Fine tuning sulfur guidelines for alfalfa

AFREC Project Report 3/31/2022 for

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Introduction

Alfalfa is grown on nearly 1 million acres and is an important forage crop for dairy, beef, sheep, and horse industries.in Minnesota. As a perennial deep-rooted crop, alfalfa improves soil quality and contributes N to subsequent crops in rotations. Alfalfa has a high demand for sulfur. Sulfur deficiencies have been reported in alfalfa in fields with low organic matter concentration which may not mineralize sufficient sulfur to match crop demand. Sulfur has been noted to impact both forage yield and quality and sulfur application has been increasing for alfalfa as well as other crops. There have been few small trials focused on comparing various sulfur products for alfalfa in Minnesota in the last ten years. Current sulfur guidelines suggest 25 lbs of S be applied on sandy soils and 15 to 25 lbs of S be applied to medium and fine textured soils with soil organic matter concentration less than 3.0%. The sandy soil guidelines are old and have not been validated by current research and the guidelines for the medium to fine textured soil are based on data from corn or alfalfa data generated from neighboring states. Past research on sources has been inconclusive whether there are differences between sulfate and elemental sulfur fertilizer sources. Longer term research may be needed to better evaluate sources due to a slower availability of sulfur from elemental sulfur due to the slow oxidation of the material. With the high demand for S by alfalfa, more research is needed on rates and sulfur sources to fine tune guidelines to ensure forage yield and quality of alfalfa is not limited.

Objectives

1. Identify the optimum rate of sulfur for maximizing alfalfa forage yield and quality
2. Compare sulfate- and elemental sulfur fertilizer sources applied annually for an alfalfa production system.

Materials and Methods

Alfalfa trials were established at Rosemount and Morris in 2020 with the purpose of evaluating alfalfa sulfur response over four years (location information is given in Table 1). Poor stand establishment at Morris required the trial to be seeded again in Fall 2020. The current plan is to use the original Morris site seeded in Spring 2020 if possible. If alfalfa growth at Morris is poor in spring of 2021 the current site will be abandoned and new treatments will be applied which will re-start the 4-year growing cycle.

Treatments applied are a combination of sulfur source and rate utilizing a split plot design. Sulfur sources include no sulfur (control), potassium sulfate, and potash MST (potash combined with elemental sulfur in every granule ~ 14%S). Sulfur application rates are 10, 20, and 30 lbs S. Sulfur sources were grouped together in main plots for by S application rate. Sulfur was applied before seeding in 2020 and then will be applied after the first cutting in 2021, 2022, and 2023.

An additional treatment block was included where a high rate of S (120 lbs S) was applied at the initial treatment application in spring 2020 and will not be re-applied over the duration of the trial. The high-rate block include three sources, potassium sulfate and potash MST used in the rate treatments plus Tiger 90 which is common elemental sulfur product containing 90% S (the no S control was not included in the high rate block). The high-rate treatments will determine how much elemental S is released over time to potentially determine 1st and 2nd year availability of the product and how long sulfate-S will remain in the soil. A high rate of P was applied the first year of the study to increase soil test P allowing for smaller maintenance rates of P to be applied over time. Fertilizer K will be applied yearly to balance K rates applied across all treatments.

Starting in 2020 and for three additional years, we will intensively management alfalfa and harvest at bud-early flower stages of maturity resulting in three to four cuttings per year. No fall cutting will occur. Each spring and fall we will measure alfalfa populations. At each cutting we will measure alfalfa yield, forage quality (crude protein, NDF, digestibility using NIRS), maturity, and total S concentration. Conducting the studies on the same fields multiple years will be advantageous as we should be able to draw sulfur concentrations down over time hopefully seeing larger yield responses in future years as sulfur is depleted in the soil. Plots will be 12' wide by 20' long. Initial soil samples will be collected by rep at 0-6, 6-12" prior to treatment application and 0-24" in fall prior to, or after, the last cutting.

Table 1. Soil series information planted crop at each location, and initial potassium soil test data from new alfalfa seedings in 2020. Soil test data was collected prior to initial treatment application.

	Soil Test				SO_4-S		
Location	Bray-P1	K	pH	OM	0-6"	6-24"	Soil Series
	---ppm---			%	---ppm---		
Morris	8	142	7.6	4.5	9.1	6.3	Aazdahl-Formdale
Rosemount	9	115	6.8	3.7	5.2	3.1	Tallula silt loam

† K, Soil test potassium (K-ammonium acetate).

Table 2. Summary of cultural practices for studies conducted in 2020 and 2021.

			Date of		
Year	Location	Cultivar†	Spring Fert.	Planting	Harvest
2020	Rosemount	P 55VR08-N221	23-Apr.	6-May	25-Aug
2021	Morris				--
	Rosemount	--	3-Jun.	--	1-Jun.
		--	--	--	28-Jun.
		--	--	--	2-Aug.
		--	--	--	18-Sept.
2022	Morris	--	15-Jun	--	10-Jun
		--	--	--	13-Jul
		--	--	--	17-Aug
		--	--	--	20-Sept
	Rosemount	--	7-Jun	--	3-Jun
		--	--	--	8-Jul
		--	--	--	9-Aug
		--	--	--	20-Sept

† P, Pioneer.

Results and Discussion

2020 Data Summary

Initial soil test data and soil series information is given in Table 1. Information is given for the location at Morris which fertilizer was applied but the alfalfa seeded did not grow due to lack of moisture. Alfalfa was re-seeded at Morris in the Fall of 2020 and spring of 2021 but did not establish. An additional seeding was made at Morris in Summer of 2021 and that sending resulting in the plots being established, but no yield data was collected in 2021. The first yield data at Morris will be collected in June of 2022. Plots were established at Rosemount in spring 2020. There were two cutting at Rosemount. The first cutting yield data were not measured due volunteer wheat from the previous year and leaf hopper damage. Yield data was collected from the second cutting. A third cutting was not taken to limit stress on the crop for overwintering.

