Sulfur placements' impacts on corn hybrids grown in a two-year corn-soybean rotation.

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AFREC Project(s) R2023-B Year 2 Report

Crop Year - 2023

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Year 2 (2023) Summary Points

- Crop circle or SPAD readings were seldom impacted by sulfur source or rate. Values were impacted by hybrid at Waseca and Lamberton during the first corn years, but there was no interaction between sulfur source or rate with hybrid.
- Corn grain yield was affected by sulfur rate at Rosemount (both sources had a similar impact on yield) while source was significant at Waseca (yield was greater with ATS). Neither 2023 site showed any increase in yield based on the source or rate of S applied.
- Corn grain yield differed between two hybrids at all four location locations. The three-way source x rate x hybrid interaction was significant at Waseca where yield was greater for the Pioneer hybrid but only when the high rate of S was applied as ATS. The Dekalb hybrid outyielded the Pioneer hybrid in 2023
- Soybean grain yield was not affected by the previous application of sulfur in 2023. Soybean grain yield did vary based on the yield of the previous corn crop with greater yield occurring for plots previously planted to the Dekalb corn which yielded less than the Pioneer.
- Soybean grain S concentration, seed protein concentration, and the relative proportion of cysteine and methionine were increased with the application of S.

Introduction

Research in Minnesota on sulfur application to corn has played an important role in understanding how much sulfur is needed by corn, how sulfur sources can impact sulfur availability, and potential options for applying sulfur. One area that has not been studied extensively is comparing placement options, band versus broadcast application of sulfur, to determine overall efficiency of placement on sulfur availability to corn. Limited data is available directly comparing band and broadcast application of sulfur in the same study. With band options becoming increasingly available more research is needed to determine whether banded sulfur is better than broadcast application of sulfur to crops.

I do not know of any current work comparing how sulfur application may affect differing hybrid genetics. Crop consultants have reported differences in how genetic sources remain green later in the season. Specifically, some genetics tend to yellow in their upper canopy late in the season which may be a result of differences in how these hybrids accumulate sulfur. There are questions whether placement and rate of sulfur can impact this upper canopy yellowing and whether band application are more efficient in reducing the yellowing in the upper canopy. These consultants also report substantial increases in yield levels for both corn and soybean over time with sulfur application. Most sulfur trials conducted in the past 10 years were only for one year and did not focus on the full cropping rotation and system over time to determine how much what is done in one year of a crop rotation affects subsequent years. One goal of this

study is to set up a series of long-term trials to further study how sulfur impacts crop yield over time which should help to determine whether sulfur can impact overall crop productivity if used over time.

One other goal of this work will be to collect additional plant tissue data to determine whether tissue sulfur concentration can be used to predict final yield. If there are differences among hybrids, then the addition of the differing hybrids in this study will help determine whether a single critical values for total sulfur can be used or whether too much variation exists in leaf S concentration to determine an optimal S concentration across hybrids.

Objectives

1. Determine if sulfur placement and rate impact the response (grain yield and yield components) of longer season corn hybrids to sulfur application.
2. Determine whether sulfur accumulation varies based on hybrid genetics; specifically, do different genetic sources vary in how they accumulate sulfur in leaf tissue and does this impact critical leaf sulfur concentrations?
3. Evaluate how sulfur application method may impact soybean yield the following year corn is grown and how sulfur application rate and method affect corn and soybean yield response over time in a two-year corn soybean rotation.

Materials and Methods

Table 1. Soil series information and initial soil test results for samples collected before initial treatment application.

	0-6" Soil Test				SO_4-S			
Location	Bray-P1	K	pH	OM	0-6	6-12	12-24	Soil Series
	ppm			%	ppm			
Rosemount	15	106	6.7	3.3	13.4	9.5	5.2	Tallula
Waseca	29	226	6.1	4.7	11.9	5.6*		Webster
Lamberton	9	179	7.4	4.7	17.9	67.6*		Canisteo
Rochester	31	247	6.0	4.4	14.1	7.3*		Mount Carroll

† K, Soil test potassium (K-ammonium acetate).
*** Sulfate-S concentration was measured for the 6-24" sampling depth at Waseca.**

Two corn locations were established in 2022 (Rosemount and Waseca) with an additional two locations in 2023 (Lamberton and Rochester). Each location will consist of a two-year corn soybean rotation where all fertilizer will be applied before the corn crop then field will be rotated to soybean where not additional fertilizer is applied. Three factors will be studied and arranged in a split- or strip plot design. Factors 1 and 2 will consist of sulfur rates (0, 18, and 36 lbs of S per acre) and two fertilizer placements by source combinations. The first placement by source combination will be pre-plant or an at planting application of ammonium sulfate [AMS (21-0-0-24)] broadcast to the soil and incorporated if possible. The second placement by source combination will be a band application of ammonium thiosulfate [ATS (12-0-0-26)] as a sub-surface band applied with the planter.

