Enhancing Continuous Corn Yields

Via ATS placement methods

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The Fluid Journal • Official Journal of the Fluid Fertilizer Foundation • Summer 2018 • Vol. 26, No. 3, Issue #101

Summary: *Selecting the appropriate sulfur (S) application rate is more important than source of S or timing of application as long as the source can supply readily available sulfate-S early in the growing season.*

Sales of S fertilizer sources have increased nearly three-fold in Minnesota in the past 15 years. Research has identified a need for S for corn in Minnesota (Kim et al., 2013), who banded ammonium thiosulfate fluid fertilizer with the planter two inches beside and below the corn seed at planting with and without 28% UAN (urea ammonium nitrate solution) and/or ammonium polyphosphate (APP, 10-3-4-0). Significant yield responses to ATS occurred when corn was grown on soils with less than 3.0% organic matter concentration in the top six inches of soil. Increased yield of corn in low organic matter soils follows with research by Sawyer and Barker (2002). However, research by Kaiser (2013) identified that yield response to S may be more likely in continuous corn in Minnesota for soils with greater than 3.0% organic matter concentration, Research by Vetsch et al. (2012) found benefits of fluid S banded on the soil surface beside the row with the planter in continuous corn production. This research has clearly demonstrated to farmers the value of incorporating S into their fertility management programs.

Elemental S and dry sources of sulfate S such as ammonium sulfate (AMS) are commonly applied to corn. Fertilizer guidelines for corn in Minnesota suggest that banding sulfur is more efficient than broadcast application (Kaiser et al. 2011). There have been questions as to what source to apply. Farmers applying phosphorus (P) and potassium (K) fertilizer in the fall want to limit risk for the loss of sulfate S and apply elemental S. The potential for oxidation of elemental S is temperature dependent and oxidation may not occur early in the growing season (Germida and Janzen 1993). Sulfur deficiencies have occurred in emerged corn in Minnesota fields where elemental S is applied. One option is delaying application of S to near time of planting. Fluid fertilizer sources containing S applied at or after planting can provide flexibility for corn farmers wanting to avoid the potential

Table 1. Initial soil test data for samples collected spring prior to treatment application.

Year	Location	Soil Series	Date of Planting	Soil Test (0-6") P	K	SO_4-S	OM	pH	0-2' SO_4-S
				----------ppm-------			-%-		-lb/ac-
2015	New Richland	Clarion	30-Apr	20	134	7	2.9	5.7	42
	Waseca	Webster	30-Apr	13	165	6	5.5	6.3	33
2016	Lamberton	Storden	19-May	12	100	5	3.5	6.2	41
	Renville	Okaboji	4-May	12†	175	6	7.8	7.7	42
2017	New Richland	Lester	12-May	52	185	13	4.4	6.1	69
	Renville	Okaboji	11-May	21†	218	10	5.3	7.4	64

P, Bray-P1 phosphorus; K ammonium acetate potassium; SO_4-S, mono-calcium phosphate extractable sulfate sulfur; OM, organic matter loss on ignition; pH, 1:1 soil:water.
†Olsen P test was used

for sulfate-S loss.

Ammonium thiosulfate (ATS) is a popular fluid fertilizer source of S in Minnesota. Starter fertilizer use is prevalent in Minnesota, but the risk for stand loss with ATS applied directly on the seed typically precludes the use of ATS as a pop-up fertilizer source (Kaiser and Rubin 2013). Clay soils make banding fertilizer beside and below the seed, such as the old 2x2 banding method difficult. The cost of fertilizer attachments for larger planters has resulted in less banding away from the seed row and increased application direction on the corn seed. Farmers currently rely on either surface band applications, such as those used by Vetsch et al. (2012) or applying ATS as a broadcast with their early pre-emergence weed control. The effectiveness of pre-emergence broadcast application of ATS has not been researched in Minnesota.

