FLUID FERTILIZER'S ROLE IN SUSTAINING SOILS USED FOR BIO-FUELS PRODUCTION

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ABSTRACT

The short- and long-term effects on soil nutrient cycling, physical properties, and biological activity of striving for higher grain yields and removing crop residues for bio-fuels production must be understood to provide more quantitative crop and soil management guidelines. Studies focusing on tillage, fertilizer rates and placement, cover crops, and other management questions are needed. Recognizing the difficulty in addressing all of these variables in a single project, this study focuses on potassium (K) and sulfur (S) requirements of no-till corn (*Zea mays* L.) grown for a bio-fuels study. Our objectives for 2007 were to: i) evaluate the performance of several S fertilizers, including liquid ammonium thiosulfate (12-0-0-26S), as S sources for corn grown in Iowa, ii) complete analyses of field and laboratory data from 2006, and iii) initiate a comprehensive tillage, nutrient management, crop residue removal, and cover crop study. Field trials conducted in 2006 and 2007 targeted low organic matter soils found on eroded hill slopes. Plots established in 2006 on a Clarion loam showed that applying 30 lb S/A increased mean plant dry weight and whole-plant S concentrations at the V5 growth stage. By mid-silk, however, S concentrations were below the sufficiency range of 0.21% to 0.50%, even when S fertilizer had been applied. Consequently, corn yield was not increased and grain moisture at harvest was not reduced by S fertilizer application. No one S fertilizer source statistically outperformed the others, although 30 lb S/A applied as 13-33-0-15S increased grain yield 7 bu/A compared with the control. On a Clarion silt loam in 2007, application of 30 lb S/A once again increased mean plant dry weight and whole-plant concentrations of S at V5, but by mid-silk, S concentrations were again below the sufficiency range. This time, application of 30 lb S/A as either 13-33-0-15S or 21-0-0-24S increased yield by more than 10 bu./A compared with the control, a difference significant at p=0.08. Below-normal precipitation during part of each growing season and significant soil variability at both sites presumably minimized the statistical response to S fertilizer. However, for several reasons including erosion of hill slopes, fewer S impurities in fertilizer materials, and decreased atmospheric deposition of S throughout the upper Midwest, our results suggest that S may quickly become a limiting nutrient for corn grown to supply bio-fuels.

INTRODUCTION

Growing crops for bio-fuel production has attracted the attention of many producers – especially in the Corn Belt states. Both corn grain and stover are being evaluated as potential bio-fuel feedstocks, because as pointed out by Dibb (2006), current U.S. energy policy calls for more than doubling ethanol use by 2012. To ensure that sustainable grain and stover yields meet both current and new demands, the short- and long-term effects of removing both grain and stover on soil nutrient cycling, physical properties, and biological activity must be understood. Research has shown that no-tillage can reduce the rate of residue decomposition, thus offering a mechanism to maintain soil organic carbon, even if some portion of the crop residue is removed for bio-fuel production (Perlack et al., 2005). Initially, the bio-fuel industry will be forced to use estimates, such as those offered by Johnson et al. (2006), to determine the amount of crop residue that must remain on the land to sustain both the farming and ethanol production enterprises. To provide more quantitative guidelines, soil management studies focusing on tillage, fertilizer rates and placement, cover crops, and other management questions are needed. Because it would be difficult to address all of these variables in a single project, this project focuses on the potassium (K) and sulfur (S) requirements of no-till corn grown for bio-fuel production.

Although the importance of providing sufficient K for corn grain production is well recognized, the potential for K deficiencies has been documented in long-term no-till and minimum-till corn production fields in the Midwest in recent years (Rehm, 1992; Borges and Mallarino, 2001). Potassium deficiencies also have been observed in several cornfields under no-till management in southeastern Iowa. In some cases, results of soil tests for K have indicated that available K should be adequate to produce optimum yields. However, the levels of available K may become stratified in the soil after several years of no-till management, so that K extracted from a soil sample collected to plow depth may not reflect the true K status in the root zone. In addition, several other factors, such as K uptake efficiency of the corn hybrid and soil calcium (Ca) and magnesium (Mg) levels, may be involved. During the last several years, researchers, consultants, and farmers have somewhat ignored the importance of K management, as compared to N and P management, simply because of the potential off-site effects of N and P.

