split N, preplant S, and additional S
19	DKC54-64RIB	38,000	Preplant N and no S
20	DKC54-64RIB	38,000	No N and preplant S
21	DKC58-64RIB	34,000	Preplant N and S
22	DKC58-64RIB	34,000	Split N and preplant S
23	DKC58-64RIB	34,000	Split N, preplant S, and additional S
24	DKC58-64RIB	34,000	Preplant N and no S
25	DKC58-64RIB	34,000	No N and preplant S
26	DKC58-64RIB	38,000	Preplant N and S
27	DKC58-64RIB	38,000	Split N and preplant S
28	DKC58-64RIB	38,000	Split N, preplant S, and additional S
29	DKC58-64RIB	38,000	Preplant N and no S
30	DKC58-64RIB	38,000	No N and preplant S

The 2023 growing season was wet in mid-May and then unusually dry, especially at Lamberton (Tables 2; Figures 1, 2). However, preplant fertilization and planting occurred after the abundant rainfall in mid-May. July, which is a critical period for corn development, was exceptionally dry at both locations, with just 1.0 and 1.6 inches of rainfall occurring at Lamberton and Waseca, respectively. This, along with dryer-than-normal weather in June, August, and September, likely contributed to the very low yields at Lamberton and below-average yields at Waseca (average = 141 and 194 bushels per acre for the treatment with all N and S applied preplant at Lamberton and Waseca, respectively).

Following the V14 fertilizer application, it remained dry at Lamberton for over two weeks, except for two small rain events of less than 0.2 inches each, so corn uptake of the V14 applied fertilizer was likely delayed at this location (Figure 1). At Waseca, about 0.6 inches of rainfall occurred 7 days after the V14 fertilizer application, thereby enabling quicker uptake of the V14-applied fertilizer at Waseca compared to Lamberton (Figure 2).

Table 2. Monthly total rainfall during the 2023 growing season at Lamberton, MN and Waseca, MN.

	Lamberton, MN	**Waseca, MN**
-------- Month --------	rainfall, departure from normal (inches)	
May	7.1 (+3.5)	6.5 (2.0)
June	2.9 (-1.1)	1.6 (-3.8)
July	1.0 (-2.8)	1.6 (-3.3)
August	2.0 (-1.3)	3.3 (-1.5)
September	0.6 (-2.6)	2.2 (-2.0)
Total (May–September)	13.6 (-4.3)	15.2 (-8.6)

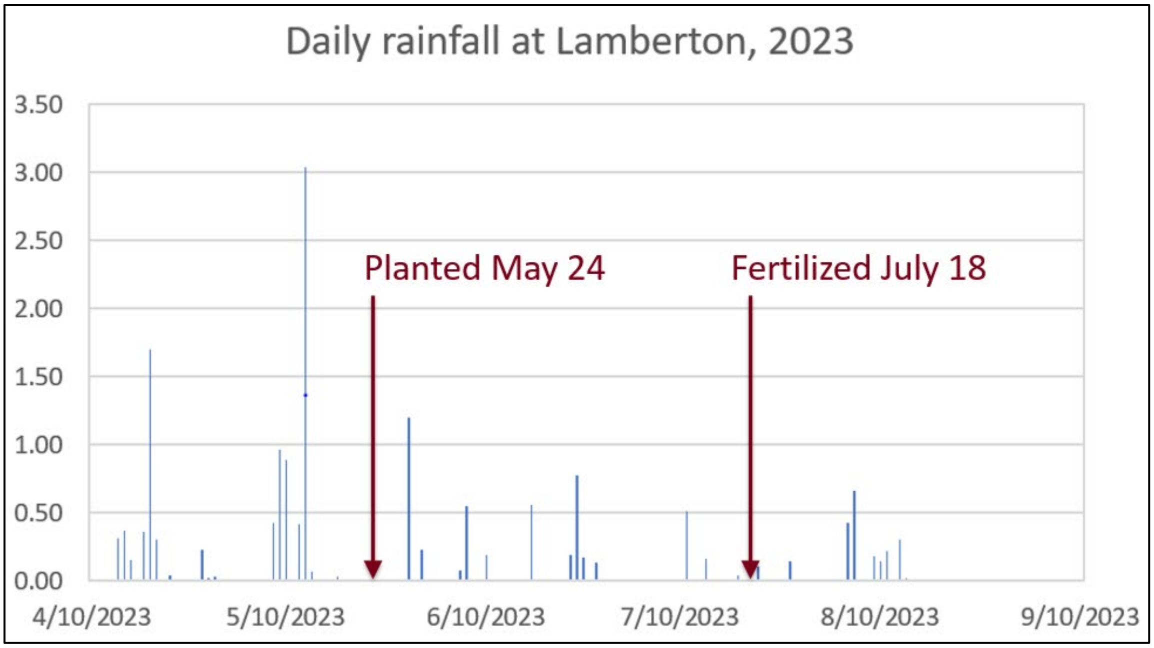

Figure 1. Daily rainfall at Lamberton, MN in 2023.

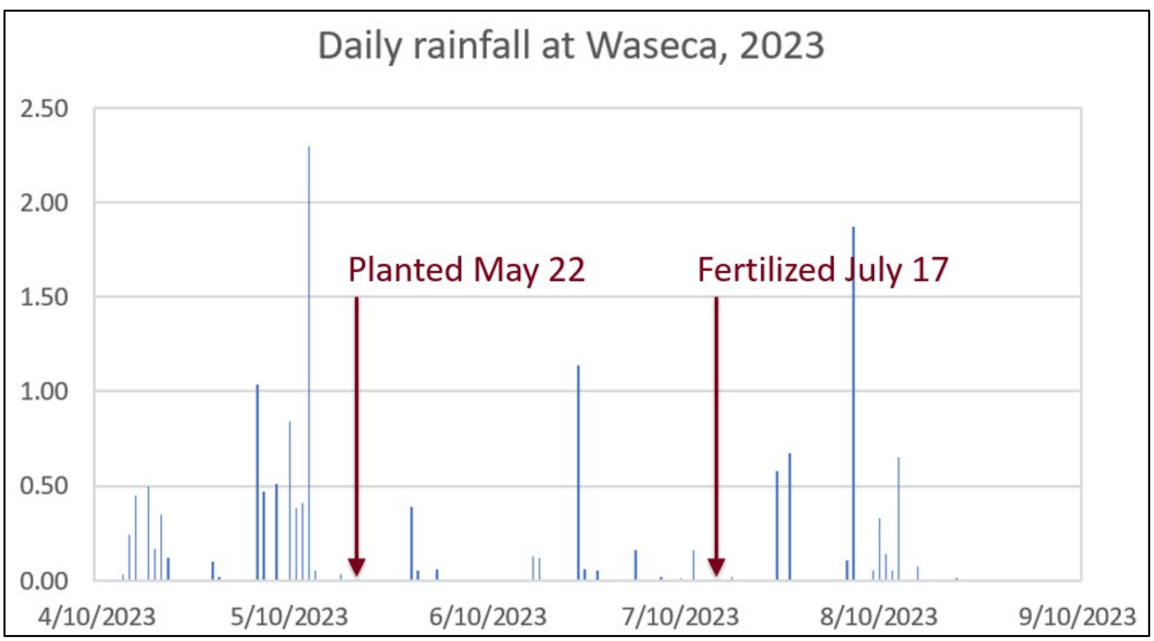

Figure 2. Daily rainfall at Waseca, MN in 2023.

