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Dealing with Sulfur Deficiency in Northeast Iowa Alfalfa Production

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Summary and Implications

Sulfur deficiencies have been shown to be associated with reduced alfalfa production. This paper documents this problem in NE IA, presenting research over the past 2 years, and provides recommendations for plant analysis as well as appropriate sulfur supplementation strategies.

Introduction

Historically, sulfur (S) deficiency has not been an issue for crop production in Iowa. Previous research documented sufficient plant available S for crop production on most soil associations. Recent studies in corn and soybean production were consistent with results of previous research conducted across Iowa. The exception was a long-standing suggestion to apply S as commercial fertilizer or livestock manure for alfalfa production on sandy soils.

However, over the past decade, alfalfa grown on some silt loam and loam soils in northeast Iowa has exhibited a slowly worsening problem with areas in fields of stunted growth and poor coloration. Recent investigations determined the growth problems were largely due to S deficiency. The following provides reasons for the developing problem, how to identify S deficiency, a summary of the research in northeast Iowa, and S fertilizer recommendations for alfalfa.

Sources of Sulfur for Crop Production

Plant-available S can originate from several sources. These include soil mineralization of soil organic matter, subsoil sulfate, manure, decomposing crop residue, atmospheric deposition, irrigation water, and commercial fertilizer. These sources are illustrated in Figure 1.

Soil

Soil organic matter and subsoil sulfate are important sources of plant available S. Over 95% of S in soil is in an organic form, and unavailable to plants. The form that plants take up is sulfate ($SO_4^{=}$). Organic compounds containing S must undergo bacterial oxidation to become plant available.

Soil organic matter contains about 58 pounds total S/acre, but less than three pounds/acre per year per one percent organic matter is estimated to become available to crops.

Iowa research in the 1970's found total S in 5-foot profiles of major soils in Iowa ranged from 114 to 1,236 pounds S/acre. The average plant available sulfate-S in five-foot soil profiles was 189 pounds per acre. The University of Wisconsin found similar results with silt loam soils providing 160 pounds/acre available S, but loamy sand soils providing only 10 pounds of available S in a three-foot soil profile.

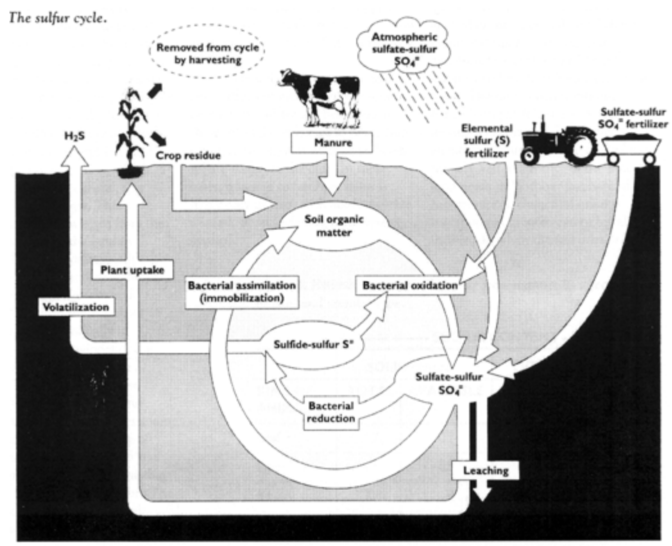

Figure 1. Sulfur cycle.

Manure

The amount of S from livestock manure varies with species and application rates (Table 1). Approximately 55% of the total manure-S becomes plant available in the year applied.

Table 1. Estimated available sulfur from manure.

