Response to Starter Applied Sulfur in Combination with Nitrogen and Phosphorus across a Landscape

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Abstract

Corn (*Zea Mays* L.) response to starter fertilizer combinations containing sulfur were studied using a replicated strip trial methodology. Combinations of nitrogen (20 lbs N), phosphorus (20 lbs P_2O_5), and sulfur (25 lbs S) were applied two inches beside and below the seed with the planter and compared with a no-starter control and 25 lbs broadcast sulfur. Early plant growth was consistently increased by starter P and sometimes by starter N, while sulfur uptake was increased by S and P application. Yield was increased at two locations by starter S and increased yields were not a result of increased plant growth (starter effect). Yields were increased when soil organic matter in the top six inches was less than 2.0%, sometimes increased when soil organic matter was greater than 2.0% but less than 4.0%, and seldom increased when organic matter was greater than 4.0%. Large yield increases from sulfur application make economic responses within the studied fields possible. Variable rate applications of sulfur may increase the profitability for corn grown in variable landscapes in southern Minnesota.

Introduction

With input and crop prices significantly fluctuating in the last few years soybean growers have been looking for ways to maximize profits per acre. Sulfur application has been increasingly questioned as a method at increasing corn yields across southern Minnesota. However, past research has not shown a positive yield benefit for sulfur applied to corn unless the soils are sandy with low organic matter (Rehm, 2005) and most research has found that soil tests for sulfur do not work in fine textured soils. Currently, 25 lbs of sulfur per acre is recommended for corn when grown on coarse textured low organic matter soils (Rehm et al., 2006). If producers are banding sulfur then recommended rates are cut to 12 to 15 lbs. For many producers band application takes place in the form of starter fertilizer (small amount of fertilizer applied with the seed at planting). In Minnesota ammonium polyphosphate [APP (10-34-0)] is a popular choice for many producers as a starter fertilizer. However, many are tempted to mix sulfur containing products with APP in order to boost yields which is risky since this is not a recommended practice due to concerns with stand loss from the seed applied fertilizer (Rehm et al., 2006). Since many producers apply their dry fertilizers in the fall there are concerns with the loss of sulfate sulfur in the early spring through leaching and not adding yield to the next year's crop.

Over the past five to ten years yellow areas attributed to nitrogen deficiency in fields have developed that have not responded to additional applications of nitrogen fertilizer. Additionally, work in Northeast Iowa has shown that sulfur deficiencies are possible in fine textured soils (Sawyer and Barker, 2002; Sawyer et. al., 2009) that were eroded or had low organic matter content. Other research in southern Minnesota has noted occasional crop responses in areas where none were expected in the past (Randall and Vetsch, unpublished data). Many fields in

Southcentral and Southeastern Minnesota have a rolling topography. In many of these fields yellowing can be visually noted throughout the growing season which could be a symptom of either sulfur or nitrogen deficiency. The question is can a specific nutrient deficiency be separated out in these areas and what kind of variability in the response to nutrient can be expected across a landscape.

A replicated strip trial study was conducted at multiple southern Minnesota locations with the following objectives:

1. Examine how different soils in a landscape may respond to sulfur fertilization
2. Evaluate how the application of nitrogen and phosphorus fertilizers mixed with sulfur may affect plant growth and the overall uptake and response from sulfur fertilization

