Sulfur Management for Iowa Crop Production

Sulfur (S) is often classified as a “secondary” essential element, mainly due to a smaller plant requirement, but also because it is less frequently applied as a fertilizer compared to nitrogen, phosphorus, and potassium. This was certainly the case in Iowa where research had not documented S deficiency or fertilization needed for optimal crop production. However, if deficient, S can have a dramatic effect on plant growth and crop productivity—more than the classification “secondary” would imply.

Before 2005, over forty years of field research with corn and soybean conducted at many locations across Iowa had measured a yield response to S application only three times out of approximately 200 trials—an indication of adequate available S supply and quite limited S deficiency. This began to change in the early 2000s as producers in northeast Iowa began to notice yellow plant foliage and reduced plant growth in areas of alfalfa fields. After investigating several potential reasons, such as plant disease, demonstration of S fertilizer application showed improved coloration and growth of alfalfa in affected areas; see example in Figure 1. Several factors for why S responses have increased include reduced deposition with precipitation, fields with no manure application, higher crop yields, and low S content in commonly applied fertilizers.

Alfalfa Response to Sulfur Fertilization

In 2005, the observations of poor alfalfa growth and production led to research trials at several northeast Iowa field sites. At each site 40 lbs S/acre applied as either ammonium sulfate or calcium sulfate (gypsum) was compared to a non-S treated control in replicated plots. The S fertilizers were applied during the first crop growth prior to harvest, and in paired locations in established alfalfa that had exhibited poor growth/coloration and alfalfa that appeared normal in growth and coloration. The alfalfa yields from those trials (Table 1) documented a large increase (doubling of yield) from the S application in the poor growth areas, but no increase in the good growth areas. This yield response was also measured in the first cutting of the second year.

Figure 1. Demonstration of S fertilizer application showing improved coloration and growth of alfalfa in affected areas.

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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 application¶	Observed coloration/growth area							
	Poor	Good	Poor	Good	Poor	Good	Poor	Good
	- - - - - ton/acre - - - - -		- - - - - - % S - - - - - -		- - - - - lb S/acre - - - - -		- - - - - ton/acre - - - - -	
None	1.18d#	2.99ab	0.14d	0.22c	2.8e	10.6d	1.10b	2.04a
AMS	2.76bc	3.26a	0.40a	0.35b	16.5bc	18.2ab	2.18a	2.22a
CaS	2.49c	3.21a	0.41a	0.37b	15.3c	18.1ab	2.14a	2.19a

† Across three field sites in 2005, Elgin (Fayette silt loam), Gunder (Downs silt loam) and West Union (Downs silt loam), Iowa. Extractable sulfate-S soil test and soil organic matter for the poor and good areas, respectively: soil sulfate-S—Elgin, 6 and 7 ppm; Gunder, 7 and 8 ppm; West Union, 6 and 7 ppm and organic matter—Elgin, 2.3 and 2.3%; Gunder, 2.7 and 2.9%; and West Union, 2.3 and 2.6%.

‡ Across two field sites in 2006 (S application in 2005), Elgin and Gunder, Iowa.

§ Sulfur concentration for six-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, $P \leq 0.10$.

Table 2. Alfalfa plant tissue 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 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 lb of elemental S applied in the spring across the entire field.

§ Sulfur concentration for six-inch plant tops collected before second cut.

¶ Soil samples collected after first cut, 0- to 6-inch depth.

Subsequent research was conducted with established alfalfa at multiple fields in northeast Iowa to study response to S rate (tables 2 and 3). Four of six sites had a yield increase to S application, with the maximum dry matter increase occurring at 12–29 lb S/acre. Most importantly, the S concentration in the plant tissue (six-inch plant top collected before cutting), indicated a critical concentration similar to that found in other research, 0.25% S. Combining data from all alfalfa research trials indicated a low to no increase in alfalfa dry matter when the tissue concentration (top six inches of growth), was greater than approximately 0.22%–0.25% S (Figure 2). With the price of alfalfa and S fertilizers, the economic break-even point would be near 0.23% S. The same success (indicating S deficiency), was not found with the soil sulfate-S test (calcium phosphate extraction) of samples from the top six inches of soil. Examples of this can be seen in tables 1–3, where the responsiveness of a site was not related to extractable soil sulfate-S concentration. More recent research at the Nashua Research and Demonstration Farm also found an alfalfa plant and production response to S application (Table 4).

Table 3. Alfalfa total dry matter for harvests collected, 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 (gypsum) in April at Nashua and in May at other sites.

‡ Waucoma site had 10 lb/acre of elemental S applied in spring across the entire field.

§ 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.

Table 4. Alfalfa total dry matter harvest and six-inch plant top S analysis at early bud stage, Nashua Research and Demonstration Farm†, 2010-2011.

Treatment	Dry matter production			Plant analysis	
	2010	2011	2-yr mean	2010	2011
	- - - - - - - - ton/acre - - - - - - - -			- - - - - % S - - - - -	
None	6.15b‡	6.44b	6.30b	0.22	0.19
Boron	6.10b	6.68b	6.39b	0.17	0.20
Sulfur	6.91a	7.85a	7.38a	0.39	0.47
Sulfur + Boron	6.67a	8.07a	7.37a	0.36	0.43

† Readlyn loam soil; 3.3% organic matter and 6-8 ppm sulfate-S soil test. Alfalfa seeded fall 2009, with sulfur applied as gypsum (40 lb S/acre) and boron (2 lb B/acre) as Borate-48 in the fall 2009 and March 2011.

‡ Means followed by the same letter within a column are not significantly different, $P \leq 0.10$.

