

SULFUR FERTILIZATION RESPONSE IN IOWA CORN AND SOYBEAN PRODUCTION

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Sulfur (S) is often classified as a “secondary” plant essential element, mainly due to a smaller plant requirement but also because it is less frequently applied as a fertilizer compared to other nutrients like the “macronutrients” nitrogen (N), phosphorus (P), and potassium (K). This has certainly been the case in Iowa where research for many years had not documented S deficiency or fertilization need for optimal corn or soybean production. However, if deficient, S can have a dramatic effect on plant growth and crop productivity – more than the classification “secondary” would imply.

In Iowa, before 2005 more than forty years of field research with corn and soybean conducted at many locations across the state had measured a yield response to S fertilizer application only three times out of approximately 200 trials – an indication of adequate available S supply and limited deficiency. This began to change in the early 2000’s as producers in northeast Iowa noticed yellow plant foliage and reduced growth in areas of alfalfa fields. After investigating several potential reasons for the growth problems, such as plant diseases, research in multiple fields documented improved alfalfa plant coloration, growth, and forage yield with S fertilizer application (Lang et al., 2006). These responses, as well as questions about deficiency symptoms in corn, led to investigation of potential response to S application in corn and soybean.

Response in Corn Fields with Suspected S Deficiency

Initial S response trials were started in 2006 corn fields where early plant growth was exhibiting dramatic S deficiency symptoms or where there was expectation of S deficiency based on research conducted with alfalfa. Calcium sulfate (gypsum) was surface broadcast applied after early corn growth at 40 lb S/acre, with a control treatment for comparison. The 40 lb S/acre rate was chosen as a non-limiting S rate to maximize any potential yield increase.

Corn yield was increased with the S application at five of six sites (Table 1). The yield increases were large, especially considering the surface side-dress application. However, the sites were chosen based on expected S deficiency, with many sites showing severe plant yellowing. With rainfall after application, plant response (increase in greenness) was observed in a short time period. Across all sites, the yield increase from S application was 38 bu/acre. 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 set of trials was conducted in 2007 to 2009 at 47 sites in north-central to northeast Iowa to determine corn response to S rate. The sites were selected to represent major soils, cropping systems, and a range in potential S response. Sites had no 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 response was determined by grain yield comparison of the no S control vs. applied S. Corn yields were averaged across responsive

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sites by fine and coarse soil textural grouping, with response models fit to the yield response. 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 20 sites in 2007, 11 of 25 sites in 2008, and no response at two sites in 2009. Ear leaf S concentration was increased at 16 sites each year in 2007-2008. Across all sites, the average yield increase was 11 bu/acre. When grouped by soil texture just for responsive sites (Figure 1), 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 36 (58%) 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 geographic area 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.

When analyzed by the responsive sites, the maximum S 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 1). 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.

One test for evaluating potential S deficiency is plant analysis for ear leaf S concentration. There is a wide range in published minimum sufficiency concentrations for corn ear leaves at the silking stage, 0.10 to 0.21% S (Jones et al., 1990; Dick et al., 2008). 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 (Figure 2), with the leaf S concentration below 0.21% S at all but one site. 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.

Another test for evaluating potential S deficiency is soil testing for extractable sulfate-S in the surface soil. Concentrations (-0 to 6-inch depth) were not related to yield response (Figure 3). Also, several sites had concentrations above the 10 ppm S level considered sufficient (Hoefl et al., 1973), but responded to 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 USA. 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. Soil organic matter has a somewhat better relationship to yield response, but for similar reasons does not clearly differentiate between responsive and non-responsive sites (Figure 4). These results highlight the complex combination of environment, soil, and crop factors that result in deficient or adequate season-long supply of available S. Visual observation of deficiency symptoms can lead to correct determination of S response (Figure 5), however, in research since 2000, there has been five times that early in the season corn plants have exhibited S deficiency symptoms, but no grain yield response was measured. Also, hidden hunger can exist where the corn plant does not exhibit deficiency symptoms but yield increase may occur (Figure 5).