Nitrogen will be applied as urea at the time AMS is applied to balance broadcast N across all treatments at the time of AMS application (urea + NBPT may be used to lessen the risk of N volatility). In addition,

28% UAN solution will be applied with the banded treatments to balance the amount of N applied in the band. Additional N, P, and K will be applied as needed.

Two long season hybrids, 103-day relative maturity or greater, will be planted at each location. A hybrid will be sourced through Bayer and one through Corteva both with the same RM and as close to the same disease and insect resistance package as possible. Each location will be laid out using a strip plot design where strips consisting of corn hybrids will be randomized side by side planted the full length of the study over tip the rate x source and placement blocks. All treatments will be replicated four times. Soybean sites will be located at Rosemount and Waseca in 2023 which were planted to corn in 2022. No fertilizer will be applied to the soybean plots and a single variety will be planted across both locations. Yield and other sampling data will be collected by the same sub-plot arrangement used for the corn years.

Corn leaf samples will be collected at the V8-V10 and R1 growth stage by sampling the uppermost fully developed leaf. Soybean trifoliate samples will be collected at the R1-R2 growth stage by sampling the uppermost fully developed trifoliate. All plant samples will be analyzed using dry combustion analysis for total S. The middle two rows of each plot will be harvested, and grain yield will be reported at 15.5% moisture content. Corn and soybean grain will be saved at harvest and analyzed for total S as well as seed size and weight. Whole soybean grain will be analyzed for seed protein and oil concentration by NIR> Soil samples will be collected in fall or spring post-harvest from the 0-24" depths and will be analyzed for total S.

Table 2. Summary of cultural practices for studies conducted from 2022 to 2023.

					Date of		
Year	Location	Crop	Cultivar 1	Cultivar 2	Spring Fert.	Planting	Harvest
2022	Rosemount	Corn	DKC 5544	P 0598	6-May	10-May	27-Oct
	Waseca	Corn	DKC 5544	P 0598	7-May	16-May	20-Oct
2023	Rosemount	Soybean	AG 21XF1	AG 21XF1	--	25-May	9-Oct
	Waseca	Soybean	AG 21XF1	AG 21XF1	--	19-May	2-Oct
	Lamberton	Corn	DKC 10533	P 0598	8-May	22-May	31-Oct
	Rochester	Corn	DKC 10533	P 0598	3-May	19-May	9-Nov

† AG, Asgrow; DKC, Dekalb; P, Pioneer.

Results and Discussion

Location Characteristics

Table 1 summarizes soil series information and soil chemical properties for samples collected prior to the initial treatment application at the four locations. Sulfur trials have been established in similar soils at each location and have shown to be S responsive. Soil test P and K were Medium to Low at Rosemount and Lamberton and high at Waseca and Rochester. I am avoiding applying broadcast P as much as possible for these studies but may have to periodically apply a small rate of MAP or DAP at Rosemount and Lamberton to keep soil test P at the Medium classification. Starter was applied 2x2 and in-furrow as 6-24-6 at both locations to supplement some P to the corn crop. Total sulfate-S concentration was measured to a depth of 24 inches. There is no interpretation for sulfate-S concentration in the soil on medium to fine textured soils so the relative responsiveness of S application cannot be fully assessed using the soil test for sulfate-S.

Table 3. Summary of ANOVA analysis for measured agronomic variables for two corn trial locations studied during 2022.

Main Effect	V5 NDRE	V10 Leaf S	V10 SPAD	R1 Ear Leaf S	R1 Up. Leaf S	R1 EL SPAD	R1 UL SPAD	Yield	Grain S	Fall SO_4-S
					P>F					
					Rosemount					
S Source	0.22	*	0.20	0.16	0.71	0.11	*	0.63	*	0.77
S Rate	0.67	0.15	0.36	0.14	0.29	0.10	0.48	0.07	0.07	0.96
So x R	0.17	0.32	0.42	0.23	0.82	0.14	0.11	0.79	0.28	0.45
Hybrid	0.22	0.54	**	0.10	0.38	0.81	0.37	*	0.33	0.36
So x Hy	0.48	0.87	0.48	0.76	0.78	0.86	0.69	0.79	0.13	0.91
Rate x Hy	0.84	0.56	0.49	0.80	0.67	0.16	0.32	0.24	0.98	0.07
R x So x H	0.86	0.06	0.16	0.74	0.22	0.68	0.19	0.21	0.36	0.38
					Waseca					
S Source	0.67	0.63	1.00	0.81	0.59	0.62	0.64	*	0.84	0.78
S Rate	0.56	0.10	0.78	0.71	0.52	0.77	0.79	0.92	0.46	0.22
So x R	0.51	0.53	0.77	0.90	0.54	0.97	0.68	**	0.53	0.76
Hybrid	**	*	***	0.11	0.26	**	0.07	*	0.33	0.33
So x Hy	*	0.55	0.38	0.64	0.55	0.84	0.25	**	0.72	0.10
Rate x Hy	0.79	0.72	0.14	0.11	0.82	0.29	0.34	0.41	0.12	0.27
R x So x H	0.80	0.75	0.57	0.51	0.64	0.08	0.30	*	0.51	0.88

, **, and * represent treatment significance at P≤0,05, 0,01, and 0,001 probability levels.*

2022 Corn trial results

A summary table for the ANOVA for all measured variables for the 2022 growing season is given in Table 3. Individual variables will be discussed in the following tables.

