SULFUR CYCLING FROM CORN IN CORN-CORN AND CORN-SOYBEAN ROTATIONS

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Abstract

Sulfur fertilizer requirements for corn grown on medium and fine textured soils have increased over the past ten years. The effect of sulfur rate and timing on the potential for sulfur cycling and carryover within a two year crop rotation, corn-corn and corn-soybean, were studied. Sulfur was applied as ammonium sulfate on the soil surface at planting and the V3-V5 growth stages at rates of 0, 10, 20, 30, and 40 lbs of S per acre during the first cropping year. Each plot was divided in two prior to the second cropping year and 0 or 25 lbs of S per acre was applied. Corn whole plant samples taken at R6 showed no consistent impacts of S on stover production. The ratio of C:S in the stover was affected at four of seven locations where the ratio decreased to the 20 lb S rate then did not change. The C:S ratio, however, did not indicate S would be mineralized for the following years' crop, nor was it immobilized. Corn grain yield was increased by 10-20 lbs of S applied per acre at three of the seven first year corn locations. Corn yield was only increased at one of three corn locations studied for a second year and soybean yield was not increased. The data indicates that S can potentially carryover from year to year on medium or fine textured soils but the mechanism for carryover is not likely a result of excess SO_4^{2-} in the corn stover.

Introduction

Application of sulfur (S) to corn (*Zea Mays*. L.) is becoming more common in the upper Midwest. Early research indicated that corn grain yield increases from the application of S only occurred on coarse textured sandy soils with low organic matter (Rehm, 1984; O'leary and Rehm, 1990). However, more recent data from Iowa (Sawyer et al, 2009; 2011) and Minnesota (Rehm, 2005; Kim et al., 2013) have identified field areas with medium textured soils where grain yield increases are becoming more common. Kim et al. (2013) stated that yield responses were directly linked to soil organic matter concentration. Soil organic matter can supply around 95-98% of the total needs of corn (Rehm and Clapp, 2008). Available sulfur released from the soil is a microbial mitigated process through mineralization (Schoenau and Malhi, 2008). Since it is a microbial process, environmental factors such as soil temperature can affect mineralization, especially is soils remain cool. Thus, where S fertilizer should be applied may not be easily determined unless the weather can be accurately predicted. It is not well known if S fertilizer can be applied as a rescue treatment for corn if no fertilizer was applied prior to or at planting. Split applications of S have been studied for corn grown on sandy soils, but there was no clear benefit from split applications of S for increasing corn grain yield (Rehm, 1993).

Plant available sulfur exists in the soil in the sulfate (SO_4^{2-}) form which can be leached (Schoenau and Malhi, 2008). This is especially true for sandy soils which have large pore spaces to water to percolate through. Yearly application of S fertilizer is recommended on sandy soils due to a greater potential for sulfur to leach (Kaiser et al., 2011). The relative rate of leaching can be questioned for medium or fine textured soils. In addition, the total acres planted in continuous corn have increased calling into question the cycling of S when corn residue, which is high in carbon (C), is incorporated into the soil. The ratio of C:S is important in determining whether sulfur will be made available for the following years' crop. A ratio of 400:1 or greater will generally result in immobilization of SO_4^{2-} in the soil which a ration less than 200:1 will result in mineralization (Schoenau and Malhi, 2008). The impacts of sulfur fertilizer on the C:S ratio of corn stover and potential impacts on cycling of S within crop rotations is not clearly established in literature. Knowing the effects of S fertilizer on the C:S ratio would be beneficial for further understanding where corn grain yield can be increased.

Research on S cycling in crop rotations is critical in the establishment of S fertilizer guidelines for corn. The rate of S needed to maximize crop yields has been established for coarse textured soils (Kaiser et al., 2011). On medium textured soils current research has shown that needs tend to be smaller at 10-15 lbs of S broadcast applied per acre (Sawyer et 2009; 2011) versus 25 lbs S recommended for coarse textured sandy soils (Kaiser et al., 2011). However, none of the previous work studied the direct impact of timing of application as either a pre-plant treatment versus side-dress, the impacts on sulfur cycling in corn stover, and the carryover potential of S to the following years' crop. A series of replicated small plot trials were established to: 1) determine the effect of sulfur rate and timing on the yield of corn; 2) determine the effect of sulfur rate on the ratio of C:S within corn stover at the end of the first application year; and 3) study whether the yield of crops within a two year rotational cycle can be maximized by a single application of fertilizer during the first cropping year.