Broadcasting ATS after planting in corn on corn, with greater amounts of residue on the soil surface, could reduce the effectiveness of S applied if soil microbes use any sulfate during the decomposition of residue. Current Minnesota research has shown that dry ammonium sulfate can be surface applied up to the V5 growth stage and be as effective as preplant application (Kaiser, 2013). Granular fertilizer can bounce off residue when applied and reach the soil surface. Fluid fertilizer would have the tendency to dry on residue. Research in Minnesota (Kent et al., unpublished data) studied the effects of fall and spring-applied UAN (preplant) and K thiosulfate on decomposition rates of corn residue and corn yield response to S. No yield responses to S occurred; therefore, the data were inconclusive as to the benefits of fluid fertilizer containing S broadcast on top of corn residue and there was no direct comparison to dry fertilizer sources.

The objective of this was to determine if a surface band application of S as ATS is more efficient than a broadcast application of ATS or AMS, and to determine if a pre-emerge broadcast application of ATS is an effective source of applying S, compared to AMS broadcast at or before planting in continuous corn.

Methodology

Two field trials were established during each of the 2015, 2016, and 2017 growing seasons (Table 1). The previous crop was corn at all locations. A single hybrid and planting rate was used at all locations (Pioneer P0157 AM1 planted at 35,000 seeds per acre). Treatments were arranged as a factorial design within a randomized complete block design replicated four times. Factor 1 was fertilizer source and placement (1, ATS banded on the soil surface 1 to 2 inches beside the row with the corn planter; 2,ATS broadcast to the surface with flat fan nozzles after planting prior to corn emergence; 3,AMS broadcast pre-or at-planting). Factor 2 consists of S rate (0,2,5,5,10, and 20 lbs S/acre). The combination of the two factors resulted in 15 treatments (5 rates x 3 S source treatments). The corn planter used was equipped with row cleaners such that the surface banded ATS is applied to the soil surface and not on corn residue. Broadcast ATS treatments were applied using standard spray equipment in a total of 15 gallons of water/fertilizer mix. Urea ammonium nitrate (28 or 32% solution) was used to equilibrate N application so that all plots receive the same amount of N at planting for the banded ATS application and with the broadcast ATS application (N rate will be calculated based on the amount of N applied with the highest ATS application). Prior to planting, 200 lbs. of N per acre were applied as either Urea or a combination of Urea and AMS for treatments that received broadcast AMS. Phosphorus and K were kept at non-limiting rates and 5 GPA of 3-18-18 was applied directly on the corn seed to all plots. Plot size was 10' wide by 50' long (4-30" rows), Pioneer P0157AM1 was planted at a rate of 35,000 plant per acre at all locations.

Soil samples were collected from depths of 0-6 and 6-24". A single composite sample of 6 cores was

Table 2. Summary of main treatment effects of pre-plant ammonium sulfate (AMS PP), ammonium thiosulfate banded to the side of the row with the planter (ATS Band), and ammonium thiosulfate applied with flat fan nozzles to the soil surface after planting (ATS Broadcast). Effects did not differ among source and application methods for any measured variable.

Source	NDRE	V10 Leaf S	R2 Leaf S	Grain Yield	Grain S
		----------%----------		-bushels ac^{-1}-	----%----
AMS PP	0.299	0.192	0.163	223	0.099
ATS Band	0.296	0.191	0.161	221	0.098
ATS Broadcast	0.296	0.193	0.163	223	0.100

Table 3. Summary of significant variable where the data analysis over all locations indicated a significant effect of sulfur rate. Within columns, numbers followed by the same letter are not significantly different at $P \leq 0.10$