	Solid manure		Liquid manure	
Manure source	Total	Available	Total	Available
	- - - lbs S/ton - - -		- lbs S/1,000 gal. -	
Horse	1.4	- -	- -	- -
Beef Cattle	1.7	0.9	4.8	2.6
Dairy Cattle	1.5	0.8	4.2	2.3
Sheep	1.8	- -	- -	- -
Swine	2.7	1.5	7.6	4.2
Chicken: old floor litter	3.2	1.8	9.0	5.0
Chicken: no floor litter	6.2	- -	- -	- -

Atmospheric Deposition

A significant source of S comes from the atmosphere, or at least used to. Sulfur contaminants from burning coal, oil, and gas are deposited to the soil by precipitation. Wisconsin Department of Natural Resources estimated that sulfur dioxide emissions decreased 50% from 1985 to 1994. The National Atmospheric Deposition Program records sulfate deposition across the United States (http://nadp.sws.uiuc.edu). Figure 2 illustrates the differences that have occurred from 1986 to 2003.

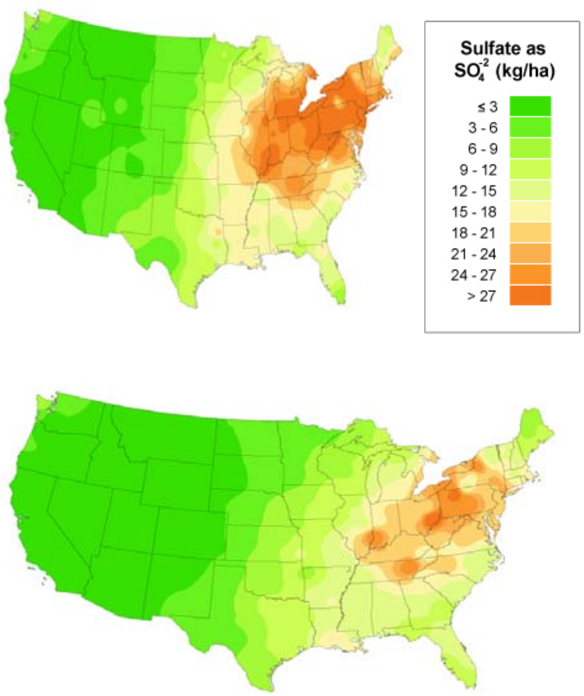

Figure 2. Atmospheric deposition of sulfate in 1986 (top) and 2003 (bottom). From the National Atmospheric Deposition Program, Coop. Extension Service, USDA.

Irrigation

Irrigation water may contain significant concentrations of S. If S supply is a concern with irrigated crops, the irrigation water should be tested for S content.

Commercial Fertilizer

In the past, commercial fertilizers such as ordinary super phosphate, contained significant amounts of S, often greater than 10 percent. Currently used concentrated phosphate fertilizers like diammonium phosphate (DAP) and monoammonium phosphate (MAP), however, contain little S (less than two percent).

Table 2 lists some common S fertilizers. All fertilizers containing the sulfate form of S are considered equally effective. Elemental S, however, is initially insoluble and unavailable to plants. It requires oxidation by soil bacteria to be converted to sulfate-S. Soil incorporation, weathering, temperature and moisture influence this transformation. So elemental S should be applied well in advance of the time the crop would need it.

Table 2. Common S containing fertilizers.

Material name	Chem. formula	Fertilizer analysis	S, %
Ammonium sulfate	$(NH_4)_2SO_4$	21 - 0 - 0 - 24	24
Amm.thiosulfate	$(NH_4)_2S_2O_3+H_2O$	12 - 0 - 0 - 26	26
Calcium sulfate	$CaSO_4$	0 - 0 - 0 - 16	16-18
Potassium sulfate	K_2SO_4	0 - 0 - 50 - 18	18-20
Pot./Mag. sulfate	$K_2SO{\cdot}2MgSO_4$	0 - 0 - 22 - 23	23
Elemental sulfur	S	0 - 0 - 0 – 90	90-100

Crop Removal

With less S being supplied from the atmosphere, lack of manure application, potential leaching of sulfate-S not intercepted by crop roots, and S removal in crop harvest, the possibility for needing S fertilizer application to the land for crop production has increased over the years. Some crops remove more S than others, i.e. alfalfa, corn silage (Table 3). Also, some crops are more significantly affected by marginal S levels, requiring S for critical plant functions, i.e. nodule development in alfalfa.