Experimental Methods

Trials were established at five locations (Table 1) that varied in fertilization history and previous crop. Plot size measured 20 feet wide by 40 feet long at all locations except for Theilman which measured 15 feet wide and 80 feet long. The large plot size was divided into a half for a second year study on the same plot areas. First year treatments consisted of a control (no sulfur fertilizer) and four sulfur rates of 10, 20 ,30 and 40 lbs of S per acre. Sulfur rates were broadcast applied on the soil surface at two timings of within 3 days after planting and at approximately the V3 to V4 growth stage (Abendroth et al., 2011). For the later application the fertilizer was broadcast between the corn rows to lessen the risk of fertilizer entering the whorl and causing leaf burning. Ammonium sulfate (21-0-0-24 N-P-K-S) was the broadcast sulfur source used because it is a highly available source of the nutrient. In order to separate out potential response to nitrogen, additional rates of fertilizer nitrogen were applied as ammonium nitrate (34-0-0) to equalize the nitrogen applied with the highest sulfur rate across all treatments for both application timings. All other nutrients were kept at non-limiting rates.

For the second year at each location studied, the previous rates x timing plots were divided in half. On one half of each plot, a single rate of 25 lbs. of S per acre was applied as ammonium sulfate while the other half received nitrogen only to balance the rate applied with ammonium sulfate. All fertilizer was applied in the spring following soil sampling and before planting. Each side by side with and without sulfur plot was used to compare yield response to the previous sulfur application.

Composite soil samples were taken prior to the first sulfur application during year 1. Soil samples were collected to a depth of 2 feet and separated out into 0-6, 6-12, and 12-24 inch depth increments. The 0-6 inch soil samples were analyzed for Bray-P1 phosphorus, ammonium acetate potassium, soil pH (1:1 soil:water), and organic matter content (loss on ignition). All depths were analyzed for soil SO_4^{2-} content by the mono-calcium phosphate method (Brown, 1998). For the first year studies, at physiological maturity six plants from each plot were sampled, the ear removed, and the stover weighed and analyzed for total S to determine plant stover yield and S uptake at the end of the season. Stover yield per acre was calculated by multiplying the plant population from each plot (as taken from the harvest rows in the spring) multiplied by the average individual plant stover weight.

Statistical analysis was conducted using the Proc MIXED procedure in SAS for fixed treatment effects of sulfur application rate and timing of application. Trial data was analyzed as a complete factorial with the no sulfur plots included with data from the pre-plant sulfur rate treatments. When the statistical analysis indicated a significant effect on main treatments ($P \leq 0.10$) treatment means were compared using least significant differences. When the analysis indicated a significant main treatment effect of sulfur rate regression analysis was used to fit a model to the data to determine optimum sulfur application rates.

Results and Discussion

Results from the initial soil test data are listed in Table 1. Soil P and K levels were High to Very High at all locations except for soil P at Theilman which was medium. Soil pH levels did not vary greatly between locations but did not appear to affect results. Soil organic matter content ranged from 2.3 to 7.2% representing a low to high range in the mineralization potential for sulfur within a soil. Soil sulfate levels varied widely but were the lowest for the Renville location. Since the soil sulfate test was not the same as used in the Minnesota recommendations a comparison to current recommendations for sand could not be done with any certainty. However, past work has noted that the recommended sulfur soil test performs poorly on fine textured soils.

Plant stover yield was not affected by sulfur rate at any location and the only significant difference was between application timing at the Theilman and Otisco locations (Table 2). In this case plant stover production was 0.4 tons per acre less when sulfur was applied as an early side-dress than the application near planting and a 0.3 ton per acre increase at Otisco. The decrease is odd since there was no effect of rate on stover yield, but may indicate there is some impact on sulfur in the early season that may affect plant growth later. However, there was no evidence of a similar effect on greenness and may not be a similar effect on yield.

Total stover produced was the least at the Renville, Theilman, and Montgomery locations averaging around 3.0 to 3.4 tons of dry matter per acre while nearly a ton more was produced (~4.0 tons dry matter per acre) at the New Ulm and Otisco sites. This is likely due to the greater fertility levels and more recent manure application at the New Ulm site or could be due to differences between the hybrids planted (data not shown). Since uptake is generally largely influenced by plant weight it appears unlikely that there would be luxury uptake of sulfur in the plant stover. There were significant differences in S uptake at two of the 2009 locations, New

Ulm and Theilman (data not shown). Overall this difference was only 1-2 lbs. of additional S taken up in the plant. At Theilman this increase was mainly due to increased plant mass, but at New Ulm the effect seemed to be more related to higher S concentrations in the plant. Overall this effect was minor and would not be expected to have major implication in S carryover to the next year. It still would be expected that little sulfur would become available from the residue for the following year.

