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. This study focuses on potassium (K) and sulfur (S) requirements of corn (*Zea mays* L.) grown for bio-energy feedstock production. Our objectives for 2008 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, and ii) establish a comprehensive tillage, nutrient management, crop residue removal, and cover crop study. As in 2006 and 2007, S fertility trials targeted low organic matter soils found on eroded hill slopes. On a Clarion loam in 2008, application of 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, even when S fertilizer had been applied. In 2008, application of 30 lb S/A as 13-33-0-15S significantly ($p<0.05$) increased grain yield by more than 12 bu/A, compared with the control. Stover yield increased 1.2 tons/A after application of 30 lb S/A as 12-0-0-26S. Based on current pricing, the replacement cost of S removed with the grain and stover is still relatively low. A 25-acre field study was also initiated at the ISU Agronomy & Agricultural/Biosystems Engineering Research Center. Continuous corn will be grown using a variety of soil and crop management systems including a 30"-row spacing, standard fertility management treatment and a twin-row, high-population treatment with increased nutrient addition in split-applications. Analysis of V6 whole plant and ear-leaf samples indicated N levels for both systems were lower than desired at both growth stages, S was approaching the lower level at V6, and K concentrations at anthesis were approaching the lower level – presumably because Ca levels were above the high rating (0.4%). Grain yield for the 30" and twin-row planting configurations averaged 171 and 183 bu/A, respectively. Corn stover was harvested using at two heights (just below the ear shank and at a stubble height of approximately 4 inches). The amount of dry stover collected averaged 2.5, 2.9, 2.8, and 3.1 tons/A for the high and low cuts of the two configurations, respectively. Residue samples collected at harvest are currently being processed to determine dry matter production and nutrient composition, so that the amount of residue returned to the soil and the amounts of nutrients removed can be calculated.

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-energy 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 factors are needed. Because it would be difficult to address all of these variables in a single project, this project focuses on potassium (K) and sulfur (S) requirements of corn grown for bio-fuel production.

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/Biosystems 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. Those results suggest that fertilizer placement can increase the positional availability of the nutrients for uptake by crop roots.

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, biochar additions to test the “charcoal vision” 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 stover removal. Specific objectives for 2008 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, and ii) establish a comprehensive tillage, nutrient management, crop residue removal, and cover crop study.

METHODS AND MATERIALS

Sulfur Study

This embedded project draws upon preliminary field research conducted in 2006 and 2007, as well as a 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). The samples were stored in field-moist condition until early 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 (SEF), 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. 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.

Pot experiments were conducted in 2007 and 2008 in a controlled-climate chamber. Each fertilizer source/rate treatment combination was replicated three times. Because space was limited in the 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 plots were established in 2008 at the Iowa State University Boyd Research Center, southwest of Ames in Boone County, Iowa. At this location, the soil is classified as a Clarion loam (fine-loamy, mixed, mesic Typic Haplaquolls). The previous crop was soybean. Plots were left undisturbed after the 2007 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 30 April, and analyzed for pH, organic matter content, extractable SO^{4-}, available P, exchangeable K, Ca, and Mg, and CEC (Table 1).

The experimental design was a randomized complete block with four replications. Fertilizer treatments were: i) control; ii) 30 lb S/A applied as SEF (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 1. Initial soil test levels for Clarion loam in 2008. Range indicates variability among all plots in study. Soil test ratings are not available for extractable S, although values of 10 ppm are considered adequate.

Soil Test Parameter	Composite	Range of Values
Bray-1 P, ppm	21 (H)	9 (L) – 36 (VH)
Exchangeable K, ppm	116 (L)	91 (L) – 177 (H)
Exchangeable Ca, ppm	2017	1379 – 2308
Exchangeable Mg, ppm	204	163 – 243
Extractable S, ppm	5.8	4 – 9
pH	6.9	5.6 – 7.6
Organic Matter, %	2.3	2.0 – 2.6
CEC, cmol(+)/kg	12.3	10.2 – 13.8

Corn (Pioneer 36V75) was planted 6 May 2008 in 30-inch rows at a seeding rate of 32,000 plants/A. Each plot consisted of five rows. Stand counts were conducted 20 June. 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 eight randomly selected plants from each plot. Samples then were analyzed for nutrient content.

Soil, plant, 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.