Table 3. Estimated removal of sulfur in harvested crops.

Crop	S content	Yield, unit/ac	S, lb/acre
Alfalfa hay	6.0 lb/ ton	6 ton	36
Corn grain	0.09 lb/ bu	180 bu	16
Corn silage	1.50 lb/ ton	20 ton	30
Oat grain & straw	0.16 lb/ bu	80 bu	13
Soybean (SB)grain	0.16 lb/ bu	50 bu	8
SB grain & straw	0.40 lb/ bu	50 bu	20

How to Identify Sulfur Deficiency

Symptoms

Sulfur is essential for protein synthesis in plants. For leguminous plants, it is also important in nodule development. Sulfur deficiency symptoms in alfalfa include a light green coloration of the whole plant, stunting, less shoot development, and reduced nodulation.

Soil Test

The soil test for S (measures sulfate-S) is not an effective means to determine S needs for crops. The estimated available S in a 6 to 8-inch soil core sample does not correlate to crop yield responses relative to S fertilizer applications. This is because the subsoil can also provide various amounts of S to crops, S mineralization can quickly change plant-available sulfate in the soil, potential S mineralization is not measured by the test, and that plant available sulfate-S can leach from the surface sample depth.

Plant Analysis

A plant analysis or plant tissue test for S is considerably more accurate than the soil test. However, it has its limitations. The test is correlated to sampling certain plant parts depending on the crop, and at a particular stage of plant growth. For example, alfalfa plants should be sampled in the bud stage by collecting the top six inches from about three dozens shoots. These shoots should be air dried in the shade before being packaged and mailed to the laboratory. Do not sample plants under obvious stresses, i.e. severe drought, insect, or disease problems. Do not collect plants near field edges bordering gravel roads. The road dust could bias the results. A 20-lb paper bag works well to hold samples (label the bag with sample ID), air-dry (in the bag), and then mail the sample (tape the bag shut and ship in a box with appropriate instruction for the laboratory). The following is a partial list of Commercial Testing Laboratories that conduct plant analysis.

Agvise, Inc., 902 13th St. North, P.O. Box 187, Benson, MN 56215, (320) 843- 4109. http://www.agviselabs.com
A & L Heartland Labs, Inc., 111 Linn St., Atlantic, IA 50022, (712) 243-6933. http://www.al-labs.com
AgSource / Belmond Labs, 1245 Hwy 69 N, Belmond IA 50421, (641) 444-3384. http://www.bellabsinc.com
Iowa Testing Laboratories, LLC, 1101 North Iowa Ave., Eagle Grove, IA 50533-0188, (515) 448-4741, WATS: 1-800-274-7645. http://www.iowatestinglabs.com
Midwest Laboratories, Inc., 13611 B. Street, Omaha, NE 68144, (402) 334-7770. http://www.midwestlabs.com
MVTL Labs, Inc., 35 West Lincolnway, Nevada, IA 50201-0440, (515) 382-5486. http://www.mvtl.com
Servi-Tech Laboratories, 1602 Park West Drive, Hastings, NE 68901, (402) 463-3522. http://www.servi-techinc.com/
Ward Laboratories, Inc., P.O. Box 788, Kearney, NE 68848, (308) 234-2418. http://www.wardlab.com

Run a Simple Field Trial

Another method to check for S deficiency is to conduct a simple field trial. Get a few pounds of a sulfate product like calcium sulfate and spread it on several small areas of an alfalfa field. Target some of the pale areas if present. A 10 by 10-foot area works well. Mark these areas for later identification, i.e. flags, stakes, etc. If you use calcium sulfate, assuming the product is 16 percent S, one-half pound of this product spread over a 10 by 10-foot area is approximately 35 pounds of S per acre. Depending on rainfall and harvest schedules, it may take 4 to 6 weeks for a measured response. If there is no significant response (visual or measured canopy height), it is likely that field or field area is not S deficient.