Sulfur fertilization is not commonly recommended for corn production in Iowa (Sawyer and Barker, 2002) and other parts of the upper Midwest, but adequate S is important (Hoeft and Walsh, 1970). Recently, positive yield responses to S fertilizer have been documented (O’Leary and Rehm, 1990; Stecker et al., 1995; Rehm, 2005; Lang et al., 2006), but as in the past (Hoeft et al., 1985), the responses have not been consistent. Responsive sites usually have coarse-textured soil, with relatively low organic matter content, which indicates that mineralization of organic S plays an important role in the soil supply of S to the crop. Under optimum soil temperature and moisture conditions, Tabatabai and Bremner (1972) showed that a significant amount of sulfate-S can be mineralized in a short period of time. However, when soils are cold in the early spring – a common occurrence in production areas of the upper Midwest under conservation tillage – S mineralization will be reduced and plant-available sulfate levels will be lower (Rehm, 2005). Moreover, in areas where soil erosion is a problem, or crop residues will be removed, organic matter levels in surface soil will tend to decrease. This will lead to reduced S mineralization and an increase in the probability of a yield response to S fertilizer.

Selection of an appropriate S fertilizer source is also a management decision faced by growers. Few studies have evaluated the various sources of S that can be used in a fertilizer program. In comparisons that have been reported, corn yields resulting from broadcast application of elemental S were no different from those in which sulfate sources were broadcast (Rehm, 1984). Rehm (2005) also reported that both fluid and dry sources of fertilizer S had an equal effect on corn grain yield, as long as contact with the seed was avoided. Similar research has not recently been conducted in Iowa.

The effectiveness of K and S fertilizers depends on both the ability of the added material to increase the soil supply of the nutrients, and the ability of the plant to respond to this increase. Changes in the soil supply of K, resulting from fertilizer addition, depend on soil type and inherent K levels (Kovar and Barber, 1990). Unfortunately, the effect of S fertilizer application on the soil supply of S is not as well understood, primarily because mineralization of organic S complicates the determination of the plant-available S in soil (Tabatabai, 1996).

The spatial distribution of fertilized soil relative to actively growing roots is also important. Karlen and Kovar (2005) reported that deep placement of preplant K fertilizer significantly increased both soil test K and plant growth in long-term tillage plots at the Iowa State University Agricultural Engineering Research Center. Rehm (2005) found that a band application of dry or liquid fertilizer S near the seed furrow significantly increased corn yields when conservation tillage was used. The results of these studies suggest that fertilizer placement can increase the positional availability of the nutrients for uptake by crop roots.

To evaluate the positional availability of K and S, traditional soil tests are of limited value, unless large blocks of soil are excavated (Stecker et al., 2001). In recent work, movement of bioavailable P from an application band into the soil profile has been successfully characterized with a sheet of bicarbonate-saturated anion exchange membrane inserted vertically into the soil profile, within and perpendicular to the row, several weeks after planting (Kovar, 2003; Kovar et al., 2004). The potential movement of plant-available K into the soil profile following a surface application of fluid fertilizer also has been evaluated with the same technique (Karlen and Kovar, 2005). Although there is significant variation among the measurements, the results do present convincing evidence that surface applications of liquid P or K fertilizer increase the availability of the nutrients in the root zone, and potentially benefit the plant throughout the remainder of the growing season. At this point, the dynamics of fertilizer S have not been evaluated.

The overall goal of this project is to evaluate the use of surface or subsurface bands of N-P-K-S fluid fertilizers to optimize positional and temporal availability of K and S in order to enhance corn grain and biomass productivity. This research is part of a much larger corn grain and residue removal study that focuses on standard and intensive fertility management, tillage, charcoal additions to test the “charcoal vision” for sustaining soil quality while producing bio-energy products, and utilization of annual or perennial cover crops to build soil carbon and help off-set potential negative impacts of stover removal. Specific objectives for 2007 were to: i) evaluate the performance of several S fertilizers, including liquid ammonium thiosulfate (12-0-0-26S), as S sources for corn grown in Iowa, ii) complete analyses of field and laboratory data from 2006, and iii) initiate a comprehensive tillage, nutrient management, crop residue removal, and cover crop study.

