CORN RESPONSE TO SULFUR IN ILLINOIS

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INTRODUCTION

Corn (*Zea mays* L.) is the most important crop in Illinois and is grown under many different soil and environmental conditions. Sulfur (S) has long been recognized as one of the essential elements for plant development. This nutrient has been classified as secondary, even though it is required in amounts similar to those of phosphorus by the corn crop. The frequency of S deficiency in corn has increased over the years since it was first seen in Illinois over three decades ago. This increase in frequency of S deficiency is likely the result of several factors, including less incidental S in fertilizers, insecticides, and fungicides; less atmospheric S deposition resulting from more rigorous emission standards; greater removal rates by increasing grain yields; increased use of conservation tillage which may reduce S availability; and fewer livestock operations causing less application of manure (Lynch, et al., 2000; Sawyer and Ebelhar, 1995).

Corn demand on the natural soil supply of S may be creating deficiencies because S fertilizers are typically not used. The primary source of S for corn comes from organic matter (OM). However, this organic S has to be oxidized by microbes to sulfate (SO_4^{2-}) before it can be utilized by the crop. Since this ion can be leached as rain water moves through the soil, it is not possible to accumulate S in the soil. Thus, S supply to the crop is dictated in large measure by microbial activity. Factors such as temperature and soil water content have an important impact on S availability. Most often S deficiencies are observed in low OM soils and coarse-textured soils where S can be easily leached out. However, S response in crops has been reported on soils that do not have these characteristics (Feyh and Lamond, 1992; Hoeft et al., 1985; Randall et al., 1981). Some of the additional conditions in which S deficiencies may occur include soils with low subsoil S supply capacity, and fine-textured soils that have been eroded.

Research on corn response to S has not been conducted for a long time in Illinois. The last statewide survey to determine corn response to S was a three-year study between 1977 and 1979 (Hoeft, et al., 1985). In that study only 5 out of 82 sites showed a significant corn grain yield response to S. An additional greenhouse study was conducted using the top 9 inches of soil from each location. The greenhouse study showed 60% of the soils were responsive to S application. The difference in response between the field and greenhouse study point out that the surface layer of many of the soils were near their maximum ability to supply S and that subsurface layers of the soil and/or atmospheric deposition are important at supplying adequate S levels for corn uptake in the field. In this early work the S contribution from the subsurface layers of the soil was not investigated. Further, in some of the sites, S deficiencies were observed early in the season, but no differences in grain yield occurred (Hoeft, personal communication). It is possible that the lack of corn-yield response to S application in many of the sites of that study were related to a large supply of S in the subsurface. The fact that S deficiency in some sites was observed only early in the season might indicate that the problem was corrected once the corn roots reached a plentiful S-supply in the deeper layers of the soil. All these evidences point out the need to quantify the S status of the soil in the subsurface.

Since that early study (Hoeft et al., 1985), a combination of increasing uptake of S by higher-yielding crops and a reduction of S inputs from the atmosphere or in the inputs used in farming today might be causing insufficient S supply for corn. In the earlier study by Hoeft et al., yield was increased, on average, over 11 bushels per acre by applying S when the soil was deficient. Inadequate supply can restrict grain yield and uptake of other nutrients. Providing an adequate supply of S is critically important to maximize profits from grain as well as to enhance efficient use of fertilizers and other inputs in the farming system. Thus, our objectives are to determine corn tissue S content and grain yield response to S application, to estimate corn response to S in relation to soil and environmental conditions for the state, and to determine the contribution of subsurface soils to the total supply of S to corn.

MATERIALS AND METHODS

The study was conducted with both small plots, with corn as the previous crop, and on-farm strip trials with no previous history (at least 5 years) of S applications. For information on study sites see Tables 1 and 2. The small-plot trials were setup as a randomized complete block with 4 replications in 10 x 30 ft. plots. Sulfur sources included ammonium sulfate $(NH_4)_2SO_4$ (21-0-0-24); two forms of MicroEssentials^{TM} S (ME S), ME S15 (13-33-0-15) and ME S10 (12-40-0-10); calcium sulfate (gypsum) $CaSO_4 \cdot 2\ H_2O$ [0-0-0-22(Ca)-17(S)]; and elemental S (0-0-0-90). All sources were applied at a rate of 24 lb S acre^{-1} except for ME S15 that was applied at 0, 12, 24, 36, and 48 lb S acre^{-1}. At most on-farm trials only one S source was applied at 0 and 30 lb S acre^{-1}. In all cases when ammonium sulfate or ME S products were used, all treatments were balanced with the appropriate nitrogen and phosphorus rate to prevent a response other than to S. All fertilizers were broadcast-applied.