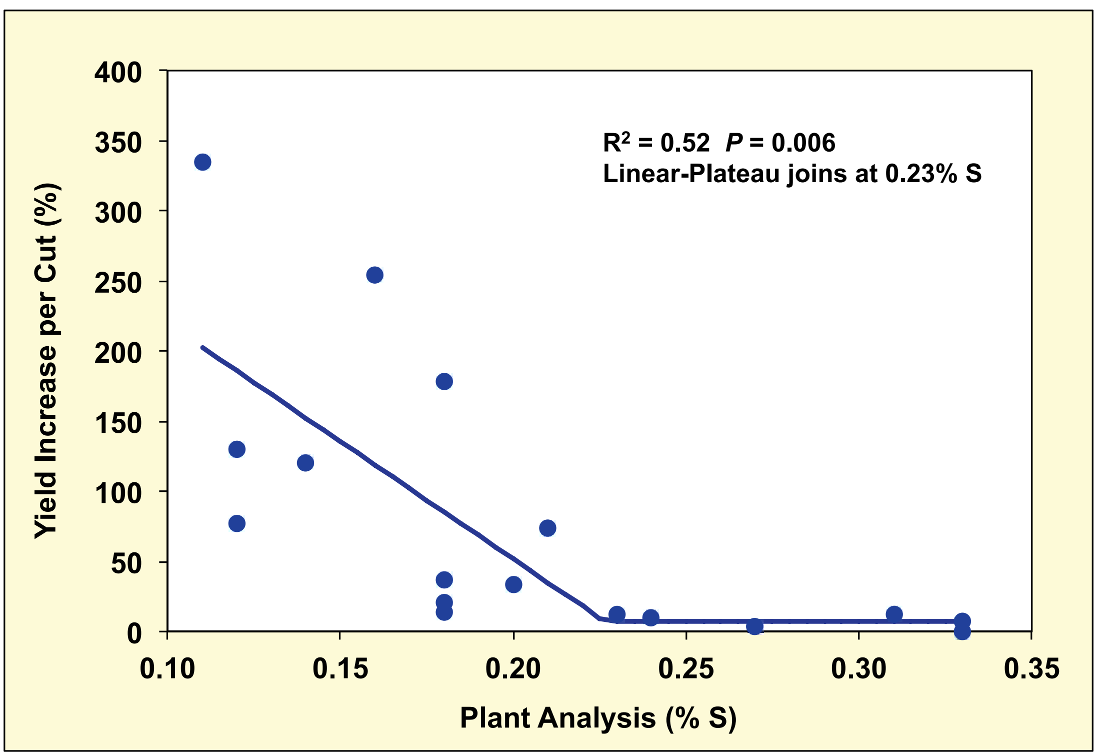


Figure 2. Alfalfa yield increase per cut from S fertilization relative to the plant tissue S concentration (six-inch plant top) in the no-S control.

Table 5. Effect of S fertilizer application on corn grain yield, 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	Chelsea lfs	9	88	108*
Delaware	Soybean	Kenyon l	13	196	204NS
Allamakee	Alfalfa†	Fayette sil	3	96	172*
Allamakee	Alfalfa†	Fayette sil	--	118	171*
Across sites				129	167*

† Following first-cut alfalfa harvest.

‡ lfs, loamy fine sand; l, loam; sil, silt loam.

§ Extractable sulfate-S in the 0- to 6-inch soil depth.

¶ Calcium sulfate applied at 40 lb S/acre. Symbol indicates statistically significant (*) or non-significant (NS) yield increase with S application, $P \leq 0.10$.

This research has documented S deficiency problems in Iowa alfalfa production fields. The majority of S deficiencies occurred in areas within fields, not entire fields. However, that non-uniformity can account for large economic losses on a field scale. Most of the soils involved were low organic matter, silt loam, and side-slope position. However, alfalfa grown on other soils has also responded to S fertilization. The need for S application is not present in all fields; for example, fields receiving livestock manure have no symptoms of S deficiency. 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 rate trials, the first 15 lb S/acre gave the largest incremental increase in yield, but the next 10–15 lb S/acre was 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

Response with Visual Sulfur Deficiency Symptoms

With the positive results from S fertilization in alfalfa, trials were started in 2006 corn fields where early plant growth was exhibiting S deficiency symptoms or where previous experience indicated soil conditions and previous crop would be conducive to S deficiency. Therefore, these sites were specifically "chosen" and not a set of sites with random potential of response to S application. These sites did not have recent or known manure history. Calcium sulfate was surface broadcast applied sidedress 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 from S application.

Corn yield increased with the calcium sulfate application at five of six sites (Table 5). 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. Across all sites, the yield increase from S application was 38 bu/acre. Since only a no-S control and one non-limiting S rate was applied, it is not possible to determine an agronomic application rate. These results indicate 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 6. Corn yield response to S application rate, Kanawha Northern Research Farm, 2011–2013.

	Higher soil organic matter site‡			Lower soil organic matter site‡		
	2011	2012	2013	2011	2012	2013
S Rate†	SC§	SCC	SCCC	SC	SCC	SCCC
lb S/acre	bu/acre			bu/acre		
0	192	82	152	187	80	174
5	184	100	171	188	99	192
10	190	105	180	187	109	191
20	191	105	179	191	113	179
40	187	111	181	183	104	185
Statistics¶	NS	*	*	NS	*	*

† Sulfur rates applied as calcium sulfate in spring 2011 and 2013.

‡ Higher soil organic matter site (5.8%), Webster clay loam and lower soil organic matter site (4.1%), Clarion loam.

§ Underlined letter C designates corn crop year of the rotation and S indicates soybean.