METHODS AND MATERIALS

Biomass Removal Study

A long-term tillage study conducted on the Clarion-Nicollet-Webster soil association at the Iowa State University Agronomy and Ag Engineering Research Center (AAERC), southwest of Ames in Boone County, Iowa, was terminated following the 2006 grain harvest. Since 1979, half of the study area was in continuous corn, while the remaining half was in a corn-soybean rotation. The original tillage treatments (moldboard plow, chisel plow, ridge-till and no-till) were imposed in 1971. During 2007, the site was deep-tilled, planted to oats, harvested to measure grain yield, baled to remove the straw, tilled again and sown with spring oat as a fall cover crop.

The new study initiated in autumn 2007 (objective iii) will focus on rates of residue removal (0, 50, and 90%), tillage (chisel plow versus no-tillage), charcoal additions for sustaining soil quality while producing bio-energy products, and use of annual or perennial cover crops to build soil carbon and help off-set potential negative impacts of corn stover removal. Because crop residue removal will substantially increase removal of P, K, and S compared to current corn and soybean grain production systems, one set of plots (each 40 x 300 ft.) will managed with standard practices (i.e., 30,000 plants/A and ~180+40+80+0 lb/A N-P_2O_5-K_2O-S) and a second set of plots will be managed with higher inputs (i.e., 45,000 plants/A and ~250+90+150+25 lb/A N-P_2O_5-K_2O-S). Actual fertilizer rates and the possible need for micronutrients in the high-fertility treatments will be based soil analyses. Conventional weed and insect control practices will be followed each year. All treatments will be replicated four times. Early-season whole plant samples and ear-leaf samples will be collected and analyzed to determine the nutritional status of the crop. Crop residue and grain yield will be measured using a single-pass combine with an 8-row header. Sub-samples of stover and grain will be analyzed for nutrient content. Specific nutrient management studies will be embedded into the overall design as critical management questions are encountered.

Sulfur Study

This embedded project draws upon preliminary field research conducted in 2006 and 2007, as well as a laboratory oriented, controlled-climate pot study for studying fundamental processes.

Laboratory Research

Soils were collected from three sites in Iowa where corn was grown. Site 1 in central Iowa (Boone County) was on a Clarion loam (fine-loamy, mixed, mesic Typic Haplaquolls). Site 2 in northeastern Iowa (Allamakee County) was on Fayette silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). Site 3 in southeastern Iowa (Scott County) had a Muscatine silt loam (fine-silty, mixed, superactive, mesic Aquic Hapludolls). After the samples were sieved to a 2 mm particle size, initial soil chemical properties were determined (Table 1). The samples were then stored in field-moist condition until January of 2007 when a laboratory experiment was initiated to determine the effect of different S fertilizer sources on plant-available soil S for the various soil types. Sulfur-enhanced MAP 13-33-0-15S (SMAP), dry 21-0-0-24S (AMS), and liquid 12-0-0-26S (ATS) materials were added to subsamples of each soil at rates equivalent to 0, 10, 20 and 40 lb S/A. A rate of 20 lb S/A is commonly applied to production fields in which S deficiencies have been observed. The material was applied and the soil and fertilizer were thoroughly mixed. A sufficient quantity of soil was treated to allow three replicates of each treatment. Following fertilizer addition, the soil was incubated at “field capacity” water content for six weeks.

Table 1. Initial properties of soils that will be used for laboratory research. Soil test ratings are not available for extractable S, although values of 10 ppm are considered adequate.

Soil	Bray-1 P	Exch. K	Exch. Ca	Exch. Mg	Extract. S	pH	OM
	------------------------ ppm			------------------------			%
Clarion loam	82 (VH)	338 (VH)	2222	228	9	6.5	2.7
Fayette sil	33 (VH)	152 (H)	2698	264	9	7.0	2.4
Muscatine sil	32 (VH)	199 (VH)	3802	497	8	6.4	4.3

After incubation, soil solution S concentration and extractable S (SO^{4-}) were determined in the fertilized and unfertilized treatments. Relative changes in the values of these soil supply parameters will be used to compare the effects of the three S sources among the soils.