Summary statistics for measured parameters for Rosemount cut 2 are given in Table 3. Alfalfa yield as affected by sulfur source, but not by sulfur rate, for the second cutting at Rosemount (Table 4. Average yield was greatest with the sulfate S and yield was not increased with MST compared to the no-sulfur control.

Data for the high fertilizer rates and for the Tiger 90 treatment are included in Table 4 as well as the following tables but was not included as part of the data analysis. For this report I only included an analysis of the three main sources applied at 10, 20, and 30 lbs of S. What is interesting is the numerical values were much less for the high fertilizer rates. This may indicate some phytotoxic impact of the high rate limiting yield. The high rate was a one-time application made in year 1 and will not be applied in subsequent years. I was curious whether the high rate

of K needed to balance K across treatments would limit yield. Since the same rate of K was applied as KCl across most rates it is unlikely that any negative impacts were due to KCl. In fact, the only treatment which did not receive KCl was the 120 lb K-sulfate treatment. The lack of a difference among the sulfur rates does indicate that the 10 lb rate was sufficient supplying all sulfur needed by alfalfa in year 1.

Table 5. Sulfur source and rate impacts on forage total sulfur concentration from cut 2 at Rosemount in 2020.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% S----------				
Rosemount	10	0.17	0.19	0.21	--	0.19b
	20	0.19	0.21	0.25	--	0.22b
	30	0.19	0.27	0.28	--	0.25a
	120	--	0.32	0.36	0.22	
	Source Avg.[1]	0.18c	0.25b	0.28a	--	

Table 6. Sulfur source and rate impacts on forage total sulfur uptake from cut 2 at Rosemount in 2020.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds S per acre----------				
Rosemount	10	4.6	5.9	5.9	--	5.4b
	20	5.2	6.5	7.1	--	6.3ab
	30	5.2	7.5	8.4	--	7.0a
	120	--	8.3	7.9	5.9	
	Source Avg.[1]	5.0b	7.0a	7.3a	--	

Forage total sulfur concentration data are listed in Table 5 and total sulfur uptake is given in Table 5. In both cases, sulfur source and sulfur rate significantly differed while the source by rate interaction was not significant. In both cases there was no different between the 10 and 20 lb rate while the 30 lb sulfur rate sulfur concentration and uptake was significantly greater than the two lower rates. Source effects were not the same considering total sulfur concentration versus sulfur uptake. In fact, the MST treatment produced the greatest concentration of sulfur in forage followed by sulfate and lastly the control. However, sulfur uptake was similar for MST compared to sulfate S which results from the combination of greater tonnage and lower sulfur concentration with sulfate versus lower tonnage and greater S concentration with MST. Again the 120 lb application rates were not included in the data analysis even though tissue sulfur

concentration appeared to increase while there did not appear to be an increase in tissue sulfur concentration when the high rate of S was applied as Tiger 90.

Forage quality parameters were not affected by sulfur source or rate. Forage protein concentration, ADF, and NDF are listed in Tables 7, 8, and 9, respectively.

Table 7. Sulfur source and rate impacts on forage protein concentration from cut 2 at Rosemount in 2020.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% Protein----------				
Rosemount	10	18.7	20.4	18.9	--	19.3
	20	18.8	19.3	19.4	--	19.2
	30	19.9	20.4	19.3	--	19.8
	120	--	20.3	17.4	18.6	
	Source Avg.[1]	19.1	20.1	18.8	--	

Table 8. Sulfur source and rate impacts on forage acid detergent fiber (ADF) concentration from cut 2 at Rosemount in 2020.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------ADF----------				
Rosemount	10	35.4	33.5	35.4	--	34.8
	20	35.4	35.4	35.5	--	35.5
	30	33.9	34.1	35.7	--	34.6
	120	--	33.5	37.0	35.8	
	Source Avg.[1]	34.9	34.1	35.9	--	

Table 9. Sulfur source and rate impacts on forage neutral detergent fiber (NDF) concentration from cut 2 at Rosemount in 2020.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------NDF----------				
Rosemount	10	47.4	45.8	47.9	--	47.0
	20	48.2	48.1	48.1	--	48.1
	30	45.7	46.4	48.3	--	46.8
	120	--	45.8	49.3	48.1	
	Source Avg.[1]	47.1	46.5	48.4	--	

2021 Data Summary

Table 10. Summary of ANOVA analysis for measured agronomic variables for data collected at Rosemount in 2021.

Main Effect	Harv. 1 Yield	Harv. 2 Yield	Harv. 3 Yield	Harv. 4 Yield	Ap. 1 Yield
	----------*P*>F----------				
	Rosemount				
S rate	0.29	0.26	0.14	0.56	0.96
S Source	**	***	***	***	***
Srt.xSource	0.48	0.27	0.25	**	0.68

Asterisks denote significance at the 0.05 (*), 0.01 (**), and 0,001 (***) probability levels.

Summary statistics for alfalfa harvest data are summarized in Table 10. Harvest data was only collected from the Rosemount location (four harvests in 2021) as Morris was not established until the middle of the summer in 2021 and no harvest data was collected. Along with individual harvest data the total amount of forage harvested between the first and second fertilizer application (Ap. 1) and the second fertilizer application and the end of the 2021 growing season (Ap. 2) were assessed to determine the effectively of each fertilizer application. The amount of forage harvested is summarized in Table 11.

Sulfur source consistently affected alfalfa yield at Rosemount while rate did not affect alfalfa yield which indicates the 10 lb application rate was sufficient to maximize yield. The 20 and 30 lb application rates did not produce higher yield and both the sulfate and MST fertilizers produced similar yield. Over the first application the addition of sulfur resulted in an average of 1064 lbs of additional forage. Assuming a forage value of $150 per ton and a sulfur price of $0.50 per lb. and $6 per acre to spread the fertilizer, a total of $69 would be returned per acre in additional yield over the cost of 10 lbs of S applied for the first fertilizer application.

Application data in Table 11 do not account for the 120 lb initial application rates. Figures 1 summarizes all yield data for the first sulfur application at Rosemount. Tiger 90 was additionally included along with potassium sulfate and MST. Alfalfa yield for the high application rates were like the 10 lb rate for the sulfate and MST sources for application 1 indicating some oxidation of Tiger 90 to sulfate flowing the first application of fertilizer.