The ratio of C:S was studied to determine whether the application of sulfur would affect the amount cycled in the corn stover. The C:S ratio near 300:1 at most sites except for the two field locations in 2011 which sulfur concentrations in the stover were less and the analysis would indicate that sulfur may be immobilized (Table 3). The samples from 2011 were run at a different lab but were run on the same machine (CNS combustion analyzer) therefore we would not expect the degree of variation found. The reason for the difference between the 2011 data and the other years is not clear. There could have been an effect of the dry weather conditions late in the season in 2011 or the differences could be due to the hybrids used (data not shown). Analysis of the data indicated that the ratio did change with sulfur fertilizer rate for the New Ulm, Montgomery, Otisco, and Alden locations. As a general trend, the C:S ratio decreased with increasing rate of sulfur applied. This decreased occurred up to the 20 lb S rate where there was no difference across sites. It is questionable whether the decrease in the C:S ratios would have significant impacts on cycling of S. Decreases in C:S ratio would not have had a significant impact on the Alden site where the concentrations were well above the 400:1 threshold. For New Ulm, Montgomery and Otisco the C:S ratio decreased but were still within the range we would not expect any release or immobilization of S. Thus, while the C:S ratio can be changed with fertilizer S it does not appear that the change would be large enough to significantly affect sulfur cycling to the next years' crop, but should not have resulted in significant immobilization of S during most years.

First year corn yield was significantly ($P \leq 0.10$) increased by sulfur rate at Renville, Theilman, and Otisco (Table 4) and was never impacted by timing. A yield response at Theilman was expected since deficiencies have been noted more commonly in southeastern Minnesota and research in Iowa has shown a yield increase from sulfur applied to similar silt loam soils. Other research has shown that the potential for a yield increase from sulfur tends to increase when soil organic matter levels in the top six inches is 3.0% or lower which would be consistent with the Otisco location. A yield response was not expected at the Renville location since the organic matter levels were near 5.0%. In this case the soil will generally mineralize enough sulfur but examination of the sulfur soil test values indicates that the site had the lowest residual soil test levels of all locations. Previous history on this location is multiple years in corn and a past, but not recent, manure history. At both the Renville and Theilman locations the 10 lb rate maximized corn yields, but there was a significant yield increase up to 20 lbs. at Otisco. The difference in the rates could be attributed both to low soil organic matter levels and a previous corn crop. More locations with similar cropping system and organic matter levels would be beneficial in order to determine if rates need to be adjusted for both previous crop and soil organic matter levels.

Effects from the first year's application of sulfur could only be clearly seen at the Renville location (Table 5) the second cropping year. At Renville, both the rate applied the previous and current year significantly affected corn yield. The interaction between the two was significant and indicates that the majority of the rate effect from the previous year's application occurred only when sulfur was not applied for the current crop. This response is reasonable since the 25 lbs applied for the second growing year should have been enough for the crop. While either of the rates applied at the Otisco site were not significant, there was a similar interaction found between the rate applied year one and year two. This interaction is again due to a rate response from the previous sulfur application but only when sulfur was not applied the current year. At Renville, corn yield responded to a maximum of 20 lbs of S per acre applied for the previous year. The amount was less at 10 lb S per acre at Otisco. The response at Otisco was interesting as it took 20 lbs of S to maximize yields in year 1. Therefore, the responsiveness of this site can be called into question. There was a significant amount of plot variability at the Medford corn site and the two soybean sites, but neither significantly responded to the application of sulfur. While limited, the yield response at Renville does indicate a potential for carryover of S to the following years' crop. Since the C:S ratio was not greatly affected the exact mechanism may likely be a direct carryover of SO_4^{2-} applied the previous year.