Sulfur Rate	NDRE	V10 Leaf S	R2 Leaf S	Grain Yield	Grain S
---lb S ac^{-1}---		----------%----------		-bushels ac^{-1}-	----%----
0	0.290c	0.186b	0.161bc	219c	0.097b
2.5	0.293bc	0.189b	0.159c	221bc	0.097b
5	0.299ab	0.190b	0.163abc	224ab	0.099ab
10	0.299ab	0.197a	0.164ab	223b	0.102a
20	0.306a	0.198a	0.165a	227a	0.102a

collected for each replication at each site. The 0-6" samples were analyzed for P, K, pH, organic matter and sulfate-S. The 6-24" samples will be analyzed for sulfate-S only. Residue levels at planting were assessed for each replication using the line transect method. Treatment performance was assessed by taking the uppermost fully develop leaf at V10 and the leaf opposite and below the primary ear at R2 from the middle two rows in each plot. Leaf samples were analyzed for total S concentration by ICP. Corn was sensed using a Crop Circle model 430 at the V5 growth stage to assess greenness and total biomass. Harvest data (corn grain yield and grain moisture concentration) was collected by hand, harvesting 20' of the middle two rows from each plot or with the use of the combine.

Data analysis was conducted pooling sites into two categories based on soil physical and chemical properties. Soils with a low S supply capacity were identified based on two of the following three criteria: slightly eroded, have slopes greater that 2%, and have a soil organic matter concentration of 3.5% or less in the top six inches. Sites with soils in this category were located at New Richland and Lamberton, Minnesota. The second site was relatively flat (less than 2% slope), had poor internal drainage, and an organic matter concentration of 4% or greater.

Data Summary (2015 to 2017)

There was no evidence of a variation in response to S rate based on source and method of application. Further summary is based on main effects of S source and S rate. There was no effect of S source or application method on any of the measured variables when averaged across rates and locations (Table 2). This indicates that the amount of S supplied by ATS was similar whether it was banded with the plater or broadcast after plating versus AMS. Analysis was also conducted based on soil organic matter concentration, but there was no difference for responses in what is considered high or low soil organic matter concentration, so the data are not shown. This indicates that ATS will perform comparably to AMS across a range of environments.

Averaged across source and placement, S rate significantly impacted all measured variables across the six locations (Table 3). Plant greenness, expressed as normalized difference red-edge (NDRE) value, increased at the V5 growth stage as S rate increased. The trend appeared to be linear, with the exception of the 5 and 10 lb S application rates which did not differ from each other. An increase in greenness, up to the largest amount of S applied, is surprising as only 10 lbs. of S per acre would be suggested for the majority of study locations.

Leaf S concentration varied among the S rates for the uppermost fully developed leaf at V10 and the leaf opposite and below the ear at R2 (Table 3). At V10, there was no difference among the 0, 2.5, and 5 lb S application rates. Leaf S concentration wag greater when 10 and 20 lbs. of S were applied but there was no difference between the 10 and 20 lb rates. At R2, leaf S concentration was greatest for the 20 lb application rate but there was no statistical difference among the 5, 10, and 20 lb rates, nor were there differences among the 0, 2.5, and 5 lb rates. In

general, an application rate between 5 to 10 lbs. should be sufficient for increasing leaf S concentration. What is interesting are the differences among the treatments based on soil organic matter classification. Data for samples collected at V10 followed a similar pattern regardless of soil organic matter concentration (Figure 1). However, for leaf S concentration at R2, S application rates differed only for the sites that were considered low in soil organic matter concentrations (4.0%), with an increasing trend from the 0 to the 10 lbs. S application rate.

The remaining sites considered high in soil organic matter showed no difference in leaf S concentration among the S application rates at the R2 growth stage. What has been noted at the sites with greater organic matter concentration is a severe yellowing of the upper leaves early in the growing season followed by dark green upper leaves, at or above the ear at tasseling or later. The data presented in Figure 1 would indicate a lack of S availability early in the growing season followed by adequate availability later on. Since S is not mobile in the plant it is likely that plants would green if S was being supplied later in the growing season and that deficiencies resulting in reduction in yield would be occurring early in the growing season. If a yield reduction does occur, mid-season tissue sampling at reproductive stages may not give an accurate assessment of S availability. Leaf S concentration at V10 and R2 were compared to corn relative yield but there was no correlation between the two leaf S concentrations and yield potential (data not shown). The lack of a relationship between leaf S concentration and yield did not vary based on soil organic matter concentration which indicated that not only may there not be a difference in S concentration, there is little to no potential for the test to predict yield potential.