Table 4. Summary of early plant vigor measured at the normalized difference red-edge (NDRE) data collected with a Crop Circle 430 active sensor collected at the corn V5 growth stage.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	0.245	0.265	0.273	0.277	0.265
	18	0.283	0.298	0.245	0.261	0.272
	36	0.291	0.304	0.268	0.267	0.283
	So. x Hy	0.273	0.289	0.262	0.268	
	Source Avg.	0.281		0.265		
	Hybrid Avg.	0.267	0.279	--	--	--
Waseca	0	0.261	0.280	0.261	0.287	0.272
	18	0.265	0.281	0.256	0.283	0.271
	36	0.264	0.283	0.261	0.294	0.275
	So. x Hy	0.263b	0.281a	0.260b	0.288a	
	Source Avg.	0.272		0.273		
	Hybrid Avg.	0.261b	0.285a	--	--	--

Plant vigor was assessed at the V5 growth stage using a Crop Circle 430. A summary of the normalized difference red-edge index is given in Table 4. Early season NDRE did not differ based on sulfur source or rate at either location. Variety did vary at Wasea with higher NDRE values in the Pioneer plots. A significant source by variety interaction was found at Waseca and did indicate a potential source variation but only for only the Pioneer hybrid. The Dekalb hybrid showed no effect of sulfur source or rate.

Table 5. Summary of corn leaf S concentration measured from the uppermost fully developed corn leaf at the V10 growth stage at two Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	0.18	0.19	0.18	0.15	0.17
	18	0.22	0.21	0.18	0.17	0.19
	36	0.22	0.20	0.19	0.23	0.21
	So. x Hy	0.21	0.20	0.18	0.18	
	Source Avg.	0.20a		0.18b		
	Hybrid Avg.	0.20	0.19	--	--	--
Waseca	0	0.20	0.18	0.21	0.20	0.19
	18	0.23	0.20	0.22	0.21	0.21
	36	0.21	0.20	0.21	0.20	0.21
	So. x Hy	0.21	0.19	0.21	0.20	
	Source Avg.	0.20		0.21		
	Hybrid Avg.	0.21	0.20	--	--	--

V10 leaf S concentration data was not available the time this report was written and will be included in the next year end report.

Table 6. Summary of SPAD meter reading collected from the middle of the uppermost fully developed corn leaf at the V10 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	41.0	47.2	43.6	41.6	43.3
	18	44.7	49.5	39.7	45.9	44.9
	36	45.3	49.0	43.9	49.4	46.9
	So. x Hy	43.6	48.5	42.4	45.6	
	Source Avg.	46.1		44.0		
	Hybrid Avg.	43.0b	47.1a	--	--	--
Waseca	0	54.1	55.7	54.3	55.1	54.8
	18	53.7	56.5	54.4	56.3	55.2
	36	54.4	55.6	54.2	55.7	55.0
	So. x Hy	54.1	55.9	54.3	55.7	
	Source Avg.	55.0		55.0		
	Hybrid Avg.	54.2b	55.8a	--	--	--

Corn V10 leaf SPAD meter readings were not affected by sulfur source or rate (Table 6). However, hybrid did vary at both locations with greater SPAD values for the Pioneer hybrid compared to the Dekalb indicating slightly greener upper canopy in the Pioneer plots. There was no interaction between hybrid and either S source or rate.

Table 7. Summary of leaf S concentration measured from the corn leaf opposite and below the ear at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	0.16	0.15	0.16	0.14	0.15
	18	0.20	0.17	0.15	0.15	0.17
	36	0.20	0.19	0.18	0.18	0.19
	So. x Hy	0.19	0.17	0.16	0.15	
	Source Avg.	0.18		0.16		
	Hybrid Avg.	0.18a	0.17b	--	--	--
Waseca	0	0.18	0.18	0.18	0.17	0.18
	18	0.19	0.16	0.19	0.16	0.18
	36	0.16	0.16	0.17	0.16	0.16
	So. x Hy	0.18	0.17	0.18	0.16	
	Source Avg.	0.17		0.17		
	Hybrid Avg.	0.18	0.17	--	--	--

R1 leaf S concentration data (ear and upper leaf) was not available the time this report was written and will be included in the next year end report.