a) To accomplish the goals/objectives "*collect 0- to 6-inch soil samples and analyze for organic matter, pH, phosphorus, potassium, and sulfate-sulfur*" and "*prior to preplant fertilization, collect 0- to 24-inch soil samples and analyze for nitrate-nitrogen*" soil samples were collected from the 0- to 6-inch and 6- to 24-inch depths in April prior to preplant fertilization. For each soil depth, one composite soil sample based on 10 cores was collected from each of the four replications at each location. The soil samples were dried in a forced-air oven at 95°F, crushed, sieved, and analyzed by the University of Minnesota Research Analytical Laboratory. Soil samples from the 0- to 6-inch soil depth were analyzed for organic matter (loss on ignition), pH (water), Bray-phosphorus (P) 1, and exchangeable potassium (K), nitrate-nitrogen (N), and sulfate-sulfur (S). Soil samples from the 6- to 24-inch depth were analyzed for nitrate-N and sulfate-S. The results of these analyses are in Table 3.

Table 3. Baseline soil-test levels from the 0- to 6-inch and 6- to 24-inch soil layers at Lamberton, MN and Waseca, MN in April 2023.[1]

Variable	Depth (inches)	Lamberton	Waseca
Organic matter, %	0–6	3.8	4.5
pH (water)	0–6	5.8	6.0
Bray-phosphorus 1, ppm	0–6	22	67
Exchangeable potassium, ppm	0–6	178	210
Nitrate-nitrogen, ppm	0–6	9.2	5.5
Nitrate-nitrogen, ppm	6–24	7.5	3.1
Sulfate-sulfur, ppm	0–6	20.2	12.3
Sulfate-sulfur, ppm	6–24	11.3	8.3

[1] Values are the average across four replications at each location.

b) To accomplish the goal/objective "*apply preplant fertilizers*", Preplant P, K, N, and S fertilizers were broadcast prior to preplant tillage. Triple super phosphate (0-46-0) and potash (0-0-60) were applied preplant to the entire experimental area at each location based on soil-test P and K levels and University of Minnesota Extension guidelines for a 260 bushel/acre yield. Preplant N and S were applied using urea (46-0-0) and pelletized gypsum (0-0-0-17S), respectively for the various treatments according to Table 1. The N and S that was applied at V14 was applied as urea ammonium nitrate (28-0-0) and ammonium thiosulfate (12-0-0-26S) placed on the soil near both sides of corn rows using the 360 Y-DROP® system. A urease inhibitor was used with both V14 applications.

c) To accomplish the goal/objective "*plant corn and apply herbicides*", corn was planted according to Table 2 on May 22, 2023 at Waseca, MN and on May 24, 2023 at Lamberton, MN using a four-row precision plot planter equipped with RTK GPS. At both locations, a preemergence herbicide was applied soon after planting, followed by a postemergence herbicide application after weed emergence.

d) To accomplish the goal/objective "*measure corn plant population*", corn plant population was measured at the four-leaf collar corn stage by counting all plants within the center two rows of each plot. The results are in Table 4.

Table 4. Corn plant population by hybrid and planting rate at Lamberton, MN and Waseca, MN in 2023.[1]

Hybrid	Planting rate	Lamberton	Waseca
	-- seeds/acre --	----------- plants/acre -----------	
DKC50-87RIB	34,000	33,100	33,600
DKC50-87RIB	38,000	36,600	37,000
DKC54-38RIB	34,000	34,700	34,500
DKC54-38RIB	38,000	37,100	37,600
DKC58-64RIB	34,000	33,600	34,100
DKC58-64RIB	38,000	37,100	37,700

[1] Values are the average across five fertilizer treatments and four replications.

e) The goal/objective "*at V14 prior to the V14 fertilizer applications, collect corn leaf samples, dry and grind them, and then analyze them for nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, iron, boron, copper, manganese, and zinc*" was mostly completed. This was done by collecting corn leaf samples at the V14 corn stage from both locations just prior to the V14 fertilizer applications. The samples were then dried, ground, and submitted to a commercial lab for analysis of N, S, P, K, calcium (Ca), magnesium (Mg), iron (Fe), boron (B), copper (Cu), manganese (Mn), and zinc (Zn). The results are shown in Tables 5–8.

For most nutrients at both locations, corn leaf nutrient levels at the V14 stage just prior to the V14 fertilizer applications were significantly affected by corn hybrid and fertilizer treatment, but not by corn planting rate. Additionally, it was rare for corn leaf nutrient levels to be significantly affected by interactions between corn hybrid, fertilizer treatment, or corn planting rate. Therefore, results are presented by hybrid (Tables 5 and 6) and fertilizer treatment (Tables 7 and 8).

The three corn hybrids of differing RM differed in their leaf nutrient levels at the V14 stage just prior to the V14 fertilizer applications (Tables 5 and 6). At both locations, leaf N, S, Fe, and B were not significantly different among hybrids. As for the other nutrients, the results varied by nutrient and location, with no consistent pattern of one hybrid having greater nutrient levels than the others, except for at Waseca where the 108 RM hybrid had the highest levels for all nutrients except Zn.

Corn leaf nutrient levels at the V14 stage just prior to the V14 fertilizer applications differed among the five fertilizer treatments (Tables 7 and 8). As with corn hybrid RM, the results differed by nutrient and location. Some key findings are as follows. At Lamberton, the "preplant N and S" treatment had the highest leaf nutrient level for all nutrients, and the "split N and preplant S" and "split N, preplant S, and additional S" also had leaf nutrient levels that were among the highest for all nutrients except N, Cu, and Mn. At Waseca, the highest leaf nutrient levels for all nutrients occurred for all treatments except the treatment with no N applied.

Table 5. Effect of hybrid relative maturity (RM) on corn leaf nutrient levels at the V14 corn stage at Lamberton, MN in 2023, just prior to the V14 fertilizer applications. Means are averaged over both planting rates and all five fertilizer treatments. Within a row, means followed by the same letter are not significantly different at the 0.05 probability level.

Variable	100 RM	104 RM	108 RM
Nitrogen, %	2.13 a	2.19 a	2.19 a
Sulfur, %	0.142 a	0.145 a	0.137 a
Phosphorus, %	0.234 c	0.255 a	0.244 b
Potassium, %	1.95 a	1.82 b	1.81 b
Calcium, %	0.252 b	0.280 a	0.296 a
Magnesium, %	0.179 c	0.199 b	0.222 a
Iron, ppm	54.6 a	61.9 a	70.6 a
Boron, ppm	11.0 a	10.2 a	10.3 a
Copper, ppm	5.16 b	5.71 a	5.23 b
Manganese, ppm	70.1 a	59.8 b	72.5 a
Zinc, ppm	18.8 a	19.2 a	16.5 b

Table 6. Effect of hybrid relative maturity (RM) on corn leaf nutrient levels at the V14 corn stage at Waseca, MN in 2023, just prior to the V14 fertilizer applications. Means are averaged over both planting rates and all five fertilizer treatments. Within a row, means followed by the same letter are not significantly different at the 0.05 probability level.