Field-Scale Sulfur Evaluation in Corn

In 2009, replicated field-length strip trials were conducted in 11 fields in central and northeast Iowa with spring preplant broadcast calcium sulfate compared to no S application. One

rate of S was used in each field, but the rate varied between sites (Table 2). These strip trials are considered a survey of potential field-scale S response in corn.

Six of the eleven fields had a corn yield increase from S application (9 bu/acre average, with a range of 5 to 13 bu/acre), with the other five fields having no S response (Table 2). This is a 55% response rate to S application, which is similar to the recent small plot research conducted in central to northeast Iowa. The yield increases were large enough to more than pay for a field-wide S application. This strip trial work confirms that field-scale S deficiency is occurring across a wide geographic area of Iowa from central to northeast Iowa.

Sulfur Fertilizer Product Evaluation in Corn

Field trials were conducted in 2006 (northeast Iowa, two sites), 2008 (northern Iowa, one site), and 2009-2010 (central to northern Iowa, two sites each year) on producer fields with loamy fine sand, silt loam, and loam soils to evaluate phosphorus-sulfur fertilizer combination products. The fertilizer sources varied somewhat, but were consistent in the product makeup. In 2006, the first year of this work, the product evaluated was a Simplot 13-33-0-15S fertilizer (SEF). No studies were conducted in 2007. In 2008, the Mosaic 13-33-0-15S (MicroEssentials MES15) product was evaluated, and in 2009-2010 the Mosaic 12-40-0-10S (MES10) product. These products are comprised of monoammonium phosphate (MAP), with S as sulfate and elemental S in approximate equal proportions. Since these products were similar in nutrient makeup, a combined analysis was performed across site years.

The following P and S treatment combinations were used at all locations. The product rates were set by the desired rate of S application, 10 and 30 lb S/acre. The P application rate was set by the highest rate of the combination product at 30 lb S/acre (66 lb P₂O₅/acre with SEF and MES15 evaluation, and 120 lb P₂O₅/acre with MES10 evaluation). For correct comparisons, rates of P were equalized when required by the specific treatment with triple superphosphate (TSP). The P rate was constant for all treatments except the S & P control where no S or P was applied. The N rate was constant across all treatments as needed for the rotation, and K was applied at 60 lb K₂O/acre as potassium chloride to all plots. Fertilizer treatments were broadcast applied in the spring, prior to tillage and/or planting depending on the tillage system.

- SP-CON: S & P control, zero P and zero S (equalize N).
- S-CON: S control, zero S (equalize N; add P at the highest P rate).
- MES/SEF-10: 10 lb S/acre from the MES/SEF product (equalize N; equalize P to highest P rate).
- AMS-10: 10 lb S/acre from ammonium sulfate (AMS) (equalize N; equalize P to highest P rate).
- MES/SEF-30: 30 lb S/acre from the MES/SEF product (equalize N; no additional P as this is the highest P rate).
- AMS-30: 30 lb S/acre from AMS (equalize N; equalize P to highest P rate).
- MAP-30: P rate used in the MES/SEF 30 lb S/acre rate applied from MAP (equalize N; apply AMS at highest S rate).

The across-site (all seven sites) combined analysis for P and S response evaluation is given in Table 3. Ear leaf P concentration was increased with all P fertilizers. The SP-CON did not have any P applied (true control), and all other treatments (including the S-CON) had P fertilizer applied. The increase in ear leaf P concentration indicates that all P fertilizers (SEF, MES, MAP, TSP) were equally effective in supplying plant available P. Ear leaf S concentration was

increased with S application from all fertilizer products. This indicates all S fertilizers (SEF, MES, AMS) were equally effective in supplying plant available S. The form of S in the SEF and MES was half sulfate and half elemental. That mix did not appear to detract from supplying plant available S. The SP-CON and S-CON treatments did not have S fertilizer applied, and therefore had the lowest S concentrations. The higher rate of S resulted in greater ear leaf S concentration, reflecting the higher application rate. The ear leaf S concentration was increased slightly with P application in the S-CON (compared to the SP-CON treatment). The P source used in that treatment was TSP. The S concentration in TSP is expected to be low; therefore, that ear leaf S increase could be due a small amount of S applied in the TSP or to enhanced uptake due to response from the applied P.

