Dealing with Sulfur Deficiencies in Crop Production: the Northeast Iowa Experience[1]

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Introduction

Over forty years of prior research in Iowa had rarely noted improved crop yield with sulfur (S) fertilization and S deficiency was not considered an issue for crop production. Statewide and regional studies conducted in Iowa during that time period with corn and soybean found yield increase from S fertilizer application only three times out of nearly 200 trials, with one multi-year study having a small average yield decrease. Research in the early 1980s had also documented sufficient plant available S in the soil profile for crop production on most Iowa soil associations. Results of recent studies in corn and soybean production in areas of Iowa outside of northeast Iowa (2000-2005) were consistent with results of the historical research.

However, over the past decade alfalfa grown on some silt loam and loam soils in northeast Iowa exhibited a slowly worsening problem with areas in fields of stunted growth and poor coloration. Investigations determined the growth problems were largely due to S deficiency, with the most prominent symptoms in field areas with low soil organic matter and side-slope landscape position. On similar soils and on coarse textured soils, early corn growth has also recently been exhibiting strong visual S deficiency symptoms.

On-farm research trials were conducted to determine alfalfa and corn response to S fertilization and evaluate specific soils and the extent of northeast Iowa affected by S deficiency. The following provides a summary of research conducted in northeast Iowa alfalfa and corn production fields, methods to identify potential S deficiency, and S fertilization guidelines.

Alfalfa Response to Sulfur Fertilization

Trials in 2005

In 2005, on-farm trials were conducted on established alfalfa fields near Elgin, Gunder, and West Union, Iowa. These sites were selected because there were large areas in the fields with both poor and good alfalfa plant coloration and growth. Within identified poor and good coloration/growth areas, three fertilizer treatments were established. The treatments consisted of a no-S application, 40 lb S/acre as ammonium sulfate, and 40 lb S/acre as calcium sulfate (gypsum). Treatments were applied after the first cut. Alfalfa harvests included second cut and third cut in 2005 at all three sites, and first cut in 2006 at the Elgin and Gunder sites.

Dry matter yields with applied S on the good areas were not different from that of the unfertilized no-S control (Table 1). However, S applied on the poor areas more than doubled yields in 2005 and nearly doubled yields in 2006. Plant analysis from the untreated poor areas was 0.14% S, clearly well below the suggested sufficiency level of 0.25% S. Plant analysis for the untreated good areas was also considered deficient at 0.22% S, but by a very small margin. The S fertilizer applications in the poor areas increased the dry matter yield nearly to those in the good areas. The two sulfate containing fertilizers provided similar results.

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Other soil characteristics, soil type, phosphorus (P) and potassium (K) soil test levels, pH, sulfate-S soil test levels, organic matter, and cation exchange capacity were largely similar within the sites. Any differences that existed did not explain differences in response found with the S treatments. The extractable sulfate-S soil test results for 0-6 inch depth soil samples (Elgin 6.3 and 7.0 ppm, Gunder 7.3 and 8.3 ppm, and West Union 6.3 and 7.0 ppm, respectively for poor and good areas) did not correspond to the coloration/growth differences in the fields, the S concentration differences found in plant analyses, or yield responses to applied S. The soil organic matter levels also did not explain plant responses (Elgin 2.3 and 2.3%, Gunder 2.7 and 2.9%, and West Union 2.3 and 2.6%, respectively for poor and good areas).

Table 1. Alfalfa forage yield, plant S analysis, and crop S removal with topdress application of S fertilizer in field areas with poor and good coloration of alfalfa.

	2005[†]						2006[‡]	
	Cuts 2+3 Dry matter yield		Cut 2 Plant top S[§]		Cuts 2+3 S removal		Cut 1 Dry matter yield	
	Observed coloration/growth area							
Sulfur application[¶]	Poor	Good	Poor	Good	Poor	Good	Poor	Good
	- - ton/acre - -		- - - % S - - -		- - lb S/acre - -		- - ton/acre - -	
None	1.18a[#]	2.99a	0.14a	0.22b	2.8a	10.6b	1.10a	2.04a
AMS	2.76b	3.26a	0.40d	0.35c	16.5cd	18.2e	2.18b	2.22a
CaS	2.49b	3.21a	0.41d	0.37c	15.3c	18.1de	2.14b	2.19a

[†] Across three field sites in 2005, Elgin (Fayette silt loam), Gunder (Fayette silt loam), and West Union (Downs silt loam), Iowa.
[‡] Across two field sites in 2006 (S application in 2005), Elgin, and Gunder, Iowa.
[§] Sulfur concentration for 6-inch plant tops collected before second cut.
[¶] Sulfur (AMS, ammonium sulfate, and CaS, calcium sulfate) applied at 40 lb S/acre after the first cut in 2005.
[#] Means followed by the same letter are not significantly different, $p \leq 0.10$.

