Understanding mechanisms of sulfur cycling in Minnesota soils and availability from fertilizer

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AFREC Project(s) R2020-R Year 2 Report

Crop Year - 2020

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Year 2 (2020) Summary Points

- Sulfur increased corn grain yield at three of four locations. Application of 5-10 lbs of S per acre was sufficient for medium to fine textured soils with soil organic matter concentrations of 4% or greater while 10-20 lbs of S was required for sandy soils (considering 2019 and 2020 data)
- Sulfate forms of sulfur generated the highest grain yield at one location while finely ground elemental S co-granulated with potash fertilizer (MST product) produced yield equal to sulfate.
- Year 2 data points to slower availability of S oxidized from Tiger 90 as yield was increased by Tiger 90 but the increase in yield was less than sulfate or MST.
- All forms of sulfur produced equal yield potential at a sandy irrigated location.
- Ion probe data show that elemental S does take time to start oxidizing in Minnesota soils and may provide long-term S availability over the growing season. Finely ground elemental S was shown to be more effective in medium-fine textured soils than an elemental S- bentonite product such as Tiger 90.
- Recovery of sulfate S following oxidation of elemental S at 5oC ranged from -5 to 25% across 26 Minnesota soils when incubated for 112 days.

Introduction

The response of corn grain yield to sulfur fertilization has been one of the major factors for increased productivity and profitability in some cropping rotations. Current projects on sulfur timing, rate, and placement have clearly demonstrated the need for sulfur. While a soil test is available for sulfur, differences in sulfate due to S application are difficult to detect with the soil test and soil test concentration of sulfate-S can be high even in soils where S responses occur. This highlights our limited understanding of how sulfur cycles among forms in the soil. Sulfate-S can be reduced in low oxygen situations but a complete reduction of sulfate to hydrogen sulfide which can be lost to the atmospheric via volatilization unlikely. Basic research on forms of sulfur in the soil is needed to better understand availability in soils across Minnesota.

Elemental sulfur is a low-cost option for supplying S to plants but must be oxidized to sulfate prior to plant uptake. Oxidation is mediated by bacteria, *Thiobacillus thiobacteria*. From previous work, we know that the activity of *Thiobacillus* tends to be low when soils remain cool. In fact, the optimum temperature for *Thiobacillus* activity is above 80°F and even at these temperatures the oxidation of elemental sulfur can take 30 days. Developing an accurate model of oxidation is important to understand how to effectively utilize elemental sulfur in cropping systems. In addition, long-term studies where elemental sulfur sources are compared to sulfate are needed to assess whether oxidation later in the growing season can lead to a buildup of sulfate which, over time, will supply enough available sulfate sulfur to a crop.

Objectives

1. Evaluate the sulfur and nitrogen supply potential from soil organic matter in 26 Minnesota soil series at different incubation temperatures
2. Determine the oxidation potential of elemental sulfur in 26 Minnesota soils
3. Compare sulfur release and availability of a sulfate source of S versus two sources of elemental S in a continuous corn rotation
4. Evaluate changes in sulfur redox state and changes in soil sulfur pools sorbed to soil solids over time
5. Evaluate response among corn hybrids for single and split application of sulfur

Materials and Methods

Study 1: (Sulfur oxidation lab study) Soils from different growing regions, including from irrigated and rain-fed fields with sandy and medium or fine textures, were compared in a growth chamber. Twenty-six soils from differing crop growing regions were collected (southwest, south central, southeast, central sands, west central MN). Leaching columns are used to incubate soils in a growth chamber. The columns consist of ¾ inch PVC pipes cut to a length of 15 inches. A mixture of 40 grams of oven dry soil and 40 grams of a fine glass beads are added to each leaching column. Treatments consisting of a no sulfur control and two sources of sulfur are thoroughly mixed with the soil before adding to the columns. For the sulfur treatments, a rate of 200 ppm of sulfur (per unit soil) is applied as calcium sulfate (gypsum) or elemental sulfur (S was an analytical grade powder). A cap is placed at the bottom of each pipe with a 5/16 inch fitting will be connected to a collection vessel by plastic tubing to collect water. Glass wool is packed at the bottom of the column to prevent loss of soil and at the top of the column to prevent the dispersion of soil on the surface when water is added. At 0, 2, 4, 8, 12, 16 and 20 weeks approximately 150 mL of water was drawn through the leaching columns. The amount of water leached will be determined by weight then water will be analyzed for nitrate-N and sulfate-S by ion chromatography. To aid in leaching a vacuum was placed on the leaching columns.