Table 11. Summary of sulfur source and rate effects on alfalfa yield at Rosemount for a total of four harvests in 2021 and the summary of total forage harvested following the first and second sulfur applications.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds per acre----------				
Rosemount Cut 1	10	3595	4020	4146	--	3920
	20	3433	4548	4186	--	4056
	30	3484	3961	3895	--	3780
	120	--	3877	3848	3800	
	Source Avg.[1]	3504b	4177a	4076a	--	
Rosemount Cut 2	10	2349	2838	2478	--	2555
	20	2277	2872	2890	--	2680
	30	2497	2856	2857	--	2737
	120	--	2976	2743	2629	
	Source Avg.[1]	2646b	3138a	3059a	--	
Rosemount Cut 3	10	2049	2672	2503	--	2408
	20	1957	2537	2631	--	2375
	30	2478	2813	2644	--	2645
	120	--	2559	2620	2305	
	Source Avg.[1]	2161b	2674a	2593a		
Rosemount Cut 4	10	4663	6174	5744	--	5527
	20	5265	6133	6141	--	5846
	30	4205	5906	6483	--	5531
	120	--	6552	6205	5701	
	Source Avg.[1]	5188b	6465a	6423a	--	
Rosemount Application 1	10	5944	6859	6624	--	6476
	20	5710	7518	7076	--	6768
	30	5981	6817	6753	--	6517
	120	--	6852	6591	6429	
	Source Avg.[1]	6353b	7440a	7258a	--	

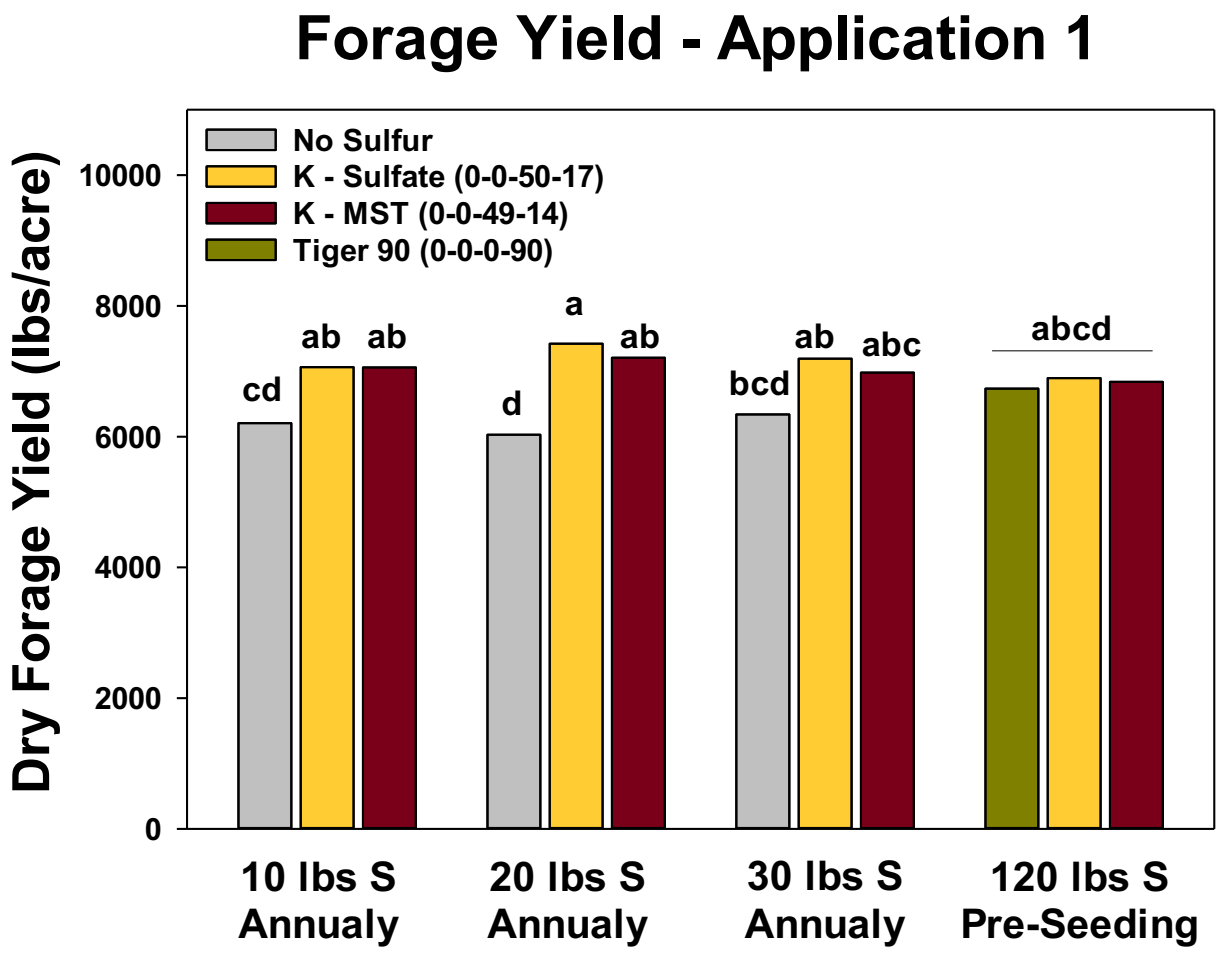

Figure 1. Summary of total forage harvested for the single 2020 harvest plus harvest 1 of 2021 representing the time between the initial fertilizer application and the second annual application made after the first harvest in 2021 at Rosemount.