Trials in 2006

In 2006, on-farm trials were conducted on established alfalfa fields near Wadena, Waucoma, Nashua, Waukon, West Union, and Lawler, Iowa. These trials compared different rates of applied S. Sites were selected to offer a wide range of responses, in that they were established on different soil types and exhibiting different degrees of poor to good coloration. Calcium sulfate was applied in the spring at 0, 15, 30, and 45 lb S/acre. Most sites were harvested at second and third cut, the Nashua site was harvested for four cuts, and harvest coordination issues resulted in loosing the second cut at West Union and the third cut at Lawler.

The sites with poor coloration had lower plant S concentrations (Table 2) and greater dry matter yield responses to S fertilizer (Table 3). The two sites with plant S above 0.25% S with no applied S did not have yield increase from applied S. The S soil test did not correspond to plant S analysis, yield response to applied S, or soil organic matter. Those sites with yield responses to S application leveled off in response at 22 to 29 lb S/acre, except the West Union site where the maximum response rate was 12 lb S/acre (Table 3).

Table 2. Alfalfa plant S concentration and site characteristics, 2006.

Sulfur rate†	Site					
	Wadena	Waucoma‡	Nashua	Waukon	West Union	Lawler
lb S/acre	- - - - - - - -	- - - - - - - -	- - - - % S§	- - - - - - - -	- - - - - - - -	- - - - - - - -
0	0.14	0.21	0.33	0.18	0.18	0.27
15	0.20	0.30	0.35	0.29	0.24	0.36
30	0.30	0.43	0.34	0.40	0.29	0.39
45	0.39	0.36	0.37	0.41	0.28	0.37
Soil SO4-S, ppm¶	7	3	7	1	6	3
Soil OM, %¶	3.1	2.1	4.2	3.8	3.3	2.6
Soil type	Fayette silt loam	Wapsie loam	Clyde-Floyd loam	Fayette silt loam	Fayette silt loam	Ostrander loam

† Sulfur applied as calcium sulfate in April at Nashua and in May at other sites.
‡ Waucoma site had 10 lb of elemental S applied in the spring across the entire field.
§ Sulfur concentration for 6-inch plant tops collected before second cut.
¶ Soil samples collected after first cut, 0 to 6 inch depth.

Table 3. Alfalfa total dry matter for harvests collected in 2006.

Sulfur rate†	Site					
	Wadena	Waucoma‡	Nashua	Waukon	West Union	Lawler
lb S/acre	- - - - - - - -	- - - - - - - -	- - - - ton/acre	- - - - - - - -	- - - - - - - -	- - - - - - - -
0	1.32	1.85	6.73	1.39	0.78	2.14
15	2.59	3.06	6.98	2.97	1.05	2.11
30	2.76	3.14	6.85	3.33	1.07	2.11
45	2.92	3.24	7.14	3.58	1.07	2.07
Statistics§	*	*	NS	*	*	NS
Max rate, lb S/acre¶	25	22	0	29	12	0
Cut harvested	2+3	2+3	1+2+3+4	2+3	3	2+4

† Sulfur applied as calcium sulfate in April at Nashua and in May at other sites.
‡ Waucoma site had 10 lb of elemental S applied in spring across the entire field.
§ Symbol indicates statistically significant (*) or non-significant (NS) yield response to S application rate, $p \leq 0.10$.
¶ Applied S rate at the maximum dry matter yield response.

Yield Response Discussion

Sulfur deficiency problems exist in northeast Iowa alfalfa production fields. The majority of S deficiencies occur in areas within fields, not entire fields. However, this non-uniformity can still account for large economic losses on a field scale. Most of the soils involved are lower organic matter, side-slope position, silt loam soils, i.e., Fayette silt loam and Downs silt loam. However, alfalfa grown on other soils has also responded to S fertilization, i.e., Wapsie loam in 2006, and Winnshiek loam and Saude loam in 2005. The latter two sites were part of trial sites conducted in 2005. Problems with S deficiency are not occurring on manured fields.

Alfalfa Plant Analysis and Economic Return

Plant analysis is currently the best available analytical method to test for S deficiency. Figure 1 represents the percent yield response to applied S in these trials relative to plant S concentration. This research supports other work that suggests S sufficiency occurs around 0.25% S.