Conclusions

The data from this study has shown clear benefits for sulfur applied to corn. Broadcast S fertilizer rates required to maximize corn grain yield ranged from 10-20 lbs. of S per acre Delaying application of sulfur up to the V3 growth stage did not have any negative impacts on corn grain yield. Application of S fertilizer did affect the ability of S to be cycled within corn stover. However, the C:S ratio never indicated that mineralization of S was likely. Sulfur fertilizer applied during the first year of a two-year crop rotation significantly affected corn yields at one of three locations and did not impact the yield of soybean at two locations. The data indicates that S can carryover from one cropping season on medium or fine textured soils. The mechanism for carryover is likely not excess SO_4^{2-} taken up by the plant and recycled in the corn stover.

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Table 1. Initial soil test data taken in the spring before treatment application and averaged from composite samples from the four replications at each study location from 0-6" depth unless otherwise specified.

			Soil Test†					
	Previous						Sulfur	
Location	Crop	Tillage	P	K	pH	OM	0-6"	0-24"
			-------ppm-------			--%--	-------lb/ac-------	
New Ulm	Soybean	Chisel	44	385	6.9	7.2	18	66
Renville	Corn	Chisel	24	209	6.8	5.1	10	40
Theilman	Soybean	No-till	14	149	7.4	2.3	14	50
Montgomery	Soybean	Chisel	79	211	6.5	2.7	27	56
Otisco	Corn	Chisel	30	185	7.2	3.1	19	62
Alden	Soybean	No-till	128	361	5.9	3.6	8	30
Medford	Corn	Chisel	39	388	7.2	6.4	11	22

†P, Bray-P1 phosphorus; K, ammonium acetate potassium; pH, soil pH (1:1); OM, soil organic matter (LOI); sulfur, potassium chloride extractable sulfur.

Table 2. Average dry stover produced as calculated by averaging stover weight of 6 plants from each plot multiplied by plant population for sulfur rates applied before corn emergence (Pre) and at V3 (Post).

		Sulfur Application rate (lb S/ac)							Summary Statistics†		
Location	Timing	0	10	20	30	40	*Avg*		Rate	Timing	R x T
2009		----------tons dry matter per acre----------							----------------*P>F*----------------		
New Ulm	Pre	3.9	4.4	4.1	3.8	3.9	4.0		0.22	0.91	0.07
	Post		4.1	4.0	4.2	4.1	4.1				
	Avg	3.9	4.3	4.0	4.0	4.0					
Renville	Pre	3.3	3.1	3.3	3.0	3.2	3.2		0.28	0.27	0.17
	Post		3.7	2.9	3.5	3.1	3.3				
	Avg	3.3	3.4	3.1	3.3	3.1					
Theilman	Pre	3.1	3.2	3.3	3.3	3.3	3.3		0.53	0.07	0.63
	Post		2.7	3.2	2.9	2.8	2.9				
	Avg	3.1	3.0	3.3	3.1	3.1					
2010											
Montgomery	Pre	3.2	3.2	3.0	3.2	3.3	3.2		0.64	0.94	0.97
	Post	3.1	3.3	3.0	3.2	3.2	3.2				
	Avg	3.1	3.3	3.0	3.2	3.3					
Otisco	Pre	3.9	3.6	4.0	3.7	4.0	3.8		0.93	0.04	0.60
	Post	4.0	4.2	3.6	4.4	4.2	4.1				
	Avg	3.9	3.9	3.8	4.0	4.1					
2011											
Alden	Pre	3.3	3.3	3.1	3.1	3.5	3.3		0.34	0.63	0.71
	Post	3.2	3.2	3.0	3.3	3.2	3.2				
	Avg	3.3	3.3	3.1	3.2	3.4					
Medford	Pre	2.7	2.7	2.7	2.9	2.8	2.8		0.90	0.79	0.67
	Post	2.6	2.8	2.8	2.7	2.8	2.7				
	Avg	2.7	2.8	2.8	2.8	2.8					

** Avg, average for rate or timing data for each location*

† Summary statistics for sulfur rate and timing main effects and their interaction (R x T). Effects are significant when at the $P \leq 0.10$ *probability level.*

Table 3. Ratio of carbon to sulfur in corn stover summarized for sulfur rates applied before corn emergence (Pre) and at V3 (Post).