Summary of Sulfur Research in Northeast Iowa

Fertilizer Trials in 2005

In 2005, on-farm trials were conducted on established alfalfa fields near Elgin, Gunder and West Union. These sites were selected because there were large areas in these fields with both poor and good alfalfa plant coloration and growth. Within each poor and good coloration area, three fertilizer treatments were established and replicated 3 times. The treatments consisted of a zero application, 40 lb S/acre as ammonium sulfate, and 40 lb S/acre as calcium sulfate (gypsum). The treatments were applied after first cut. Alfalfa harvests included second cut and third cut in 2005 at all three sites, and first cut in 2006 at the Elgin and Gunder sites (Table 4).

Dry matter yields of S fertilized plots on the good coloration areas were not significantly different from that of the unfertilized treatment. However, S fertilized plots on the poor coloration areas more than doubled yields in 2005 and nearly double yields in 2006. Plant analysis for the untreated poor areas was 0.14 percent S, clearly well below the recommended sufficiency level of 0.25 percent S. Plant analysis for the untreated good areas was also considered deficient at 0.22 percent S, but by a very small margin. The S fertilizer treatments in the poor coloration areas increased the dry matter yield nearly up to the level found in the good coloration areas. The two sulfate containing fertilizers provided similar results.

Other soil characteristics, soil type, P and K soil test levels, pH, sulfate-S soil test levels, organic matter, and cation exchange capacity were largely similar within the sites (Table 5). Any differences that did exist, such as STP at the Elgin and Gunder sites and STK at the West union site, did not explain differences found with the S fertilizer treatments. The S soil test results did not correspond to the coloration differences in the fields, the percent S differences found in the plant analysis, or yield responses to applied S.

Fertilizer Trials in 2006

In 2006, on-farm trials were conducted on established alfalfa fields near Wadena, Waucoma, Nashua, Waukon, West Union and Lawler. These trials compared different rates of S. Sites were selected to offer a wide range of responses, in that they were established on different soil types and exhibiting different degrees of poor to good coloration. Calcium sulfate was applied in the spring at 0, 15, 30 and 45 lb S/acre with either three or four replications in each trial. Most sites were harvested at second and third cut, the Nashua site was harvested for 4 cuts, and some harvest coordination issues resulted in loosing the second cut at West Union and the third cut at Lawler.

The sites with poor coloration had lower percent S plant analysis (Table 6) and greater dry matter yield responses to S fertilizer (Table 7). The two sites with plant S above 0.25 percent S with no applied S did not have statistically significant yield increases from applied S. The S soil test did not correspond to percent S plant analysis, yield response to applied S, or soil organic matter. Those sites with significant yield responses to S fertilizer leveled off in the response at about 25 pounds of S/acre (Table 7, maximum rate, lb S/acre).

Discussion

Sulfur deficiency problems exist in northeast Iowa alfalfa production fields. The majority of S deficiency problems occur in areas within fields, not entire fields. However, this non-uniformity can still account for large economic losses on a field scale. Most of the soils involved are lower organic matter, side-slope position, silt loam soils, i.e. Fayette silt loam and Downs silt loam. However, lighter textured loam soils have also responded to S fertilizer in these trials, i.e. Wapsie loam in 2006, Winnshiek loam and Saude loam in 2005. The latter two soils were also part of trial sites conducted in 2005. Problems with S deficiency are not occurring on heavily manured fields.

Plant analysis is currently the best available analytical method to test for S deficiency. Figure 3 represents the percent yield response in these trials relative to S plant analyses. This research supports other work that suggests S sufficiency is reached around 0.25 percent S.