Economic response follows the same relationship. Figure 2 represents the average yield increase per cut from S fertilization relative to the initial plant S concentration with no S applied. At concentrations more than 0.22 to 0.25% S, the yield response is less than 0.1 ton/acre per cutting (non-statistically significant yield responses). Assuming an equivalent response for the total yield in a three-cut system, and alfalfa valued at $85/ton as-is ($100/ton dry matter basis), the gross profit when the alfalfa plant S concentration is less than 0.22 to 0.25% is quite high. With S fertilizer and application costs estimated at $20 per acre, the economic breakeven point falls near 0.25% S. Several of the trials in this research had plant S concentrations well below 0.25%. The overall net economic return in these trials averaged $50 per acre.

Since S fertilizer costs have been changing rapidly, and S fertilizer products/forms vary in price, the economic picture could change from that mentioned above. Also, application timing does vary for different S fertilizer forms. For instance, elemental S should be applied well ahead of the crop need to allow for conversion to the plant-available sulfate form.

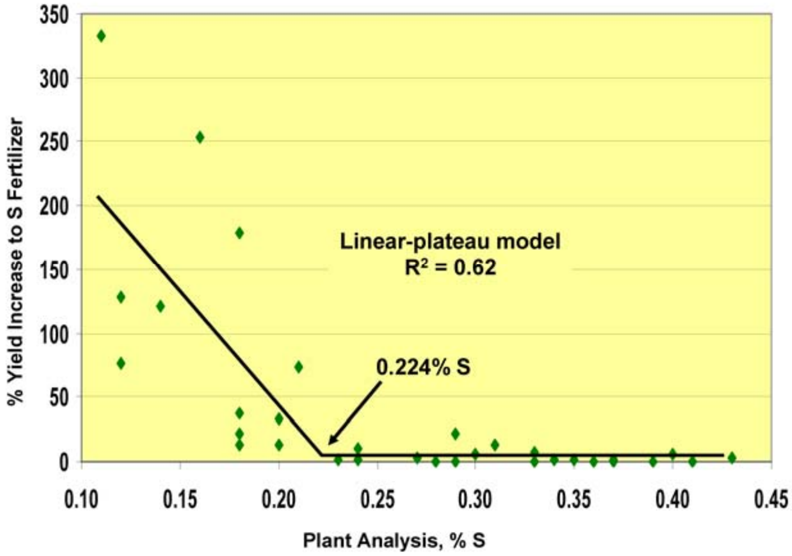

Figure 1. *Yield increase from S fertilization relative to the alfalfa plant S concentration (6-inch plant top) with no S applied.*

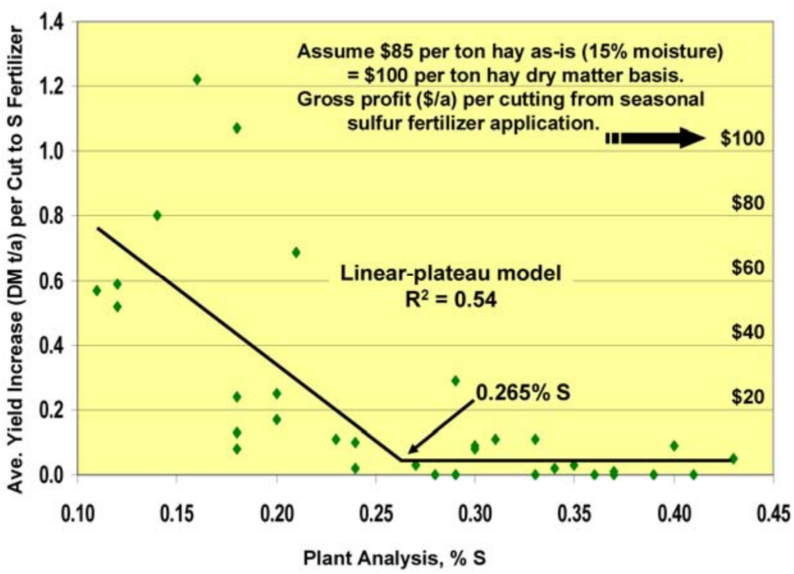

Figure 2. *Yield increase per cut and economic return from S fertilization relative to the alfalfa plant S concentration (6-inch plant top) with no S applied.*

Summary

Currently, if an S deficiency is found (i.e., through plant analysis or field response trial), the amount of S fertilizer recommended is 20 to 30 pounds S/acre. Where deficiencies occurred in the 2006 trials, the first 15 pounds of S/acre gave the largest incremental increase in yield, but the next 15 pounds of S/acre was still profitable in most trials. Also, S fertilizers do not need to be applied each year as alfalfa will respond to S applied in a prior year. Therefore, it is possible to apply the crop needs for multiple years in one application. That rate will be more than is needed for just one year.