Table 1. Soil series information, planted crop at each location, and initial potassium soil test data from phosphorus studies conducted in 2019. Soil test data was collected in the Fall at trial establishment from each main plot.

	Soil Test				SO_4-S			
Location	Bray-P1	K	pH	OM	0-6	6-12	12-24	Soil Series
	ppm			%	ppm			
Becker	127	164	6.8	1.6	8.8	8.8	8.3	Hubbard
Morris	37	198	7.9	5.8	12.4	14.2	13.2	McIntosh
Rosemount	29	171	5.4	4.2	11.5	10.5	8.3	Tallula
Waseca	17	170	5.7	4.7	10.1	9.4	7.1	Clarion-Webster

† K, Soil test potassium (K-ammonium acetate); CCE, calcium carbonate equivalency.

Study 2: (Long term S study) Long term S research trials were established at four locations in 2019 (Table 1) Since oxidation occurs later in the growing season a multi-year approach is needed to determine if the late oxidized S 1) can be carried over to the following year; and 2) if repeated application of elemental S can eventually provide adequate amounts of sulfate-S to corn. Studies will be established using a split plot design. Main plots will consist of S fertilizer rate and sub-plots will consist of S sources.

Sulfur source treatments will be a no sulfur control and three sources of S which consist of potassium sulfate, Tiger 90 (60-800 micron elemental S and bentonite mixture, and a co-granulated S source. Co-granulated S materials, similar to what is contained in the micro-essentials line of products, are becoming more available and allow for a more even distribution of elemental S as each fertilizer granule contains S along with N and P unlike Tiger 90 which is 90% S so the amount of product applied per acre is small. The co-granulated product used for this study is a potash-based material consisting of 49% K_2O and 13.6% S manufactured by Sulvaris (Calgary, AB) where the S is micronized to a smaller particle size ($\leq$40 microns) than Tiger 90. The use of a potash source eliminates the use of phosphate materials such as MAP, DAP, or TSP which can contain from 1-2% total S and can affect the ability to detect a response to S in a field study.

High P testing sites were selected, and additional P fertilizer was applied as a combination of in-furrow and 2x2 application of 6-24-6. Rates varied by site but typically were 5 gallons 6-24-6 in furrow at medium to fine textured sites plus 10 gallons 2x2. The in-furrow application rate was reduced to 3 GPA at Becker which is a sandy soil. The 6-24-6 product was tested by ICP and averaged 667 mg S L^{-1}.

All sulfur products will be applied to supply 5, 10, and 20 lbs of S per acre annually and treatments will be re-applied by hand to each plot every year. Additional K as 0-0-60 will be applied to balance K across plots and N will be applied at non-limiting rates. Plots are 20' in width (except for Waseca which was 15' in width) which allow for sub-dividing later during a second phase which will focus on draw-down of sulfur the soil. All treatments are replicated four times at each location and all fertilizer is applied in spring and incorporated prior to planting.

Corn grain yield response to S will be measured in all plots. Corn leaf tissue samples will be collected at V10 by sampling the uppermost fully developed leaf and at R1 sampling the ear leaf and the 2nd leaf from the top of the plant to be analyzed for total S concentration. A subsample of grain will be saved from each plot, ground, and analyzed for total S concentration. All samples will be analyzed for total S concentration using combustion analysis. Along with plant tissue tests canopy sensing was conducted at V5 using a crop circle 430 and at V10 and R1 using SPAD chlorophyll meters sampling the sample part of the canopy where leaf samples are collected.