Research Methods

Four corn trials were established in 2008 and 2009 (Table 1). Field sites were selected that had topographical variability (i.e. summit, footslope, toesplope landscape positions. A replicated strip trial methodology was used at each location. Fertilizer strips measuring 10 to 20 feet (4 to 8 30 inch corn rows) wide and 520 to 880 feet long were established parallel to the direction of the corn rows in which six treatments were applied, randomized, and were replicated three to four times at each location. Treatments were a control with no starter or sulfur fertilizer, broadcast sulfur applied at 25 lbs S per acre and four starter fertilizer mixes were applied as field length strips. The starter fertilizer treatments consisted of 20 lbs of N/acre, 20 lbs of P_2O_5/ac, and 25 lbs of S/acre applied in combinations of N only, N+P, N+S, and N+P+S. Liquid fertilizer treatments were applied two inches beside and below the seed with a John Deere 7000 series planter equipped to simultaneously apply 28% UAN, ammonium polyphosphate (10-34-0), and ammonium thiosulfate (12-0-0-26s) to achieve the targeted starter rates. Dry potassium sulfate (0-0-50-18s) was used as the broadcast sulfur source and potassium chloride (0-0-60) was applied at high enough rates to limit crop response to strips not receiving potassium sulfate (potassium application rate was identical across the trial areas). Additional nitrogen and phosphorus fertilizer and lime were applied according to recommended rates by the farmer.

Within each rep across treatment strips the field areas were segmented into 120 foot increments for soil sampling. These increments represented grid cells within the trial area measuring 60 to 120 feet wide and 120 feet long (0.17 to 0.34 acres). Soil samples were collected from the 0-6, 6-12, and 12-24 inch depths from the center of each grid cell. Each sample consisted of a composite of 6 to 8 cores taken from each cell. Soil samples were analyzed for Bray-P1 phosphorus, ammonium acetate potassium, soil organic matter, and pH (Table 1) by methods recommended in the North-central region (Brown, 1998). Additionally, sulfate sulfur was run by extraction with KCl on all sampling depths. At the V4 to V6 growth stage (Ritchie et al., 1986), the above ground portion corn was collected from the centers of each treated strip within each grid cell. Plants were dried and weighed to determine plant weight. Fields were harvested with a research grade combine in which the middle 60 feet of each individual treatment within a grid cell was harvested, and a subsample of grain was taken for analysis of sulfur content. Whole plant samples were collected at the R6 corn and R8 soybean growth stage from selected areas within each trial.

Statistical analysis was conducted on strip mean averages using the PROC MIXED procedure in SAS (SAS Institute, 2002). When the analysis indicated a significant ($P \leq 0.05$) main treatment effect either least significant difference (LSD) or non-orthogonal single degree of freedom contrasts were used to assess the effects of individual nutrients on studied factors. Effects of N were assessed by comparing the check without sulfur versus N starter, phosphorus by comparing N starter only versus N + P and N + S starter versus N + P + S, and sulfur by comparing the check without sulfur versus broadcast S, N only versus N + S, and N + P versus N + P + S. To assess effects of soil factors on yield and growth of corn, grid cells were separated by soil organic matter level and analyzed with PROC GLM. When there was a significant main treatment effect differences between treatments were assessed using LSD $P \leq 0.05$. Regression analysis was conducted using the PROC NLIN procedure in SAS.

Results and Discussion

Soil test averages across grid cells are listed in Table 1. Soil P and K tested in the High to Very High categories (Rehm, 2006) at the Clarkfield and Albert Lea locations and were Low to Medium at Isanti and Clarks Grove. Soil organic matter levels were the lowest at the Isanti location which is classified as a fine sandy loam soil. This location would be considered to be a site highly responsive to sulfur based on previous research. The lowest organic matter average for the site with a loam or clay loam texture was at Clarks Grove which averaged 2.0% in the top six inches. The standard deviation in soil organic matter values was low at this site indicating little variability across the trial area. The greatest variability in soil organic matter levels was at the Albert Lea location which averaged 3.9%. However the range in organic matter at this location was about 1.0% to nearly 9.0% (not shown). Soil sulfur levels were consistent within locations. The only exception was at Isanti west where the standard deviation was the highest in the top six inches. Average soil sulfur level was the lowest for most soil depths at the Clarkfield location which had the highest average six inch soil organic matter levels.