Soil samples were collected at V6 development stage from the 0-6, 6-12 and 12-24 inch depth and plant tissue samples (leaf opposite and below the ear) were collected at early silking (R1 development stage) for S analysis. Soil S was analyzed by the Mehlich 3 extraction (Rao and Sharma, 1997). Yield data was collected from the center two rows of each plot at the research centers and by various methods using yield monitor or weigh wagon at the on-farm sites. Data were analyzed using the MIXED procedure of SAS (SAS Institute, 2009). Years, blocks (replications) and their interactions with treatments were considered random effects. Results of significance are at $p<0.1$.

RESULTS AND DISCUSSION

Small-Plot Trials

Grain yield

Locations varied considerably in grain yield, likely due to large differences in growing conditions between sites (Figure 1). Averaged across S rates, yields ranged from 207 bushels acre^{-1} in NWARC to 137 bushels acre^{-1} in Menard County. Within location there was no significant difference due to S rate (Figure 1). In fact at some of the locations the yield at the check plot (zero S rate) was numerically higher than the yield for the highest S rate. A few locations (CSREC, Lee county, Menard County, NWARC, and OrrARC) showed a trend for higher yields with S rate. Most of these sites had coarser soil textures and low organic matter content. Restricting analysis to those locations and considering S rate as a categorical variable in the analysis, we observed a significant difference for the 24 lb acre^{-1} rate producing a 13 bu acre^{-1} increase compared with the unfertilized check (Figure 2). However, all other S rates were similar to the check. We also observed that growing season conditions can have an important impact on the potential for S response. At the CSREC location, in 2009 the 24 lb S acre^{-1} rate increased yield by 21 bushels acre^{-1} and in 2010 by 31 bushels acre^{-1}, whereas in 2011, probably due to dry conditions, no response to S was observed (data not shown).

Source of S also produced no significant difference in grain yield averaged across locations (Figure 3). However, elemental S and gypsum applications resulted in numerically lower yields compared to other sources with more readily plant-available S. Ammonium sulfate provides all of the S in plant-available form and the ME S products contain half of the S in plant-available sulfate form and half in elemental (slowly available) form. Over a two-year period (2009 and 2010) at the Brownstown Research Center (BARC) the ME S and ammonium sulfate sources products yielded higher than elemental S and gypsum, while gypsum increased yields relative to the elemental S source (Figure 4). These data illustrate the potential benefit of using S sources that have readily available S to the plant. We observed no differences due to S source at BARC during 2011. Regardless, even during 2009 and 2010, this location showed no response to S rate (similar to the data in Figure 1), thus, the fact that there was a differential response to S source may be of little relevance.

Soil analysis

The Illinois Agronomy Handbook indicates that soil test levels of 12 lb S acre^{-1} or less are considered insufficient for corn production, a response to S applications is unlikely with test levels above 22 lb S acre^{-1} and values between these two test levels considered low (Fernández and Hoeft, 2009). Soil test values for all small-plot locations were above 12 lb S acre^{-1} but only the 12-24 inch depth at DSAC was above the 22 lb S acre^{-1} level (Figure 5). These data illustrate that soil test for S is not extremely reliable at predicting responsive sites. Further, these data highlight the importance of using soil S data along with other information to make appropriate interpretation of soil S results. One of our objectives was to quantify soil S levels at deeper layers to determine the potential contribution of these soil layers to plant S availability. We observed that with exception of the DSAC location, subsurface layers represent an S pool at most similar to the surface layer (Figure 5). The southeastern portion of Illinois is where highest atmospheric S deposition occurs (http://nadp.sws.uiuc.edu). It is possible that greater atmospheric deposition and subsequent leaching caused the observed increase in S levels deeper in the soil. We also observed that broadcast application of S in the spring increased soil S levels mostly on the top 6 inches and to a lesser degree in the 6 to 12 inch depth increment (Figure 6).

Tissue analysis

Sulfur rate increased ear-leaf tissue S level at R1 development stage at Lee county, Menard county, and NWARC (Figure 7). Other locations showed increasing trends, though significant differences were not observed. Except for the three lower rates at Menard county, ear-leaf tissue levels for all locations and S rates were above the suggested critical level of 0.15% S reported in the Illinois Agronomy Handbook (Fernández and Hoeft, 2009). The Menard county location also had the lowest yields and ear-leaf S content for the different S fertilizer rates followed similar patterns to those of yield (Figure 1).

On-Farm Trials

Grain yield

Corn yield was significantly impacted by S fertilization at Menard county (site 4) and Iroquois county (site 10) (Figure 8). In Woodford county (site 16) there was an 8 bushel acre^{-1} increase, but it was not statistically significant. An application of 30 lb S acre^{-1} (applied as ammonium sulfate) produced a 51 bushel acre^{-1} yield increase compared to the unfertilized check at the Menard county site. This site was on an Onarga sandy loam soil low in organic matter (Table 2). Sulfur deficiencies were observed visually in the leaves early in crop development and plant height as well as internode length was reduced when S was not applied (data not shown). The Iroquois county site was on an Andres loam soil (Table 2) and an application of 30 lb S acre^{-1} (applied as ammonium sulfate) produced a 20 bushel acre^{-1} yield increase compared to the unfertilized check. These data indicate that while response to S might not be widely observed, where S is deficient, the potential for response to a S application can be substantial.