"Sulfur is required to maximize corn grain yield"

Corn grain yield varied among S application rates across sources, timing, and location (Table 3). The 20 lb. S per acre application rate produced the greatest yield but did not differ from the 5 lb. application rate. For some reason, the 10 lb. application rate produced less yield than 20 lbs. but again, the 10 lb. application rate did not differ from the 5. The 2.5 lb. application rate produced slightly more yield than the 0 but was slightly less than 5 lbs. In total, the 5 lb. application rate appears to be optimal for S application regardless of source. In addition, there was little difference in the effect on yield based on organic matter concentration (Figure 2). The 2.5 lb. S application rate did not differ from the 5 lb. application rate, but the 20 did differ from the 2.5 lb. rate when soil organic matter concentration was less than four percent. The 5 lb. application rate generally did not result in less yield statistically, compared to the other rates, indicating that 5 lbs.

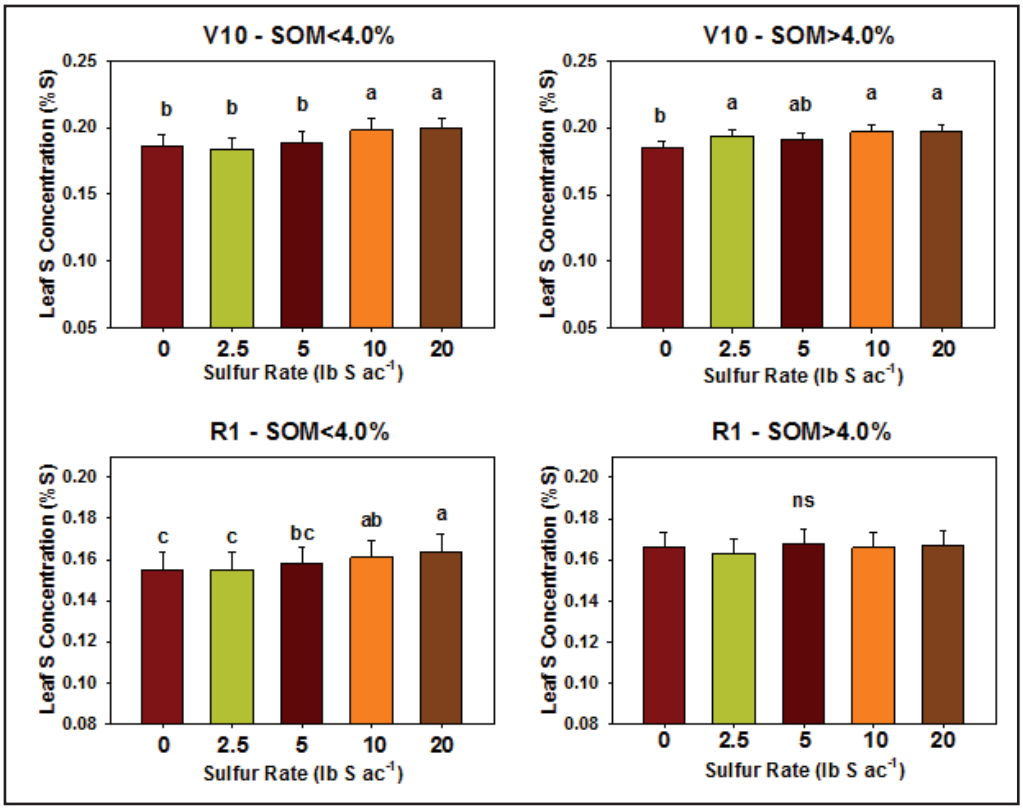

Figure 1. Summary of the impact of sulfur application rate on leaf sulfur concentration at V10 and R2 averaged across sources and timing based on organic matter concentration in the top six inches of soil. Small letters indicate treatment significant at P<0.10 based on sample timing and soil organic matter concentration.