¶ Indicates statistically significant (*) or non-significant (NS) yield response to S application rate, $P \leq 0.10$.

Response to Sulfur Fertilization Rate

An expanded set of trials was conducted in 2007–2009 at forty-seven 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. Most sites were on producer fields and 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 versus applied S. Corn yields were averaged across responsive sites by fine and coarse soil textural groupings, with regression 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 increased with S fertilizer application at 17 of 20 sites in 2007, 11 of 25 sites in 2008, and neither of the two sites in 2009. Ear leaf S concentration increased at 16 sites (individual site responses not shown). Across all sites, the average yield increase was 11 bu/acre. When grouped by soil texture for responsive sites, the yield increase was 15 bu/acre for fine-textured soils (loam, silt loam, silty clay loam, and clay loam) and 28 bu/acre for coarse-textured soils (fine sandy loam, loamy fine sand, and sandy loam). Grain yields increased with S application at 62% of fine-textured soil sites and 64% of coarse-textured soil sites. These are frequent and large yield increases to S fertilization. However, sites located toward the north central and central geographic areas of Iowa—where soils are higher in clay, which can retain sulfate-S—had a lower frequency of corn grain yield response to S fertilization. Other factors affecting potential need for S fertilization may explain the high response rate in the northeast area of Iowa.

Additional S rate trials were conducted from 2011–2013, at the Kanawha Northern Research Farm on Clarion loam (4.1% organic matter) and Webster clay loam (5.8% organic matter) soils (Table 6). Interestingly, there was no corn yield increase from S application the first year; however, in the following two years, yields increased from S applied the previous year or when reapplied. These results highlight the inconsistency that can occur with S responses in corn, where yield increase can be non-existent to very large in the same field area any given year, and response may even occur on soils with high organic matter levels.

An important question; what is the economic optimum S rate? When analyzed for the responsive sites, the maximum response rate for the twenty-one fine-textured

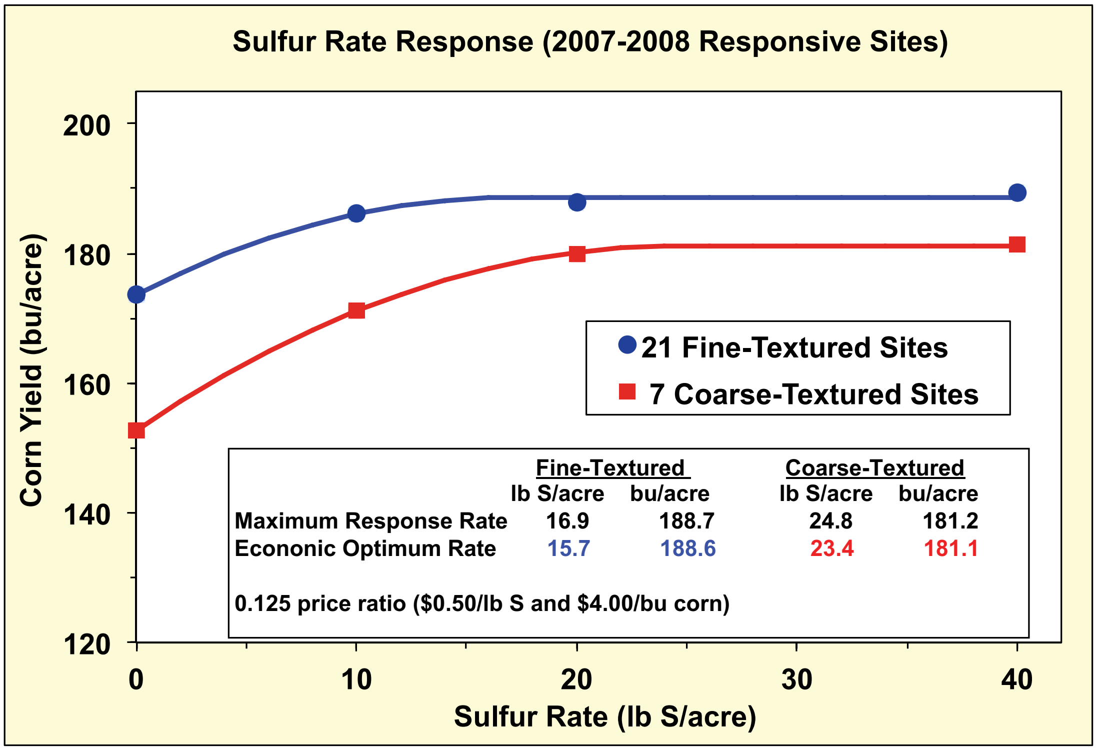


Figure 3. Corn grain yield response to S application rate at responsive sites, 2007–2008.