Tissue analysis

Averaged across all site-years, tissue analysis from the on-farm trials were above the suggested critical level of 0.15% S (Fernández and Hoeft, 2009) (Figure 9). Ear-leaf S values ranged from 0.11 to 0.29% across all sites with mean and median values of 0.20%. Unfortunately, no tissue samples were obtained at the Menard County site where a grain yield response was observed. Ear-leaf tissue samples at the Iroquois county site, where there was a yield response to S, contained 0.18% S for the fertilized treatment and 0.15% S for the unfertilized check.

SUMMARY

While the frequency of response to S across all the studies was low, the data showed the importance of having adequate S fertility. From the limited number of sites in this study, response to S seems to be most likely at sites with low organic matter, coarse texture, or sloping fields where organic matter may be low. There is also some evidence that seems to indicate there is potential for a yield advantage when using S sources that contain readily available S forms. Additional locations and years would be necessary to more clearly identify the potential for S response under different environments in Illinois.

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Table 1. Year, locations and soil types for small-plot trials.

Year	Location†	County	Soil Type
2009-2011	CSRC	Champaign	Wyanet silt loam 5-10% slope
2009	NIARC	DeKalb	Flanagan silt loam
2010	NIARC	DeKalb	Drummer
2011	NIARC	DeKalb	Catlin silt loam 0-2%
2009	BARC	Fayette	Cisne silt loam
2010-2011	BARC	Fayette	Bluford silt loam 0-2%
2010	Amboy	Lee	Wyanet fine sandy loam 2-5%
2011	Mendota	Lee	Ayr sandy loam 2-5%
2011	Havana	Mason	Plainfield sand 1-7%
2010	Middletown	Menard	Broadwell Silt loam
2009	OrrARC	Pike	Downs silt loam
2009-2011	DSAC	Pope	Belknap silt loam 0-2%
2009	NWARC	Warren	Sable silty clay loam

†Acronyms are various University of Illinois Crop Sciences Research Centers, others are towns near study sites.

Table 2. Year, locations and soil type for the different on-farm trial sites.

Site #	year	County	Soil Type
1	2009	Ford	Drummer silty clay loam
2	2009	Logan	Buckhart silt loam till substratum 2-5%
3	2009	Peoria	Rozetta silt loam 1-5% eroded
4	2009	Menard	Onarga sandy loam
6	2009	Champaign	Kendall silt loam 0-2%
7	2009	Champaign	Pella silty clay loam 0-2%
8	2010	Champaign	Flanagan silt loam 0-2%
9	2010	Bureau	Flanagan silt loam 0-2%
10	2010	Iroquois	Andres loam
11	2010	Christian	Virden silty clay loam 0-2%
12	2010	Champaign	Flanagan silt loam 0-2%
13	2010	Champaign	Xenia silt loam 2-5%
14	2010	Douglas	Sabina silt loam 0-2%
15	2010	Vermillion	Drummer silty clay loam
16	2010	Woodford	Ross loam 0-2%
17	2010	McHenry	Dickinson sandy loam 0-2%
18	2010	McHenry	Dickinson sandy loam 0-2%
19	2011	Shelby	Bluford silt loam 0-2%
20	2011	Champaign	Flanagan silt loam
21	2011	Champaign	Drummer silty clay loam
22	2011	Franklin	Cisne silt loam
23	2011	Effingham	Darmstadt silt loam
24	2011	Champaign	Drummer silty clay loam
25	2009	Livingston	Crane loam
26	2009	Marion	Cisne -Huey silt loams, 0-2%
27	2010	Warren	Sable silty clay loam 0-2%

