DEALING WITH SULFUR DEFICIENCIES IN CROP PRODUCTION: THE IOWA EXPERIENCE

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Introduction

Research conducted for more than forty years (prior to approximately 2005) in Iowa rarely noted improved crop yield with sulfur (S) fertilization. Studies during that time period with corn and soybean found yield increase from S fertilizer application only three times out of approximately 200 trials. Research in the early 1980's had also documented sufficient plant available S in the soil profile for crop production on most Iowa soil associations. Results of recent studies (2000-2005) in corn and soybean were consistent with the historical research. An example is research presented at this conference (Sawyer and Barker, 2002) where there was no corn or soybean yield increase from S application at six sites in Iowa across two years.

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 issues 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 was also exhibiting strong visual S deficiency symptoms.

The research reported here is from on-farm trials conducted to determine alfalfa and corn response to S fertilization in north-central to northeast Iowa. The following provides a summary of research, evaluation of methods to identify potential S deficiency, and S fertilization guidelines.

Alfalfa Response to Sulfur Fertilization

Trials in 2005

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 adjacent poor and good areas, an unfertilized no-S control, 40 lb S/acre as ammonium sulfate, and 40 lb S/acre as calcium sulfate (gypsum) were topdress applied after the first cut. Alfalfa was harvested for plant dry matter determination at the second and third cut in 2005 at all sites, and first cut in 2006 at the Elgin and Gunder sites.

Dry matter yields with applied S in the good areas were not different from that of the unfertilized no-S control (Table 1). However, S applied in the poor areas more than doubled yield for two cuts in 2005 and nearly double yield with the first cut in 2006. Plant tissue analysis (Table 1) from the untreated poor areas was 0.14% S, clearly less than the suggested sufficient range of 0.26–0.50% S and the low range of 0.20–0.25% S, and at a deficient concentration of <0.20% S

(Schulte and Kelling, 1992). Plant tissue S concentration for the untreated good areas was marginal, at 0.22% S. 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 the same results, indicating nitrogen (N) was not a component of the improved yield.

Table 1. Alfalfa forage yield, plant S analysis, and harvest S removal with S fertilizer application in field areas with observed poor and good plant coloration/growth.

	2005†						2006‡	
	Cuts 2+3 Dry matter yield		Cut 2 Plant top S§		Cuts 2+3 S removal		Cut 1 Dry matter yield	
Sulfur	Observed coloration/growth area							
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, $p \leq 0.10$.

Other soil characteristics, such as soil type, soil test phosphorus (P) and potassium (K), pH, extractable sulfate-S, organic matter, and cation exchange capacity were largely similar within the sites. Any differences that existed did not explain response or lack of response to S application. The extractable sulfate-S soil test results for 0-6 inch depth 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 observed 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 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).

Trials in 2006

Sulfur rate trials were conducted on established alfalfa fields near Wadena, Waucoma, Nashua, Waukon, West Union and Lawler, Iowa. Sites were selected to offer a wide range of responses, as they were established on different soil types and exhibiting different degrees of poor to good plant 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 (visual observation and data not shown) had lower plant tissue S concentrations (Table 2) and greater dry matter yield responses to S application (Table 3). The two sites with plant tissue S greater than 0.25% S with no applied S did not have yield response with S application. The S soil test did not correspond to plant tissue S analysis, yield response to applied S, or soil organic matter. Three sites that responded to S application had maximum yield response rate at 22–29 lb S/acre, with the West Union site at 12 lb S/acre (Table 3).

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

	Site					
Sulfur rate†	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 SO_4-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 lbs 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.

	Site					
Sulfur rate†	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 lbs 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. Problems with S deficiency are not occurring on manured fields.

Alfalfa Plant Tissue Analysis and Economic Return

Plant tissue analysis is currently the best available analytical method to test for S deficiency in Iowa alfalfa production. Figure 1 represents the percent yield response to applied S in trials relative to plant tissue S concentration. This research supports previous work that suggests S sufficiency occurs near 0.25% S. Economic response follows the same relationship. At tissue concentrations above 0.22–0.25% S, the yield response was below 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 was quite high when the alfalfa 6-inch plant top S concentration was less than 0.22–0.25%. With S fertilizer and application costs estimated at $20 per acre, the economic breakeven point would fall near 0.25% S. Several of the trials had plant tissue S concentrations well below 0.25%, with the average net economic return at $50 per acre. Since S fertilizer costs have been changing rapidly, and S fertilizer products/forms vary in price, the economic return could change from that mentioned above.