Variable	100 RM	104 RM	108 RM
Nitrogen, %	2.34 a	2.42 a	2.45 a
Sulfur, %	0.152 a	0.158 a	0.158 a
Phosphorus, %	0.228 b	0.242 a	0.243 a
Potassium, %	1.76 a	1.74 a	1.79 a
Calcium, %	0.428 b	0.404 b	0.474 a
Magnesium, %	0.241 ab	0.227 b	0.254 a
Iron, ppm	79.3 a	89.5 a	84.3 a
Boron, ppm	7.95 a	7.78 a	7.38 a
Copper, ppm	6.69 a	7.00 a	6.49 a
Manganese, ppm	60.0 ab	52.2 b	63.5 a
Zinc, ppm	21.7 a	20.8 a	18.5 b

Table 7. Effect of nitrogen (N) and sulfur (S) fertilizer treatment on corn leaf nutrient levels at the V14 corn stage at Lamberton, MN in 2023, just prior to the V14 fertilizer applications. Means are averaged over all three hybrids and both planting rates. Within a row, means followed by the same letter are not significantly different at the 0.05 probability level.

Variable	Preplant N and S	Split N and preplant S	Split N, preplant S, and additional S	Preplant N and no S	No N and preplant S
Nitrogen, %	2.52 a	2.30 b	2.33 b	2.28 b	1.41 c
Sulfur, %	0.157 a	0.151 a	0.154 a	0.138 b	0.108 c
Phosphorus, %	0.252 a	0.246 a	0.256 a	0.252 a	0.215 b
Potassium, %	1.83 a	1.83 a	1.90 a	1.86 a	1.89 a
Calcium, %	0.298 a	0.283 a	0.300 a	0.277 a	0.222 b
Magnesium, %	0.215 a	0.204 ab	0.211 a	0.196 b	0.173 c
Iron, ppm	66.2 ab	81.8 a	73.0 ab	57.0 b	33.7 c
Boron, ppm	11.7 ab	11.2 ab	12.0 a	10.8 b	6.8 c
Copper, ppm	6.52 a	5.79 b	6.31 ab	54.0 c	2.82 d
Manganese, ppm	89.0 a	66.3 c	77.9 b	72.1 bc	32.0 d
Zinc, ppm	19.8 a	19.3 ab	20.3 a	18.5 b	12.8 c

Table 8. Effect of nitrogen (N) and sulfur (S) fertilizer treatment on corn leaf nutrient levels at the V14 corn stage at Waseca, MN in 2023, just prior to the V14 fertilizer applications. Means are averaged over all three hybrids and both planting rates. Within a row, means followed by the same letter are not significantly different at the 0.05 probability level.

Variable	Preplant N and S	Split N and preplant S	Split N, preplant S, and additional S	Preplant N and no S	No N and preplant S
Nitrogen, %	2.60 a	2.58 a	2.56 a	2.52 a	1.75 b
Sulfur, %	0.162 a	0.167 a	0.165 a	0.164 a	0.123 b
Phosphorus, %	0.249 a	0.246 a	0.241 a	0.241 a	0.214 b
Potassium, %	1.74 a	1.80 a	1.78 a	1.79 a	1.71 a
Calcium, %	0.443 a	0.455 a	0.450 a	0.440 a	0.388 b
Magnesium, %	0.243 a	0.246 a	0.244 a	0.238 a	0.234 a
Iron, ppm	83.3 a	90.8 a	87.6 a	87.1 a	72.9 a
Boron, ppm	8.02 a	8.24 a	8.66 a	8.03 a	5.55 b
Copper, ppm	7.11 a	7.59 a	7.30 a	7.17 a	4.47 b
Manganese, ppm	59.9 a	61.6 a	64.3 a	65.3 a	41.8 b
Zinc, ppm	21.3 a	22.1 a	21.3 a	21.7 a	15.1b

f) To accomplish the goal/objective "*Apply V14 fertilizer treatments*", the V14 fertilizer treatments were applied using a custom-built one-row 360 Y-DROP® applicator at Lamberton, MN on July 18 and at Waseca, MN on July 17.

g) To accomplish the goal/objective "*after corn has reached physiological maturity, collect whole-plant samples of corn, separate them into grain, cob, and stover fractions, and dry and weigh them*", whole-plant corn samples were collected from each plot at the R6 growth stage (physiological maturity) in late September at Lamberton, MN and in early October at Waseca, MN. Ears were separated from the rest of the plant (stover). Ears were dried, weighed, and shelled, after which grain and cobs were weighed separately. Stover was weighed, chipped, sub-sampled in the field, with sub-samples weighed wet and again after drying. These data were used to calculate whole plant dry matter yield.

h) To accomplish the goal/objective "*harvest plots with a combine to measure grain yield and moisture content*", plots were end-trimmed and harvested using a plot combine in late October at both locations. Grain yield was adjusted to 15% moisture content. There were few meaningful significant interactions among fertilizer treatment, hybrid, and planting rate for corn grain yield or grain moisture content at harvest for either location. Therefore, the results are shown separately for the main effects of fertilizer treatment, hybrid, and planting rate, and as averages over all levels of the other variables (Tables 9–14).

At Lamberton, corn grain yield was low and was significantly less only for the treatments with no N or no S. At Waseca, corn grain yield was below normal and reduced only for the treatment with no N applied (Table 9). The 104 RM hybrid yielded the most at Lamberton, whereas the 104 and 108 RM hybrids yielded the most at Waseca (Table 10). At both locations, corn grain yield was not significantly different between the two planting rates (Table 11).

Corn grain moisture content at harvest was not significantly different among fertilizer treatments at Lamberton, but at Waseca it was higher for the treatment with no N applied (Table 12). At both locations, grain moisture content at harvest was highest for the 108 RM hybrid (Table 13) and it was not significantly different between the two planting rates (Table 14).

i) To accomplish the goal/objective "*analyze the corn grain, cob, and stover samples that were collected at physiological maturity for nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, iron, boron, copper, manganese, and zinc*", the samples were dried immediately after sampling, ground, and later analyzed for N, S, P, K, Ca, Mg, Fe, B, Cu, Mn, and Zn. These nutrient concentration data were used to calculate whole-plant uptake of these nutrients, as described below.

j) To accomplish the goal/objective "*calculate corn whole-plant dry matter yield and uptake of nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, iron, boron, copper, manganese, and zinc*", corn whole plant dry matter yield was calculated as the sum of dry matter yield for grain, cob, and stover. Whole-plant nutrient uptake was calculated as the sum of the products of dry matter yield and nutrient concentration for grain, cob, and stover. The results for corn whole-plant dry matter yield and nutrient uptake are shown in Tables 9–14.