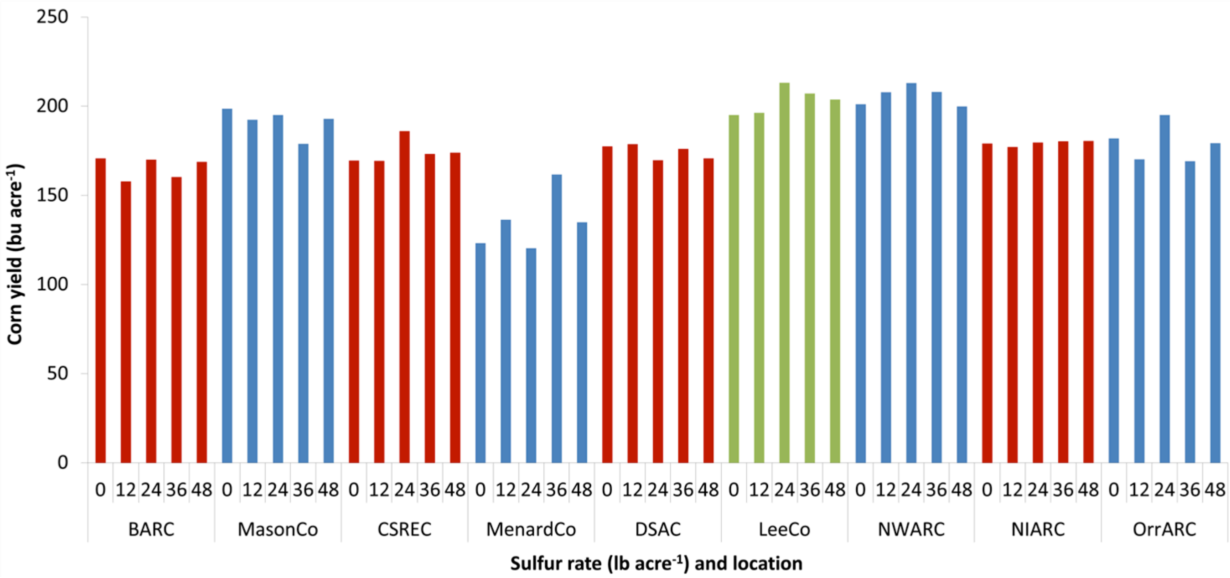

Figure 1. Corn yield at the different small-plot trial locations for the different sulfur rates (0 to 48 lb S acre^{-1}) applied as ME S15. BARC, CSREC, DSAC, and NIARC represent three-year averages; LeeCo represents two-year averages; all others are one year averages.

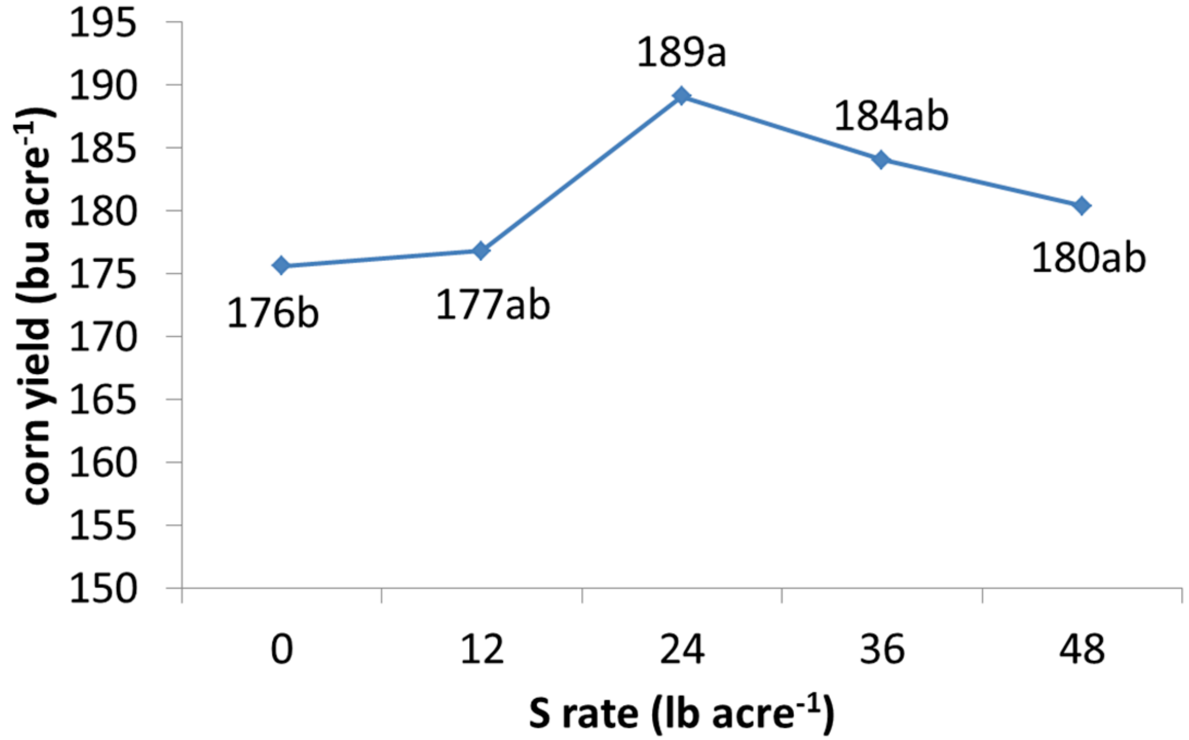

Figure 2. Corn yield averaged across CSRC, Lee county, Menard county, NWARC, and OrrARC locations (eight site-years) where the numerical response to sulfur at each individual site appeared largest. Values followed by the same letter are not significantly different (*p*>0.1).