A series of pot experiments was conducted in a controlled-climate chamber. Each fertilizer source/rate treatment combination was replicated three times. Because space was limited in the controlled-climate chamber, three individual experiments were conducted, with one complete replicate grown each time. Pre-germinated corn (Pioneer 36N71) seedlings were planted in each pot. After 21 days, pots were harvested. Total dry matter production and nutrient (S, N, P, K) uptake from each treatment have been measured. Although data analyses are incomplete, the data are being used to compare S sources and to determine if S source by soil type interactions occurred.

Field Research

Field Sites and S Fertilizer Treatments

Field plots were established in 2006 at the Iowa State University Boyd Research Center, southwest of Ames in Boone County, Iowa. At this location, the soil is a Clarion loam (fine-loamy, mixed, mesic Typic Haplaquolls). The previous crop was soybean. Plots were left undisturbed after the 2005 harvest. Spring tillage included one pass with a disk and one pass with a field cultivator. Plot size was 12.5 ft. by 250 ft. (0.072A). Soil samples (0-6 in.) were collected with a hand probe from each plot 7 March, and analyzed for pH, organic matter content, extractable SO^{4-}, available P, exchangeable K, Ca, and Mg, and CEC (Table 2).

In 2007, plots were established at the Iowa State University AAERC. At this location, the soil is a Clarion silt loam (fine-loamy, mixed, mesic Typic Haplaquolls). The previous crop was soybean. Plots were left undisturbed after the 2006 harvest. Spring tillage included one pass with a disk and one pass with a field cultivator. Plot size was 12.5 ft. by 90 ft. (0.026A). Soil samples (0-6 in.) were collected with a hand probe from each plot 21 April, and analyzed as outlined for 2006 (Table 2).

The experimental design each year was a randomized complete block with four treatments and four replications. Fertilizer treatments were: i) control; ii) 30 lb S/A applied as SMAP (13-33-0-15S); iii) 30 lb S/A applied as AMS (21-0-0-24S); and iv) 30 lb S/A applied as liquid ATS(12-0-0-26S). The dry materials (treatments ii and iii) were applied as a subsurface band two inches to the side of the seed row and three inches below the soil surface, while the liquid was applied at planting as a surface dribble two inches to the side of the seed row. Six weeks after planting, N fertilizer was applied to all plots. Accounting for the N applied with the S fertilizer treatments, all plots received a total of 155 lb N/A.

Table 2. Initial soil test levels in Clarion loam (2006) and Clarion silt loam (2007). Range indicates variability among all plots at each location. Soil test ratings are not available for extractable S, although values of 10 ppm are considered adequate.

Soil Test Parameter	Composite		Range of Values	
	2006	2007	2006	2007
Bray-1 P, ppm	35 (VH)	30 (VH)	15 (Opt) – 60 (VH)	13 (Opt) – 55 (VH)
Exchangeable K, ppm	180 (VH)	123 (Opt)	123 (Opt) – 304 (VH)	98 (L) – 146 (Opt)
Exchangeable Ca, ppm	2320	2933	1881 – 2585	2178 – 4052
Exchangeable Mg, ppm	232	437	192 – 275	322 – 540
Extractable S, ppm	3.6	8.5	1 – 7	7 – 13
pH	6.9	6.2	6.2 – 7.2	5.5 – 7.4
Organic Matter, %	2.2	3.2	1.9 – 2.5	2.4 – 4.4
CEC, cmol(+)/kg	14.3	22.4	12.6 – 15.4	17.7 – 31.9

Field Measurements

Corn (Pioneer 36N71) was planted 21 April 2006 in 30-inch rows at a seeding rate of 30,000 plants/A. Each plot consisted of five rows. In 2007, corn (Fontanelle 4693) was planted 2 May in 30-inch rows at a seeding rate of 32,000 plants/A. Again, each plot consisted of five rows. Stand counts were conducted each year. The effect of S fertilizer on early-season nutrient uptake was determined by analysis of whole-plant samples collected at the V5 to V6 growth stage. Ear-leaf samples were also collected at the mid-silk growth stage and analyzed for total nutrient content. The center three rows of each plot were harvested with a small plot combine equipped with a moisture meter and electronic scale to determine final yield and grain moisture. Grain and stover samples were collected by hand harvesting six randomly selected plants from each plot. Samples then were analyzed for nutrient content.