Early plant growth was significantly ($P \leq 0.05$) affected by one or more treatments at three locations (Table 2). At Clarkfield there were no treatment differences across the trial area due to any starter or sulfur fertilizer treatment (LSD $P \leq 0.05$). At Albert Lea only treatments receiving phosphorus increased early plant growth. At Clarks Grove phosphorus treatments increased growth the most of any treatment more than nitrogen alone which was slightly better than the control, broadcast sulfur, and nitrogen and sulfur starter treatments. This data is in agreement with past research that has shown that either phosphorus or nitrogen is responsible for early plant growth responses (Bermudez and Mallarino, 2002). At Isanti the combination of nitrogen, phosphorus, and sulfur increased growth more than nitrogen and phosphorus and nitrogen and sulfur which were approximately similar. This response was not expected since soil P was low at this location (Table 1) and a deficiency of sulfur would be expected due to the soil textural class and low soil organic matter at this location. It is likely that growth was limited in all treatments due to either a phosphorus or sulfur deficiency and that the growth increase may not have been due to a true starter effect at this location. Because of this it is likely that sulfur would not be responsible for a true starter effect and that a deficiency would be apparent if sulfur availability was low at a location.

Early season sulfur uptake was significantly ($P \leq 0.05$) increased at the same three locations as early plant growth (Table 3). At the three locations where uptake was increased, the combination of nitrogen, phosphorus, and sulfur increased uptake the greatest (LSD $P \leq 0.05$). At Clarks Grove nitrogen and phosphorus alone increased uptake greater than the control, nitrogen or sulfur alone, and their combination, but less than N + P + S. At Isanti no treatment besides N + P + S increased uptake greater than the control. At Albert Lea the addition of sulfur always produced slightly greater sulfur uptake than similar treatments without sulfur. The addition of sulfur generally increased plant sulfur concentration (not shown), but plant growth significantly influenced sulfur uptake early in the season. While phosphorus did more consistently increase plant growth uptake was not maximized by phosphorus alone.

Analysis of strip mean data at each location showed no significant ($P \leq 0.05$) increase in yield at any location in spite of large variations in numerical values within treatments (Table 4). For example, at Albert Lea the control treatment averaged 168 bu/ac while the N + S treatment was 212 bu/ac. It is likely that the large variation in potential for yield response across some locations were affecting the analysis. Large variations in soil test values may influence the potential for yield responses within individual locations. Soil test phosphorus and sulfur were used to compare treatment responses but results were inconclusive therefore data are not shown. The relationship between 0-6" soil test sulfur and yield response to sulfur was better correlated than any other factor. Data in Figure 1 shows yield response to sulfur compared to soil organic matter level at Clarkfield, Clarks Grove, and Albert Lea. Data from Isanti was left out due to potential interactions with low soil test P within that location. The regression between soil organic matter (0-6") and yield response to sulfur shows a yield increase until 2.6% (r^2=0.39). However, several points from Albert Lea included in the data set appeared to be responsive to a higher soil organic matter value. These data points were excluded from the analysis, but their inclusion only resulted in a change of 0.1%. This data was used to divide soil organic matter levels into Low, Medium, and High levels to analyze individual areas within the trials separately similar to an analysis conducted by Bermudez and Mallarino (2002).