Soil test S will be measured from each main block at the beginning of the trial at the 0-6, 6-12, and 12-24" depth and in the fall post-harvest at a 0-12 and 12-24" sampling depth. All soil samples were extracted using the mono-calcium phosphate procedure.

Past research has shown limited impacts of S application on increasing soil test S measurable. Plant root simulator (PRS) probes, sold by Western Ag. Innovations, were installed in the 10 lb S rate main blocks in all fertilizer sources and were sampled over a period of 8 sampling dates. A total of four anion probes were installed between the center two corn rows in an area 5' in each direction from the center of each plot. The PRS probes were installed in the soil to a depth of roughly 4-5 inches. At each sampling date the probes were removed from the soil, washed with deionized water, and new probes were re-installed into the slots created by the old probes. A garden knife was used to apply back pressure on the probes to ensure good contact between the soil and ion exchange membranes. Probes were sent to Western Ag. Innovations to be extracted and analyzed for sulfate-S sorbed.

Soil samples (0-6 and 6-12") were collected prior to the initial PRS instillation and each time PRS probes are installed and removed. A total of three cores were sampled from between the rows where PRS probes were installed and were analyzed for sulfate-S using the mono-calcium phosphate procedure.

A second set of cores were collected from the no-sulfur sub-plot using a zero-contamination soil core and sleeve for XANES analysis. A total of four cores were taken, one from each sub-plot, were vacuum sealed and were frozen to be stored for later analysis.

Table 2. Summary of cultural practices for studies conducted in 2019. Soil test data was collected in the Fall at trial establishment from each main plot.

			Date of		
Year	Location	Cultivar†	Spring Fert.	Planting	Harvest
2019	Becker	DK 50-08	3-May	4-May	24-Oct
	Morris	DK 50-08	14-May	15-May	14-Nov
	Rosemount	DK 50-08	7-May	16-May	28-Oct
	Waseca	DK 50-08	15-May	16-May	24-Oct
2020	Becker	DK 41-38	6-May	6-May	15-Oct
	Morris	DK 41-38	11-May	11-May	26-Oct
	Rosemount	DK 41-38	1-May	12-May	13-Oct
	Waseca	DK 41-38	4-May	7-May	15-Oct

† Dk, Dekalb.

‡ Fall fertilizer (fert.) was applied the fall the previous year in which the study was harvested.

Table 3. Summary of PRS probe installation and removal dates at four Minnesota locations during 2019.

			Date of removal for individual sampling times							
Year	Location	Install	1	2	3	4	5	6	7	8
2019	Becker	6-May	23-May	10-Jun	25-Jun	11-Jul	2-Aug	23-Aug	13-Sept	3-Oct
	Morris	15-May	30-May	13-Jun	2-Jul	16-Jul	6-Aug	28-Aug	16-Sept	16-Oct
	Rosemount	17-May	4-Jun	18-Jun	3-Jul	17-Jul	8-Aug	29-Aug	20-Sept	15-Oct
	Waseca	16-May	3-Jun	18-Jun	3-Jul	23-Jul	12-Aug	29-Aug	20-Sept	15-Oct
2020	Becker	6-May	21-May	3-Jun	17-Jun	30-Jun	23-Jul	12-Aug	2-Sept	28-Sept
	Morris	11-May	26-May	8-Jun	22-Jun	7-Jul	27-Jul	20-Aug	8-Sept	9-Oct
	Rosemount	12-May	28-May	9-Jun	24-Jun	7-Jul	29-Jul	11-Aug	9-Sept	7-Oct
	Waseca	7-May	20-May	5-Jun	16-Jun	2-Jul	21-Jul	11-Aug	2-Sept	30-Sept