Soil-test, plant tissue, and yield data were analyzed using a general linear models (GLM) procedure of SAS (SAS Institute, 1999). Multiple comparisons among variables with significant treatment effects were tested with the Tukey-Kramer method at the 0.05 level of significance, unless otherwise noted.

RESULTS AND DISCUSSION

Biomass Removal Study

A field study was initiated on Clarion-Nicollet-Webster Association soils at the Iowa State AAERC to quantify the impact of harvesting crop residue for bio-fuels on the soil resource. Soil samples were collected in October of 2006. Following sample collection, the site was deep-ripped to minimize carry-over from the long-term tillage treatments. In spring of 2007, oats were planted to prevent soil erosion and remove legacy nutrients from the soil. The oats were harvested in mid-July, using GPS to identify the historical tillage treatments. Grain yield averaged 94.4 and 95.0 bu/A for the long-term continuous corn and rotated blocks, respectively. A tillage legacy was still evident despite deep ripping the entire site in November 2006. Oat yields averaged 99, 96, 94, 94, and 90 bu/A for the historical chisel, disk, moldboard, ridge-till, and no-till treatments, respectively. Straw was baled from the entire area but it was not possible to measure individual treatment yields. New plots [16 rows (40 ft) wide] were established, sprayed with glyphosate to control weeds and remained fallow for approximately eight weeks. From soil test results, the lowest Bray-1 P value (14 ppm) and lowest exchangeable K value (83 ppm) were measured in the 4-8 inch depth. These soil test values would rank as low for P and very low for K. Based on these results, 90 lb P_2O_5/A and 240 lb K_2O/A were broadcast over the entire research site in September and mixed with the surface soil by chisel plowing. Surface or subsurface bands of N-P-K-S fluid fertilizers will be utilized to provide the N, P, K, and S for both standard and high fertility treatments in the new biomass study. Rates will be finalized in the spring of 2008 and the material applied either pre-plant or at the time of planting.

Sulfur Study

Effect of Sulfur Fertilizer on Plant Nutrition

Sulfur fertilizer had no effect on emergence in either year, with a mean of 87.8% and values ranging from 79% to 95% in 2006, and a mean of 87% and values ranging from 83% to 92% in 2007. This was expected, given that the material was not placed in the seed furrow.

Sulfur addition to Clarion loam in 2006 affected early plant growth and both N and S concentrations of the plant tissue (Table 3). Application of 30 lb S/A as 13-33-0-15S increased mean plant dry weight at the V5 growth stage. The trend was similar when 21-0-0-24S and 12-0-0-26S were used as S sources. Application of S increased whole-plant concentrations of S at the five-leaf stage, regardless of S source (Table 3). A tissue concentration of 0.15% S is considered adequate for corn at this growth stage (Mills and Jones, 1996). As predicted by the initial soil tests (Table 2), whole-plant P and K concentrations at V5 (Table 3) were within or slightly above the sufficiency ranges. Nitrogen concentrations, however, were below the published critical value of 3.5% (Mills and Jones, 1996), suggesting that both the N applied with the S fertilizers and the soil N from the previous soybean crop were not sufficient to support the corn crop before additional N was sidedressed six weeks after planting.

Sulfur addition to Clarion silt loam in 2007 also affected early plant growth and both N and S concentrations of the plant tissue (Table 3). Application of 30 lb S/A as 13-33-0-15S increased mean plant dry weight at the V5 growth stage. No differences were found when 21-0-0-24S and 12-0-0-26S were used as S sources. Application of S increased whole-plant concentrations of S at the five-leaf stage, regardless of S source (Table 3). Whole-plant P concentrations at V5 (Table 3) were within or slightly above the sufficiency ranges, as predicted by soil testing (Table 2),. Nitrogen and K concentrations, however, were below the published critical values of 3.5% N and 2.5% K (Mills and Jones, 1996). This again suggests that soil N and N applied at planting were not sufficient to support the crop before additional N was sidedressed. With respect to K, soils in four of the 16 plots in the trial tested below optimum, so low tissue K concentrations are a reflection of this problem.

Table 3. Effect of 30 lb S/A on whole-plant dry weight, and sulfur (S), nitrogen (N), phosphorus (P), and potassium (K) concentrations at the V5 growth stage of corn grown on a Clarion loam in 2006 and a Clarion silt loam in 2007. Values are least square means of four replications. Values within each year followed by the same letter are not significantly different at the 0.05 level.