Since relative yields were generally lower when soil organic matter levels were below 2.0% this value was considered Low. Responses above 4.0% were rarely seen therefore this level was considered high. Yield responses were sometimes between 2.0 and 4.0% therefore this level was considered to be Medium. Figure 2 shows the analysis by soil organic matter levels for each location. At Clarkfield organic matter levels were Medium and High and there was no response to any starter or sulfur treatment at his location (LSD $P \leq 0.05$). At Isanti all cells fell in the low category but there was no significant yield response. This was likely due to interactions between low P and S at this location. In addition this site was significantly limited by soil moisture mid to late in the growing season which caused some plots to have very low yields limiting the potential for yield responses. This field would likely see a high potential for response to sulfur during most years. At Clarks Grove the trial was divided into both Low and Medium organic matter values, but yields were only increased by sulfur when organic matter levels were Low (<2.0%). In this case single degree of freedom contrasts indicated a significant increase in yield from sulfur applied as a starter. This field also tested low is soil P, but there was no evidence of a yield increase due to this nutrient. It was surprising that broadcast sulfur did not increase yields compared to starter applied sulfur. This effect could be a result of the band placement or a potential interaction between nitrogen and sulfur which could not be determined with the experimental design. The Albert Lea location had the greatest differences in soil organic matter levels with areas testing Low, Medium, and High. These areas represented hilltop, sideslope, and toeslope positions, respectively. When soil organic matter was High there was no yield increase from sulfur or starter fertilizer treatments and yield potential was the highest within the field. When soil organic matter levels were Low sulfur increased yields the greatest and nitrogen increased yields slightly less. This indicates that sulfur may give the greatest potential yield increase at these organic matter levels, but nitrogen may also influence yield and may be an important factor as well. When soil were greater than 2.0% but less than 4.0% the starter applied sulfur resulted in the greatest yield increase while starter N and broadcast S also increased yields, but not at the same magnitude. It is likely that for similar field the application of sulfur would generally result in a positive yield benefit and that targeted application of sulfur may provide the best return for a corn producer.

Conclusions

Sulfur fertilization increased corn yields consistently when soil organic matter levels were below 2.0% and sometimes between 2.0 and 4.0%. Early plant growth was consistently increased by starter P. Early plant growth responses were not translated into yield responses. Sulfur uptake was increased by both phosphorus and sulfur fertilization. Yield tended to be increased by the application of the most limiting nutrient at the sites studied which was sulfur. Within fields, sulfur fertilizer can potentially lead to large yield increases especially on eroded knolls or eroded side hills. Variable rate application may lead to the greatest potential economic response.

Acknowledgments

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Tables and Figures

Table 1. Soil test averages across grid cells for corn locations from the 0-6, 6-12, and 12-24" soil depths.

Year	Location	County	Soil† Series	Soil† Class	Depth	Soil Test (0-6") Olsen P	Soil Test (0-6") Potassium	Soil Test (0-6") pH	SOM‖ AVG	SOM‖ StDEV	Sulfur‖ AVG	Sulfur‖ StDEV
						-----------ppm-----------			----------%----------		-------ppm-------	
Corn Locations												
2008	Clarkfield	Y. Medicine	Nishna	CL	0-6	34	188	6.4	4.3	0.7	4.7	1.6
					6-12	11	130		3.9	0.7	4.9	0.9
					12-24	8	133		3.3	1.0	2.9	0.8
2008	Clarks Grove	Freeborn	Lester	L	0-6	11	96	6.4	2.0	0.6	9.1	1.1
					6-12	6	84		1.7	0.6	3.2	1.3
					12-24	7	89		1.6	1.0	2.8	0.8
2008	Isanti West	Isanti	Zimmerman	FSL	0-6	9	86	7.8	0.7	0.2	8.7	2.2
					6-12	5	57		0.4	0.2	5.3	2.1
					12-24	6	48		0.2	0.2	5.9	1.6
2009	Albert Lea	Freeborn	Hamel/Lester	L	0-6	22	155	6.4	3.9	2.1	5.3	0.7
					6-12	16	79		3.9	2.6	4.8	1.0
					12-24	9	89		3.1	1.7	4.5	0.7

† Cl, clay loam; L, loam; FSL, fine sandy loam; SL, silt loam
‖ AVG, average across grid cells; StDEV, standard deviaiton across grid cells.