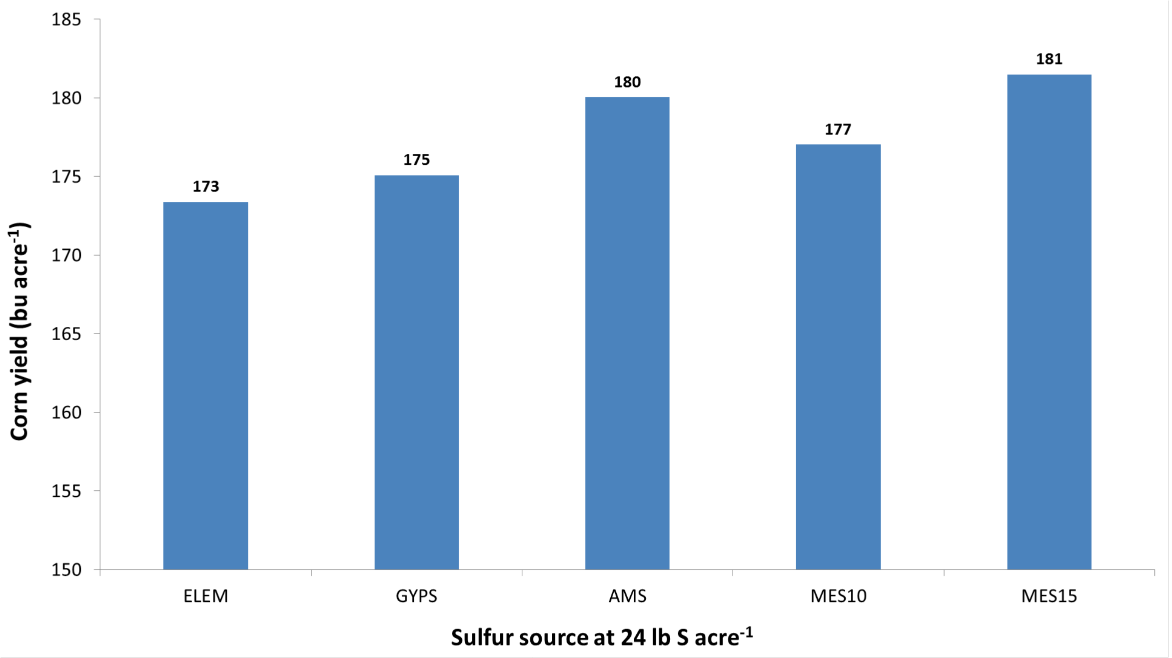

Figure 3. Corn yield for the 24 lb S acre^{-1} rate as affected by different sulfur sources (from left to right: elemental, gypsum, ammonium sulfate, ME S10, and ME S15) averaged across all small-plot trial locations and years (18 site-years).

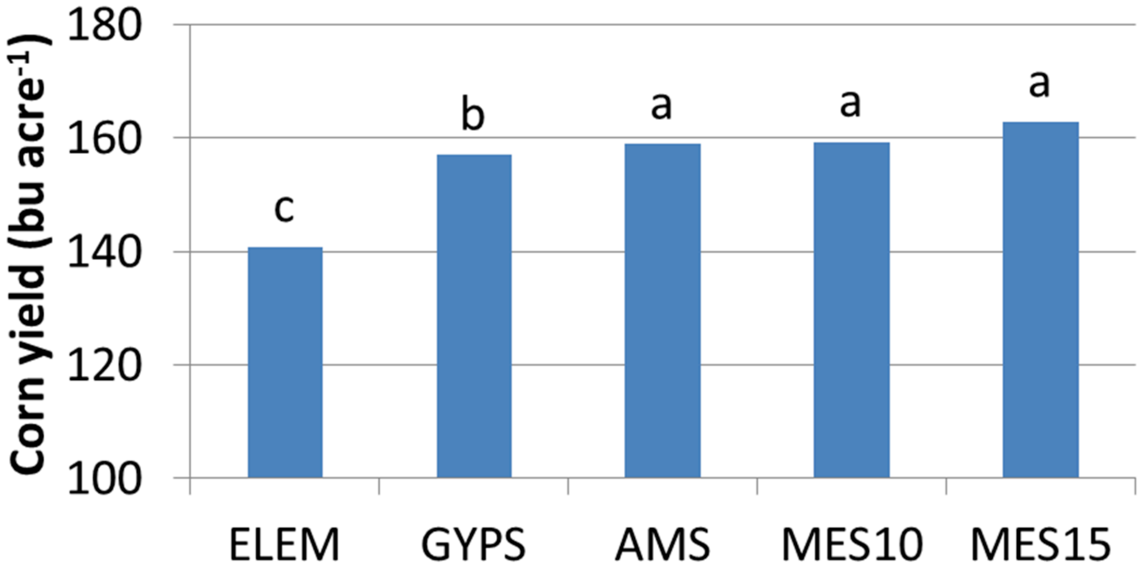

Figure 4. Corn yield for the 24 lb S acre^{-1} rate as affected by different sulfur sources averaged across 2009 and 2010 at BARC. Bars followed by the same letter are not significantly different (p>0.1).