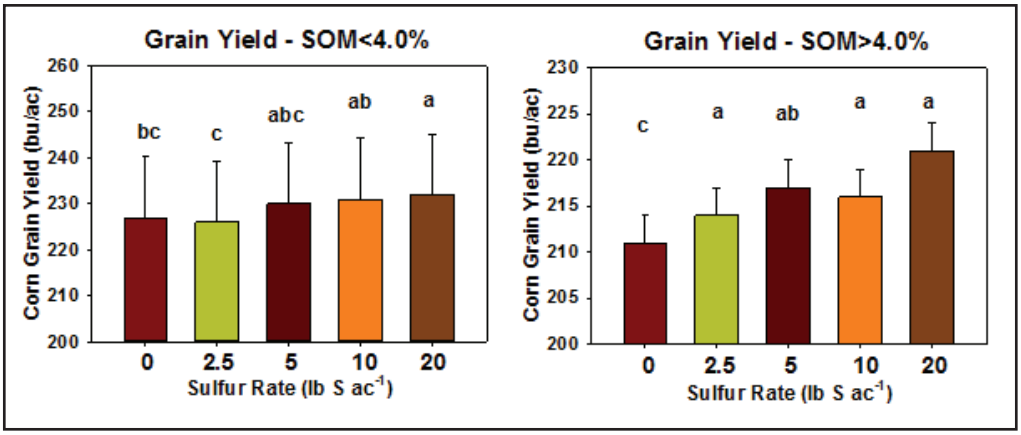

Figure 2. Summary of the impact of sulfur application rate on corn grain yield (adjusted to 15.5% moisture concentration) averaged across sources and timing based on organic matter concentration in the top six inches of soil. Small letters indicate treatment significant at P<0.10 based on sample timing and soil organic matter concentration.