Table 8. Summary of leaf S concentration measured from the uppermost fully developed corn leaf at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	0.17	0.17	0.18	0.15	0.17
	18	0.20	0.20	0.18	0.19	0.19
	36	0.20	0.19	0.20	0.20	0.20
	So. x Hy	0.19	0.19	0.19	0.18	
	Source Avg.	0.19		0.18		
	Hybrid Avg.	0.19	0.18	--	--	--
Waseca	0	0.17	0.17	0.17	0.16	0.17
	18	0.19	0.18	0.19	0.18	0.18
	36	0.17	0.17	0.20	0.20	0.19
	So. x Hy	0.18	0.17	0.19	0.18	
	Source Avg.	0.17		0.18		
	Hybrid Avg.	0.18	0.18	--	--	--

Table 9. Summary of SPAD meter reading collected from the middle of the corn leaf opposite and below the ear at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	53.8	52.4	53.2	51.2	52.6b
	18	58.8	59.9	50.5	53.9	55.7ab
	36	57.7	58.8	56.4	56.7	57.4a
	So. x Hy	56.7	57.0	53.4	53.9	
	Source Avg.	56.9		53.6		
	Hybrid Avg.	55.1	55.5	--	--	--
Waseca	0	52.4	54.7	52.8	54.3	53.6
	18	51.7	54.7	52.4	54.5	53.3
	36	53.0	54.0	52.5	55.0	53.6
	So. x Hy	52.4	54.5	52.6	54.6	
	Source Avg.	53.4		53.6		
	Hybrid Avg.	52.5b	54.5a	--	--	--

Table 10. Summary of SPAD meter reading collected from the uppermost fully developed corn leaf at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	45.0	44.6	46.6	42.3	44.6
	18	49.0	48.2	42.3	43.2	45.7
	36	48.0	47.1	46.3	46.0	46.8
	So. x Hy	47.3	46.6	45.0	43.8	
	Source Avg.	47.0a		44.4b		
	Hybrid Avg.	46.2	45.2	--	--	--
Waseca	0	46.1	44.5	45.8	43.4	45.0
	18	45.7	44.0	45.3	45.2	45.0
	36	44.6	41.2	45.6	44.3	43.9
	So. x Hy	45.5	43.2	45.6	44.3	
	Source Avg.	44.3		44.9		
	Hybrid Avg.	45.5a	43.8b	--	--	--

Leaf SPAD readings from the leaf opposite and below and the uppermost fully developed leaf at the R1 growth stage are summarized in Tables 9 and 10, respectively. At Rosemount, ear leaf SPAD readings were affected by S rate but not by source. SPAD readings were increased with the 18 lb S rate and did not differ between 18 and 36 lbs S per acre. Sulfur source only affected upper leaf SPAD readings at Rosemount where AMS had higher readings compared to ATS. At Waseca, source and rate did not impact ear- or upper leaf SPAD readings but variety affect both. Interestingly, SPAD values were greater for the Pioneer hybrid for the ear leaf readings, but the Pioneer SPAD values were less for the Upper leaf

readings indicating greener mid-canopy leaves but more yellow upper canopy leaves with the Pioneer hybrid. Again, there were no significant interactions between hybrid and sulfur source or rate.

Table 11. Summary of corn grain yield (reported at 15.5% moisture) response to S source and rate at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
				bushels per acre		
Rosemount	0	172	185	185	174	179b
	18	209	218	179	192	200a
	36	196	205	196	213	203a
	So. x Hy	192	203	187	193	
	Source Avg.	196		191		
	Hybrid Avg.	183b	205a	--	--	--
Waseca	0	213	224	213	220	217
	18	217	222	209	227	219
	36	212	213	219	232	219
	So. x Hy	214bc	220b	213c	227a	
	Source Avg.	217b		220a		
	Hybrid Avg.	214b	224a	--	--	--

Corn grain yield data are summarized in Table 11. Hybrid varied at both locations with greater yield for the Pionner hybrid compared to the Dekalb. There were no significant interactions between variety and either S source or rate at Rosemount. Sulfur rate differed at Rosemount with higher yield for the 18 lb S rate compared to the control, and no additional increase in yield for the 36 lb rate over 18 lbs S per acre. At Waseca there was a significant source and variety by source interaction. The variety by source interaction indicated yield was the greatest when ATS was applied with the Pioneer hybrid. This combination of ATS with the Pioneer hybrid resulted in greater yield than either source with the Dekalb hybrid and AMS with the Pioneer hybrid. At Waseca, ATS tended to produce greater yield but the effect was less pronounced for the Dekalb hybrid. This is only the first year of this study so more years will help to determine whether there is consistency in the effect of source based on variety over time.

Corn grain S concentration is summarized in Table 12.

Table 12. Summary of corn grain S concentration response to S source and rate at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Rosemount	0	0.086	0.093	0.091	0.078	0.087b
	18	0.114	0.118	0.094	0.086	0.103a
	36	0.115	0.111	0.107	0.104	0.109a
	So. x Hy	0.105	0.107	0.097	0.089	
	Source Avg.	0.106a		0.092b		
	Hybrid Avg.	0.101	0.098	--	--	--
Waseca	0	0.106	0.110	0.100	0.097	0.103
	18	0.107	0.112	0.111	0.110	0.110
	36	0.114	0.101	0.113	0.106	0.109
	So. x Hy	0.109	0.107	0.108	0.105	
	Source Avg.	0.108		0.106		
	Hybrid Avg.	0.109	0.106	--	--	--

Corn grain S concentration data was not available the time this report was written and will be included in the next year end report.