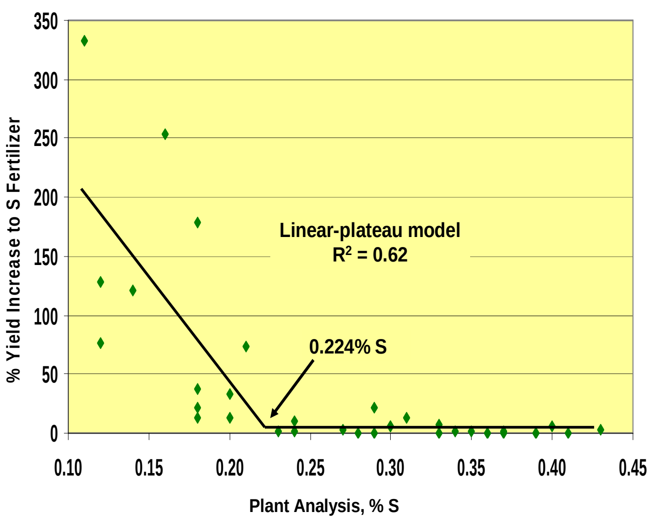

Figure 3. The percent yield increase from S fertilization relative to the alfalfa plant S concentration with no S applied.

Economic response follows the same relationship. Figure 4 represents the average yield increase per cut from S fertilization relative to the initial percent S plant concentration. At concentrations above 0.22 to 0.25 percent S, the yield response falls below 0.1 ton per acre per cutting (non-statistically significant yield responses). Assuming an equivalent response for the total in a three-cut system, and alfalfa valued at $85/ton as-is ($100/ton dry matter basis), the gross profit when the alfalfa plant S concentration is less than 0.22 to 0.25 percent sulfur is quite high. With sulfur fertilizer and application costs estimated at $20 per acre, the economic breakeven point falls near 0.25 percent S. Several of the trials in this research had plant S concentrations well below 0.25 percent. The overall net economic return in these trials averaged $50 per acre.

Since elemental S fertilizer costs about one-third as much as sulfate-S fertilizer forms, the economic picture would change from that mentioned above. Application timing would change also, considering that elemental S should be applied well ahead of the crop need to allow for the conversion of elemental S to the sulfate form.

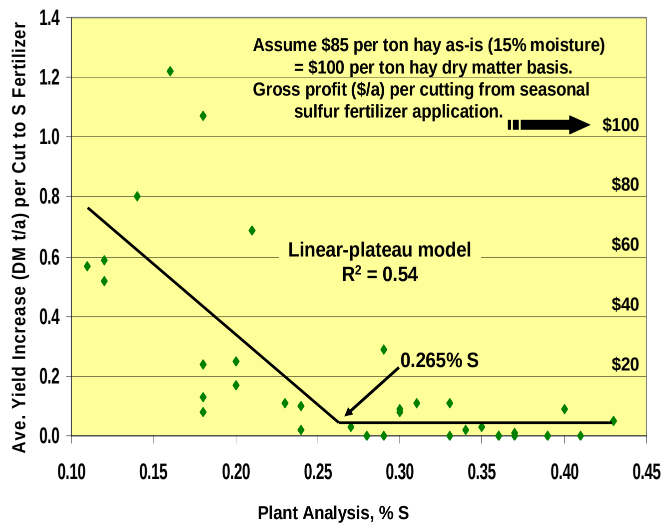

Figure 4. The average yield increase per cut from S fertilization relative to the alfalfa plant S concentration with no S applied.

Currently, if S deficiency is found (i.e. through plant analysis or field trial), the amount of S fertilizer recommended is usually 20 to 30 pounds S/acre. Where deficiencies occurred in the 2006 trials, the first 15 pounds of S/acre gave the largest incremental increase in yield, but the next 15 pounds of S/acre was still profitable in most trials. Also, S fertilizers do not need to be applied each year as alfalfa will respond to S applied in a prior year. Therefore, it is possible to apply the crop needs for multiple years in one application. That rate will be more than is needed for just one year. Additional research would help to refine these recommendations.

Table 4. Alfalfa forage yield, S plant analysis, and S crop removal with topdress applications of S fertilizer in field areas with poor and good coloration of alfalfa.