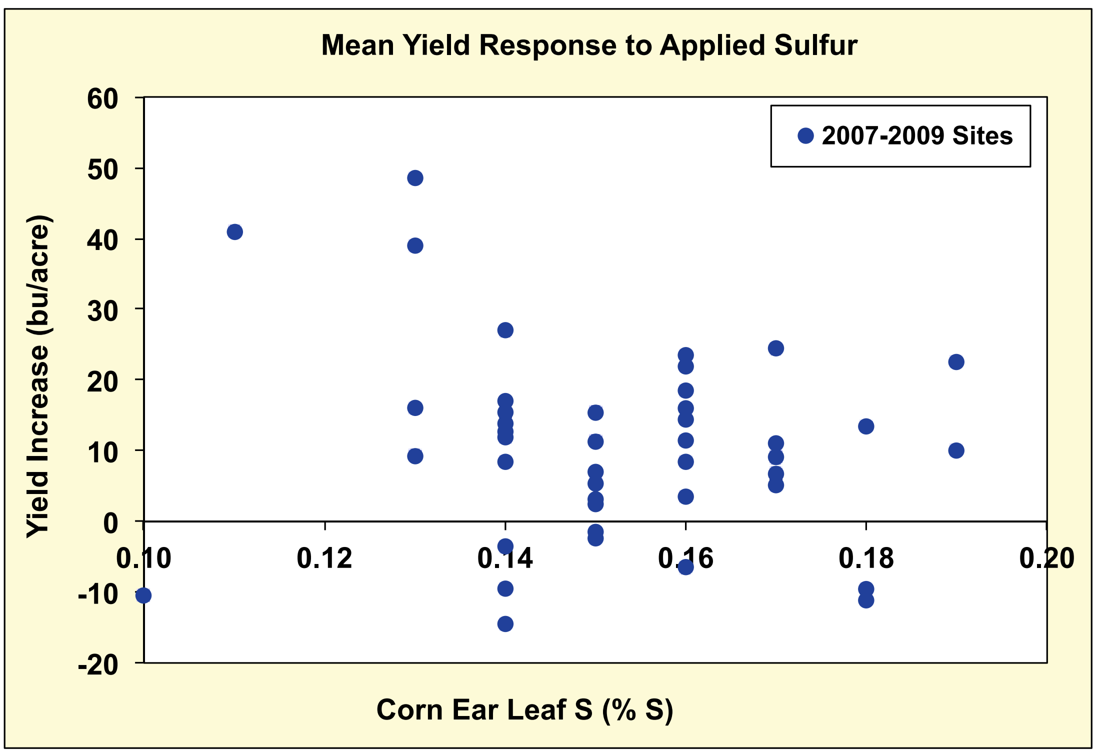


Figure 4. Corn grain yield response to S application as related to ear leaf S concentration in the no-S control, 2007–2009.

soil sites was 17 lb S/acre, with an economic optimum rate at 16 lb S/acre (Figure 3). For the seven 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 multiplied by price) is low compared to the yield return (yield increase times corn price).

One test for evaluating potential S deficiency is plant analysis for ear leaf S concentration (Figure 4). There is a wide range of published minimum sufficiency concentrations for corn ear leaves at silking, 0.10%–0.21% S. 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.

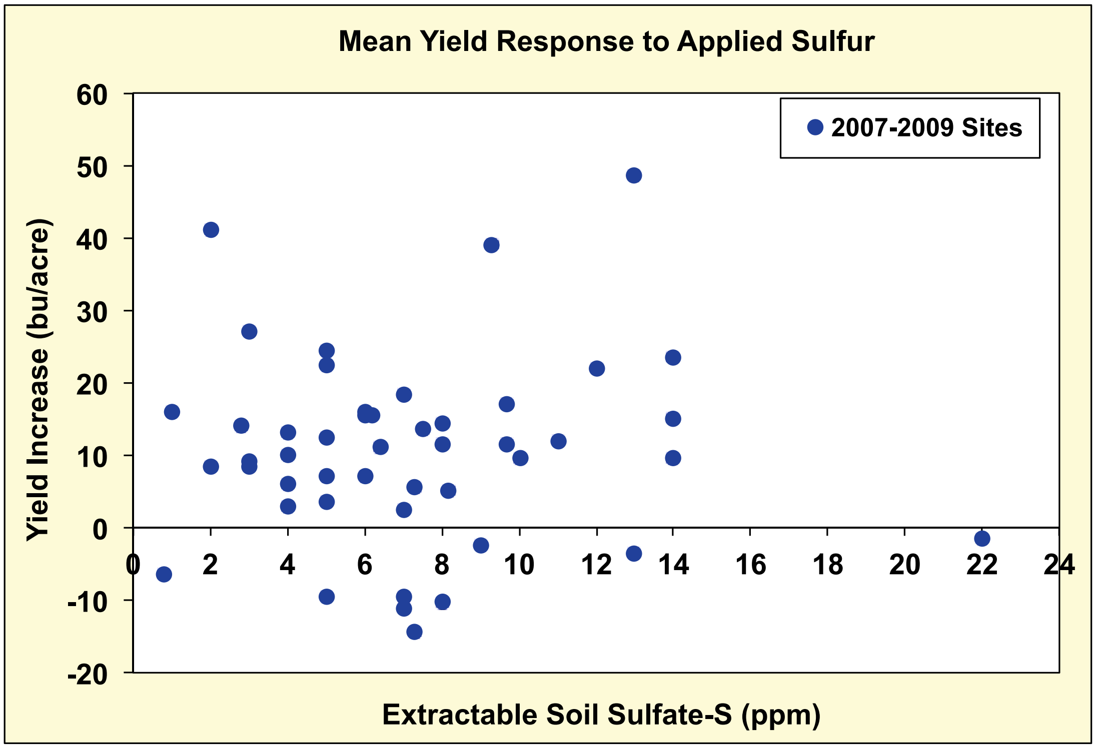


Figure 5. Corn grain yield response to S application as related to extractable soil sulfate-S concentration (0- to 6-inch soil depth) in the no-S control, 2007–2009.