The corn grain yield was increased with all P fertilizer product applications. Along with the leaf P concentration increase, this yield response indicates an overall response to P application. The uniformity in yield response also indicates all P fertilizers were equally effective in supplying plant available P. The S-CON treatment did not have S applied, and the yield with that treatment was the same as treatments where P and S was applied. Therefore, the across-site yield response appears to be due to P and not S.

Soybean Response to Sulfur Application

Recent research trials with S application to soybean have been limited. In 2000 and 2001 there were no yield increases to S application rate each year at six Iowa State University research farms across Iowa. In 2008, there were two rate trials, one at central Iowa and one in northeast Iowa. The trial in northeast Iowa had a yield increase at one S rate, but not others. In 2011, there was one trial on a sandy soil in southeast Iowa, with no yield response to S application. Additional research is needed with direct S application to soybean, and to study potential residual response in the year after application to corn.

Summary

Corn grain yield increase to S fertilization has occurred with high frequency. Also, the magnitude of yield increase has been large. Across the small plot S rate studies, 60% of the sites had a statistically significant yield increase to applied S fertilizer: 68% of sites with loam, silt loam, fine sandy loam, loamy fine sand, and sandy loam textural classes; and 14% of sites with silty clay loam or clay loam textural classes. 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 soils in areas neighboring northeast Iowa. However, the research also shows that corn does not respond to S application in all fields. It has been frustrating that a single test has not been found to be reliable for detecting potential for S response in corn and soybean. Plant tissue testing has worked well in alfalfa, but nothing similar in corn. The difficulty in determining consistency of yield response is that there are multiple sources of plant-available S, including surface soil, subsoil, and atmospheric. And, a marginal deficiency can be overcome in-season by a change in organic matter mineralization, rooting depth, precipitation, or co-application with fertilizers. In addition, the amount of S uptake in corn is not large (in recent research, at 200 bu/acre, 8 lb S/acre in grain and 13 lb S/acre total aboveground), and can be easily met by a small change in supply from multiple sources. Research continues to evaluate potential tools for determining S deficiencies and application requirement, including tools like an index of sufficiency.

Suggestions for Managing Sulfur Applications in Corn

- The extractable sulfate-S concentration in the 0- to 6-inch soil depth is not reliable for indicating potential S deficiency or need for S application.
- The S concentration in ear leaves collected at silking can indicate low S supply, but a specific critical concentration with modern hybrids could not be established in this research.
- For confirmed S deficiencies, on fine-textured soils apply approximately 15 lb S/acre and on coarse-textured soils 25 lb S/acre.
- Sulfur deficiencies have been documented and large crop yield response measured in some fields. However, we are uncertain about the geographic extent of S deficient soils across Iowa. Soil and field conditions increasing chance of S deficiency include: low organic matter soils, side-slope landscape position, eroded soils, coarse-textured soils, low subsoil sulfate content, alfalfa previous crop, no manure application, and no S applied in fertilizers. With reduced- and no-till systems, reduced or lack of soil mixing and cooler soils reduce mineralization which slows release of S from organic materials, a main source of plant-available S.
- Research to date has not fully documented the variability of deficiency within corn fields. Site-specific response is possible, but inexpensive and reliable methods are needed to “map” S deficiency. This is especially problematic in corn and soybean as symptoms are not always present or obvious, especially with minor S deficiency and small but economic yield response (Figure 5). Research and development is needed to provide tools for reliable S deficiency detection.

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Table 1. Effect of S fertilizer application on corn grain yield in fields with high probability of S deficiency (showing early plant deficiency symptoms or expectation of S deficiency based on research conducted with alfalfa), 2006.