Total Sulfur uptake for each harvest in 2021 are summarized in Table 12. Sulfur source and rate always impacted the total amount of S removed through alfalfa harvest at Rosemount due to differences in forage yield. There did appear to be some luxury uptake of S due to instances were rate did not affect yield but S removal was increased with increasing rate of applied S, which could be seen with much higher removal of S with the 120 lb S rate. The total amount of S removed for the first sulfur application is included in Table 12. This data only includes two cuts, the only cutting taken for yield in 2020 plus cut 1 in 2021. Based on the data for the two cuttings only roughly 30% of the S applied with the fertilizer treatments was taken up. Again, this update only accounts for two of four cuts expected between 2020 and 2021. Even though there was no difference in forage yield between the 10, 20, and 30 lb S rates, there was about 1 additional lb of S taken up and removed through harvest accounting for roughly 10% of what was applied. This again indicates that S can be taken up by the alfalfa plant even if it is not needed to increase forage yield.

Table 12. Summary of sulfur source and rate effects on alfalfa total sulfur uptake for each of four harvest timings during the 2021 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds S per acre----------				
Rosemount Cut 1	10	5.8	7.6	7.4	--	6.9b
	20	5.1	8.7	8.9	--	7.5ab
	30	5.6	8.3	9.3	--	7.8a
	120	--	9.8	11.4	7.5	9.6
	Source Avg.[1]	5.5b	8.2a	8.5a	--	
Rosemount Cut 2	10	4.3	6.3	5.2	--	5.3b
	20	3.8	7.7	7.0	--	6.1ab
	30	4.6	8.0	7.3	--	6.6a
	120	--	9.5	9.2	5.2	8.0
	Source Avg.[1]	4.2c	7.9a	7.2b	5.2	
Rosemount Cut 3	10	3.5	6.1	5.1	--	4.9b
	20	3.4	7.1	6.0	--	5.5ab
	30	4.2	7.3	6.5	--	6.0a
	120	--	6.2	7.5	4.3	6.0
	Source Avg.[1]	3.7c	6.7a	6.3b	4.3	
Rosemount Cut 4	10	7.2	11.7	10.7	--	9.9
	20	7.4	10.0	13.4	--	10.3
	30	5.9	13.6	16.1	--	11.9
	120	--	12.6	15.3	9.9	12.6
	Source Avg.[1]	6.8b	12.0a	13.9a	9.9	
Rosemount Ap1	10	10.3	13.5	13.2	--	12.4b
	20	10.3	15.2	16.0	--	13.8a
	30	10.8	15.8	17.7	--	14.8a
	120	--	18.1	19.3	13.3	16.9
	Source Avg.[1]	10.5b	15.6a	16.6a	13.3	

Table 13. Summary of sulfur source and rate effects on alfalfa protein concentration for each of four harvest timings during the 2021 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% Protein----------				
Rosemount	10	17.5	19.7	18.6	--	18.6
	20	17.5	19.5	20.2	--	19.1
	30	18.8	18.8	19.3	--	19.0
	120	--	20.8	19.8	18.7	
	Source Avg.[1]	17.9b	19.3a	19.4a	--	
Rosemount	10	20.5	22.2	20.7	--	21.1
	20	19.3	23.0	22.3	--	21.5
	30	20.4	23.1	22.7	--	22.1
	120	--	23.5	23.1	21.6	
	Source Avg.[1]	20.1b	22.7a	21.9a	--	
Rosemount	10	17.2	19.7	18.9	--	18.6
	20	17.8	19.8	19.8	--	19.1
	30	17.2	18.9	19.3	--	18.4
	120	--	20.3	19.8	18.2	
	Source Avg.[1]	17.4b	19.4a	19.3a	--	
Rosemount	10	17.5	19.0	18.6	--	18.4
	20	16.6	19.0	19.3	--	18.3
	30	17.1	20.1	20.3	--	19.2
	120	--	20.2	19.7	18.6	
	Source Avg.[1]	17.1b	19.4a	19.4a	--	

Protein concentration in the alfalfa biomass was consistently affected by sulfur source but was not affected by sulfur rate (Table 13). In all cases the two sources of sulfur, sulfate and MST, increased protein concentration similarly on average by around 2.0% for all harvests. Protein concentration was the greatest for the second Cutting.

Table 14. Summary of sulfur source and rate effects on alfalfa acid detergent fiber (ADF) for each of four harvest timings during the 2021 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% ADF----------				
Rosemount	10	34.2	32.2	34.2	--	33.5
	20	33.4	33.2	31.9	--	32.8
	30	32.0	34.5	33.7	--	33.4
	120	--	32.6	32.7	33.9	
	Source Avg.[1]	33.2	33.2	33.3	--	
Rosemount	10	30.3	30.9	31.3	--	30.8
	20	30.6	31.0	31.1	--	30.9
	30	29.9	30.7	30.3	--	30.3
	120	--	29.4	30.3	31.1	
	Source Avg.[1]	30.2	30.9	30.9	--	
Rosemount	10	29.7	30.0	30.6	--	30.1
	20	28.2	30.3	30.5	--	29.6
	30	30.0	31.5	29.9	--	30.5
	120	--	29.5	29.1	29.8	
	Source Avg.[1]	29.3b	30.6a	30.3a	--	
Rosemount	10	35.7	37.4	37.1	--	36.7
	20	38.8	37.8	39.2	--	38.7
	30	36.4	37.3	39.6	--	37.8
	120	--	38.6	36.0	38.7	
	Source Avg.[1]	37.0	37.5	38.7	--	

Alfalfa acid- and neutral detergent fiber were not impacted by sulfur rate and source at Rosemount in 2021 (Tables 14 and 15).