Biomass Removal Study

A new study was initiated on the Clarion-Nicollet-Webster soil association at the Iowa State University Agronomy & Agricultural/Biosystems Engineering Research Center (AAERC), southwest of Ames in Boone County, Iowa. The study focuses on rates of residue removal (0, 50, and 90%), tillage (chisel plow versus no-tillage), biochar 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 substantially increases removal of P, K, and S compared to current corn and soybean grain production systems, one set of plots (40 x 280 ft.) is managed with standard practices and a second set of plots is managed with higher inputs. Conventional weed and insect control practices are being followed. The study includes 22 treatments that are replicated four times. Early-season whole plant samples and ear-leaf samples were collected and analyzed to determine the nutritional status of the crop. Crop residue and grain yields were 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.

RESULTS AND DISCUSSION

Sulfur Study

Effect of Sulfur Fertilizer on Plant Nutrition

Sulfur fertilizer had no effect on plant emergence in 2008, with a mean of 87% and values ranging from 83% to 89%. This was expected, given that the material was not placed in the seed furrow.

Sulfur addition to Clarion loam in 2008 affected early plant growth and both N and S concentrations of the plant tissue (Table 2). 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 also increased whole-plant concentrations of S at the five-leaf stage (Table 2), although a concentration of 0.15% S is considered adequate for corn at this growth stage (Mills and Jones, 1996). Whole-plant P and K concentrations at V5 (Table 2) were within the sufficiency ranges of 0.30% to 0.50% for P and 2.5% to 4% for K, even though the soil initially tested low in K (Table 1). Nitrogen concentrations were well 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. This may have been due to N losses caused by excessive rainfall received in the weeks following planting. A statewide average of 9.03 inches of rain (2.45 inches is normal for the period) was received during the first two weeks of June (Hillaker, 2009).

Table 2. 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 2008. 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}	------------------- % --------------------			
Control	5.4b	0.15b	2.40b	0.36a	3.73a
13-33-0-15S (SEF)	7.9a	0.17ab	2.64ab	0.39a	3.23a
21-0-0-24S (AMS)	6.6ab	0.19a	2.96a	0.33a	3.22a
12-0-0-26S (ATS)	7.0ab	0.18ab	2.50ab	0.32b	3.41a

At mid-silk in 2008, only P concentrations in ear leaves (Table 3) were in the sufficiency range (0.25% to 0.50%) for all treatments (Mills and Jones, 1996). The N and K concentrations in the ear leaves were below the sufficiency ranges of 2.70% to 4.00% for N and 1.70% to 3.00% for K. 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 3). These problems with nutrient uptake by the crop may also be related to the poor growing conditions in central Iowa during June and early

July (Hillaker, 2009). The insufficient ear-leaf K levels are more likely the result of low initial soil test K, which would limit soil K supply to the roots as the growing season progressed.

Table 3. 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 2008. 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
	------------------ % --------------------			
Control	0.14a	2.45a	0.28ab	1.58a
13-33-0-15S (SEF)	0.16a	2.65a	0.32a	1.53a
21-0-0-24S (AMS)	0.15a	2.54a	0.27b	1.61a
12-0-0-26S (ATS)	0.16a	2.46a	0.29ab	1.59a

Effect of Sulfur Fertilizer on Yield

In 2008, corn grain yield was increased ($p<0.05$) by an application of 30 lb S/A as 13-33-0-15S to the Clarion loam soil at this location (Table 4). An application of 30 lb S/A as 12-0-0-26S significantly increased corn stover yield, compared with the control treatment. When a less conservative level of significance was used ($p<0.10$), grain yield results did not change; however, a stover yield response was observed for both the 13-33-0-15S and 12-0-0-26S materials. Again, above-normal precipitation during part of the growing season and significant soil variability at this site likely affected the measured yield response to S fertilizer. In most cases, S removals with harvested grain and stover were higher when S fertilizer was applied (Table 5), suggesting that the corn crop took advantage of the increased soil supply of S. The cost of replacing the available S was relatively low (Table 5), but would have been profitable only for the 13-33-0-15S treatment.

Table 4. Effect of 30 lb S/A on corn grain yields, grain moisture at harvest, and stover yields in 2008. Values are least square means of four replications. For comparative purposes, values for least significant differences (LSD) at both the 0.05 and 0.10 levels of significance are given.