There were few significant interactions of meaningful importance among fertilizer treatment, hybrid, and planting rate for corn whole plant dry matter yield and corn aboveground nutrient uptake at physiological maturity for either location. Therefore, the results are shown as averages for the main effects of fertilizer treatment, hybrid, and planting rate (Tables 9–14).

At both locations, corn whole plant dry matter yield was not significantly different among fertilizer treatments that received N fertilizer, but corn whole plant dry matter yield for the treatment that did not receive N fertilizer was 38% lower at Lamberton and 50% lower at Waseca (Tables 9 and 12). Corn whole plant dry matter yield was not significantly different among hybrids at Lamberton (Table 10), but at Waseca it averaged 9% less for the 100 RM hybrid compared to the 104 and 108 RM hybrids (Table 13). There were no significant differences between planting rates for corn whole plant dry matter yield at either location (Tables 11 and 14).

At Lamberton, corn aboveground uptake of N at physiological maturity was not significantly different among the four fertilizer treatments with N applied, and greatest uptake of S occurred only in the treatments involving "preplant N and S" and "split N, preplant S, and additional S" (Table 9). At Lamberton, corn uptake of P, K, Ca, and Cu was not significantly different among the four fertilizer treatments where N was applied, while corn uptake of B, Mn, and Zn was greatest for the fertilizer treatment involving preplant N and S. Corn uptake of Mg at Lamberton was greatest with "preplant N and S" and "split N and preplant S", while corn uptake of Fe was greatest with "preplant N and S" and "split N, preplant S, and additional S."

At Lamberton, corn nutrient uptake at physiological maturity was not significantly affected by hybrid for the nutrients N, S, K, Mg, Cu, and Zn, while corn uptake of Ca, B, and Fe was significantly greater for the 108 RM compared to the 100 and 104 RM hybrids (Table 10). Corn uptake of Mn at Lamberton was greatest for the 100 RM hybrid.

Averaged across fertilizer treatments and hybrids, corn aboveground nutrient uptake at maturity was not significantly different between the two planting rates for any measured nutrient except P, for which the planting rate of 34,000 seeds/acre resulted in 5% greater uptake of P than 38,000 seeds/acre (Table 11).

At Waseca, which had much higher corn grain yield and whole plant dry matter yield at maturity, corn aboveground uptake of N, S, K, Ca, Mg, B, Cu, and Zn at maturity were greatest for the treatments receiving N fertilizer (Table 12). For Fe and Mn, corn uptake of these nutrients at maturity was greatest for the fertilizer treatments "preplant N and S", "split N, preplant S, and additional S", and "preplant N and no S". Corn uptake of P was greatest for the fertilizer treatments "preplant N and S", "split N and preplant S", and "preplant N and no S". For all measured nutrients, corn uptake of them at maturity was lowest for the fertilizer treatment where no N was applied.

Corn nutrient uptake at maturity at Waseca did not differ among the three hybrids for N, S, Mn, and Cu, but greatest uptake of K, Ca, Mg, B, and Fe occurred only with the 108 RM hybrid, while greatest uptake of P occurred with the 104 RM hybrid, and greatest uptake of Zn occurred with the 104 and 108 RM hybrids (Table 13). Corn aboveground nutrient uptake at maturity at Waseca was not significantly different between the two planting rates for any measured nutrient except for Mg and Zn; for Mg and Zn, uptake of these nutrients was significantly greater with 34,000 seeds/acre compared to 38,000 seeds (Table 14).

k) To accomplish the goal/objective "*measure dry kernel weight and calculate kernels per square foot*", a grain sample from each plot was collected during combine harvesting. These grain samples were oven-dried until constant mass, then 300 kernels of each sample were counted and weighed. The 300-kernel weights were then divided by 300 to obtain weight per kernel, which is one of the two primary yield components of corn. The other primary yield component of corn is kernels per square foot. This was calculated by adjusting grain yield to 0% moisture and dividing it by kernel weight. The results for kernel weight and kernels per square foot are shown in Tables 9–14.

At Lamberton, where corn grain yield was greatest for the fertilizer treatments that received both N and S, the 104 RM hybrid, and either planting rate (Tables 9–11), weight per kernel was greatest for the fertilizer treatments receiving N fertilizer, except for the treatment with split N, preplant S, and additional S, which was unexpectedly lower. Weight per kernel was also greater for the 104 and 108 RM hybrids compared to the 100 RM hybrid (Table 10), and it was also greater for the planting rate of 34,000 seeds/acre compared to 38,000 seeds/acre (Table 11). Kernels per square foot at Lamberton was also greatest for the fertilizer treatments receiving N fertilizer (Table 9) and the 100 and 104 RM hybrids (Table 10), but it was not significantly affected by planting rate (Table 11).

At Waseca, where grain yield was greatest for treatments that received N fertilizer, weight per kernel was not significantly affected by fertilizer treatment, and kernels per square foot were reduced only with the fertilizer treatment involving "no N and preplant S" (Table 12). Additionally, weight per kernel at Waseca was greatest with the 108 RM hybrid and either planting rate, while kernels per square foot were greatest with the 104 RM hybrid and either planting rate (Tables 13 and 14).

l) Another goal/objective that was accomplished was "*calculate corn recovery efficiency, physiological use efficiency, and agronomic use efficiency of nitrogen and sulfur fertilizers*". These parameters were calculated as follows for each combination of hybrid and planting rate:

   i) Recovery efficiency of N and S fertilizers = [(corn aboveground nutrient uptake in the treatment with fertilization – corn aboveground nutrient uptake in the corresponding control treatment without fertilization) / (fertilizer rate in the treatment with fertilization)]

   ii) Physiological use efficiency of N and S fertilizers = [(corn grain yield in the treatment with fertilization – corn grain yield in the corresponding treatment without fertilization) / (corn aboveground nutrient uptake in the treatment with fertilization – corn aboveground nutrient uptake in the corresponding treatment without fertilization)]

   iii) Agronomic use efficiency of N and S fertilizers = [(corn grain yield in the treatment with fertilization – corn grain yield in the corresponding treatment without fertilization) / (fertilizer rate in the treatment with fertilization)]

   The three indices of corn use efficiency of N and S fertilizers listed above were not significantly different among the first three fertilizer treatments at either location (Tables 9 and 12). At Lamberton, the three indices of corn use efficiency of N and S fertilizers were not significantly affected by hybrid RM or planting rate, except for recovery efficiency of fertilizer S, which was slightly greater with the planting rate of 34,000 seeds/acre compared to 38,000 seeds/acre (Tables 10 and 11). At Waseca, the three calculated indices of corn use efficiency of N and S fertilizers were not significantly different among planting rates (Table 14) but were affected by hybrid (Table 13). The 108 RM hybrid had values that were among the greatest for the three calculated indices of corn use efficiency of N and S fertilizers, except for recovery efficiency of fertilizer S. The values for corn use efficiency of S fertilizers were especially low at Waseca, where grain yield in the non-S-fertilized treatment was not significantly different than that of the other treatments that received N fertilizer (Table 12).