Corn Response to Sulfur Fertilization

Three studies were conducted in northeast Iowa corn fields in 2006 and 2007 to evaluate S fertilization response in corn. The first study was designed to evaluate a new P and S containing fertilizer product. Only treatments related to evaluation of S response are presented here. The second study was targeted to determine if S deficiency was responsible for visual plant yellowing (chlorosis) in early corn growth, and if so, the response to early sidedress applied S fertilizer. The third study was designed to evaluate corn response to S fertilization rate and the extent of S deficiency in northeast Iowa. All of these studies provide insight into the potential for corn yield response to S application and the magnitude of S deficiency in northeast Iowa corn production.

Sulfur Fertilizer Product Evaluation

Two sites were chosen on producer fields in Allamakee and Winneshiek counties in 2006, a Seaton silt loam and a Renova loam soil. The previous year crops were soybean and long-term grazed grass pasture, respectively. Other than grazing, neither site had a history of manure application. Tillage following soybean was shallow disking in the spring and no-till corn planted into the grass pasture.

Fertilizer treatments were broadcast by hand prior to spring tillage, or corn planting for the no-till grass pasture site. For this report, only the following selected treatments are presented: S control (S-CON), ammonium sulfate (AMS) at 10 (AMS-10) and 30 (AMS-30) lb S/acre, and a Simplot 13-33-0-15S product (SEF) at 10 (SEF-10) and 30 (SEF-30) lb S/acre. The SEF product contained half of the S as sulfate and half as elemental. Nitrogen (N) and P applications were equalized on all plots.

Soil samples (0-6 inch depth) were collected in spring prior to any tillage and treatment application. Extractable sulfate-S was 8 ppm at both sites. Corn ear leaf samples were collected at the silking corn growth stage and analyzed for total S. Grain yields were determined for each plot.

The yield difference between the control (S-CON) and 10 lb S/acre (AMS-10 and SEF-10) was 15 bu/acre (Table 4). There was no yield increase to additional S application with the 30 lb S/acre rate. Corn ear leaf S concentration was increased with application of AMS and SEF fertilizers (Table 4). Grain yields and leaf S concentrations with AMS and SEF were the same, indicating similar plant-available S supply from both S fertilizer sources. Leaf S concentration with no S applied was low and S application increased leaf S concentration. Application of 30 lb S/acre increased leaf S concentration compared to the 10 lb S/acre rate. Despite this increase in leaf S, yield was not increased with the higher S rate.

Table 4. Effect of S fertilizer product and application rate on corn ear leaf S concentration and grain yield combined across sites, 2006.

Sulfur application[†]	Ear leaf S concentration	Grain yield
	%	bu/acre
S-CON	0.15	196
SEF-10	0.18	211
AMS-10	0.18	211
SEF-30	0.21	204

AMS-30	0.20	207

Application contrast	Statistics ($p>F$)	
SEF-10 & SEF-30 vs. AMS-10 & AMS-30	0.6620	0.7433
S-CON vs. AMS-10	0.0001*	0.0467*
AMS-10 vs. AMS-30	0.0166*	0.5796

† S-CON, S control; SEF, 13-33-0-15S product; AMS, ammonium sulfate product; 10 or 30 indicates the rate of S applied.
* Indicates statistical significance of the contrast, $p \leq 0.10$.

Corn Response to Sulfur Application with Visual Deficiency Symptoms

In 2006, six sites were selected based on expectation of S deficiency, either through visual observation of early plant S deficiency symptoms being present or previous experience indicating that soil conditions and previous crop would be conducive to S deficiency. Therefore, sites were considered specifically "chosen," and not a set of sites with random potential of response to S application. Sites did not have recent or known manure application history.

Calcium sulfate was surface broadcast applied sidedress after early corn growth at 40 lb S/acre, with a control treatment for comparison. A non-limiting S rate was chosen to allow measurement of S response, with the expectation that the 40 lb S/acre rate would maximize any potential yield increase. Soil samples (0-6 inch depth) were collected before S application. Grain yields were determined for each plot.

Corn yield was increased with the sidedress calcium sulfate application at five of six sites (Table 5). The yield increases were quite large, especially considering the surface sidedress fertilizer application after plant early growth. However, the sites were chosen based on expected S deficiency, with many sites showing severe plant yellowing. Therefore, substantial yield increase might be expected. With rainfall after application, plant response (increase in greenness) was observed in a short time period. This would also indicate an expected plant growth and yield increase. The site with no response to S application (and high yield with no S) did have the highest extractable soil sulfate-S concentration.