Table 15. Summary of sulfur source and rate effects on alfalfa neutral detergent fiber (NDF) for each of four harvest timings during the 2021 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% NDF----------				
Rosemount	10	46.0	42.5	46.1	--	44.9
	20	45.4	44.3	42.8	--	44.2
	30	42.9	46.1	44.8	--	44.6
	120	--	43.5	43.4	45.9	
	Source Avg.[1]	44.8	44.3	44.6	--	
Rosemount	10	41.0	40.1	41.9	--	41.0
	20	42.2	40.4	41.1	--	41.2
	30	39.8	39.9	39.3	--	39.7
	120	--	37.9	39.9	42.0	
	Source Avg.[1]	41.0	40.1	40.8	--	
Rosemount	10	42.4	41.0	42.3	--	41.9
	20	40.4	41.4	42.3	--	41.4
	30	42.7	43.3	41.5	--	42.5
	120	--	40.3	40.5	42.4	
	Source Avg.[1]	41.8	41.9	42.0	--	
Rosemount	10	45.6	46.8	46.2	--	46.2
	20	47.3	48.1	47.6	--	47.6
	30	45.9	46.7	48.2	--	47.0
	120	--	46.7	45.4	47.7	
	Source Avg.[1]	46.3	47.2	47.4	--	

Table 16. Summary of sulfur source and rate effects on soil 2' sulfur concentration for spring and fall sample timings at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds SO4-S per acre----------				
Rosemount	10	56	54	52	--	54b
Fall	20	55	63	60	--	60a
2020	30	54	56	56	--	55ab
	120	--	109	62	54	
	Source Avg.[1]	56	58	56	--	
Rosemount	10	49	46	45	--	46
Spring	20	46	48	51	--	48
2021	30	48	43	51	--	47
	120	--	58	87	44	
	Source Avg.[1]	47	46	49	--	
Rosemount	10	52	49	48	--	50
Fall	20	49	56	51	--	52
2021	30	50	52	57	--	53
	120	--	70	74	48	
	Source Avg.[1]	50	52	52	--	
Morris	10	19	18	18	--	18a
Fall	20	17	19	18	--	18a
2021	30	17	16	16	--	16b
	120	--	16	16	18	
	Source Avg.[1]	18	18	17	--	

Table 16 summarizes soil sulfate data on two-foot soil samples at Rosemount and 0–6-inch soil samples taken in fall from Morris. Sulfur source did not affect the amount of extractable sulfate-sulfur in the soil samples for any of the samples at either location. Sulfur rate impacted the amount of sulfate extracted at Rosemount and Morris in the fall after the respective first applications (Fall 2020 at Rosemount and Fall 2021 at Morris). The lack of different in soil sulfate where resulting yield increases were seen further support the lack of benefit for the soil sulfate-sulfur test in Minnesota. Higher concentrations of sulfate-sulfur were found in the soil for the 120 lb application rates but very little different was found between the 10, 20, and 30 lbs rate. When significant, the amount of sulfurate sulfur in the soil tended to decrease from the 10 to 30 lb application rates.

2022 Data Summary

Table 17. Summary of ANOVA analysis for measured agronomic variables for data collected at Morris and Rosemount in 2022.

Main Effect	Harv. 1 Yield	Harv. 2 Yield	Harv. 3 Yield	Harv. 4 Yield	Ap. 2 Yield
	----------*P*>F----------				
			Morris		
S rate	0.73	0.74	0.96	0.79	0.87
S Source	0.28	*	*	*	*
Srt.xSource	0.49	0.66	0.95	0.17	0.61
			Rosemount		
S rate	0.62	0.35	0.43	0.08	0.42
S Source	***	***	***	***	***
Srt.xSource	0.23	0.23	0.07	0.21	0.37

Asterisks denote significance at the 0.05 (*), 0.01 (**), and 0,001 (***) probability levels.

Summary statistics for alfalfa harvest data for 2022 are summarized in Table 17. Harvest data was collected from four cuttings at both Morris and Rosemount in 2022. Along with individual harvest data the total amount of forage harvested between the second and third fertilizer application (Ap. 2) at Rosemount and Morris. Data for the first application, Ap. 1, is not summarized for Morris as it would only include the first cutting of 2022. The Ap 2 summary for Morris only includes cuts 2, 3, and 4 from 2022.

At Morris, sources varied after fertilizer was applied in 2022 and were seen for cuts 2, 3, and 4 (Table 18). Rate never differed at Morris. Forage yield was only increased with sulfate was used for cuts 2, and 3 and MST did not increase yield over the non-fertilized control until Cut 4 where MST alone increased forage yield while sulfate was no different from the control. Considering cuts 2 through 4 in 2022, total forage yield was greatest with sulfate and was only slightly increased with MST. The 2022 growing season was relatively dry at Morris so it makes sense that the elemental S may have taken more time to oxidize to a plant available for and that the bulk of the sulfate applied may have been taken up by the plant with not enough remaining at cut 4 to increase yield.

Sulfur source consistently affected alfalfa yield at Rosemount while rate only was significant at the fourth cutting (Table 19). There was no difference in yield between plots receiving sulfate versus MST and the 10 lb rate was sufficient for all times except cut 4 where 20 lbs of S maximized yield. Considering the second application, there was no difference between yield produced by sulfate versus MST and the 10 lb S rate resulted in the greatest yield with no additional yield produced with increasing rates of S.

For the second sulfur application an additional 3345 lbs of forage were produced with the application of 10 lbs of S. Assuming a forage value of $150 per ton and a sulfur price of $0.50 per lb. and $6 per acre to spread the fertilizer, a total of $235 would be returned per acre in

additional yield over the cost of fertilizer application at Rosemount. Over the two years the application of 10-20 lbs of S resulted in a net return of $304 per acre. Forage quality was not factored into the total but could potentially increase net return at Rosemount where protein was increased with S. Net return has not been calculated at Morris as a full four cuts has not been taken at the site at this time.

Table 18. Summary of sulfur source and rate effects on alfalfa yield at Morris for a total of four harvests in 2022 and the summary of total forage harvested following the second sulfur applications encompassing cuts 2, 3, and 4 in 2022.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds per acre----------				
Morris Cut 1	10	1363	1435	1698	--	1499
	20	1415	1391	1512	--	1439
	30	1457	1363	1383	--	1401
	120	--	1589	1608	1419	1539
	Source Avg.[1]	1412	1444	1550	1419	
Morris Cut 2	10	3060	3370	3224	--	3218
	20	3189	3412	3112	--	3238
	30	3265	3424	3368	--	3352
	120	--	3477	3327	3242	3349
	Source Avg.[1]	3171b	3421a	3258b	3242	
Morris Cut 3	10	3205	3640	3265	--	3370
	20	3247	3753	3140	--	3380
	30	3186	3737	3368	--	3430
	120	--	3192	3329	3993	3504
	Source Avg.[1]	3213b	3581a	3275b	3993	
Morris Cut 4	10	1704	1853	1820	--	1792
	20	1770	1823	1932	--	1841
	30	1704	1664	2252	--	1873
	120	--	1587	2003	1793	1794
	Source Avg.[1]	1726b	1732b	2002a	1793	
Morris Application 2	10	7969	8863	8310	--	8381
	20	8206	8988	8184	--	8459
	30	8155	8825	8987	--	8656
	120	--	8255	8658	9028	8647
	Source Avg.[1]	8110b	8733a	8535ab	9028	