m) Another goal/objective that was accomplished was "*conduct an economic analysis that includes cost, revenue, and net return for the different treatments*". For this, the cost was calculated for each treatment, and included only those costs that differed among treatments (i.e., seed amount, N and S fertilizers, urease inhibitor for the V14 fertilizer applications, and the custom application cost for the V14 fertilizer application). Costs of production were based on quotes from local suppliers. The cost of seed for all three hybrids was set at $3.66/1,000 seeds; therefore, the cost of the treatment with 38,000 seeds/acre was $14.64/acre greater than that of the treatment with 34,000 seeds/acre. For the fertilizer treatments, the cost of urea (46-0-0) was set at $0.60/lb N, the cost of pelletized gypsum (0-0-0-17S) was set at $0.60/lb S, the cost of urea ammonium nitrate (liquid 28-0-0) was set at $0.67/lb N, the cost of ammonium thiosulfate (liquid 12-0-0-26S) was set at $0.1832/lb of product ($0.70/lb S), the cost of a urease inhibitor for the V14 fertilizer applications was set at $7.00/acre, and the V14 custom fertilizer application was set at $13.65/acre based on the Iowa State University Extension custom rate survey. The cost of the experimental treatments are shown in Tables 9–14.

   Revenue was calculated by plot as the product of corn grain yield and corn selling price (set at $4.50 per bushel), minus drying costs for grain harvest moisture above 15% (set at $0.035 per percentage point of moisture per bushel). Partial net return was calculated for each plot as revenue minus treatment cost. Data for revenue and partial net return were analyzed statistically and the results are shown in Tables 9–14.

At Lamberton, where corn grain yield and revenue were greatest for the three fertilizer treatments where both N and S were applied, the 104 RM hybrid, and either planting rate, partial net return was greatest with the two fertilizer treatments where all N was applied preplant, the 104 and 108 RM hybrids, and the planting rate of 34,000 seeds/acre (Tables 9–11). At Waseca, where corn grain yield and revenue were greatest with the four fertilizer treatments where N was applied, the 104 and 108 RM hybrids, and either planting rate, partial net return was greatest with the fertilizer treatment receiving preplant N and no S fertilizer, the 104 and 108 RM hybrids, and the planting rate of 34,000 seeds/acre (Tables 12–14).

Table 9. Corn yield, grain moisture at harvest, grain yield components, economic parameters, aboveground nutrient uptake at maturity (R6 stage), and indices of N and S fertilizer use efficiency as affected by fertilizer treatment at Lamberton, MN in 2023, averaged across three hybrids and two planting rates.

Variable	Preplant N and S	Split N and preplant S	Split N, preplant S, and additional S	Preplant N and no S	No N and preplant S
Grain yield (bu/acre at 15%)	141 a [1]	134 ab	130 ab	128 b	75 c
Grain moisture at harvest (%)	17.5 a	17.1 a	17.2 a	17.7 a	17.5 a
Weight per kernel (mg)	227 a	219 ab	212 b	227 a	188 c
Kernels per square foot	247 a	242 a	245 a	225 a	162 b
Treatment cost ($/acre) [2]	291	314	318	276	147
Revenue ($/acre)	621 a	592 ab	575 ab	566 b	335 c
Partial net return ($/acre)	334 a	277 b	266 b	290 ab	188 c
Whole plant dry matter yield at R6 (tons/acre)	8.57 a	8.33 a	8.05 a	7.94 a	5.12 b
Aboveground N uptake at R6 (lb N/acre)	183 a	175 a	171 a	174 a	86 b
Recovery efficiency of fertilizer N (lb increase in aboveground N uptake at R6 per lb N applied)	0.415 a	0.382 a	0.363 a	0.374 a	---
Physiological N use efficiency (bushels gained per 1-lb increase in aboveground N uptake at R6)	0.676 a	0.669 a	0.629 a	0.196 a	---
Agronomic N use efficiency (bushels gained per lb N applied)	0.271 a	0.245 a	0.227 a	0.209 a	---
Aboveground S uptake at R6 (lb S/acre)	11.29 a	10.53 ab	10.34 ab	9.65 b	6.02 c
Recovery efficiency of fertilizer S (lb increase in aboveground S uptake at R6 per lb S applied)	0.0659 a	0.0278 a	0.0236 a	---	-0.1492 b
Physiological S use efficiency (bushels gained per 1-lb increase in aboveground S uptake at R6)	-0.3 a	11.3 a	11.8 a	---	12.0 a
Agronomic S use efficiency (bushels gained per lb S applied)	0.476 a	0.313 a	0.202 a	---	-2.148 b
Aboveground P uptake at R6 (lb P/acre)	21.6 a	21.0 a	20.2 a	21.1 a	16.6 b
Aboveground K uptake at R6 (lb K/acre)	108 a	104 a	105 a	112 a	76 b
Aboveground Ca uptake at R6 (lb Ca/acre)	33.4 a	31.3 a	31.9 a	31.3 a	17.3 b
Aboveground Mg uptake at R6 (lb Mg/acre)	32.9 a	30.6 ab	29.2 b	28.9 b	18.6 c
Aboveground B uptake at R6 (lb B/acre)	7.59 a	7.11 ab	6.92 b	7.01 b	5.05 c
Aboveground Fe uptake at R6 (lb Fe/acre)	110 a	92 bc	99 ab	97 bc	87 c
Aboveground Mn uptake at R6 (lb Mn/acre)	76.7 a	61.5 b	62.6 b	64.8 b	30.3 c
Aboveground Cu uptake at R6 (lb Cu/acre)	9.37 a	10.09 a	7.83 a	8.28 a	5.63 a
Aboveground Zn uptake at R6 (lb Zn/acre)	25.4 a	22.9 b	22.2 b	23.7 ab	20.1 c

[1] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

[2] Includes only those costs that differed among treatments.

Table 10. Corn yield, grain moisture at harvest, grain yield components, economic parameters, aboveground nutrient uptake at maturity (R6 stage), and indices of N and S fertilizer use efficiency as affected by corn hybrid relative maturity (RM) at Lamberton, MN in 2023, averaged across five fertilizer treatments and two planting rates.