Across all sites, the yield increase from S application was 38 bu/acre (Table 5). This yield increase would easily cover the required S fertilization cost. Since only one non-limiting S rate was applied, it is not possible to determine an economic application rate. These results indicate that a substantial corn yield increase to S application is possible when soil conditions are conducive to low S supply and severe S deficiency exists. In this study, those conditions were coarse textured soils and a soil/landscape position similar to that with documented S deficiency in alfalfa.

Table 5. Effect of S fertilizer application on corn grain yield, 2006.

Site	County	Previous crop†	Soil type‡	Soil SO_4-S§	Grain yield	
					- S	+ S¶

				ppm	- - - bu/acre - - -	
L1	Buchanan	Sb	Sparta lfs	6	123	151*
L2	Buchanan	Sb	Sparta lfs	7	154	198*
T1	Delaware	Sb	Chelsa lfs	9	88	108*
T2	Delaware	Sb	Kenyon l	13	196	204NS
WK	Allamakee	A	Fayette sil	3	96	172*
WT	Allamakee	A	Fayette sil	--	118	171*
Across Sites					129	167*

† Sb, soybean; A, first-cut alfalfa harvested.
‡ lfs, loamy fine sand; l, loam; sil, silt loam.
§ Extractable sulfate-S in the 0-6 inch soil depth.
¶ Sulfur applied at 40 lb S/acre. Symbol indicates statistically significant (*) or non-significant (NS) yield increase with S application, $p \leq 0.10$.

Corn Response to Sulfur Fertilization Rate

An expanded study was conducted in 2007 at twenty sites to determine corn response to S rate of application. The sites were selected to represent major soils and cropping systems in northeast Iowa (Table 6), and were chosen to represent a range in potential S response. Sites did not have a recent or known manure application history. Calcium sulfate was surface broadcast applied with no incorporation shortly after planting at 0, 10, 20, and 40 lb S/acre. Soil samples (0-6 inch depth) were collected before S application. At the silking growth stage corn ear leaf samples were collected and analyzed for total S. Grain yields were determined for each plot. Quadratic-plateau regression models were fit to the mean grain yield response for the fine and coarse textured soil sites. Economic optimum S rate was determined with S fertilizer at $0.50/lb S and corn grain at $4.00/bu.

Corn grain yield was increased with S application at seventeen of the twenty sites in 2007 (Figure 3) and leaf S concentration was increased at sixteen sites (Figure 4). Across all sites, the average yield increase was 18 bu/acre. When grouped by soil texture, the yield increase was 15 bu/acre for the fine textured soils (loam and silt loam) and 25 bu/acre for the coarse textured soils (loamy sand and sandy loam). These are large yield increases to S fertilization. The yield levels were quite high in 2007, with an average yield (with S application) of 201 bu/acre at the fine textured soil sites and 190 bu/acre for the coarse textured soil sites.

When analyzed across S rate, the maximum response rate for the fourteen fine-textured soil sites was 15 lb S/acre, with an economic optimum rate at 14 lb S/acre (Figure 5). For the six coarse-textured soil sites, the maximum response rate was 26 lb S/acre, with an economic optimum rate at 24 lb S/acre.

Corn ear leaf S concentrations were generally low without S application (Figure 4). The application of S increased leaf S concentration, but was not a large increase (across sites, an increase of 0.03% S with the 40 lb S/acre rate). Only one of the three non-responding sites had no increase in leaf S concentration with S application. Ear leaf S concentration in the control (zero applied S) can be used as a guide for identification of potential S deficiency. Figure 6 shows this relationship for yield response to the 40 lb S/acre rate. There is considerable variation in yield response across a wide range in concentrations, and since most sites had a yield increase to applied S a critical concentration cannot be established. A critical concentration or the low end of a sufficiency range is not well established for corn ear leaf S, with reported values of 0.15 to 0.21% S. Since leaf S concentrations were low at all sites, and all but three sites responded to S application, it is possible that the sites in these trials could all be considered deficient. Research continues to better delineate a critical concentration for ear leaf S.

The extractable soil sulfate-S concentrations in the control (Table 6 and Figure 7) were not related to yield response to applied S. Also, several sites had concentrations above the 10 ppm S level reported as sufficient, but still had large yield increase with S application. This has been found in other studies where the sulfate-S soil test has not been reliable for predicting crop response to S application on soils in the Midwest. Supply of crop-available S is related to more than the sulfate-S concentration in the top six inches of soil, thus the poor relationship between yield response and soil test.