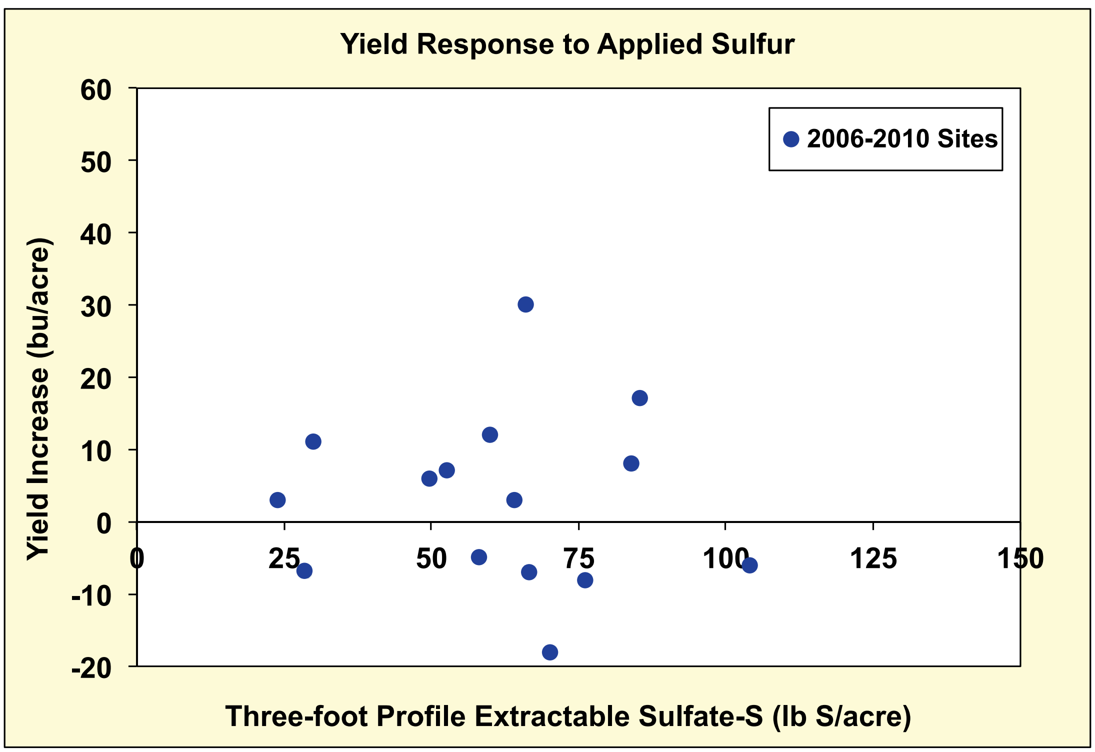


Figure 6. Corn grain yield response to S application as related to three-foot profile extractable soil sulfate-S in the no-S control, 2006–2010.

Therefore, it was not possible to define a critical level from this S rate research. Sulfur application increased leaf S concentration, but there 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.

Another test for evaluating potential S deficiency is soil testing for extractable sulfate-S. Soil test concentrations from the 0- to 6-inch depth (Figure 5) or 3-foot profile (Figure 6) were not related to yield response. Also, several sites had soil tests above the 10 ppm sulfate-S level considered sufficient by some interpretations, but responded to S application. This has been found in other studies where

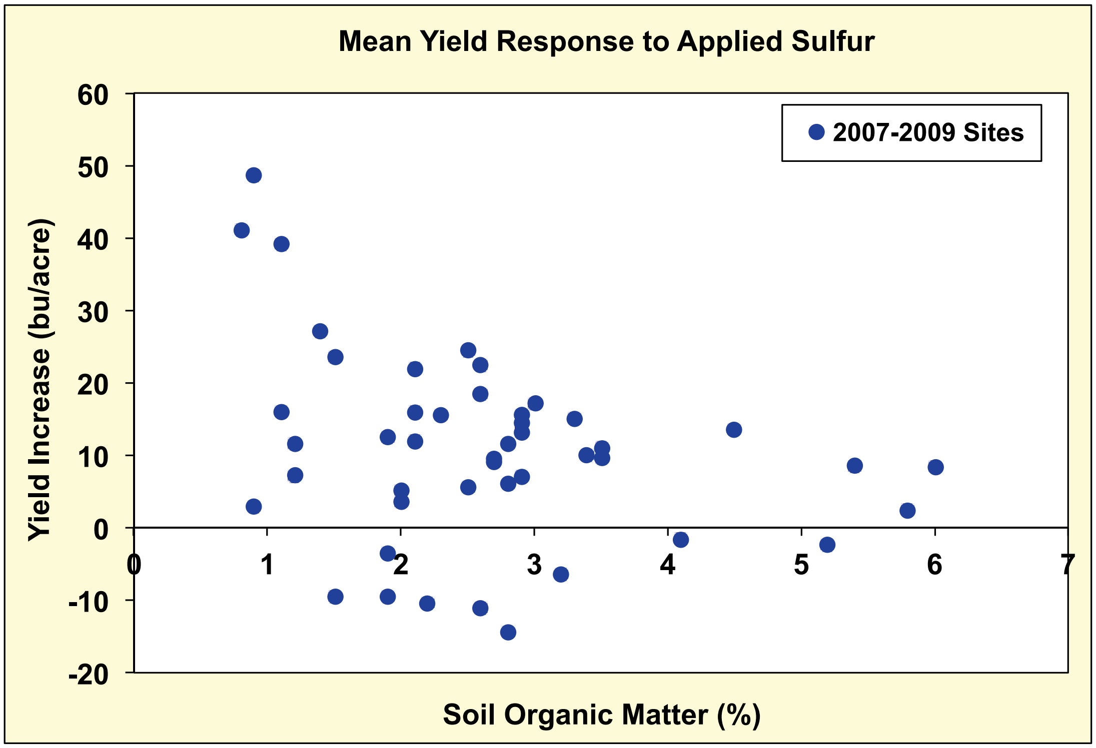


Figure 7. Corn grain yield response to S application as related to soil organic matter level (0- to 6-inch soil depth) in the no-S control, 2007–2009.

the sulfate-S soil test has not been reliable for predicting crop response to S application on soils in the Midwest United States. 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 sulfate-S 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 7). Yield responses tended to be high with low organic matter soils (less than approximately 3.5%), and low with high soil organic matter soils; however, there was considerable variation in response across organic matter levels, including responses in high organic matter soils. An attempt was made to determine a multiple-regression fit of these plant and soil tests versus corn yield response from S application. However, no relationship could be found. These results highlight the complex combination of environmental, soil, and crop factors that result in deficient or adequate season-long supply of available S. Visual observation of severe deficiency symptoms can often lead to correct determination of S response (Figure 8), but hidden nutrient deficiencies can exist where the corn plant does not exhibit deficiency symptoms but yield increase may occur (or may not).