		Sulfur Application rate (lb S/ac)							Summary Statistics†		
Location	Timing	0	10	20	30	40	*Avg*		Rate	Timing	R x T
2009		---------------------C:S---------------------							-------------*P>F*-------------		
New Ulm	Pre	298	288	252	223	281	268		0.04	0.08	0.05
	Post		292	269	291	265	279				
	Avg	298	290	261	257	273					
Renville	Pre	345	325	342	314	322	330		0.44	0.77	0.75
	Post		342	331	317	331	330				
	Avg	345	333	337	316	327					
Theilman	Pre	335	332	295	303	267	306		0.41	0.38	0.87
	Post		321	324	343	289	319				
	Avg	335	326	309	323	278					
2010											
Montgomery	Pre	252	248	255	241	227	244		0.09	0.28	<0.01
	Post	273	269	219	249	256	253				
	Avg	263	258	237	245	241					
Otisco	Pre	278	268	268	244	269	266		0.08	0.38	0.12
	Post	301	275	263	268	247	271				
	Avg	290	272	266	256	258					
2011											
Alden	Pre	790	768	700	670	707	727		0.10	0.27	0.99
	Post	754	722	678	609	696	692				
	Avg	772	745	689	639	702					
Medford	Pre	838	788	832	854	871	836		0.35	0.49	0.63
	Post	921	708	836	746	825	807				
	Avg	879	748	834	800	848					

* *Avg, average for rate or timing data for each location*

† *Summary statistics for sulfur rate and timing main effects and their interaction (R x T). Effects are significant when at the* $P \leq 0.10$ *probability level.*

Table 4. Average corn yield data collected for sulfur application rates applied before plant emergence (Pre) or as an early side-dress application at V3 (Post).

		Sulfur Application rate (lb S/ac)							Summary Statistics†		
Location	Timing	0	10	20	30	40	*Avg*		Rate	Timing	R x T
2009		----------bushels per acre----------							----------------*P>F*---------------		
New Ulm	Pre	249	251	239	252	243	247		0.70	0.24	0.07
	Post		256	255	245	249	251				
	Avg	249	253	247	248	246					
Renville	Pre	179	203	200	203	195	196		0.08	0.72	0.78
	Post		210	201	213	191	205				
	Avg	179	207	201	208	194					
Theilman	Pre	194	222	216	217	219	215		0.02	0.09	0.75
	Post		218	217	209	218	216				
	Avg	194	220	216	213	219					
2010											
Montgomery	Pre	226	227	219	221	229	224		0.63	0.14	0.22
	Post	196	229	224	221	211	216				
	Avg	211	228	221	221	220					
Otisco	Pre	182	205	218	213	210	205		<0.01	0.99	0.99
	Post	184	206	213	211	214	206				
	Avg	183	205	215	212	212					
2011											
Alden	Pre	225	228	227	231	229			0.27	0.17	0.46
	Post	227	215	224	230	216					
	Avg	226	222	226	231	223					
Medford	Pre	166	171	159	164	159			0.78	0.77	0.85
	Post	163	165	172	164	162					
	Avg	165	168	166	164	161					

** Avg, average for rate or timing data for each location*

† Summary statistics for sulfur rate and timing main effects and their interaction (R x T). Effects are significant when at the $P \leq 0.10$ *probability level.*

Table 5. Summary of corn and soybean yield as affected by sulfur fertilizer applied before the previous crop (Rate 1) and a fresh application for the second year (Rate 2).

		Sulfur Application rate (lb S/ac)							Summary Statistics†		
Location	Timing	0	10	20	30	40	*Avg*		Rate 1	Rate 2	R1 x R2
2010		----------tons dry matter per acre----------							----------------*P>F*--------------		
Renville	0	184	206	213	220	210	209		0.04	0.06	<0.01
Corn	25	222	220	214	212	217	216				
	Avg	203	213	213	216	213					
Theilman	0	61	61	64	61	68	63		0.28	0.52	0.03
Soybean	25	61	59	65	65	60	62				
	Avg	61	60	64	63	64					
2011											
Montgomery	0	41	40	44	40	41	41		0.16	0.31	0.71
Soybean	25	42	41	44	41	42	42				
	Avg	41	40	44	41	42					
Otisco	0	184	190	196	190	191	190		0.78	0.41	0.01
Corn	25	191	193	198	202	198	196				
	Avg	187	191	197	196	195					
2012											
Medford	0	204	210	202	193	202	202		0.89	0.53	0.37
Corn	25	197	206	204	201	195	201				
	Avg	200	208	203	197	198					

** Avg, average for rate or timing data for each location*

† Summary statistics for sulfur rate and timing main effects and their interaction (R x T). Effects are significant when at the $P \leq 0.10$ *probability level.*

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