Soil sulfate-S content was measured post-harvest but did not vary based on sulfur source, rate, or hybrid (Table 13).

Table 13. Summary of post-harvest two-foot soil extractable sulfate-S response to S source and rate at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
		pounds sulfate-S per acre				
Rosemount	0	123	115	133	136	126
	18	139	148	116	117	130
	36	129	119	130	118	124
	So. x Hy	130	127	126	123	
	Source Avg.	129		125		
	Hybrid Avg.	128	125	--	--	--
Waseca	0	96	103	113	114	107
	18	94	95	97	86	93
	36	119	118	122	110	117
	So. x Hy	103	105	111	103	
	Source Avg.	104		107		
	Hybrid Avg.	107	104	--	--	--

Table 14. Summary of ANOVA analysis for measured agronomic variables for two soybean trial locations studied during 2023.

Main Effect	R1 Leaf S Conc.	Yield	Grain S Conc.	Protein	Oil	Cysteine	Methionine	Fall Soil S
				P>F				
				Rosemount				
S Source	0.30	0.60	0.24	0.71	0.27	0.15	0.10	0.73
S Rate	0.92	0.53	0.58	0.42	0.47	*	0.19	0.79
So x R	0.76	0.19	0.34	*	0.10	0.82	0.47	0.51
Hybrid	0.33	***	0.34	0.82	0.51	0.67	0.40	0.73
So x Hy	0.24	0.81	0.65	0.58	0.17	0.89	0.81	0.69
Rate x Hy	0.53	0.34	0.75	*	0.17	0.52	0.19	0.72
R x So x H	0.23	0.43	0.77	0.18	0.22	0.73	0.35	0.98
				Waseca				
S Source	0.94	0.60	*	*	*	*	**	0.32
S Rate	0.30	0.12	0.21	0.07	0.70	**	*	0.12
So x R	0.99	0.27	0.57	0.31	0.87	0.08	0.31	*
Hybrid	0.94	*	0.89	0.74	0.44	0.92	0.85	0.42
So x Hy	0.74	0.90	0.76	0.36	0.44	0.76	0.85	0.80
Rate x Hy	0.92	0.44	0.50	0.34	*	0.18	0.34	0.13
R x So x H	0.73	0.38	0.67	*	0.67	0.21	0.09	0.41

, **, and * represent treatment significance at P≤0,05, 0,01, and 0,001 probability levels.*

2023 Soybean Results

There were very few responses to sulfur at the two soybean locations in 2023. Soybean trifoliate S concentration (Table 15) and grain yield (Table 16) were not impacted by sulfur applied the previous year before corn at either location. However, soybean grain yield did vary at both locations based on the previous corn hybrid. In both cases soybean grain yield was higher for plots planted to the Dekalb hybrid in 2022. From Table 11, the Dekalb hybrid yielded less in 2022 compared to the Pioneer hybrid.

The only consistent significant impact of the previous sulfur application was on seed S concentration, protein, and cysteine and methionine content at Waseca. Seed cysteine content was also impacted by S application at Rosemount. The increase in the amount of S does indicate some carryover potential for S from the year of application to the following year. While grain yield was not impacted the benefit to protein content was somewhat surprising but the increase in seed S concentration and slightly higher S containing protein has been seen in the past.

Table 15. Summary of soybean trifoliate S concentration for the uppermost fully developed trifoliate (leaflets and petiole) at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
				%S		
Rosemount	0	0.284	0.290	0.295	0.269	0.284
	18	0.302	0.283	0.281	0.276	0.285
	36	0.275	0.289	0.285	0.275	0.281
	So. x Hy	0.287	0.287	0.287	0.273	
	Source Avg.	0.287		0.280		
	Hybrid Avg.	0.287	0.280	--	--	--
Waseca	0	0.250	0.257	0.257	0.246	0.253
	18	0.245	0.242	0.246	0.246	0.245
	36	0.275	0.278	0.298	0.282	0.282
	So. x Hy	0.257	0.259	0.264	0.258	
	Source Avg.	0.258		0.259		
	Hybrid Avg.	0.258	0.259	--	--	

Table 16. Summary of soybean grain yield (reported at 13% moisture) response to S source and rate at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
				bushels per acre		
Rosemount	0	35.7	33.9	44.9	40.1	38.7
	18	48.6	46.0	35.1	32.3	40.5
	36	37.9	36.3	38.0	36.7	37.2
	So. x Hy	40.7	38.7	39.3	36.3	
	Source Avg.	38.1		38.6		
	Hybrid Avg.	39.3a	37.4b	--	--	--
Waseca	0	62.6	62.5	61.4	60.5	61.7
	18	64.2	62.3	64.6	63.4	63.6
	36	63.1	61.1	63.9	62.5	62.6
	So. x Hy	63.3	62.0	63.3	62.1	
	Source Avg.	62.2		61.6		
	Hybrid Avg.	62.7a	61.1b	--	--	--