County	Previous crop	Soil type [†]	Soil SO ₄ -S [‡]	Grain yield	
				- S	+ S [§]
			ppm	---- bu/acre ----	
Buchanan	soybean	Sparta lfs	6	123	151*
Buchanan	soybean	Sparta lfs	7	154	198*
Delaware	soybean	Chelsa lfs	9	88	108*
Delaware	soybean	Kenyon l	13	196	204 ^{NS}
Allamakee	alfalfa	Fayette sil	3	96	172*
Allamakee	alfalfa	Fayette sil	--	118	171*
Across sites				129	167*

[†] 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 after planting. Symbol indicates statistically significant (*) or non-significant (^{NS}) yield increase with S application, $p \leq 0.10$.

Table 2. Sulfur strip trials conducted in central and northeast Iowa corn fields, 2009.

Site	County	Previous crop	Special remarks [†]	S rate	Corn yield	
					- S	+ S
				lb S/acre	--- bu/acre ---	
3	Greene	corn	a	40	225	229
4	Greene	corn	a	40	210	215*
5	Greene	corn	b	40	217	228*
6	Dallas	soybean	--	40	201	200
9	Dallas	corn	c	40	147	152*
10	Dallas	corn	a, d	40	135	134
1	Fayette	soybean	--	15	224	236*
2	Howard	soybean	--	20	186	192*
7	Dubuque	soybean	--	30	216	229*
8	Floyd	---	e	20	199	203
11	Winneshiek	soybean	--	30	215	212

[†] Special remarks

a) Planter split with two hybrids.

b) Sixteen of twenty four rows cultivated.

c) Visual S deficiency symptoms on June 17, corn at V6-V7 growth stage.

d) Field had manure history.

e) Only two replications and considerable yield data missing from two strips.

* Significantly different yield than with no S applied, $p \leq 0.10$. If no symbol, then yields are not statistically different.

Table 3. Evaluation of combination P and S fertilizers, mean response across seven sites, 2006-2010.

Treatment [†]	Ear leaf P	Ear leaf S	Grain yield
	%	%	bu/acre
SP-CON	0.24b [‡]	0.14d	194b
S-CON	0.28a	0.15c	209a
MES/SEF-10	0.28a	0.17b	213a
AMS-10	0.28a	0.16b	211a
MES/SEF-30	0.28a	0.19a	208a
AMS-30	0.28a	0.18a	212a
MAP-30	0.28a	0.18a	212a

[†] See the text for a description of the specific treatments. The number behind the treatment code indicates the S rate.

[‡] Letters indicate significant difference at $p \leq 0.05$.

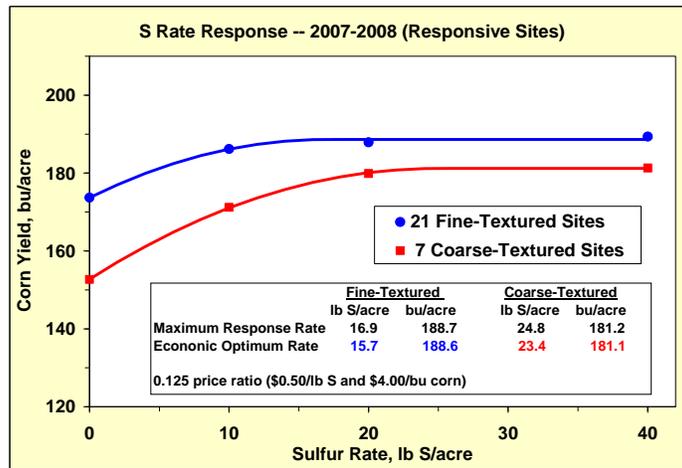


Figure 1. Corn grain yield response to S application rate at responsive sites.