Table 6. Site information for the S rate study, 2007.

Site	County	Previous crop†	Soil OM‡	Soil	
				SO_4-S‡	Soil type§
			%	ppm	
B	Black Hawk	Sb	1.9	5	Olin fsl
C	Buchanan	Sb	2.7	3	Readlyn l
D	Buchanan	Sb	0.8	2	Sparta lfs
E	Buchanan	Sb	1.4	3	Flagler sl
F	Buchanan	Sb	0.9	13	Sparta lfs
G	Delaware	Sb	2.0	5	Burkhardt-Saude sl
H	Delaware	Sb	2.5	5	Clyde-Floyd l
I	Delaware	Sb	2.6	7	Saude l
J	Delaware	Sb	1.1	6	Dickinson fsl
K	Delaware	Sb	0.9	4	Olin fsl
L	Delaware	Sb	3.4	4	Kenyon l
M	Fayette	Sb	2.6	5	Kenyon l
O	Clayton	C	1.5	14	Dorchester sil
Q	Clayton	Sb	2.9	5	Downs sil
R	Clayton	Sb	2.7	10	Fayette sil
U	Clayton	A	2.1	1	Fayette sil
W	Winneshiek	Sb	2.8	4	Downs sil
X	Allamakee	C	2.1	12	Fayette sil
Y	Allamakee	C	2.3	6	Downs sil

Z	Allamakee	C	2.1	11	Downs sil

† Sb, soybean; C, corn; A, alfalfa.
‡ Soil organic matter and extractable sulfate-S in the 0-6 inch soil depth.
§ fsl, fine sandy loam; l, loam; sl, sandy loam; sil, silt loam.

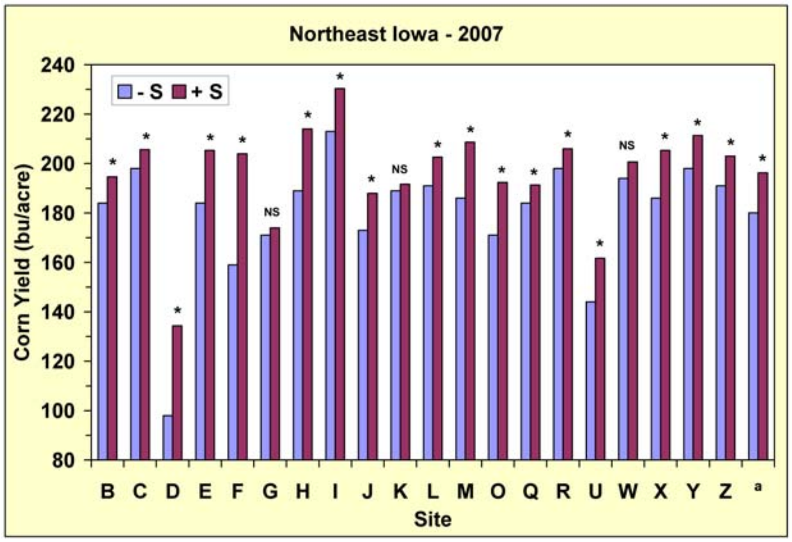

Figure 3. *Corn grain yield response to S application (no S vs. plus S), 2007. The average across all sites is designated by (a), (*) indicates statistically significant response to S, and (NS) indicates non-significant response to S ($p \leq 0.10$).*

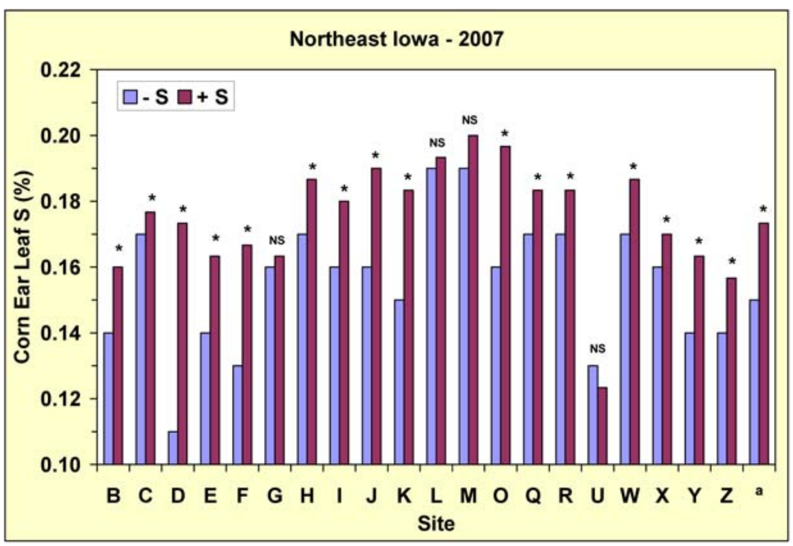

Figure 4. *Corn ear leaf S concentration response to S application (no S vs. plus S), 2007. The average across all sites is designated by (a), (*) indicates statistically significant response to S, and (NS) indicates non-significant response to S ($p \leq 0.10$).*