Table 18. Summary of soybean grain S concentration response to S source and rate at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
				%S		
Rosemount	0	0.335	0.326	0.291	0.288	0.310
	18	0.316	0.307	0.328	0.313	0.316
	36	0.346	0.354	0.326	0.318	0.336
	So. x Hy	0.332	0.329	0.315	0.306	
	Source Avg.	0.330		0.311		
	Hybrid Avg.	0.324	0.317	--	--	--
Waseca	0	0.265	0.258	0.253	0.248	0.256
	18	0.286	0.293	0.255	0.250	0.271
	36	0.291	0.296	0.266	0.274	0.282
	So. x Hy	0.281	0.282	0.258	0.257	
	Source Avg.	0.282a		0.258b		
	Hybrid Avg.	0.269	0.270	--	--	--

Table 19. Summary of soybean grain protein concentration response to S source and rate at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
		% Protein @ 13% Moisture				
Rosemount	0	34.1	34.9	33.6	33.7	34.1
	18	33.9	33.8	34.3	34.2	34.0
	36	34.4	34.0	34.5	34.4	34.4
	So. x Hy	34.1	34.2	34.1	34.1	
	Source Avg.	34.2		34.1		
	Hybrid Avg.	34.2	34.2	--	--	--
Waseca	0	33.3	33.4	33.1	33.3	33.3b
	18	33.3	33.4	33.4	33.1	33.3b
	36	33.9	33.6	33.2	33.6	33.6a
	So. x Hy	33.5	33.5	33.2	33.3	
	Source Avg.	33.5a		33.3b		
	Hybrid Avg.	33.4	33.4	--	--	--

Table 20. Summary of soybean grain oil concentration response to S source and rate at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
		% Oil @ 13% Moisture				
Rosemount	0	18.7	18.6	19.1	19.0	18.9
	18	18.5	18.8	19.0	19.3	18.9
	36	18.6	19.1	18.6	18.4	18.7
	So. x Hy	18.6	18.8	18.9	18.9	
	Source Avg.	18.7		18.9		
	Hybrid Avg.	18.8	18.9	--	--	--
Waseca	0	18.8	18.8	19.0	18.8	18.9
	18	18.6	19.0	18.8	19.2	18.9
	36	18.6	18.6	19.0	18.8	18.8
	So. x Hy	18.7	18.8	18.9	18.9	
	Source Avg.	18.7b		18.9a		
	Hybrid Avg.	18.8	18.9	--	--	--

Table 21. Summary of soybean grain cysteine response to S source and rate at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
		Cysteine as % of total protein				
Rosemount	0	0.50	0.52	0.49	0.50	0.50b
	18	0.52	0.51	0.50	0.50	0.51b
	36	0.53	0.53	0.52	0.52	0.52a
	So. x Hy	0.52	0.52	0.50	0.50	
	Source Avg.	0.50		0.52		
	Hybrid Avg.	0.51	0.51	--	--	--
Waseca	0	0.50	0.51	0.51	0.51	0.51b
	18	0.53	0.53	0.52	0.50	0.52a
	36	0.55	0.54	0.51	0.52	0.53a
	So. x Hy	0.52	0.53	0.51	0.51	
	Source Avg.	0.52a		0.51b		
	Hybrid Avg.	0.52	0.52	--	--	--

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Table 22. Summary of soybean grain methionine concentration response to S source and rate at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
		Methionine as % of total protein				
Rosemount	0	0.52	0.53	0.51	0.51	0.51
	18	0.53	0.52	0.51	0.51	0.52
	36	0.52	0.53	0.52	0.53	0.53
	So. x Hy	0.52	0.53	0.51	0.52	
	Source Avg.	0.52b		0.51b		
	Hybrid Avg.	0.52	0.52	--	--	--
Waseca	0	0.51	0.51	0.50	0.51	0.50b
	18	0.51	0.51	0.51	0.50	0.50b
	36	0.52	0.52	0.51	0.51	0.51a
	So. x Hy	0.51	0.51	0.51	0.50	
	Source Avg.	0.51a		0.50b		
	Hybrid Avg.	0.51	0.51	--	--	--

Table 17. Summary of soil test SO_4-S after harvest response to S source and rate at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
		lb SO_4-S per acres in a 2-foot soil sample				
Rosemount	0	82	81	97	92	88
	18	96	94	85	77	88
	36	80	84	72	74	78
	So. x Hy	86	86	84	81	
	Source Avg.	86		83		
	Hybrid Avg.	85	84	--	--	--
Waseca	0	68	73	98	89	82
	18	71	70	70	84	74
	36	96	78	89	76	85
	So. x Hy	78	74	85	83	
	Source Avg.	76		84		
	Hybrid Avg.	82	78	--	--	--

Table 18. Summary of ANOVA analysis for measured agronomic variables for two corn trial locations studied during 2023.