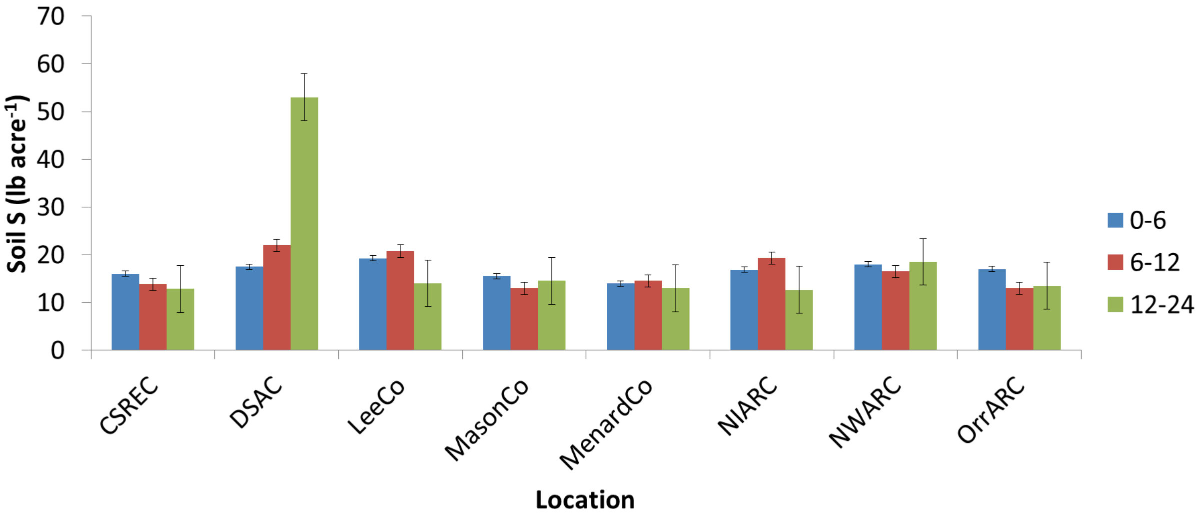

Figure 5. Soil sulfur test levels at different soil depths for various small-plot trial locations for the check (unfertilized plots) collected at V6 corn development stage. BARC, CSREC, and NIARC represent three-year averages; LeeCo represents two-year averages; all others are one year averages. Error bars represent standard error of the mean (*n*= 12, 8, and 4 for three-, two-, and one-year averages, respectively).

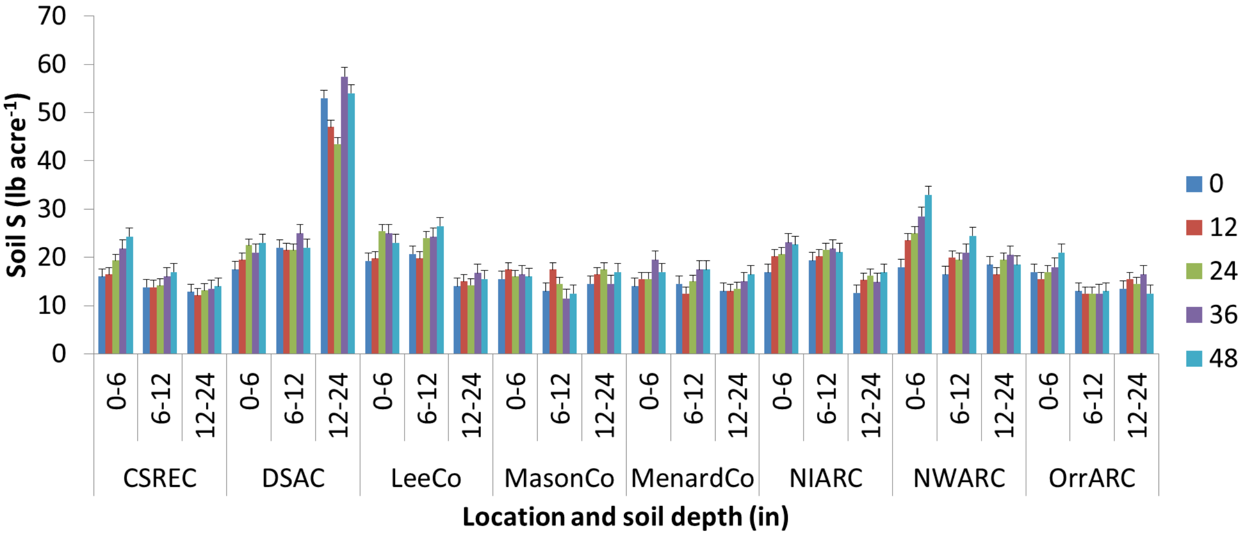

Figure 6. Soil sulfur test levels at different soil depths for various small-plot trial locations for the different sulfur rates (0 to 48 lb S acre^{-1}) collected at V6 corn development stage. BARC, CSREC, and NIARC represent three-year averages; LeeCo represents two-year averages; all others are one year averages. Error bars represent standard error of the mean (*n*= 12, 8, and 4 for three-, two-, and one-year averages, respectively).