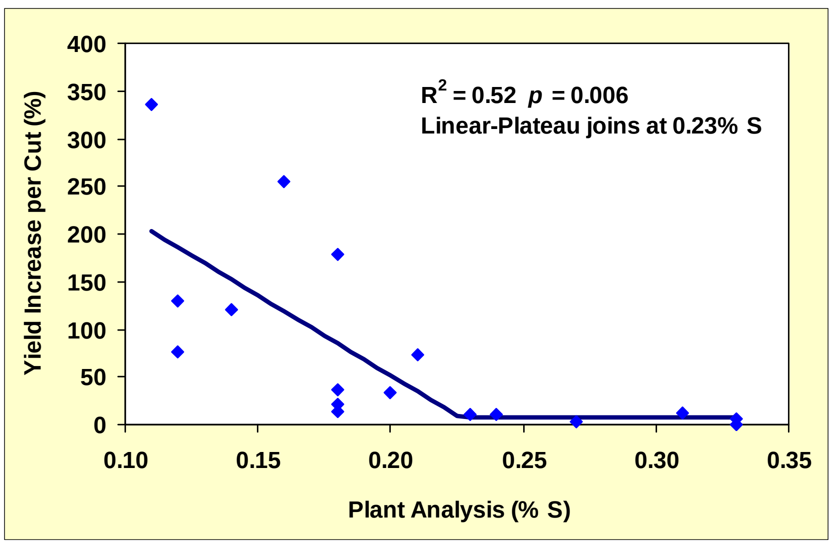

Figure 1. Yield increase per cut from S fertilization relative to the alfalfa plant tissue S concentration (6-inch plant top) with no S applied.

Summary

If an S deficiency is confirmed in alfalfa (through plant tissue analysis or field response trial), the amount of S fertilizer recommended is 20–30 lb S/acre. Where deficiencies occurred in the 2006 trials, the first 15 lb S/acre gave the largest incremental increase in yield, but the next 15 lb S/acre was still profitable at most sites. Also, S fertilizers do not need to be applied each year as alfalfa will respond to S applied in a prior year.

Corn Response to Sulfur Fertilization

Three studies were conducted in north-central to northeast Iowa corn fields in 2006–2008 to evaluate S fertilization response in corn. The first study was designed to evaluate P and S containing fertilizer products. 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 evaluated corn response to S fertilization rate and through many sites the extent of S deficiency. All of these studies provide insight into the potential for corn response to S application and the magnitude of S deficiency in north-central to northeast Iowa corn production.

Sulfur Fertilizer Product Evaluation

Two sites were chosen on producer fields in Allamakee and Winneshiek counties (northeast Iowa) 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. In 2008, a site was located in Cerro Gordo county (north-central Iowa) on a Readlyn loam soil with no-tillage corn following soybean (several years of no-tillage). The fertilizer products evaluated were a Simplot and Mosaic 13-33-0-15S product (Simplot SEF in 2006 and Mosaic MES15 in 2008). The SEF and MES products contained half of the S as sulfate and half as elemental.

Fertilizer treatments were broadcast by hand prior to spring tillage or corn planting at the no-till sites. For this report, only treatments related to S response are discussed (S control, ammonium sulfate at 10 and 30 lb S/acre, and SEF and MES at 10 and 30 lb S/acre). Nitrogen and P rates were equalized. At the 2006 sites, the extractable soil sulfate-S concentrations were 6–8 ppm in the top 36 inches (8 ppm in the 0-6 inch depth). At the 2008 site, the extractable soil sulfate-S concentrations were 4–6 ppm in the top 36 inches (4 ppm in the 0-6 inch depth).

In 2006, the corn grain yield response across sites between the control and 10 lb S/acre as ammonium sulfate or SEF was 15 bu/acre (196 vs. 211 bu/acre). There was no yield increase to additional S application with the 30 lb S/acre rate for either S fertilizer. The ear leaf S concentration was increased from 0.15% S in the control to 0.18% and 0.21%, respectively, for the 10 and 30 lb S/acre rates. The leaf S concentration and corn grain yield was the same for both ammonium sulfate and SEF, indicating similar plant-available S supply from both fertilizer products.