Main Effect	V5 NDRE	V10 Leaf S	V10 SPAD	R1 Ear Leaf S	R1 Up. Leaf S	R1 EL SPAD	R1 UL SPAD	Yield	Grain S	Fall SO_4-S
					P>F					
					Lamberton					
S Source	0.26	0.77	0.79	*	0.44	0.11	0.32	0.48	0.14	
S Rate	0.17	**	***	0.27	0.36	0.82	0.55	0.43	0.10	
So x R	0.34	0.10	***	0.12	*	0.73	0.28	0.07	0.46	
Hybrid	0.59	0.90	*	0.74	0.07	0.52	**	**	*	
So x Hy	0.32	0.20	0.46	0.16	0.49	0.61	0.30	0.33	0.62	
Rate x Hy	0.07	0.50	0.58	**	0.09	0.46	0.07	0.77	0.80	
R x So x H	0.84	0.76	0.95	0.66	0.63	0.64	0.74	*	0.08	
					Rochester					
S Source	0.39	0.67	0.40					*	0.92	*
S Rate	0.27	0.11	0.34					0.74	0.38	0.42
So x R	0.81	0.43	0.73					0.42	0.90	0.53
Hybrid	0.16	0.88	**					0.06	***	0.94
So x Hy	0.99	0.54	0.61					0.77	0.74	0.34
Rate x Hy	0.35	0.06	0.82					0.06	0.29	0.98
R x So x H	0.62	*	0.96					0.98	0.16	0.82

, **, and * represent treatment significance at P≤0,05, 0,01, and 0,001 probability levels.*

2023 Corn trial results

A summary table for the ANOVA for all measured variables for the 2023 growing season is given in Table 18. Individual variables will be discussed in the following tables. No data were collected at R1 at Rochester due to a loss of leaves by a hail event that occurred in July. Yield data was collected at Rochester as planned.

Table 19. Summary of early plant vigor measured at the normalized difference red-edge (NDRE) data collected with a Crop Circle 430 active sensor collected at the corn V5 growth stage.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Lamberton	0	0.197	0.202	0.204	0.199	0.201
	18	0.231	0.216	0.211	0.194	0.213
	36	0.215	0.224	0.214	0.213	0.216
	So. x Hy	0.214	0.214	0.210	0.202	
	Source Avg.	0.214		0.206		
	Hybrid Avg.	0.212	0.208	--	--	--
Rochester	0	0.268	0.270	0.249	0.244	0.258
	18	0.282	0.270	0.276	0.264	0.273
	36	0.292	0.279	0.284	0.278	0.283
	So. x Hy	0.281	0.273	0.270	0.262	
	Source Avg.	0.277		0.266		
	Hybrid Avg.	0.275	0.267	--	--	--

Table 20. Summary of corn leaf S concentration measured from the uppermost fully developed corn leaf at the V10 growth stage at two Minnesota locations during the 2023 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Lamberton	0	0.22	0.23	0.26	0.27	0.24b
	18	0.32	0.30	0.30	0.31	0.31a
	36	0.31	0.30	0.28	0.28	0.29a
	So. x Hy	0.28	0.28	0.28	0.29	
	Source Avg.	0.28		0.28		
	Hybrid Avg.	0.28	0.28	--	--	--
Rochester	0	0.24	0.24	0.23	0.24	0.24
	18	0.24	0.22	0.23	0.23	0.23
	36	0.23	0.24	0.25	0.24	0.24
	So. x Hy	0.23	0.23	0.24	0.24	
	Source Avg.	0.23		0.24		
	Hybrid Avg.	0.24	0.23	--	--	--

Table 21. Summary of SPAD meter reading collected from the middle of the uppermost fully developed corn leaf at the V10 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Lamberton	0	41.1	43.4	44.4	47.7	44.2b
	18	46.2	47.8	43.6	46.0	45.9a
	36	46.4	47.9	45.4	47.2	46.7a
	So. x Hy	44.6	46.3	44.5	47.0	
	Source Avg.	45.5		45.7		
	Hybrid Avg.	44.5b	46.7a	--	--	--
Rochester	0	54.6	55.6	54.3	56.0	55.1
	18	54.0	55.2	54.8	56.1	55.0
	36	53.5	55.1	53.4	55.5	54.4
	So. x Hy	54.0	55.3	54.1	55.9	
	Source Avg.	54.6		55.0		
	Hybrid Avg.	54.1b	55.6a	--	--	--

Early season NDRE measured at V5 was not impacted by any main effect (Table 19) Corn V10 leaf SPAD meter readings were not affected by sulfur source or rate at Rosemount but V10 SPAD was affected by rate at Lamberton (Tables 20 and 21). However, SPAD readings between hybrid did vary at both locations with greater SPAD values for the Pioneer hybrid compared to the Dekalb indicating slightly greener upper canopy in the Pioneer plots, which is similar to 2022. There was no interaction between hybrid and either S source or rate.