Treatment	Dry Weight	Nutrient			
		S	N	P	K
	g plant^{-1}	------------------- % --------------------			
		2006 Field Trial			
Control	4.3b	0.17b	3.13b	0.47a	4.16a
13-33-0-15S (SMAP)	7.4a	0.21a	3.43a	0.46a	3.51a
21-0-0-24S (AMS)	6.1ab	0.21a	3.49a	0.44a	3.81a
12-0-0-26S (ATS)	5.8ab	0.23a	3.18b	0.42b	3.92a
		2007 Field Trial			
Control	6.0b	0.16b	2.89b	0.34a	2.01a
13-33-0-15S (SMAP)	8.9a	0.20a	3.24ab	0.37a	1.71a
21-0-0-24S (AMS)	7.2ab	0.19a	3.27a	0.31a	1.85a
12-0-0-26S (ATS)	5.5b	0.18a	2.94ab	0.33a	1.81a

At mid-silk in 2006, both N and P tissue concentrations in ear leaves (Table 4) were in the sufficiency ranges (2.70% to 4.00% for N and 0.25% to 0.50% for P) for all treatments (Mills and Jones, 1996). The K concentration in the tissue, however, was below the sufficiency range of 1.70% to 3.00 %. More important, the S concentration in the tissue was also below the sufficiency range of 0.21% to 0.50%, even when S was applied (Table 4). Given that precipitation was below normal during this part of the 2006 growing season, the soil supply of both K and S may have been limited. Although the total amount of exchangeable K in the soil (Table 2) was more than adequate, low soil water content would have limited diffusive flux of K to the corn roots. Because soil supply of S is mainly via mass flow (Barber, 1995), low concentrations of S in soil solution and low soil water content would have had a combined negative effect on the amount of S reaching the roots.

In 2007, only tissue N concentrations in ear leaves (Table 4) were in the sufficiency range for all treatments. The P and K concentrations in the tissue were below the sufficiency ranges of 0.25% to 0.50% for P and 1.70% to 3.00 % for K. As in 2006, the S concentration in the tissue was below the sufficiency range for all treatments (Table 4). Given that precipitation was below normal during both June and July of 2007, the soil supply of P, K, and S probably was limited. Although the amount of plant-available P in the soil (Table 2) was more than adequate, low soil water content would have limited diffusive flux of P. With exchangeable K levels near the critical value and water availability less than adequate, diffusive flux of K to the roots certainly was limited. Again, low concentrations of S in soil solution and low soil water content negatively affected soil supply of S.

Table 4. Effect of 30 lb S/A on ear-leaf sulfur (S), nitrogen (N), phosphorus (P), and potassium (K) concentrations at the mid-silk stage of corn grown on a Clarion loam in 2006 and a Clarion silt loam in 2007. Values are least square means of four replications. Values within each year followed by the same letter are not significantly different at the 0.05 level.

Treatment	Nutrient			
	S	N	P	K
	------------------- % --------------------			
	2006 Field Trial			
Control	0.16a	2.89a	0.24a	1.24a
13-33-0-15S (SMAP)	0.16a	2.87a	0.26a	1.23a
21-0-0-24S (AMS)	0.15a	2.80a	0.24a	1.17a
12-0-0-26S (ATS)	0.16a	2.82a	0.25a	1.24a
	2007 Field Trial			
Control	0.14a	2.68a	0.22a	1.06a
13-33-0-15S (SMAP)	0.15a	2.74a	0.21a	1.03a
21-0-0-24S (AMS)	0.16a	2.86a	0.20a	1.03a
12-0-0-26S (ATS)	0.16a	2.88a	0.21a	1.03a

Effect of Sulfur Fertilizer on Corn Yield

In 2006, corn yield was not increased and grain moisture at harvest was not reduced by S fertilizer application to the Clarion loam soil at this location. Therefore, no one S fertilizer source outperformed the others (Table 5). An application of 30 lb S/A as 13-33-0-15S added seven bu./A compared with the control treatment, but the difference was not significant ($p<0.05$) because of the variability among the treatment plots. When a less conservative level of significance was used ($p<0.10$), however, a yield response was observed. Again, below-normal precipitation during part of the growing season and significant soil variability at this site likely affected the measured yield response to S fertilizer. Sulfur removals with harvested grain and corn residue were similar among the treatments (Table 5), suggesting that soil S in the control plots was further depleted after harvest.