In 2008, despite visual S deficiency symptoms on small corn plants where no S was applied, there was no yield response to S application with either S product or rate of application (172 vs. 168 bu/acre, respectively, for the control and S application average). The ear leaf S concentration was also not influenced by S application from the ammonium sulfate or the low rate of MES, but was increased with the highest rate of MES (0.16% S in the control and 0.19% with MES).

Corn Response to Sulfur Application with Visual Deficiency Symptoms

In 2006, six sites were selected in northeast Iowa 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 expectation the 40 lb S/acre rate would maximize any potential yield increase.

Corn yield was increased with the sidedress calcium sulfate application at five of six sites (Table 4). The yield increases were quite large, especially considering the surface sidedress fertilizer application. 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 applied S) did have the highest extractable soil sulfate-S concentration.

Table 4. Effect of S fertilizer application on corn grain yield, 2006.

County	Previous crop†	Soil type‡	Soil SO_4-S§	Grain yield - S	Grain yield + S¶
			ppm	- - - bu/acre - - -	
Buchanan	Sb	Sparta lfs	6	123	151*
Buchanan	Sb	Sparta lfs	7	154	198*
Delaware	Sb	Chelsa lfs	9	88	108*
Delaware	Sb	Kenyon l	13	196	204^{NS}
Allamakee	A	Fayette sil	3	96	172*
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, $p \leq 0.10$.

Across all sites, the yield increase from S application was 38 bu/acre (Table 4). 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.

Corn Response to Sulfur Fertilization Rate

An expanded study was conducted in 2007 and 2008 at 45 sites in north-central to northeast Iowa to determine corn response to S rate of application. In 2008 a greater proportion of sites were located in the north-central Iowa area. The sites were selected to represent major soils and cropping systems, and were chosen to represent a range in potential S response. Most sites were on producer fields. 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. Individual site S responsiveness was determined by contrast comparison of the no S control application vs. applied S. Means and statistical analyses were computed across all sites and by fine and coarse soil textural grouping, with site as a random effect. Quadratic-plateau regression models were fit to the grain yield response for the fine- and coarse-textured responsive site groupings. 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 fertilizer application at 17 of the 20 sites in 2007 and 11 of the 25 sites in 2008 (Figure 2), and ear leaf S concentration was increased at 16 sites each year (data not shown). Across all sites, the average yield increase was 13 bu/acre. When grouped by soil texture for responsive sites, the yield increase was 15 bu/acre for the fine-textured soils (loam, silt loam, silty clay loam, and clay loam) and 28 bu/acre for the coarse-textured soils (fine sandy loam, loamy fine sand, and sandy loam). Grain yields increased with S application at 21 of 34 (62%) fine-textured soil sites and 7 of 11 (64%) coarse-textured soil sites. These are frequent and large yield increases to S fertilization. However, sites located more toward the north-central and central geographic areas of Iowa had a lower frequency of yield response to S application, indicating soil or other factors affecting potential need for S fertilization that are different from the northeast area of Iowa.