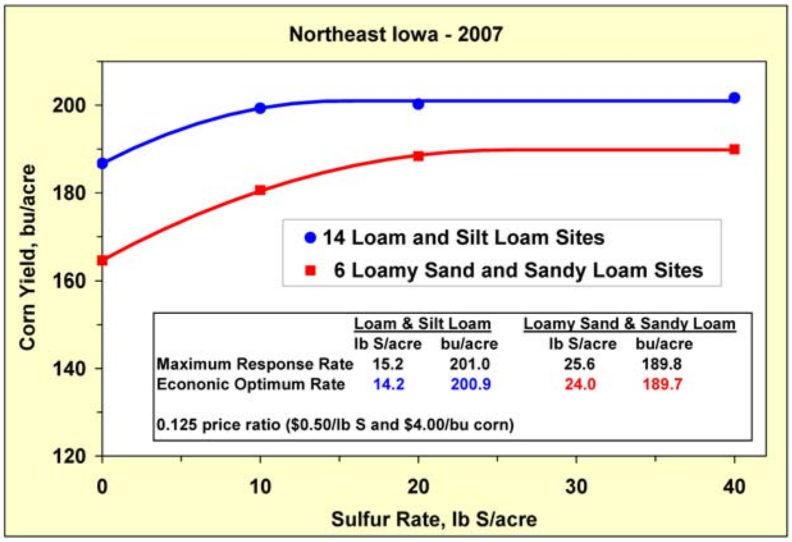

Figure 5. *Corn grain yield response to S rate of application, 2007.*

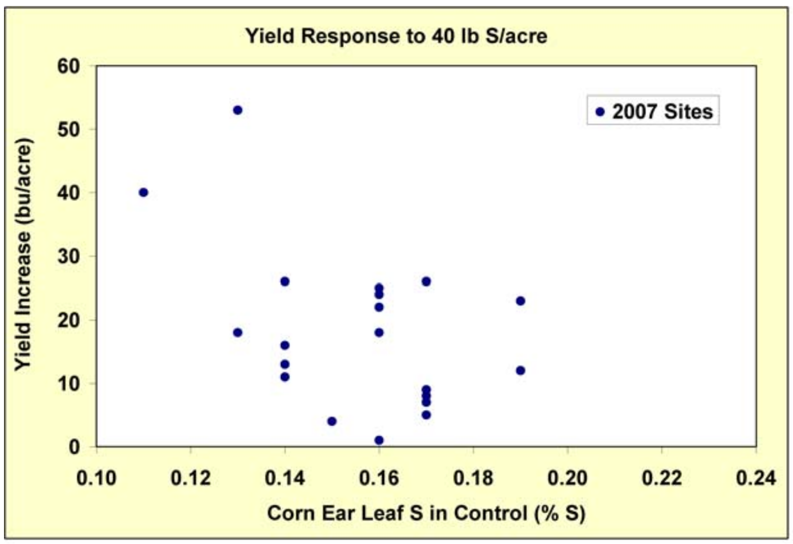

Figure 6. *Corn grain yield response to S application as related to ear leaf S concentration in the no-S control, 2007.*

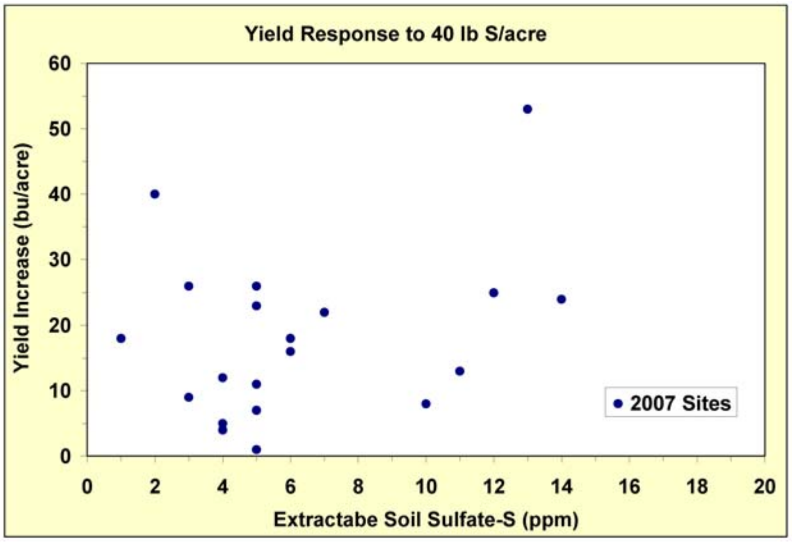

Figure 7. *Corn grain yield response to S application as related to extractable soil sulfate-S concentration (0-6 inch soil depth), 2007.*