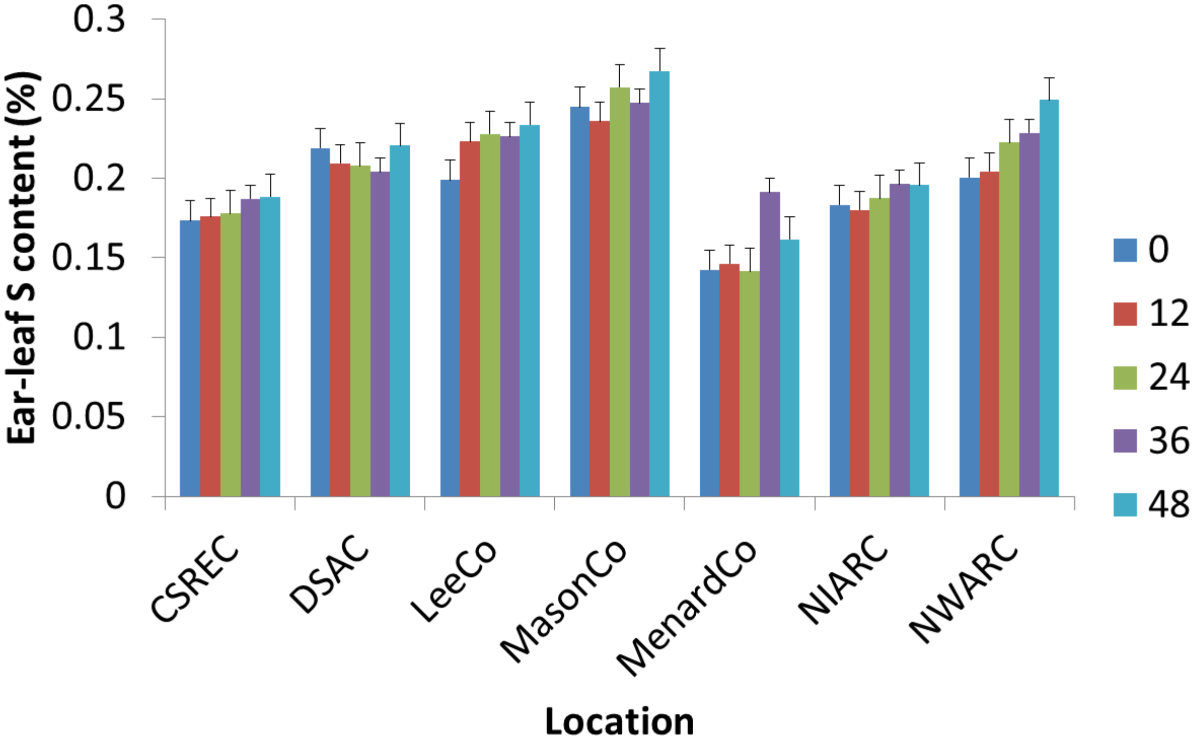

Figure 7. Corn ear-leaf sulfur content for various small-plot trial locations for the different sulfur rates (0 to 48 lb S acre-1) collected at R1 corn development stage. CSREC and NIARC represent two-year averages; all others are one year averages. Error bars represent standard error of the mean (*n*= 8 and 4 for two- and one-year averages, respectively).