Sulfur Fertilizer Product Evaluation

Field trials were conducted in 2006 (Northeast Iowa, two sites), 2008 (Northern Iowa, one site), and 2009 (Central to Northern Iowa, two sites), on producer fields to evaluate phosphorus-sulfur fertilizer co-products; Simplot and Mosaic 13-33-0-15S product (Simplot SEF in 2006, and Mosaic MES15 in 2008) and Mosaic 12-40-0-10S (MES10 in 2009). The SEF and MES products contained half of the S as sulfate and half as elemental. These products were compared to ammonium sulfate. The fertilizer products were broadcast by hand prior to spring tillage or corn planting. Treatments related to S response were an S control, ammonium sulfate at 10 and 30 lb S/acre, and SEF and MES at 10 and 30 lb S/acre. Nitrogen and phosphorus rates were equalized. The extractable sulfate-S concentrations were 4–8 ppm in the top six inches soil across sites.

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 *v.* 211 bu/acre). There was no yield increase to additional S application with the 30 lb S/acre rate for either 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.

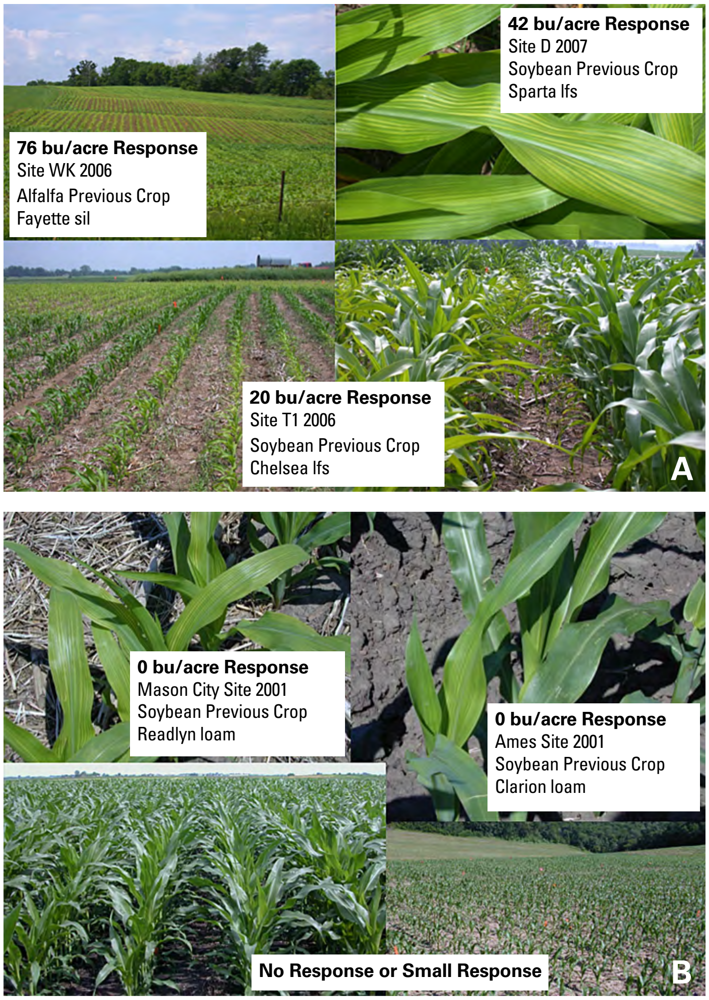


Figure 8. Corn expressing dramatic S deficiency symptoms and having large yield increase from S application (photo grouping A), and corn not showing deficiency symptoms and either having a small yield increase or no increase from S application (photo grouping B).

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 (a no-till site), 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 (MES or ammonium sulfate) or rate of application (172 *v.* 168 bu/acre, respectively, for the control and S application average). In 2009, the ear leaf S concentration increased with application of both MES and ammonium sulfate, however, there was no corn yield response to applied S. These results indicate that the phosphorus-sulfur fertilizer co-products supplied crop available S to corn and were similar to an all sulfate form.

Strip-Trials for Field-Scale Sulfur Evaluation

Replicated strip trials (Table 7) with a comparison of no S applied to a non-limiting S rate as calcium sulfate applied preplant were conducted from 2009–2012 in thirty producer fields (Central, Southwest, Western, Northwest and Northeast Iowa). Since only one S rate was used, the needed S application rate cannot be determined; however,

Table 7. Sulfur field strip trials with corn, 2009–2013.