Table 22. Summary of leaf S concentration measured from the corn leaf opposite and below the ear at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Lamberton	0	0.15	0.13	0.18	0.17	0.16
	18	0.17	0.18	0.17	0.18	0.18
	36	0.16	0.16	0.17	0.18	0.17
	So. x Hy	0.16	0.16	0.17	0.18	
	Source Avg.	0.16b		0.18a		
	Hybrid Avg.	0.17	0.17	--	--	--

Ear and upper leaf samples were not collected at Rochester in 2023 due to hail. Ear leaf S concentration was impacted by hybrid but not by S source or rate (Table 22). Upper leaf S concentration was not affected by source, rate or hybrid. This is like what happened in 2022 at both locations.

Table 23. Summary of leaf S concentration measured from the uppermost fully developed corn leaf at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Lamberton	0	0.17	0.17	0.20	0.20	0.18
	18	0.20	0.20	0.20	0.20	0.20
	36	0.19	0.19	0.17	0.18	0.18
	So. x Hy	0.18	0.19	0.19	0.19	
	Source Avg.	0.19		0.19		
	Hybrid Avg.	0.18b	0.19a	--	--	--

Table 24. Summary of SPAD meter reading collected from the middle of the corn leaf opposite and below the ear at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Lamberton	0	46.9	48.0	49.2	50.0	48.5
	18	47.1	48.0	49.4	50.8	48.8
	36	47.0	47.6	49.2	47.9	47.9
	So. x Hy	47.0	47.9	49.2	49.5	
	Source Avg.	47.4		49.3		
	Hybrid Avg.	48.1	48.7	--	--	--

Table 25. Summary of SPAD meter reading collected from the uppermost fully developed corn leaf at the R1 growth stage at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
Lamberton	0	41.5	39.3	43.2	40.3	41.1
	18	43.7	40.0	44.7	39.2	41.9
	36	41.9	39.7	43.7	41.3	41.7
	So. x Hy	42.3	39.7	43.8	40.3	
	Source Avg.	41.0		42.0		
	Hybrid Avg.	43.1a	40.0b	--	--	--

Leaf SPAD readings from the leaf opposite and below and the uppermost fully developed leaf at the R1 growth stage are summarized in Tables 24 and 25, respectively. Ear leaf SPAD values were not affected by source, rate, or hybrid. However, upper leaf SPAD values differed by hybrid like 2022, the Pioneer hybrid had a significantly lower SPAD values than the Dekalb. No interactions were present between source or rate and hybrid.

Table 26. Summary of corn grain yield (reported at 15.5% moisture) response to S source and rate at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
				bushels per acre		
Lamberton	0	133	109	128	135	126
	18	145	134	133	118	132
	36	132	127	131	117	127
	So. x Hy	137	123	131	123	
	Source Avg.	130		127		
	Hybrid Avg.	134a	123b	--	--	--
Rochester	0	178	175	163	161	169
	18	181	168	175	162	172
	36	178	171	172	167	172
	So. x Hy	179	171	170	163	
	Source Avg.	175a		167b		
	Hybrid Avg.	175a	167b	--	--	--

Corn grain yield data are summarized in Table 26. Hybrid varied at only at Rochester with greater yield for the Dekalb hybrid. Source or rate did not impact corn grain yield. Corn grain yield was low overall at Lamberton due to drought. The lower yield may have limited the potential for S response. Yield at Rochester was relatively high considering a significant loss of leaves due to hail. Corn grain S concentration is summarized in Table 27 and was affected by hybrid at both locations where grain S concentration was greater for the Pioneer hybrid, and grain S concentration increased with increasing S application rate.

Table 27. Summary of corn grain S concentration response to S source and rate at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
				---%S--		
Lamberton	0	0.119	0.123	0.115	0.130	0.122b
	18	0.122	0.133	0.130	0.141	0.131a
	36	0.122	0.135	0.128	0.133	0.129a
	So. x Hy	0.121	0.130	0.124	0.135	
	Source Avg.	0.126		0.129		
	Hybrid Avg.	0.123b	0.132a	--	--	--
Rochester	0	0.109	0.123	0.107	0.122	0.115
	18	0.110	0.119	0.109	0.123	0.115
	36	0.104	0.117	0.106	0.116	0.111
	So. x Hy	0.107	0.120	0.107	0.120	
	Source Avg.	0.114		0.114		
	Hybrid Avg.	0.107b	0.120a	--	--	--

Soil sulfate-S content was measured post-harvest but did not vary based on sulfur source, rate, or hybrid (Table 28). Soil samples were collected at Lamberton, but samples were not analyzed at the time of this report.

Table 28. Summary of post-harvest two-foot soil extractable sulfate-S response to S source and rate at four Minnesota locations during the 2022 growing season.

		Sulfur Source x Hybrid				
		AMS		ATS		
Location	S Rate (lb/ac)	Dekalb	Pioneer	Dekalb	Pioneer	Rate Avg
		pounds sulfate-S per acre				
Lamberton	0					
	18					
	36					
	So. x Hy					
	Source Avg.					
	Hybrid Avg.			--	--	--
Rochester	0	93	88	84	88	88
	18	95	92	84	87	90
	36	98	99	86	87	92
	So. x Hy	95	93	84	87	
	Source Avg.	94a		86b		
	Hybrid Avg.	90	90	--	--	--