Sulfur	2005[1]						2006[2]	
	Cuts 2+3		Cut 2	Cuts 2+3	Cut 1			
	Dry matter yield		Plant top Sulfur		Sulfur removal		Dry matter yield	
	Observed Growth Area							
Treatment[3]	Poor	Good	Poor	Good	Poor	Good	Poor	Good
	ton/acre		- - - % S - - -		lb S/acre		ton/acre	
None	1.18a	2.99a	0.14a	0.22b	2.8a	10.6b	1.10a	2.04a
Am. sulfate	2.76b	3.26a	0.40d	0.35c	16.5cd	18.2de	2.18b	2.22a
Ca. sulfate	2.49b	3.21a	0.41d	0.37c	15.3c	18.1e	2.14b	2.19a

[1] Three field sites in 2005, Elgin, Gunder and West Union, Iowa.
[2] Two field sites in 2006, Elgin and Gunder, Iowa.
[3] Sulfur (ammonium sulfate and calcium sulfate) were applied at 40 lb S/acre after first cut in 2005.
[4] Treatment means followed by the same letter are not significantly different, 90% probability level.

Table 5. Soil characteristics for 2005-2006 research trials, Elgin, Gunder, West Union.

		Observed Growth Area					
		Poor	Good	Poor	Good	Poor	Good
Site	Soil	STP		STK		pH	
		- - - - - - - - - ppm - - - - - - - - -					
Elgin	Fayette silt loam	30	15	144	155	7.0	7.2
Gunder	Fayette silt loam	43	21	240	220	7.0	6.9
West Union	Downs silt loam	24	26	164	92	7.2	7.1

		Observed Growth Area					
		Poor	Good	Poor	Good	Poor	Good
Site	Soil	SO_4-S		OM		CEC	
		- - - ppm - - -		- - - % - - -		meq/100g	
Elgin	Fayette silt loam	6.3	7.0	2.3	2.3	20.2	16.4
Gunder	Fayette silt loam	7.3	8.3	2.7	2.9	19.3	16.7
West Union	Downs silt loam	6.3	7.0	2.3	2.6	17.8	14.1

Samples collected after first cut, 0 to 6 inch depth.

Table 6. Alfalfa plant S concentration and site characteristics, 2006.

Sulfur rate[1]	Site: Wadena	Waucoma[2]	Nashua	Waukon	West Union	Lawler
lb S/acre	- - - - - - - % S[3] - - - - - - -					
0	0.14	0.21	0.33	0.18	0.18	0.27
15	0.20	0.30	0.35	0.29	0.24	0.36
30	0.30	0.43	0.34	0.40	0.29	0.39
45	0.39	0.36	0.37	0.41	0.28	0.37
[4]Soil SO_4-S, ppm	7	3	7	1	6	3
[4]Soil OM, %	3.1	2.1	4.2	3.8	3.3	2.6
[5]Soil	Fayette	Wapsie	Floyd-Clyde	Fayette	Fayette	Ostrander

[1]Sulfur applied as calcium sulfate in April at Nashua and in May at the other sites.
[2]Waucoma site had 10 lbs of elemental S applied in spring across the entire field.
[3]Sulfur concentration (% S) for 6-inch plant tops collected before second cut.
[4]Soil samples collected after first cut, 0 to 6 inch depth.
[5]Soil texture: Fayette silt loam, Wapsie loam, Floyd-Clyde loam, Ostrander loam.

Table 7. Alfalfa total dry matter for the harvests collected in 2006.

	Site					
Sulfur rate[1]	Wadena	Waucoma[2]	Nashua	Waukon	West Union	Lawler
lb S/acre	- - - - -	- - - - - - -	ton/acre	- - - - - - -	- - - - - - -	- - - - - - -
0	1.32	1.85	6.73	1.39	0.78	2.14
15	2.59	3.06	6.98	2.97	1.05	2.11
30	2.76	3.14	6.85	3.33	1.07	2.11
45	2.92	3.24	7.14	3.58	1.07	2.07
Significance (90%)	*	*	NS	*	*	NS
Max rate, lb S/acre	25	22	0	29	12	0
Cut harvested	2+3	2+3	1+2+3+4	2+3	3	2+4

[1]Sulfur applied as calcium sulfate in April at Nashua and in May at the other sites.
[2]Waucoma site had 10 lbs of elemental S applied across the entire field in spring.