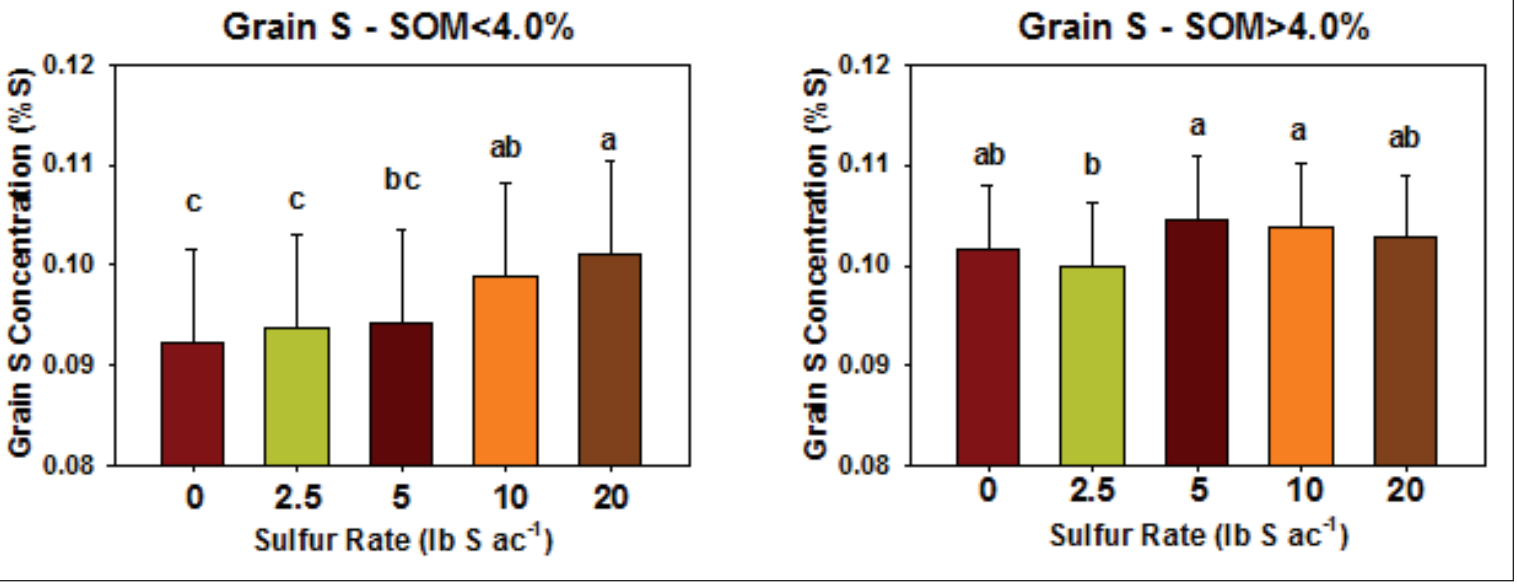

Figure 3. Summary of the impact of sulfur application rate on corn grain sulfur concentration (reported on a dry basis) averaged across sources and timing based on organic matter concentration in the top six inches of soil. Small letters indicate treatment significant at P<0.10 based on sample timing and soil organic matter concentration.

of S should be enough to maintain optimal yield, regardless of organic matter concentration.

The lack of an interaction between source and rate indicates that S supplied by ATS is similar to AMS and that, based on total S applied, there is no relative efficiency of banded S versus broadcast. Elemental S is released into the soil when ATS is applied and elemental S oxidation is difficult to predict in Minnesota soils. The fact that thiosulfate will provide sulfate S initially makes it a better product to consider than elemental S. Any elemental S oxidized later in the growing season will be available but the sulfate S released early will be readily used in the early stages of crop development. We could not measure oxidation potential in this study so the rate and relative potential for oxidation of elemental S in the soils tested is not known. It is clear that ATS can be applied at the same rate as AMS and not impact corn grain yield.

Grain S concentration varied among the rates of S applied (Table 3). The impact of S rate on grain S concentration was similar to that which occurred for the V10 leaf S concentration. Grain S concentration was greatest when at least 10 lbs. of S was applied. When considering differing organic matter concentrations, grain S concentration only differed from the control at low organic matter sites (less than 4.0% organic matter in the top six inches). There was a general increasing trend for a greater concentration of S in the grain as S rate increased for the low organic matter sites. In other research (Kim et al., 2013), S deficiencies have been expressed with decreased grain S concentration. What is surprising is the lack of difference in the higher organic matter sites, even though grain yield was impacted.

The lack of difference from the control for grain S concertation was similar to the lack of a response in R2 leaf S concentration shown in Figure 2. This lack of difference would again point to more S supplied by the soil later in the growing season and that any yield effects occurred due to early S deficiencies. This information is important as it indicates the potential for S deficiencies to occur on a wider range of locations across Minnesota. Previous suggestions for S application on soils with 4.0% organic matter concentration or less may not fully address the deficiencies across the state. Responses to 5 to 10 lbs. of S do indicate that only a small rate of S is required to get maximum yield potential. Fluid fertilizer sources are ideal for applying lower rates of S consistently across fields to get the needed amount of nutrient while minimizing costs.

Summing up

Sulfur is required to maximize corn grain yield in continuous corn across a wide range of soils across Minnesota. Assessing for S deficiencies using plant analysis will not be adequate for situations where S may be limiting for a short time early in the growing season. Application of S at a rate of 5 to 10 lbs. per acre before corn is adequate to produce maximum yield in situations where soil organic matter concentration is above and below 4.0% in the top six inches. There is no advantage for applying S as AMS versus ATS fluid, either banded on the soil surface to the side of the seed row with the plant or broadcast to the soil surface with flat fan nozzles in 15 gallons of water to the acre, prior to corn emergence. Total S application rate should not be changed when broadcasting or banding S as ATS versus broadcast AMS. Selecting the appropriate S application rate is more important than source of S or timing of application as long as the source can supply readily available sulfate S early in the growing season. Ammonium thiosulfate would be an ideal method to apply S at or after planting when using low (10 lbs. or less) application rates consistently across fields.

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