Variable	100 RM	104 RM	108 RM
Grain yield (bu/acre at 15%)	116 b [1]	129 a	120 b
Grain moisture at harvest (%)	17.1 b	17.0 b	18.1 a
Weight per kernel (mg)	205 b	217 a	222 a
Kernels per square foot	223 ab	237 a	212 b
Treatment cost ($/acre) [2]	269	269	269
Revenue ($/acre)	516 b	572 a	525 b
Partial net return ($/acre)	247 b	308 a	258 a
Whole plant dry matter yield at R6 (tons/acre)	7.45 a	7.73 a	7.61 a
Aboveground N uptake at R6 (lb N/acre)	156 a	157 a	160 a
Recovery efficiency of fertilizer N (lb increase in aboveground N uptake at R6 per lb N applied)	0.368 a	0.372 a	0.410 a
Physiological N use efficiency (bushels gained per 1-lb increase in aboveground N uptake at R6)	0.613 a	0.461 a	0.554 a
Agronomic N use efficiency (bushels gained per lb N applied)	0.211 a	0.266 a	0.238 a
Aboveground S uptake at R6 (lb S/acre)	9.54 a	9.41 a	9.75 a
Recovery efficiency of fertilizer S (lb increase in aboveground S uptake at R6 per lb S applied)	0.0147 a	-0.0124 a	-0.0262 a
Physiological S use efficiency (bushels gained per 1-lb increase in aboveground S uptake at R6)	8.9 a	8.0 a	9.2 a
Agronomic S use efficiency (bushels gained per lb S applied)	-0.3357 a	-0.3830 a	-0.3357 a
Aboveground P uptake at R6 (lb P/acre)	18.6 b	22.1 a	19.6 b
Aboveground K uptake at R6 (lb K/acre)	101 a	100 a	103 a
Aboveground Ca uptake at R6 (lb Ca/acre)	28.4 b	26.7 b	31.9 a
Aboveground Mg uptake at R6 (lb Mg/acre)	27.7 a	27.5 a	29.0 a
Aboveground B uptake at R6 (lb B/acre)	6.61 b	6.38 b	7.22 a
Aboveground Fe uptake at R6 (lb Fe/acre)	95 b	89 b	106 a
Aboveground Mn uptake at R6 (lb Mn/acre)	68.5 a	54.8 b	54.2 b
Aboveground Cu uptake at R6 (lb Cu/acre)	9.89 a	9.36 a	5.47 a
Aboveground Zn uptake at R6 (lb Zn/acre)	21.9 a	23.7 a	23.0 a

[1] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

[2] Includes only those costs that differed among treatments.

Table 11. Corn yield, grain moisture at harvest, grain yield components, economic parameters, aboveground nutrient uptake at maturity (R6 stage), and indices of N and S fertilizer use efficiency as affected by corn planting rate at Lamberton, MN in 2023, averaged across five fertilizer treatments and three corn hybrids.

Variable	34,000 seeds/acre	38,000 seeds/acre
Grain yield (bu/acre at 15%)	123 a [1]	120 a
Grain moisture at harvest (%)	17.6 a	17.3 a
Weight per kernel (mg)	221 a	209 b
Kernels per square foot	222 a	226 a
Treatment cost ($/acre) [2]	262	276
Revenue ($/acre)	547 a	529 a
Partial net return ($/acre)	288 a	254 b
Whole plant dry matter yield at R6 (tons/acre)	7.57 a	7.62 a
Aboveground N uptake at R6 (lb N/acre)	157 a	159 a
Recovery efficiency of fertilizer N (lb increase in aboveground N uptake at R6 per lb N applied)	0.366 a	0.401 a
Physiological N use efficiency (bushels gained per 1-lb increase in aboveground N uptake at R6)	0.518 a	0.567 a
Agronomic N use efficiency (bushels gained per lb N applied)	0.245 a	0.231 a
Aboveground S uptake at R6 (lb S/acre)	9.55 a	9.58 a
Recovery efficiency of fertilizer S (lb increase in aboveground S uptake at R6 per lb S applied)	0.0179 a	-0.0338 b
Physiological S use efficiency (bushels gained per 1-lb increase in aboveground S uptake at R6)	8.8 a	8.6 a
Agronomic S use efficiency (bushels gained per lb S applied)	0.232 a	-0.858 a
Aboveground P uptake at R6 (lb P/acre)	20.6 a	19.6 a
Aboveground K uptake at R6 (lb K/acre)	100 a	102 a
Aboveground Ca uptake at R6 (lb Ca/acre)	28.8 a	29.2 a
Aboveground Mg uptake at R6 (lb Mg/acre)	28.1 a	28.0 a
Aboveground B uptake at R6 (lb B/acre)	6.73 a	6.75 a
Aboveground Fe uptake at R6 (lb Fe/acre)	96 a	98 a
Aboveground Mn uptake at R6 (lb Mn/acre)	57.7 a	60.7 a
Aboveground Cu uptake at R6 (lb Cu/acre)	9.40 a	7.08 a
Aboveground Zn uptake at R6 (lb Zn/acre)	23.2 a	22.5 a

[1] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

[2] Includes only those costs that differed among treatments.

Table 12. Corn yield, grain moisture at harvest, grain yield components, economic parameters, aboveground nutrient uptake at maturity (R6 stage), and indices of N and S fertilizer use efficiency as affected by fertilizer treatment at Waseca, MN in 2023, averaged across three hybrids and two planting rates.

Variable	Preplant N and S	Split N and preplant S	Split N, preplant S, and additional S	Preplant N and no S	No N and preplant S
Grain yield (bu/acre at 15%)	194 a [1]	199 a	196 a	199 a	87 b
Grain moisture at harvest (%)	22.4 c	22.4 c	22.3 c	22.8 b	23.7 a
Weight per kernel (mg)	291 a	297 a	296 a	297 a	290 a
Kernels per square foot	265 a	267 a	263 a	266 a	120 b
Treatment cost ($/acre) [2]	291	314	318	276	147
Revenue ($/acre)	820 a	846 a	831 a	844 a	364 b
Partial net return ($/acre)	529 b	531 b	513 b	568 a	217 c
Whole plant dry matter yield at R6 (tons/acre)	9.12 a	9.21 a	9.07 a	8.96 a	4.52 b
Aboveground N uptake at R6 (lb N/acre)	169 a	165 a	164 a	164 a	64 b
Recovery efficiency of fertilizer N (lb increase in aboveground N uptake at R6 per lb N applied)	0.448 a	0.429 a	0.412 a	0.409 a	---
Physiological N use efficiency (bushels gained per 1-lb increase in aboveground N uptake at R6)	1.176 a	1.170 a	1.209 a	1.199 a	---
Agronomic N use efficiency (bushels gained per lb N applied)	0.453 a	0.488 a	0.432 a	0.450 a	---
Aboveground S uptake at R6 (lb S/acre)	12.68 a	12.33 a	12.45 a	11.96 a	6.19 b
Recovery efficiency of fertilizer S (lb increase in aboveground S uptake at R6 per lb S applied)	0.0291 a	0.0150 a	0.0141 a	---	-0.2303 b
Physiological S use efficiency (bushels gained per 1-lb increase in aboveground S uptake at R6)	-4.7 b	-3.8 b	-6.5 b	---	22.1 a
Agronomic S use efficiency (bushels gained per lb S applied)	-0.211 a	0.113 a	0.116 a	---	-4.488 b
Aboveground P uptake at R6 (lb P/acre)	32.7 a	30.2 ab	29.7 b	30.7 ab	20.1 c
Aboveground K uptake at R6 (lb K/acre)	100 a	97 a	101 a	97 a	58 b
Aboveground Ca uptake at R6 (lb Ca/acre)	27.9 a	26.3 a	27.9 a	27.0 a	13.7 b
Aboveground Mg uptake at R6 (lb Mg/acre)	25.4 a	24.9 a	25.6 a	25.5 a	14.6 b
Aboveground B uptake at R6 (lb B/acre)	3.34 a	3.05 b	3.30 ab	3.30 ab	2.18 c
Aboveground Fe uptake at R6 (lb Fe/acre)	49 ab	47 b	55 a	52 ab	35 c
Aboveground Mn uptake at R6 (lb Mn/acre)	40.3 ab	38.2 b	44.6 a	43.3 ab	21.3 c
Aboveground Cu uptake at R6 (lb Cu/acre)	2.15 a	2.02 a	2.28 a	2.07 a	0.67 b
Aboveground Zn uptake at R6 (lb Zn/acre)	30.0 a	28.4 a	28.6 a	29.2 a	24.2 b

[1] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

[2] Includes only those costs that differed among treatments.