Table 19. Summary of sulfur source and rate effects on alfalfa yield at Rosemount for a total of four harvests in 2022 and the summary of total forage harvested following the second sulfur application encompassing cuts 2, 3, an4 in 2021 and Cut 1 in 2022.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds per acre----------				
Rosemount Cut 1	10	3104	3782	3997	--	3628
	20	2729	4387	4156	--	3757
	30	2812	3790	4120	--	3574
	120	--	4127	4427	4098	4217
	Source Avg.[1]	2882b	4021a	4175a	4098	
Rosemount Cut 2	10	1953	2574	2729	--	2419
	20	1926	3258	3033	--	2739
	30	1720	3090	3187	--	2666
	120	--	3398	3345	2551	3098
	Source Avg.[1]	1866b	3080a	3073a	2551	
Rosemount Cut 3	10	1259	2306	2087	--	1884
	20	1199	2282	2444	--	1975
	30	1270	2144	2597	--	2003
	120	--	2534	2303	1960	2266
	Source Avg.[1]	1243b	2316a	2358a	1960	
Rosemount Cut 4	10	960	1870	1802	--	1544b
	20	896	2057	2237	--	1730a
	30	888	1788	2007	--	1561b
	120	--	1937	1925	1614	1826
	Source Avg.[1]	915b	1913a	1993a	1614	
Rosemount Application 2	10	12165	15467	14722	--	14118
	20	12228	15929	15819	--	14659
	30	11992	15364	16105	--	14487
	120	--	16213	15994	14733	15647
	Source Avg.[1]	12128b	15743a	15660a	14733	

Application data in Table 11 do not account for the 120 lb initial application rates. Figure 2 summarize all yield data for the second sulfur application (at Rosemount only). Tiger 90 was additionally included along with potassium sulfate and MST. Tiger 90 treatment resulted in less yield compared to sulfate and MST for the second application timing, but Tiger 90 did increase alfalfa yield. I will continue to track the residual impacts of the high-rate treatments over time.

However, it will be interesting to see if the yield of Tiger 90 will start to decline over time indicating poor long-term availability.

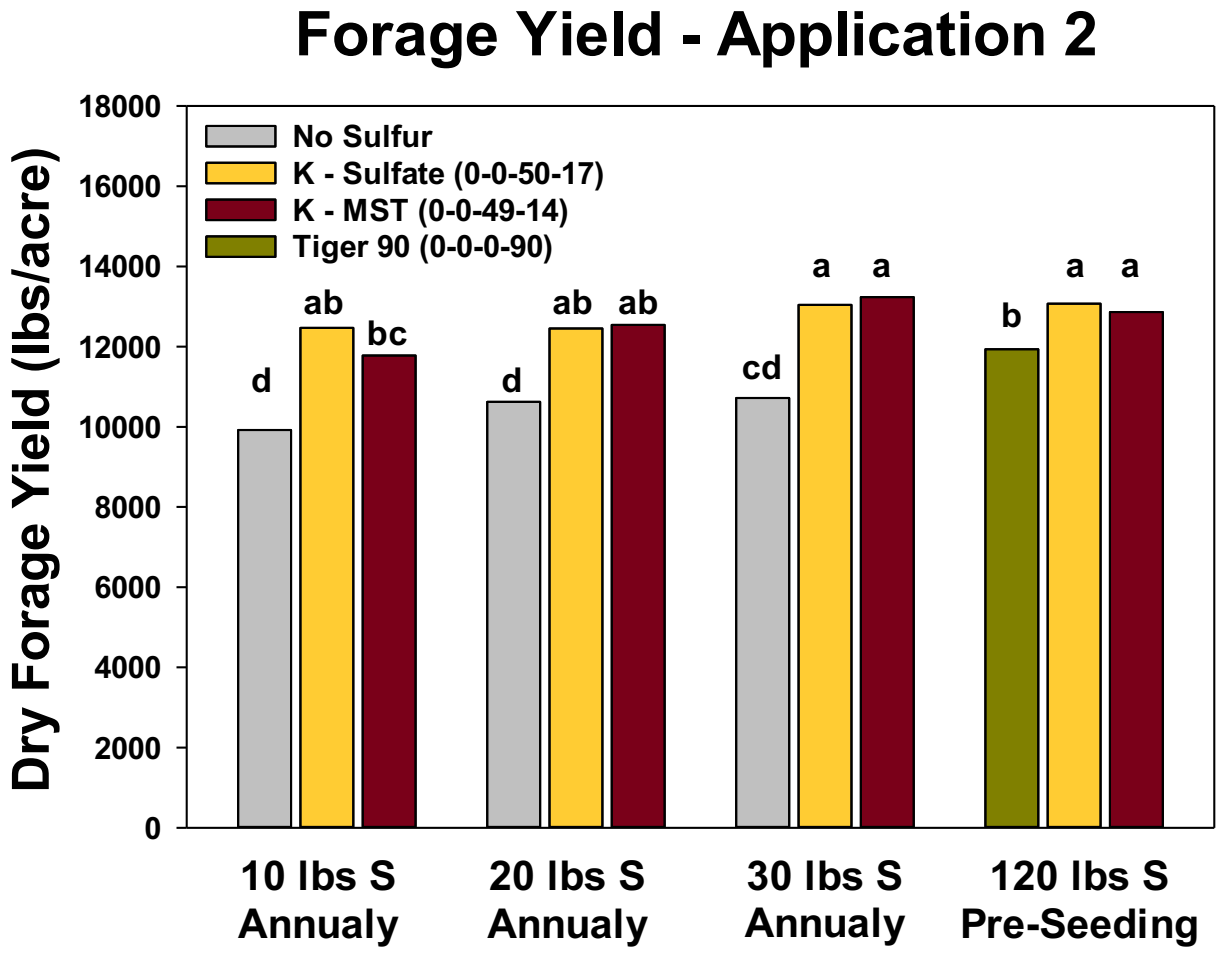

Figure 2. Summary of total forage harvested for harvests 2 through 4 in 2022 representing the time between second annual application made after the first harvest in 2022 and the end of the 2022 growing season at Rosemount.