Treatment	Grain Yield*	Grain Moisture	Stover Yield
	-- bu/A --	-- % --	tons/A
Control	192	17.2	3.36
13-33-0-15S (SEF)	204	16.6	3.97
21-0-0-24S (AMS)	192	17.0	3.65
12-0-0-26S (ATS)	194	16.7	4.51
LSD (0.05)	7	0.7	0.69
LSD (0.10)	5	0.6	0.56

*Yields adjusted to 15.5 % moisture.

Table 5. Removals of S with harvested corn grain and stover for each treatment in 2008, and estimated S replacement cost. Values are least square means of four replications. For comparative purposes, values for least significant differences (LSD) at both the 0.05 and 0.10 levels of significance are given.

Treatment	S Removals		Replacement Cost
	Grain	Stover	
	------ lb S/A ------		$/A*
Control	7.7	1.9	10.40
13-33-0-15S (SEF)	10.7	2.6	14.41
21-0-0-24S (AMS)	9.3	2.2	12.46
12-0-0-26S (ATS)	9.9	2.6	13.54
LSD (0.05)	1.4	0.7	
LSD (0.10)	1.1	0.5	

*Based on $1.0833 per lb S (January '09) as ammonium sulfate ($520/ton).

Biomass Removal Study

A 25-acre field study was initiated in 2008 at the ISU Agronomy & Agricultural/Biosystems Engineering Research Center. Continuous corn will be grown using a variety of soil and crop management systems including: (1) 30" row spacing, standard fertility management; (2) twin-row, high-population with increased nutrient addition in split-applications; (3) conventional management with bio-char additions (a by-product of thermochemical biomass conversion technologies); and (4) annual or perennial cover crops incorporated into conventional management systems. Systems 1 and 2 are components of this Fluid Fertilizer Foundation project. Pioneer Brand 36V75 corn was planted on May 5, 2008. Fertilizer applications in 2008 for the two systems totaled 190+140+290+20 lb/A (N-P_2O_5-K_2O-S) for the standard fertility treatment and 250+152+294+20 lb/A (N-P_2O_5-K_2O-S) for the high fertility treatment. Whole-plant samples were collected at the V6 growth stage and at physiological maturity. Tissue samples from opposite and below the primary ear leaf were collected at anthesis. Analysis of the V6 and "ear leaf" samples (Table 6) indicated N levels for both systems were lower than desired (3.5 to 5.0% or 2.75 to 3.25%) at both growth stages, S was approaching the lower level at V6 (0.15 to 0.5%), and K concentrations at anthesis were approaching the lower level (1.75 to 2.25%) – presumably because Ca levels were above the high rating (0.4%). Limiting K due to high Ca and Mg on Des Moines lobe soils was the focus of an earlier project at this site (Karlen and Kovar, 2005), and efforts are continuing to raise the overall available level of K, especially now that additional K will be removed by harvesting the stover.

Corn grain and stover were harvested using a single-pass combine system (Fig. 1). Grain yield for systems 1 and 2 averaged 171 and 183 bu/A, respectively. Corn stover was harvested at two heights (just below the ear shank and at a stubble height of approximately 4 inches). The amount of dry stover collected averaged 2.5, 2.9, 2.8, and 3.1 tons/A for the high and low cuts of treatments 1 and 2, respectively. Whole plants collected at physiological maturity and residue samples from the machine harvest are being processed to determine dry matter production and nutrient composition, so that the amount of residue returned to the soil and the amounts of nutrients removed can be calculated. These values will be used to guide fertilizer recommendations for 2009.

Table 6. Plant tissue analysis at V6 and anthesis for conventional and intensive management systems near Ames, IA in 2008.

Nutrient	V6 (whole plant)		Anthesis (‘ear leaf’)	
	Conventional	Twin-Row	Conventional	Twin-Row
	-------------------- % --------------------			
N	3.09	2.81-	2.53	2.44
P	0.40	0.36	0.33	0.32
K	3.86	3.72	1.86	1.92
Ca	0.44	0.44	0.57	0.55
Mg	0.29	0.31	0.29	0.31
S	0.18	0.16	0.17	0.16
	-------------------- ppm --------------------			
Al	63	59	15	15
B	7	6	9	8
Cu	7	6	8	8
Fe	149	136	93	90
Mn	57	51	55	55
Zn	27	24	18	17

Figure 1. Single-pass corn grain and stover harvest operation near Ames, IA.

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