Table 13. Corn yield, grain moisture at harvest, grain yield components, economic parameters, aboveground nutrient uptake at maturity (R6 stage), and indices of N and S fertilizer use efficiency as affected by corn hybrid relative maturity (RM) at Waseca, MN in 2023, averaged across five fertilizer treatments and two planting rates.

Variable	100 RM	104 RM	108 RM
Grain yield (bu/acre at 15%)	167 b [1]	181 a	178 a
Grain moisture at harvest (%)	20.9 c	23.1 b	24.1 a
Weight per kernel (mg)	285 c	278 b	320 a
Kernels per square foot	232 b	256 a	221 b
Treatment cost ($/acre) [2]	269	269	269
Revenue ($/acre)	716 b	763 a	743 a
Partial net return ($/acre)	447 b	494 a	474 a
Whole plant dry matter yield at R6 (tons/acre)	7.67 b	8.36 a	8.49 a
Aboveground N uptake at R6 (lb N/acre)	141 a	146 a	149 a
Recovery efficiency of fertilizer N (lb increase in aboveground N uptake at R6 per lb N applied)	0.398 b	0.372 b	0.503 a
Physiological N use efficiency (bushels gained per 1-lb increase in aboveground N uptake at R6)	0.937 b	1.371 a	1.258 a
Agronomic N use efficiency (bushels gained per lb N applied)	0.362 c	0.433 b	0.561 a
Aboveground S uptake at R6 (lb S/acre)	10.82 a	11.16 a	11.38 a
Recovery efficiency of fertilizer S (lb increase in aboveground S uptake at R6 per lb S applied)	-0.0538 b	-0.0001 a	-0.0752 b
Physiological S use efficiency (bushels gained per 1-lb increase in aboveground S uptake at R6)	2.3 a	7.5 a	-4.5 a
Agronomic S use efficiency (bushels gained per lb S applied)	-1.059 ab	-0.816 a	-1.478 b
Aboveground P uptake at R6 (lb P/acre)	27.1 b	30.8 a	28.2 b
Aboveground K uptake at R6 (lb K/acre)	82 c	90 b	100 a
Aboveground Ca uptake at R6 (lb Ca/acre)	20.9 b	22.1 b	30.7 a
Aboveground Mg uptake at R6 (lb Mg/acre)	22.0 b	23.0 b	24.6 a
Aboveground B uptake at R6 (lb B/acre)	2.58 c	2.93 b	3.59 a
Aboveground Fe uptake at R6 (lb Fe/acre)	44 b	43 b	55 a
Aboveground Mn uptake at R6 (lb Mn/acre)	37.3 a	36.7 a	38.5 a
Aboveground Cu uptake at R6 (lb Cu/acre)	1.80 a	1.79 a	1.91 a
Aboveground Zn uptake at R6 (lb Zn/acre)	26.8 b	29.2 a	28.2 a

[1] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

[2] Includes only those costs that differed among treatments.

Table 14. Corn yield, grain moisture at harvest, grain yield components, economic parameters, aboveground nutrient uptake at maturity (R6 stage), and indices of N and S fertilizer use efficiency as affected by corn planting rate at Waseca, MN in 2023, averaged across five fertilizer treatments and three corn hybrids.

Variable	34,000 seeds/acre	38,000 seeds/acre
Grain yield (bu/acre at 15%)	177 a [1]	174 a
Grain moisture at harvest (%)	22.7 a	22.7 a
Weight per kernel (mg)	296 a	293 a
Kernels per square foot	237 a	236 a
Treatment cost ($/acre) [2]	262	276
Revenue ($/acre)	747 a	735 a
Partial net return ($/acre)	485 a	458 b
Whole plant dry matter yield at R6 (tons/acre)	8.32 a	8.03 a
Aboveground N uptake at R6 (lb N/acre)	148 a	142 a
Recovery efficiency of fertilizer N (lb increase in aboveground N uptake at R6 per lb N applied)	0.437 a	0.412 a
Physiological N use efficiency (bushels gained per 1-lb increase in aboveground N uptake at R6)	1.207 a	1.170 a
Agronomic N use efficiency (bushels gained per lb N applied)	0.439 a	0.487 a
Aboveground S uptake at R6 (lb S/acre)	11.33 a	10.92 a
Recovery efficiency of fertilizer S (lb increase in aboveground S uptake at R6 per lb S applied)	-0.0441 a	-0.0420 a
Physiological S use efficiency (bushels gained per 1-lb increase in aboveground S uptake at R6)	2.0 a	1.5 a
Agronomic S use efficiency (bushels gained per lb S applied)	-1.012 a	-1.223 a
Aboveground P uptake at R6 (lb P/acre)	29.4 a	28.0 a
Aboveground K uptake at R6 (lb K/acre)	92 a	89 a
Aboveground Ca uptake at R6 (lb Ca/acre)	25.2 a	23.9 a
Aboveground Mg uptake at R6 (lb Mg/acre)	23.8 a	22.6 b
Aboveground B uptake at R6 (lb B/acre)	3.08 a	2.99 a
Aboveground Fe uptake at R6 (lb Fe/acre)	47 a	48 a
Aboveground Mn uptake at R6 (lb Mn/acre)	37.8 a	37.3 a
Aboveground Cu uptake at R6 (lb Cu/acre)	1.91 a	1.76 a
Aboveground Zn uptake at R6 (lb Zn/acre)	28.9 a	27.2 b

[1] Includes only those costs that differed among treatments.

[2] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

n) To accomplish the goal/objective "*share results from this project with farmers and agricultural professionals through Extension activities*", the results from this project were shared with farmers and agricultural professionals through presentations at the University of Minnesota Extension Institute for Agricultural Professionals Research Update Meetings at Owatonna, MN on January 3, 2024, at Willmar, MN on January 4, 2024, and at the virtual edition of these meetings on February 9, 2024, at the University of Minnesota Southern Research and Outreach Center Winter Crops Day on January 11, 2024, and at the University of Minnesota Extension Nutrient Management Conference at Mankato, MN on February 20, 2024.

3) MULTI-YEAR SUMMARY FOR KEY METRICS OF CROPPING SYSTEM PERFORMANCE

The fertilizer treatments are of greatest importance in this study, as the effects of hybrid and planting rate were often insignificant and inconsistent. Therefore, the results for the fertilizer treatments are shown in Tables 15 and 16, averaged across hybrids and planting rates, for the variables of most practical importance.