Table 2. Early plant growth average values across trial locations for treatment with and without sulfur. Treatments means within locations with the same letter following numbers are not significantly different (LSD $P \leq 0.05$)

County	No Starter† - S	No Starter† + S	Starter N - S	Starter N + S	Starter N + P - S	Starter N + P + S	*P* >F
	----------------------------g/plant----------------------------						
Clarkfield	**6.65**	**6.69**	**7.13**	**6.68**	**7.37**	**7.21**	**ns**
Clarks Grove	**1.70c**	**1.71c**	**1.85bc**	**1.78c**	**2.16ab**	**2.26a**	**0.01**
Isanti	**2.09cd**	**1.98d**	**1.97d**	**2.49bc**	**2.59b**	**3.08a**	**<0.001**
Albert Lea	**6.22b**	**6.35b**	**6.20b**	**6.22b**	**7.76a**	**8.20a**	**0.008**

† No Starter, strip average that did not receive starter fertilizer without (-S) and with (+S) broadcast sulfur.

Table 3. Early plant sulfur uptake average values across trial locations for treatment with and without sulfur. Treatments means within locations with the same letter following numbers are not significantly different (LSD $P \leq 0.05$)

County	No Starter† - S	No Starter† + S	Starter N - S	Starter N + S	Starter N + P - S	Starter N + P + S	*P* >F
	----------------------------mg/plant----------------------------						
Clarkfield	**19.9**	**20.3**	**19.7**	**19.6**	**21.3**	**21.9**	**ns**
Clarks Grove	**4.7d**	**5.2c**	**5.2c**	**5.2c**	**5.5b**	**7.0a**	**<0.001**
Isanti	**4.3bc**	**4.0c**	**3.9c**	**5.1b**	**5.2b**	**6.2a**	**<0.001**
Albert Lea	**13.0c**	**14.6bc**	**12.9c**	**15.6b**	**14.6bc**	**20.9a**	**<0.001**

† No Starter, strip average that did not receive starter fertilizer without (-S) and with (+S) broadcast sulfur.

Table 4. Corn grain yield average values across trial locations for treatment with and without sulfur. Treatments means within locations with the same letter following numbers are not significantly different (LSD $P \leq 0.05$)

County	No Starter†		Starter N		Starter N + P		P>F
	- S	+ S	- S	+ S	- S	+ S	
	----------------------------bu./acre----------------------------						
Clarkfield	161	162	164	161	164	165	ns
Clarks Grove	160	159	164	176	160	171	ns
Isanti	85	82	77	83	79	90	ns
Albert Lea	168	187	188	212	193	203	ns

† No Starter, strip average that did not receive starter fertilizer without (-S) and with (+S) broadcast sulfur.