Summary

Corn grain yield increase to S fertilization has occurred with high frequency in these studies. Also, the magnitude of yield increase has been large. Across the two years and three studies, 82% of the sites had a yield increase to applied S fertilizer. By study, across-site yield increases averaged 15, 18, and 38 bu/acre. Analyzed across S rate, the economic optimum S rate was 14 lb S/acre for fine-textured soils and 24 lb S/acre for coarse-textured soils. This research indicates a dramatic change in need for S fertilization in northeast Iowa, and that S application is an economically viable fertilization practice on many soils.

In addition, this work indicates that more research is critically needed. Not only to continue study on soils in northeast Iowa but also for a larger geographic area extending into central and southeast Iowa. If the responses found in these studies are indicative of potential S fertilization need in other geographic areas, then yields of corn and other crops could be suffering due to S deficiency. In addition, additional information is needed regarding plant and soil S tests, plant S stress sensing, site characteristics, and S deposition in order to develop better predictive indices of S deficiency and need for S fertilization. These tools would provide better decision-making and enhance positive economic return to S fertilization for producers.

Suggestions for Managing Sulfur Applications in Production Fields

- For alfalfa, the S concentration in samples from the top 6 inches of plants at the early bud stage is a good indicator of potential S deficiency and need for S application. Concentrations less than 0.22 to 0.25% S should be considered deficient and S applied.
- For alfalfa, the extractable sulfate-S concentration in the 0-6 inch soil depth does not indicate potential S deficiency or need for S application.
- For S deficient alfalfa fields, apply 20 to 30 lb S/acre. Sulfur fertilizers do not need to be applied each year, as alfalfa will respond to S applied in a prior year. Therefore, it is possible to apply the crop needs for multiple years in one application. That rate will be more than is needed for just one year. Sulfate forms of S fertilizers, since the sulfate form

is immediately available for plant uptake, can be applied after any cutting. Good yield response has been measured with applications in-season, even in dry periods. This flexibility allows for rapid correction of S deficiencies found through plant analysis. Elemental S, since it must be oxidized by microbes to the sulfate form, should be applied some time ahead of crop need.

- Manure is a good source of S, and eliminates the need for S fertilizer application.
- For corn, the extractable sulfate-S concentration in the 0-6 inch soil depth does not indicate potential S deficiency or need for S application.
- For corn, the S concentration in ear leaves collected at silking can indicate low S supply, but a specific critical concentration with modern hybrids has not yet been established in this research.
- For S deficiencies in corn, on fine-textured soils apply 15 lb S/acre and on coarse-textured soils apply 24 lb S/acre.
- Sulfur deficiencies have been documented and dramatic crop yield response measured in some fields. However, at this time we are uncertain about the geographic extent of S deficient soils in northeast Iowa and nearby regions. Some common soil conditions where S deficiency has been found include low organic matter soils, side-slope landscape positions, eroded soils, and coarse soil textures. Sulfur deficiency symptoms and yield responses have been noted in reduced- and no-till systems with fine-textured soils in nearby areas of Iowa and other states. Lack of soil mixing and cooler soils reduce mineralization, which slows release of S from organic materials, a main source of S. Research trials currently under way will help understand the extent of S deficiency.
- Research to date has also not fully documented the variability of deficiency within fields. Work with alfalfa clearly showed differential response in poor and good coloration/growth areas, indicating that whole fields would not respond to S application. However, it is likely most prudent to simply fertilize entire fields when deficiency exists rather than attempt site-specific applications because of the relatively low cost of S fertilization, many fields indicating considerable area with S deficiency, large yield increases with S application, and need to plant sample for determining S deficiency. Site-specific response is possible, but inexpensive and reliable methods are needed to "map" S deficiency. This is especially problematic in corn as visual symptoms are not always present or obvious, especially with minor S deficiency and small but economic yield response. Research and development is needed to provide tools for reliable S deficiency detection.

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