County	Year	Previous Crop	S Rate†	- S	+ S
			lb S/acre	- - bu/acre - -	
Greene	2009	Corn	40	225	229
Greene	2009	Corn	40	210	215*
Greene	2009	Corn	40	217	228*
Dallas	2009	Soybean	40	201	200
Dallas	2009	Corn	40	147	152*
Dallas	2009	Corn	40	135	134
Fayette	2009	Soybean	15	224	236*
Howard	2009	Soybean	20	186	192*
Dubuque	2009	Soybean	30	216	229*
Floyd	2009	---	20	199	203
Winneshiek	2009	Soybean	30	215	212
Lyon	2011	Soybean	23	209	203
Osceola	2012	Soybean	23 Res‡	188	185
Lyon	2012	Soybean	23 Res	203	199
Sioux	2012	Soybean	23 Res	173	175
Mills	2012	Soybean	17	217	218
Taylor	2012	Soybean	17	99	106*
Lyon	2012	Soybean	15	157	160
Osceola	2012	Soybean	15	198	197
Dickinson	2012	Soybean	15	213	214
Lyon	2012	Soybean	15	140	134*
Lyon	2012	Soybean	15	88	79
Crawford	2012	Soybean	15	100	132*
Monona	2012	Soybean	15	190	195
Monona	2012	Soybean	15	232	228
Clay	2012	Soybean	15	231	235*
Monona	2013	Corn	15 Res	228	240
Osceola	2013	Soybean	15 Res	201	205
Monona	2013	Soybean	15 Res	230	236*
Taylor	2013	Soybean	17	172	181*

† Sulfur applied in spring preplant as calcium sulfate.
‡ Sulfur applied to previous-year crop.
* Indicates significant difference between no S and applied S at $P \leq 0.10$.

Example Sulfur Fertilizers

Ammonium Sulfate (21-0-0-24)
Ammonium Thiosulfate (12-0-0-26)
Calcium Sulfate (gypsum) (0-0-0-17)
Elemental Sulfur (0-0-0-90)
Magnesium Sulfate (0-0-0-14)
Potassium Magnesium Sulfate (0-0-22-23)
Potassium Sulfate (0-0-50-18)
Nitrogen-Phosphorus-Sulfur products (ex. 13-33-0-15)
By-products (analysis varies)
- Lysine manufacturing
- Soybean soapstock processing
- Wallboard (gypsum)
- Flue gas desulfurization

potential yield increase from S application can be determined as an adequate to above adequate S rate was applied. These strip trials are considered a survey of potential field-scale S response. Yield increase from S application occurred in eleven fields. This was a 37% response rate, somewhat lower than the small-plot research. For the responding sites, the average yield increase from S application was 10 bu/acre, with a range of 4–32 bu/acre. These yield increases are large enough to more than pay for field-scale S application. These strip trials confirm that S deficiency is occurring across a wide geographic area of Iowa, and at a frequency that justifies S application to corn.

Soybean Response to Sulfur Fertilization

There has been limited recent research conducted on S response in soybean in recent years. In 2011–2013 there were thirteen strip trials on producer fields in West-Northwestern Iowa where a spring preplant non-limiting S rate (as calcium sulfate) was compared to no S. Two sites had a soybean yield increase (15% response rate) from applied S (Table 8), with an average 4 bu/acre yield increase. In 2008, there were two small-plot sites with multiple S rates applied as calcium sulfate. Neither site had a soybean yield response. From this limited data, expectation of soybean yield increase from S application is low. In addition, S applied to corn would help moderate any potential response with soybean following corn.

Table 8. Sulfur field strip trials with soybean, 2009–2013.

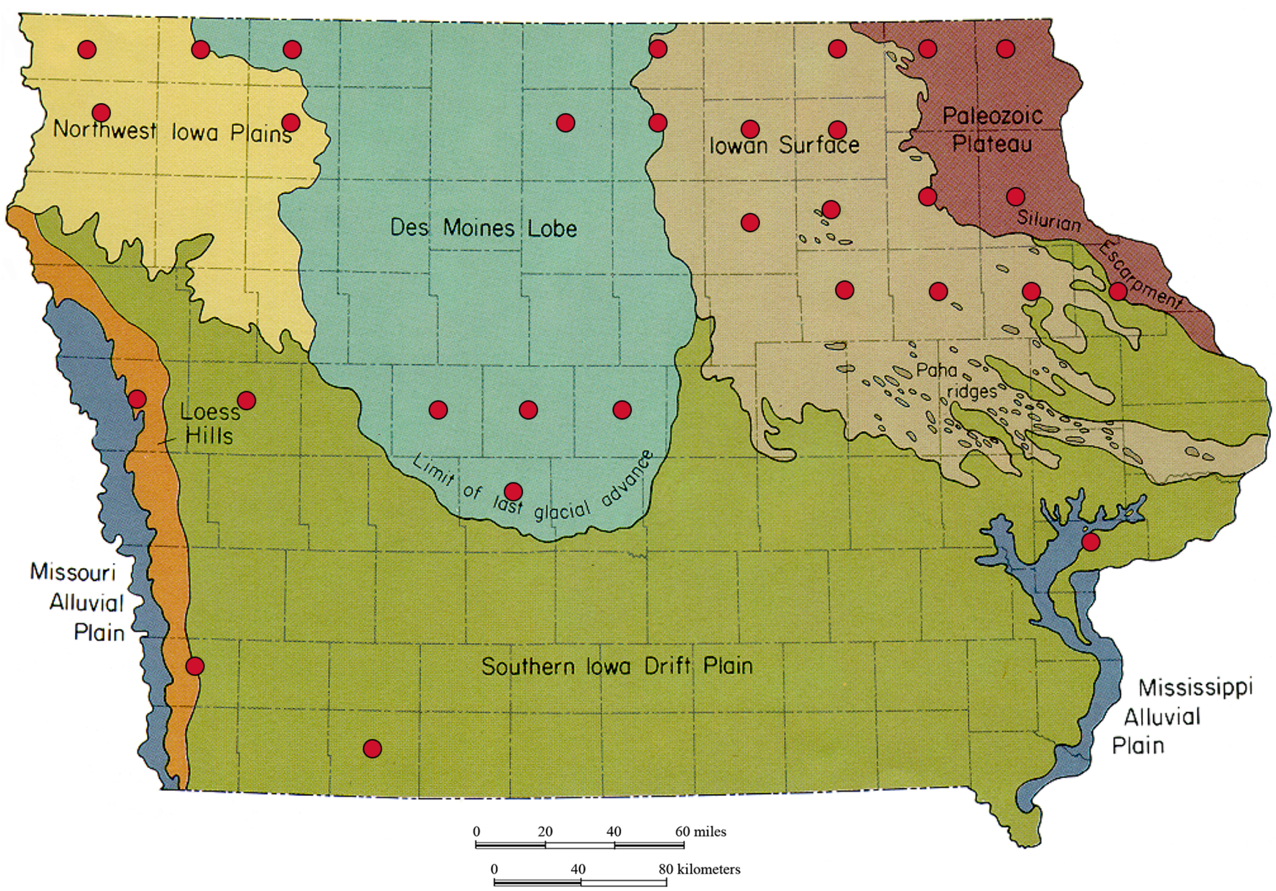
County	Year	Previous Crop	S Rate†	- S	+ S
			lb S/acre	- - bu/acre - -	
Osceola	2011	Corn	23	70.9	68.8
Lyon	2011	Corn	23	60.4	60.9
Lyon	2011	Corn	23	60.8	59.3
Sioux	2011	Corn	23	74.3	73.6
Osceola	2012	Corn	15	50.2	52.4
Monona	2012	Corn	15	64.3	63.3
Lyon	2013	Corn	15 Res‡	40.5	44.3*
Lyon	2013	Corn	15 Res	43.7	42.7
Lyon	2013	Corn	15 Res	55.5	53.6
Crawford	2013	Corn	15 Res	45.0	49.1*
Monona	2013	Corn	15 Res	69.3	69.5
Clay	2013	Corn	15 Res	54.8	55.2
Taylor	2013	Corn	17	45.3	44.1