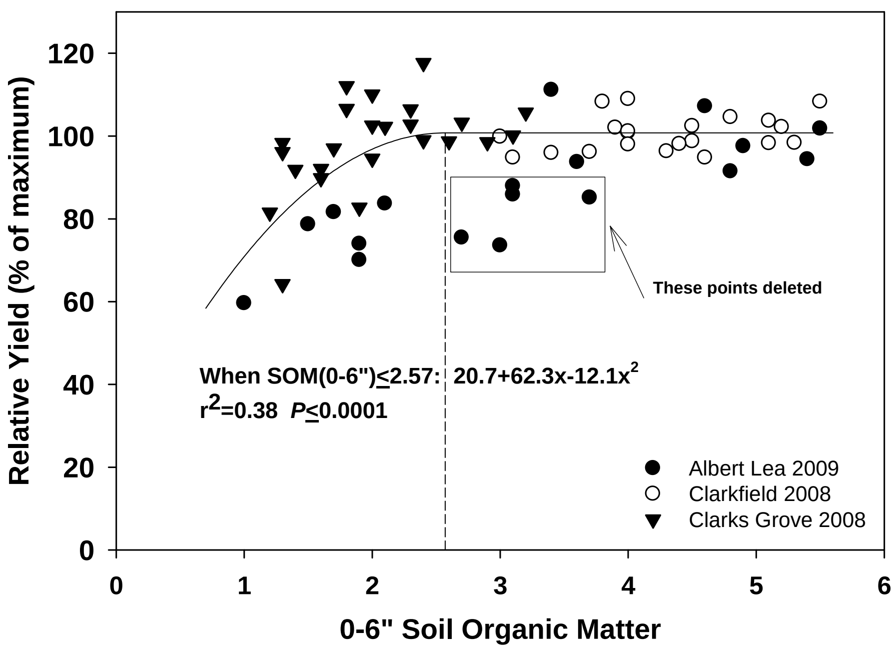

Figure 1. Comparison of relative corn yields for treatments with and without sulfur versus soil organic matter (0-6”) at all locations with clay- or loam soil textures. Points within the outlined box were not included in the final data analysis

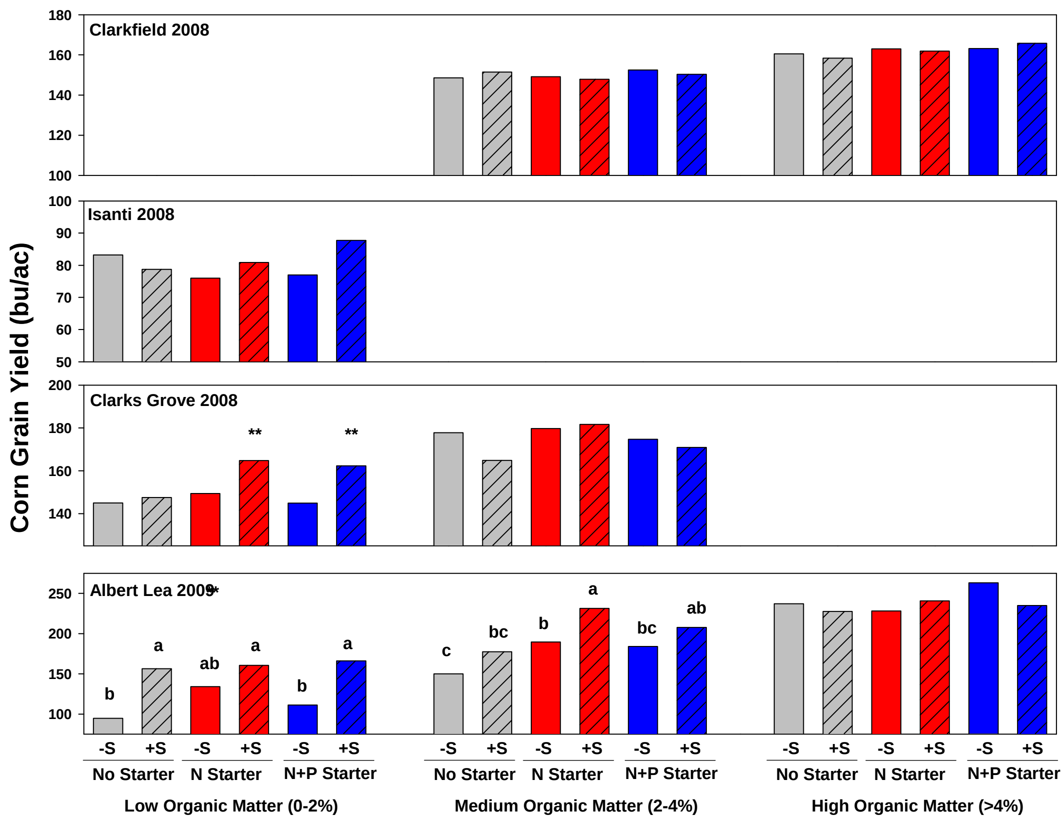

Figure 2. Analysis of actual corn grain yield by soil organic matter level at each location for Low (0-2%), Medium (2-4%), and High (>4%) levels in the top 6" of soil based on data in Figure 1. Small letters above bars represent LSD values ($P \leq 0.05$) within organic matter levels. (**. Indicates a significant response according to single degree of freedom contrasts)

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