Total Sulfur uptake for each harvest in 2022 has not been determined at this time. Samples were processed and sent to the U of M soil testing laboratory but the data have not been returned at this time.

Table 20. Summary of sulfur source and rate effects on alfalfa total sulfur uptake for each of four harvest timings during the 2022 growing season at Morris, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds S per acre----------				
Morris	10					
	20					
	30					
	120					
	Source Avg.[1]					
Morris	10					
	20					
	30					
	120					
	Source Avg.[1]					
Morris	10					
	20					
	30					
	120					
	Source Avg.[1]					
Morris	10					
	20					
	30					
	120					
	Source Avg.[1]					

Table 21. Summary of sulfur source and rate effects on alfalfa total sulfur uptake for each of four harvest timings during the 2022 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds S per acre----------				
Rosemount	10					
	20					
	30					
	120					
	Source Avg.[1]					
Rosemount	10					
	20					
	30					
	120					
	Source Avg.[1]					
Rosemount	10					
	20					
	30					
	120					
	Source Avg.[1]					
Rosemount	10					
	20					
	30					
	120					
	Source Avg.[1]					

Table 22. Summary of sulfur source and rate effects on alfalfa protein concentration for each of four harvest timings during the 2022 growing season at Morris, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% Protein----------				
Morris	10	25.7	26.0	25.1	--	25.6
	20	25.8	26.9	27.1	--	26.6
	30	25.7	26.6	29.1	--	27.1
	120	--	26.0	25.7	28.8	26.8
	Source Avg.[1]	25.7	26.4	26.7	28.8	
Morris	10	26.0	26.3	27.7	--	26.7
	20	26.5	27.3	27.0	--	26.9
	30	26.9	26.0	26.1	--	26.3
	120	--	27.0	27.3	26.1	26.8
	Source Avg.[1]	26.5	26.7	27.0	26.1	
Morris	10	25.2	22.3	26.3	--	24.6
	20	26.0	26.5	26.3	--	26.3
	30	24.9	23.8	27.8	--	25.5
	120	--	29.2	25.7	24.3	26.4
	Source Avg.[1]	25.4	25.4	26.5	24.3	
Morris	10	20.3	21.4	22.4	--	21.4
	20	21.1	22.7	20.5	--	21.5
	30	19.1	23.2	18.5	--	20.3
	120	--	24.5	21.2	25.3	23.7
	Source Avg.[1]	20.2	23.0	20.7	25.3	

Total protein in the forage was relatively higher at Morris compared to Rosemount but was not impacted by sulfur source or rate at Morris in 2022 (Table 22).

Table 23. Summary of sulfur source and rate effects on alfalfa protein concentration for each of four harvest timings during the 2022 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% Protein----------				
Rosemount	10	16.5	18.0	18.0	--	17.5
	20	15.8	19.0	19.5	--	18.1
	30	16.0	18.7	19.2	--	18.0
	120	--	19.0	18.7	17.9	18.5
	Source Avg.[1]	16.1b	18.7a	18.9a	17.9	
Rosemount	10	17.7	22.8	21.1	--	20.5b
	20	17.7	22.3	23.3	--	21.1b
	30	18.4	23.9	24.4	--	22.2a
	120	--	22.8	23.2	21.3	22.4
	Source Avg.[1]	17.9b	23.0a	23.0a	21.3	
Rosemount	10	19.0	23.1	22.4	--	21.5b
	20	18.2	24.6	24.7	--	22.5a
	30	19.0	25.4	24.3	--	22.9a
	120	--	25.5	25.5	21.6	24.2
	Source Avg.[1]	18.7b	24.6a	24.2a	21.6	
Rosemount	10	17.8	20.8	20.5	--	19.7b
	20	17.5	23.7	22.4	--	21.2a
	30	18.2	24.6	23.0	--	21.9a
	120	--	22.5	22.8	19.0	21.4
	Source Avg.[1]	17.8c	22.9a	22.2b	19.0	

Protein concentration in the alfalfa biomass was consistently affected by sulfur source and rate at Rosemount in 2022 (Table 23). In most cases the two sources of sulfur, sulfate and MST, increased protein concentration similarly on average almost 4.0 to 5.0 % higher for all harvests. There was some evidence of a very small difference between sulfate and MST for cut 4. Sulfur rate differed for cuts 2, 3, and 4 with the 30 lb S rate resulting in the greatest protein concentration at cut 2 while the 20 lb S rate was greatest for cuts 3 and 4.

Table 24. Summary of sulfur source and rate effects on alfalfa acid detergent fiber (ADF) for each of four harvest timings during the 2022 growing season at Morris, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% ADF----------				
Morris	10	34.7	39.8	37.9	--	37.5
	20	37.1	35.1	37.3	--	36.5
	30	39.6	36.6	38.4	--	38.2
	120	--	42.3	38.5	38.8	39.9
	Source Avg.[1]	37.2	38.4	38.1	38.8	
Morris	10	39.9	42.6	40.2	--	40.9
	20	38.8	39.8	40.0	--	39.5
	30	39.7	40.8	39.9	--	40.1
	120	--	40.2	41.3	41.7	41.0
	Source Avg.[1]	39.5	40.8	40.3	41.7	
Morris	10	40.6	42.7	43.2	--	42.2
	20	42.5	39.1	43.7	--	41.7
	30	42.2	45.7	40.1	--	42.6
	120	--	43.2	41.5	40.2	41.6
	Source Avg.[1]	41.7	42.7	42.1	40.2	
Morris	10	42.0	41.1	41.5	--	41.5
	20	43.4	40.6	42.3	--	42.1
	30	43.4	42.1	43.4	--	43.0
	120	--	40.5	42.8	39.5	40.9
	Source Avg.[1]	42.9	41.1	42.5	39.5	

Forage ADF was not affected by sulfur source or rate at Morris in 2022 (Table 24).