† Sulfur applied in spring preplant as calcium sulfate.
‡ Sulfur applied to previous-year crop.
* Indicates significant difference between no S and applied S at $P \leq 0.10$.

Research Summary

The first extensive documentation of crop response to S fertilization in Iowa occurred in Northeast Iowa alfalfa fields, and revealed that a change was needed in the consideration of S fertilization for Iowa crops. This initial discovery of S deficiency and large yield response in alfalfa could be expected as alfalfa has a higher S demand than other crops grown in Iowa. Corn grain yield response to S fertilization was also found, and with high frequency—the magnitude of yield increase was sometimes large. Across small-plot S rate studies, 60% of sites had a statistically significant yield increase to applied S fertilizer; 72% of sites with loam, silt loam, fine sandy loam, loamy fine sand, and sandy loam textural class; and 14% of sites with silty clay loam or clay loam textural class. The economic optimum S rate was 16 lb S/acre for fine-textured soils and 23 lb S/acre for coarse-textured soils. In all field-strip trials, 37% of trials had a corn yield increase from S application. From 2006 to 2013, there has been approximately 110 S trials in thirty counties, statewide (see Figure 9), with corn yield response at 47% of sites across all trials. For soybean, research has been limited and frequency of S response much lower than with corn. This recent research indicates a change in need for S fertilization in Iowa, especially in alfalfa and corn, and is an economically viable practice in many fields.

Landform Regions of Iowa



Resource: *Landforms of Iowa* by Jean C. Prior for the Iowa Department of Natural Resources. Illustration by Patricia J. Lohmann.

Figure 9. Counties with at least one corn or soybean S trial, 2006–2013.

Suggestions for Managing Sulfur Applications

- For alfalfa, the S concentration in tissue samples from the top six 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 0.23–0.25% S marginal.
- For alfalfa, 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.
- For confirmed S deficiency in alfalfa, apply 20–30 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 likely. 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 application 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 or at seeding.
- 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- to 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 critical concentration with modern hybrids has not been established.
- For confirmed S deficiencies in corn, on fine-textured soils apply approximately 15 lb S/acre and on coarse-textured soils 25 lb S/acre. Application at suggested rates should be adequate for corn and the next corn or soybean crop.
- Sulfur deficiencies have been documented and large yield response measured in many fields, but not all, and there is still uncertainty about the overall geographic extent of S deficient soils across Iowa. Some common conditions where S deficiency has been more prevalent include coarse-textured soils, low organic matter soils, side-slope landscape position, eroded soils, alfalfa crop, corn following alfalfa, and reduced- and no-till systems. Lack of soil mixing and cooler soils reduce mineralization which slows release of S from organic materials, a main source of available S. Loss of organic matter from eroded soils reduces potential available S from mineralization.
- Response to S application is unlikely in fields receiving manure, incidental S contained in various fertilizers, and S in irrigation water.
- Research to date has not fully documented the variability of deficiency within fields. Work with alfalfa showed differential response in poor and good coloration/growth areas, indicating that whole fields would not respond to S application. If within-field deficient areas could be identified, or areas with conditions more commonly having S deficiency, site-specific S application would provide improved return compared to whole field application. However, it is likely 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, and large potential yield increases with S application. Site-specific response is possible, but inexpensive and reliable methods are needed that can identify potential for S deficiencies.

Prepared by
John E. Sawyer, professor of agronomy and extension soil fertility specialist, Iowa State University
Brian J. Lang, field agronomist, Iowa State University Extension and Outreach
Daniel W. Barker, assistant scientist, Department of Agronomy, Iowa State University

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