At the AAERC location in 2007, application of 30 lb S/A as either 13-33-0-15S or 21-0-0-24S added more than 10 bu./A compared with the control treatment, and the difference was significant at $p=0.08$ (Table 6). Based on an estimated concentration of S (0.09%) in the harvested grain, S removals were similar among the treatments (Table 6). Similar to 2006, below-normal precipitation during the middle of the growing season and significant soil variability at this site likely affected the measured yield response to S fertilizer.

Table 5. Effect of 30 lb S/A on corn yields, grain moisture at harvest, and S removals in grain and stover in 2006. Values are least square means of four replications. Values followed by the same letter are not significantly different at the 0.05 level. For comparative purposes, values for least significant differences at other levels of significance are given.

Treatment	Grain Yield*	Grain Moisture	S Removals	
	-- bu/A --	-- % --	----------- lb S/A -----------	
Control	170a	14.5a	7.29a	4.42a
13-33-0-15S (Simplot)	177a	14.6a	8.30a	4.50a
21-0-0-24S (AMS)	172a	14.5a	8.08a	4.13a
12-0-0-26S (ATS)	171a	14.4a	8.03a	4.90a
LSD (0.05)	7.5	0.54	1.04	0.73
LSD (0.10)	6.1	0.44	0.84	0.64

*Yields adjusted to 15.5 % moisture.

Table 6. Effect of 30 lb S/A on corn yields and grain moisture at harvest in 2007. Values are least square means of four replications. Values followed by the same letter are not significantly different at the 0.05 level. Estimated S removals in harvested grain are also given for each treatment. For comparative purposes, values for least significant differences at other levels of significance are given.

Treatment	Grain Yield*	Grain Moisture	Estimated S Removals
	-- bu/A --	-- % --	lb S/A
Control	176a	14.9a	8.80a
13-33-0-15S (Simplot)	186a	14.6a	9.29a
21-0-0-24S (AMS)	186a	14.7a	9.30a
12-0-0-26S (ATS)	183a	14.6a	9.10a
LSD (0.05)	13	0.4	0.64
LSD (0.10)	10	0.3	0.52

*Yields adjusted to 15.5 % moisture.

SUMMARY

To evaluate the use of N-P-K-S fluid fertilizers to optimize positional and temporal availability of K and S for bio-fuel corn production, a field study was initiated on Clarion-Nicollet-Webster Association soils at the Iowa State AAERC in 2007. Preliminary planning, including soil testing and blanket fertilizer application, was completed, and corn production will proceed in 2008.

Field trials were conducted in 2006 and 2007 to evaluate S fertilizer responses on selected eroded hill slope soils in central Iowa. In field trials on Clarion loam in 2006, application of 30 lb S/A increased mean plant dry weight and whole-plant concentrations of S at the V5 growth stage. At the mid-silk growth stage, however, S concentration in the tissue was below the sufficiency range, even when S fertilizer had been applied. Consequently, corn yield was not increased and grain moisture at harvest was not reduced by S fertilizer application. When a less conservative level of significance was used ($p<0.10$), however, a yield response was observed. No one S fertilizer source outperformed the others, although 30 lb S/A as 13-33-0-15S added seven bu./A compared with the control treatment. Below-normal precipitation during part of the growing season and significant soil variability at this site likely affected the response to S fertilizer.

In field trials on Clarion silt loam in 2007, results were similar to those of 2006. Application of 30 lb S/A increased mean plant dry weight and whole-plant concentrations of S at the V5 growth stage. At the mid-silk growth stage, however, S concentration in the tissue was below the sufficiency range, even when S had been applied. Nevertheless, application of 30 lb S/A as either 13-33-0-15S or 21-0-0-24S added more than 10 bu./A compared with the control treatment, and the difference was significant at p=0.08. Below-normal precipitation during part of the growing season and significant soil variability at this site likely affected the response to S fertilizer. Because surface soil on hill slopes often is eroded, fertilizer materials contain less S as an impurity, and atmospheric deposition of S has decreased in the upper Midwest, the results of these trials suggest that S may quickly become a limiting nutrient in bio-fuels production systems.

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