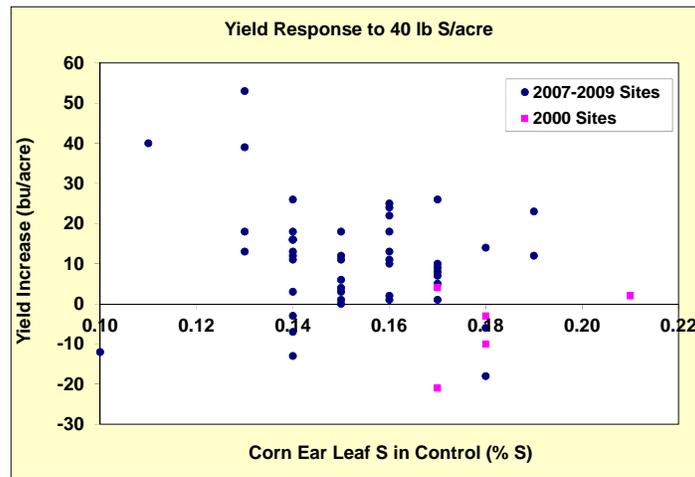


Figure 2. Corn grain yield response to S application as related to ear leaf S concentration in the no-S control.

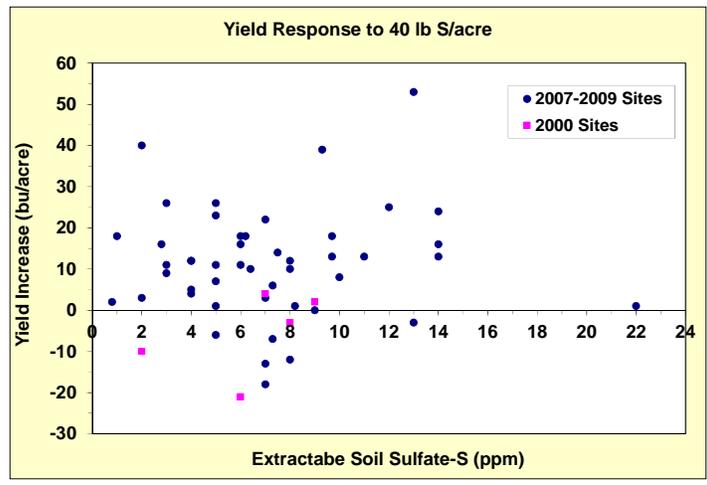


Figure 3. Corn grain yield response to S application as related to extractable soil sulfate-S concentration, 0- to 6-inch soil depth in the no-S control.

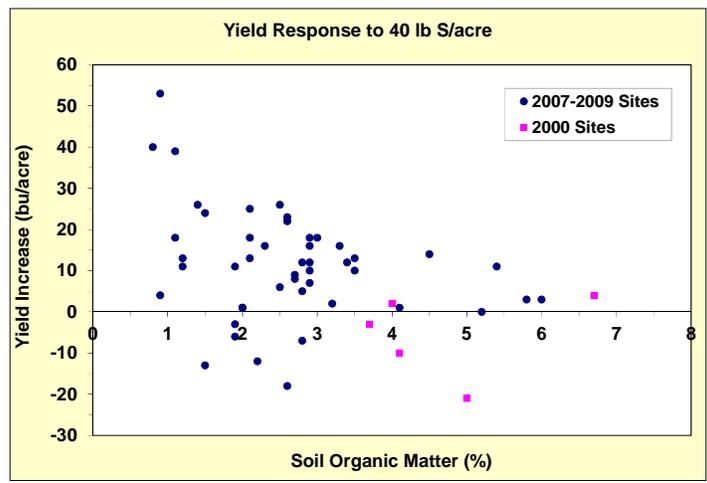


Figure 4. Corn grain yield response to S application as related to soil organic matter, 0-6 inch soil depth in the no-S control.



Figure 5. Corn expressing dramatic S deficiency symptoms and having large yield increase from S application (photo grouping A), and corn not showing deficiency symptoms and either having a yield increase or no increase from S application (photo grouping B).