Table 25. Summary of sulfur source and rate effects on alfalfa acid detergent fiber (ADF) for each of four harvest timings during the 2022 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% ADF----------				
Rosemount	10	32.9	35.6	36.3	--	34.9
	20	35.0	33.9	35.3	--	34.8
	30	35.7	35.4	35.0	--	35.4
	120	--	36.8	36.8	35.6	36.4
	Source Avg.[1]	34.5	35.4	35.9	35.6	
Rosemount	10	39.5	35.2	39.9	--	38.2
	20	39.5	40.0	38.8	--	39.5
	30	35.8	38.5	39.5	--	37.9
	120	--	40.7	37.5	36.1	38.1
	Source Avg.[1]	38.3	38.6	38.9	36.1	
Rosemount	10	36.5	38.8	37.1	--	37.5
	20	36.6	35.6	37.0	--	36.4
	30	37.0	35.2	38.2	--	36.8
	120	--	37.7	34.4	36.4	36.2
	Source Avg.[1]	36.7	36.8	36.7	36.4	
Rosemount	10	35.0	35.1	34.8	--	35.0
	20	34.4	34.9	36.4	--	35.2
	30	34.7	34.3	34.2	--	34.4
	120	--	34.4	33.8	36.0	34.7
	Source Avg.[1]	34.7	34.7	34.8	36.0	

Forage ADF was not affected by sulfur source and rate at Rosemount in 2022 (Table 25).

Table 26. Summary of sulfur source and rate effects on alfalfa neutral detergent fiber (NDF) for each of four harvest timings during the 2022 growing season at Morris, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% NDF----------				
Morris	10	51.9	57.8	54.7	--	54.8
	20	53.8	50.7	53.6	--	52.7
	30	56.5	53.1	54.8	--	54.8
	120	--	59.0	54.9	56.1	56.7
	Source Avg.[1]	54.1	55.2	54.5	56.1	
Morris	10	56.4	59.6	56.2	--	57.4
	20	55.2	55.4	56.8	--	55.8
	30	54.6	56.9	54.5	--	55.3
	120	--	53.7	57.8	58.1	56.5
	Source Avg.[1]	55.4	56.4	56.3	58.1	
Morris	10	52.9	57.5	56.8	--	55.8
	20	56.4	51.4	57.0	--	54.9
	30	54.5	58.7	50.6	--	54.6
	120	--	55.3	53.9	53.5	54.2
	Source Avg.[1]	54.6	55.7	54.6	53.5	
Morris	10	56.7	56.1	56.6	--	56.5
	20	59.1	56.0	57.2	--	57.4
	30	59.3	57.2	59.9	--	58.8
	120	--	54.7	57.5	51.3	54.5
	Source Avg.[1]	58.4	56.0	57.8	51.3	

Forage NDF was not affected by sulfur source or rate at Morris in 2022 (Table 26).

Table 27. Summary of sulfur source and rate effects on alfalfa neutral detergent fiber (NDF) for each of four harvest timings during the 2022 growing season at Rosemount, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------% NDF----------				
Rosemount	10	47.0	50.0	50.1	--	49.0
	20	49.1	46.7	48.9	--	48.2
	30	49.4	49.3	48.5	--	49.1
	120	--	50.4	50.8	48.5	49.9
	Source Avg.[1]	48.5	49.1	49.6	48.5	
Rosemount	10	52.7	49.3	53.4	--	51.8
	20	51.5	52.6	54.0	--	52.7
	30	48.3	52.9	53.4	--	51.5
	120	--	54.4	51.9	50.1	52.1
	Source Avg.[1]	50.8b	52.3ab	53.2a	50.1	
Rosemount	10	46.0	47.9	47.1	--	47.0
	20	46.4	44.5	45.6	--	45.5
	30	47.0	43.4	45.9	--	45.4
	120	--	45.6	42.7	46.0	44.7
	Source Avg.[1]	46.5	45.4	45.3	46.0	
Rosemount	10	47.0	47.3	46.7	--	47.0
	20	46.1	46.9	47.2	--	46.7
	30	46.8	46.3	46.3	--	46.5
	120	--	45.4	45.6	48.4	46.5
	Source Avg.[1]	46.6	46.5	46.5	48.4	

Forage NDF was only affected by S source at Cut 2 at Rosemount in 2022 (Table 27). Both sources resulted in a greater NDF value at Cut 2.

Table 28. Summary of sulfur source and rate effects on soil 2' sulfate-S content for spring and fall sample timings at Rosemount, MN and 0-1' sulfate-S content at Morris, MN.

Location	S Rate (lb/ac)	Sulfur Source				Rate Avg
		Control	K_2SO_4	K-MST	Tiger 90	
		----------pounds SO4-S per acre----------				
Morris	10	40	42	40	--	40
Spring	20	39	42	41	--	41
2022	30	38	38	40	--	39
	120	--	36	41	39	39
	Source Avg.[1]	39	40	40	39	
Morris	10	78	86	81	--	82
Fall	20	80	82	80	--	81
2022	30	85	89	87	--	87
	120	--	82	87	83	84
	Source Avg.[1]	81	85	84	83	
Rosemount	10	51	45	45	--	47
Spring	20	43	43	49	--	45
2022	30	43	41	47	--	44
	120	--	50	47	42	46
	Source Avg.[1]	46	45	47	42	
Rosemount	10	95	91	83	--	90
Fall	20	95	88	91	--	91
2022	30	83	89	90	--	87
	120	--	100	87	94	93
	Source Avg.[1]	91	92	88	94	

Table 28 summarizes soil sulfate data on two-foot soil samples at Rosemount and 0–6-inch soil samples taken in fall from Morris. In spite of treatment effects on forage yield, there was no effect of sulfur source or rate on extractable sulfate-S in spring or fall of 2022 at either site.