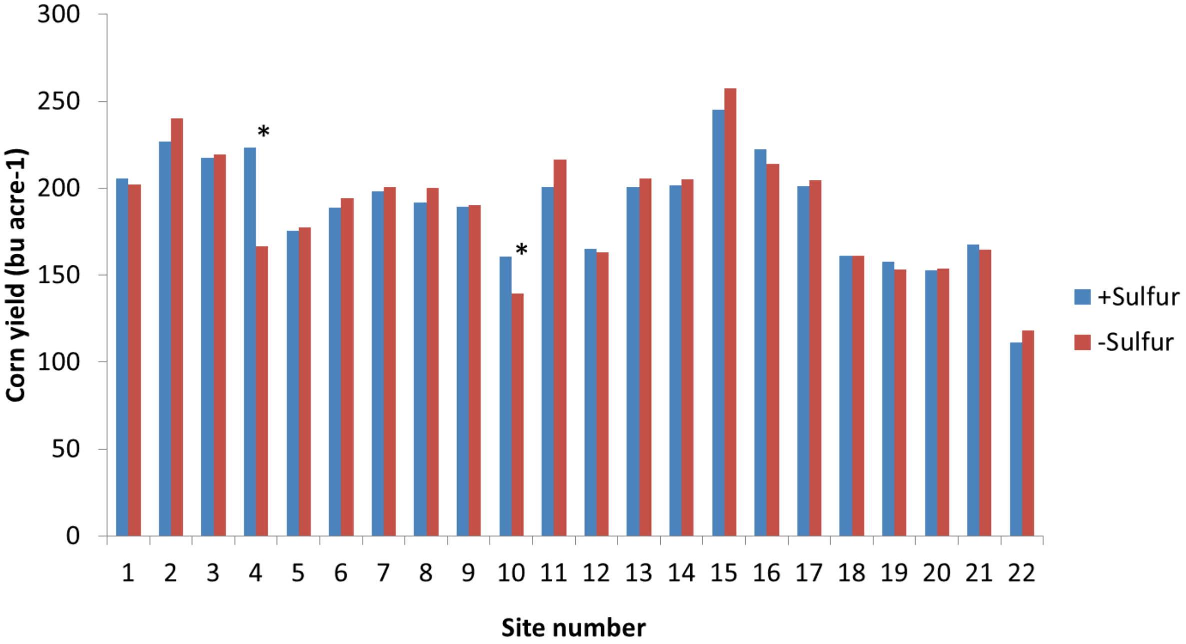

Figure 8. Corn yield response to sulfur for various on-farm trial locations. * indicates significant difference (*p*<0.1).

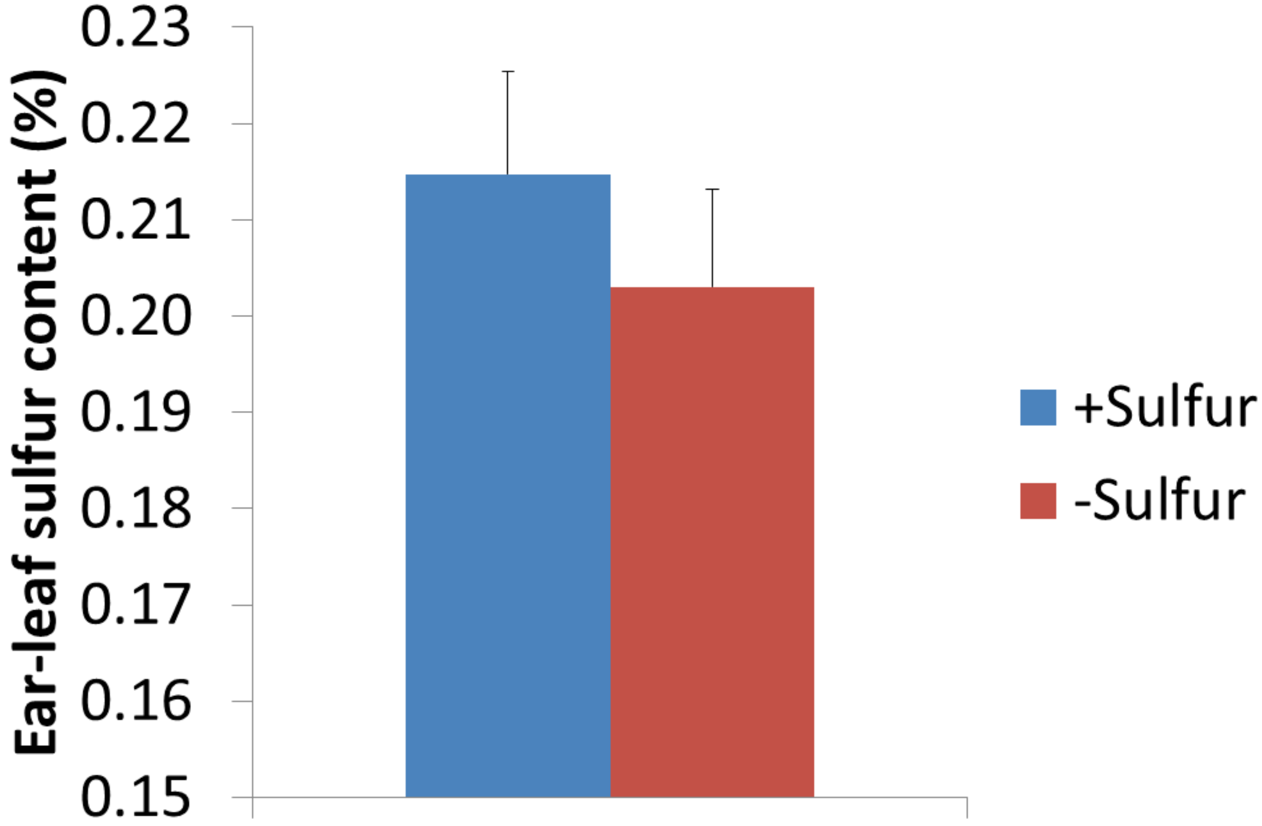

Figure 9. Corn ear-leaf sulfur content averaged across 18 site-years of on-farm trials collected at R1 corn development stage. Error bars represent standard error of the mean (*n*= 59).