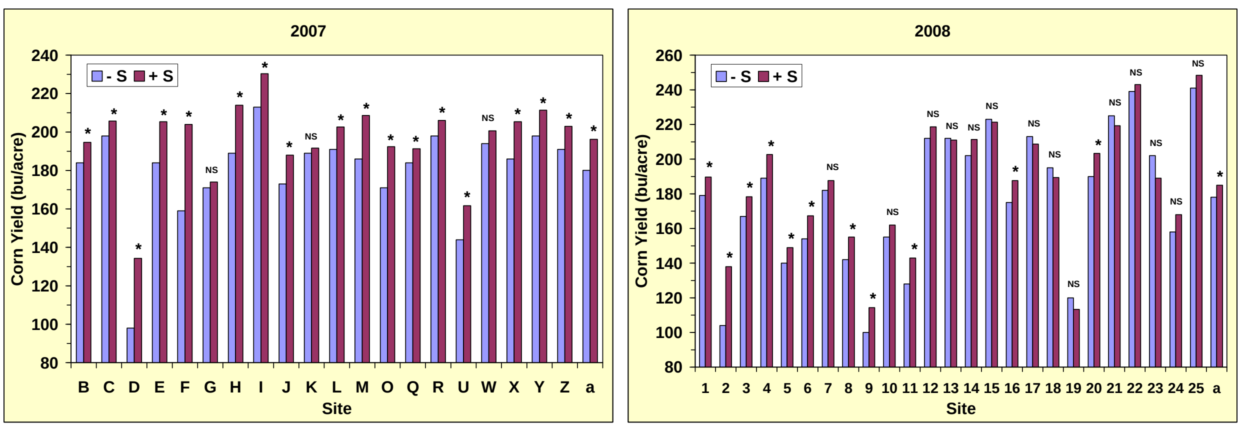

Figure 2. Corn grain yield response to S application (no S vs. plus S), 2007 and 2008. The average across all sites is designated by (a), (*) indicates statistically significant response to S, and (^{NS}) indicates non-significant response to S ($p \leq 0.10$).

For producers, an important question is what is the economic optimum S application rate? When analyzed for the responsive sites, the maximum response rate for the 21 fine-textured soil sites was 17 lb S/acre, with an economic optimum rate at 16 lb S/acre (Figure 3). For the 7 coarse-textured soil sites, the maximum response rate was 25 lb S/acre, with an economic optimum rate at 23 lb S/acre (Figure 3). The economic optimum S rate is near the maximum response because the fertilizer cost (rate times price) is low compared to the yield return (yield increase times corn price).

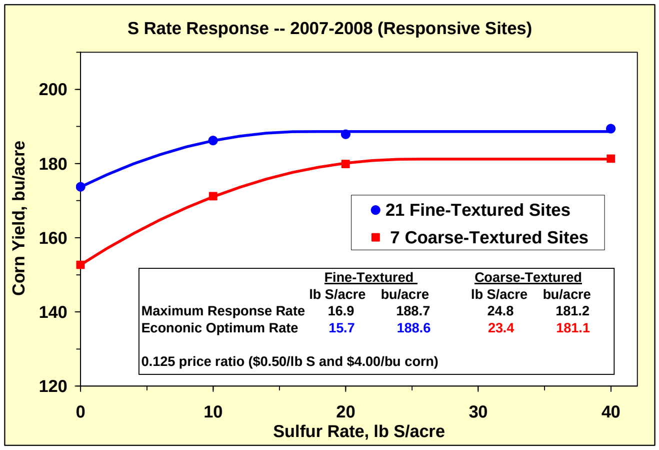

Figure 3. Corn grain yield response to S application rate at responsive sites, 2007-2008.

Ear leaf S concentration in the control (zero applied S) can be used as a guide for potential corn yield response to S application. Figure 4 shows this relationship for yield response to 40 lb S/acre application. There is a wide range in published minimum sufficiency concentrations for corn ear leaves at tassel/silking, 0.12 to 0.21% S (Jones et al., 1990). The current study does not confirm or refute these minimum levels. Across measured leaf S concentrations there was no clear relationship between ear leaf S and yield response. Therefore, it is not possible to define a critical level from this study. Sulfur application increased leaf S concentration, but was not a large increase (across sites, an increase of 0.02% S with the 40 lb S/acre rate). With the 40 lb S/acre rate, the leaf S concentration was below 0.21% S at all but one site (data not shown).