Table 15. Corn grain yield, treatment cost, and partial net return at Lamberton, MN and Waseca, MN in 2022 and 2023, averaged across three hybrids and two planting rates.

Variable	Location	Year	Preplant N and S	Split N and preplant S	Split N, preplant S, and additional S	Preplant N and no S	No N and preplant S
Grain yield (bu/acre at 15%)	Lamberton	2022	164 a [1]	160 a	157 a	163 a	162 a
		2023	141 a	134 ab	130 ab	128 b	75 c
	Waseca	2022	238 a	236 a	241 a	236 a	140 b
		2023	194 a	199 a	196 a	199 a	87 b
Treatment cost ($/acre) [2]	Both	Both	291	314	318	276	147
Partial net return ($/acre)	Lamberton	2022	441 bc	403 cd	382 d	452 b	579 a
		2023	334 a	277 b	266 b	290 ab	188 c
	Waseca	2022	760 a	727 b	745 ab	761 a	468 c
		2023	529 b	531 b	513 b	568 a	217 c

[1] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

[2] Includes only those costs that differed among treatments.

<u>Key findings for corn grain yield</u>:

1) In this study, there were very low grain yields in both years at Lamberton, very high yields in 2022 at Waseca, and intermediate yields in 2023 at Waseca. In both years at Waseca and in 2022 at Lamberton, grain yield was not reduced when sulfur fertilizer was withheld. In 2023 at Lamberton, grain yield was reduced by 9% for the treatment of "preplant N and no S", compared to the treatment with "preplant N and S". The non-N-fertilized control did not yield less than the other treatments at Lamberton in 2022, possibly due to residual N carryover following the 2021 drought, coupled with the low yields in 2022.

2) There was no advantage to split-application of N or to applying additional S at the V14 corn stage.

Key findings for treatment cost and partial net return:

1) Moving from preplant N to split-application of N increased the treatment cost by $23/acre, and adding additional S at the V14 corn stage increased the treatment cost by another $5/acre.

2) In the drought year of 2022 at Lamberton, the control treatment “no N and preplant S” had the highest partial net return because corn grain yield did not respond to N fertilizer. In 2023 at Lamberton, which was another drought year, the treatments where all N fertilizer was applied preplant had highest partial net return. The same was true in 2022 at Waseca, except in that site-year the “split N, preplant S, and additional S” treatment also produced a partial net return that was among the highest of all treatments. In 2023 at Waseca, where corn grain yield was not increased with S fertilizer, the “preplant N and no S” treatment had the greatest partial net return.

Table 16. Corn aboveground uptake of N and S at maturity (R6 stage), along with recovery efficiency and agronomic use efficiency of N and S fertilizers at Lamberton, MN and Waseca, MN in 2022 and 2023, averaged across three hybrids and two planting rates.

Variable	Location	Year	Preplant N and S	Split N and preplant S	Split N, preplant S, and additional S	Preplant N and no S	No N and preplant S
Aboveground N uptake at R6 (lb N/acre)	Lamberton	2022	162 a [1]	154 a	157 a	158 a	111 b
		2023	183 a	175 a	171 a	174 a	86 b
	Waseca	2022	210 ab	201 b	204 ab	213 a	111 c
		2023	169 a	165 a	164 a	164 a	64 b
Recovery efficiency of fertilizer N (lb increase in aboveground N uptake at R6 per lb N applied)	Lamberton	2022	0.255 a	0.216 a	0.230 a	0.236 a	---
		2023	0.415 a	0.382 a	0.363 a	0.374 a	---
	Waseca	2022	0.500 a	0.451 a	0.461 a	0.513 a	---
		2023	0.448 a	0.429 a	0.412 a	0.409 a	---
Agronomic N use efficiency (bushels gained per lb N applied)	Lamberton	2022	-0.0003 a	0.0289 a	-0.0221 a	0.0049 a	---
		2023	0.271 a	0.245 a	0.227 a	0.209 a	---
	Waseca	2022	0.493 a	0.509 a	0.477 a	0.455 a	---
		2023	0.453 a	0.488 a	0.432 a	0.450 a	---
Aboveground S uptake at R6 (lb S/acre)	Lamberton	2022	11.3 a	10.4 b	11.1 ab	9.0 c	8.9 c
		2023	11.29 a	10.53 ab	10.34 ab	9.65 b	6.02 c
	Waseca	2022	16.2 a	16.0 a	16.5 a	14.9 b	10.3 c
		2023	12.68 a	12.33 a	12.45 a	11.96 a	6.19 b
Recovery efficiency of fertilizer S (lb increase in aboveground N uptake at R6 per lb S applied)	Lamberton	2022	0.0941 a	0.0580 a	0.0620 a	---	-0.0032 b
		2023	0.0659 a	0.0278 a	0.0236 a	---	-0.1492 b
	Waseca	2022	0.049 a	0.042 a	0.048 a	---	-0.184 b
		2023	0.0291 a	0.0150 a	0.0141 a	---	-0.2303 b
Agronomic S use efficiency (bushels gained per lb S applied)	Lamberton	2022	-0.0126 a	-0.0533 a	0.0633 a	---	0.0712 a
		2023	0.476 a	0.313 a	0.202 a	---	-2.148 b
	Waseca	2022	0.03 a	0.13 a	0.43 a	---	-3.82 b
		2023	-0.211 a	0.113 a	0.116 a	---	-4.488 b

[1] Within a row, values followed by the same letter are not significantly different at the 0.05 probability level.

<u>Key findings for corn aboveground N uptake at R6, recovery efficiency of N fertilizer, and agronomic use efficiency of N fertilizer</u>:

1) Compared to preplant application of N, split-application did not increase corn aboveground N uptake at maturity (R6), corn recovery efficiency of fertilizer N, or agronomic N use efficiency in either year at both locations.

Key findings for corn aboveground S uptake at R6, recovery efficiency of S fertilizer, and agronomic use efficiency of S fertilizer:

1) Corn aboveground S uptake at maturity was never increased when additional S was applied, and it was decreased when S was not applied in both years at Lamberton and in only 2022 at Waseca. Split-application of N, with or without additional S at the V14 corn stage did not increase corn aboveground S uptake, corn recovery efficiency of fertilizer S, or agronomic S use efficiency in either year at both locations.

4) CHALLENGES ENCOUNTERED

There were no significant challenges encountered.

5) FINANCIAL OVERVIEW

A financial summary is provided below in Table 17. For the entire project period of April 7, 2023 through March 31, 2024, the overall expenses for this project were equal to that which was budgeted. For the entire project period, the expenses for each cost category were similar (within $570) to the budgeted amounts.

Table 17. Financial summary for April 7, 2023 through March 31, 2024.

Cost category	**Budgeted, $**	**Expenses, $**	**Remaining, $**
Salaries and fringe	25,055.00	25,507.66	-452.66
Supplies and services	560.00	102.93	457.07
Lab analyses	12,770.00	13,339.20	569.20
Travel	851.00	747.90	103.10
Research plot fees	1,100.00	550.00	550.00
Total	40,336.00	40,336.00	0.00