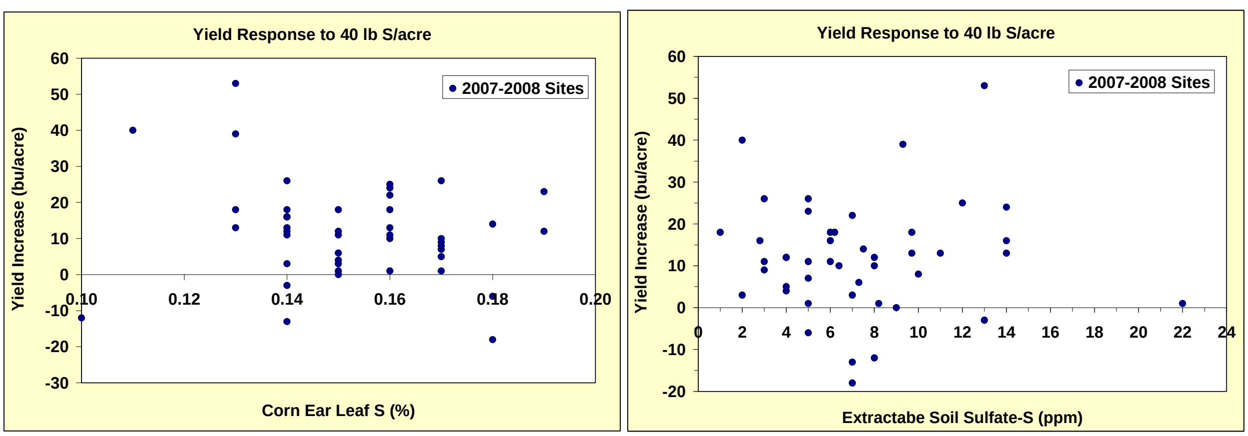

Figure 4. Corn grain yield response to S application as related to ear leaf S concentration and extractable soil sulfate-S concentration (0-6 inch soil depth) in the no-S control, 2007-2008.

The extractable soil sulfate-S concentrations in the control (no applied S) (Figure 4) were not related to yield response. Also, several sites had concentrations above the 10 ppm S level considered sufficient (Hoeft et al., 1973), but still responded to S application. This has been found in other studies where the sulfate-S soil test has not been reliable for predicting crop responses to S application on soils in the Midwest USA (Hoeft et al., 1985; Sawyer and Barker, 2002). 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 relative yield and soil test.

Summary

Corn grain yield increase to S fertilization has occurred with high frequency. Also, the magnitude of yield increase has been large. Across the two years of rate studies, 62% of the sites had a statistically significant yield increase to applied S fertilizer, with similar frequency for fine- and coarse-textured soils. The across-site yield increase averaged 19 bu/acre for the responsive sites. Analyzed across S rate, the economic optimum S rate was 16 lb S/acre for fine-textured soils and 23 lb S/acre for coarse-textured soils. This research indicates a change in need for S fertilization, especially in northeast Iowa and the associated soils, and that S application is an economically viable fertilization practice on many soils. However, the research also shows that corn does not respond to S application in all fields or field areas and that chance of S response decreases outside of the northeast Iowa geographic area.

In addition, this work indicates that more research is needed to study S response in corn and other row crops across a larger geographic area of Iowa, extending into central, north-central and east-central Iowa, and the associated soils in those regions. Also, additional evaluations are needed to develop tools for 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 tissue samples from the top 6 inches of plants at the early bud stage is a good indicator of S deficiency and need for S application. Concentrations less than 0.23% S should be considered deficient and S applied, with concentrations of 0.22–0.25% S marginal.
- For alfalfa, the extractable sulfate-S concentration in the 0-6 inch soil depth is not reliable for indicating potential S deficiency or need for S application.
- For confirmed 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, and some luxury uptake is possible. 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 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 is not reliable for indicating 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 confirmed S deficiencies in corn, on fine-textured soils apply approximately 15 lb S/acre and on coarse-textured soils apply 25 lb S/acre.
- Sulfur deficiencies have been documented and large crop yield response measured in some fields. However, at this time we are uncertain about the geographic extent of S

deficient soils, especially in areas nearby northeast Iowa. Some common soil conditions where S deficiency has been found include low organic matter soils, side-slope landscape position, eroded soils, and coarse-textured soils. 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 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.

Acknowledgements

Appreciation is extended to Honeywell International Inc., J.R. Simplot Company, Mosaic Fertilizer, LLC, and the Foundation for Agronomic Research for partial financial support of this research. Appreciation is also extended to the many producer and agribusiness cooperators who allowed us to use their fields and assisted with the field sites.

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PROCEEDINGS OF THE

THIRTY-NINTH
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Volume 25

November 18-19, 2009
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Des Moines, IA

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Published by:
International Plant Nutrition Institute
2301 Research Park Way, Suite 126
Brookings, SD 57006
(605) 692-6280
Web page: www.IPNI.net