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Sulfur for Alfalfa in New York State

Quirine Ketterings[1], Greg Godwin[1], Sanjay Gami[1], Kevin Dietzel[1], Jerry Cherney[2], and Karl Czymmek[1,3]

[1]Nutrient Management Spear Program, Department of Animal Science, [2]Department of Crop and Soil Sciences, and [3]PRODAIRY, Department of Animal Science, Cornell University

Introduction

Following the passing of the Clean Air Act in 1970 and the introduction of sulfur (S)-free phosphorus fertilizer and pesticides, incidental addition of S to fields through atmospheric deposition (from powerplant discharges and other sources) and fertilizer application has decreased drastically in New York. For example, total S deposition at the Aurora Research Farm was estimated to be 14 lbs/acre in 1979-1981 versus 6 lbs/acre in 2008. Sulfur is an essential plant nutrient for processes such as photosynthesis and nitrogen (N) fixation. Therefore, it is important to re-evaluate S needs for crops like alfalfa, which removes an estimated 5 lbs S/ton of hay (DairyOne Forage Laboratory, 2010). Soil organic matter mineralization, crop residue and manure addition can all supply S. In past NY studies (Klausner et al., 1982; 1984), S supply from organic sources and S deposition was sufficient to meet alfalfa S requirements but current deposition data indicate that S removal by an average alfalfa crop now exceeds S deposition at all 11 weather monitoring locations in the state (NADP/NTN, 2010), raising the question whether soil S supply alone can meet crop S demands, especially for light textured, low organic matter soils with limited S supplying capacity.

Tissue testing has been the preferred tool for determining S deficiencies. It is commonly accepted that 0.25-0.50% S in the top 6 inches of the alfalfa plants at late bud to early blooming stage is optimal. This means the critical tissue S level below which a deficiency is expected is 0.25%. Some laboratories offer a soil S test as an additional test if requested by growers. Both laboratory and field research were needed to determine the effectiveness of these tests in determining S availability across the wide range of soils in New York State.

Laboratory and field studies were conducted to determine (1) the accuracy and effectiveness of six different soil S extraction methods in detecting S fertilizer addition; (2) the difference in soil test S as impacted by laboratory equipment use (ICP-AES versus turbidimetric-spectroscopy); (3) effectiveness of tissue S testing in determining S deficiency; and (4) impact of S addition on alfalfa yield.

How was the research conducted?

Part 1: soil testing methodologies

Four NY soils were incubated in a growth chamber with one of six S application rates (0, 25, 50, 75, 100 and 150 lbs S/acre) applied as $CaSO_4$ (gypsum). Samples were incubated in the dark for four weeks at room temperature and water was added weekly to maintain moisture content of 60 to 75% of field capacity throughout the incubation. Samples were remixed 14 d after initiation of the incubation to stimulate aeration and ensure thorough contact between the soil and the gypsum. After the 4-wk incubation, samples were oven-dried and ground to pass 2 mm and analyzed for extractable S using six extracting solutions: (1) 1.0 *M* ammonium acetate (Vendrell et al., 1990); (2) 0.016 *M* potassium phosphate (Jones et al., 1972); (3) 0.01 *M* monocalcium phosphate (Schulte and Eik, 1988); (4) 0.01 *M* calcium chloride (Williams and Steinberg, 1959), (5) Morgan sodium acetate (Morgan, 1941); and (6) Mehlich-3, a mixture of acetate, ammonium-nitrate, ammonium fluorite, nitric acid and EDTA (Mehlich, 1984). The four soil types were: Adams, Knickerbocker, Sunapee and Stafford.

Part 2: Alfalfa response to S addition

An 8-farm comparison of yield and quality of alfalfa with and without S fertilizer was conducted to evaluate the effects of a single S fertilizer application on alfalfa yield, residual S, and the effectiveness of soil and tissue testing in identifying S responsiveness over a 2-yr period. The farms included four in northern NY (sites 1 through 4), and one each in central (site 5), eastern (site 6), southern (site 7), and western NY (site 8). The locations were selected to include at least four S deficient sites (based on tissue testing). Treatments included a no-S control and two S sources ($CaSO_4$ and $K_2SO_4.2MgSO_4$), both applied at 150 lbs S/acre. The two S sources were chosen (1) to separate a Ca, Mg or K response from an S response; and (2) to be consistent with similar NY trials conducted by Klausner in 1981-1983. The S rates were high to assess residual effects of the fertilizer application in the second year after application, addressing the question if a single S application can benefit alfalfa for up to two years. Each field trial was conducted in four replications. The treatments were applied directly after the 1st cutting. One field (site 3) received an (accidental) liquid manure application on 10 June 2009, after the 1st cutting. No manure was applied to any of the other locations. Soil samples were taken prior to S addition, after the final cutting of the season in 2008 (the 3rd or 4th cutting), at green-up (end of March or early April) in 2009, and at the 3rd and final cutting (August or early September) in 2009. Soils were analyzed for $CaCl_2$ extractable S (the test that was most promising as a predictor for S availability in the laboratory study). Tissue samples (top 6 inches) were taken on the same day as the 3rd cutting in both years, and consisted of sampling 30-35 individual plants within the plot (treatment) area but just outside the actual harvest area. Forage subsamples were taken at each cutting to determine moisture content and forage quality parameters. All forage analyses were done at Cumberland Valley Analytical Services, Inc. in Hagerstown, MD. Plant tissue analyses were performed at Brookside Laboratories Inc. in New Knoxville, OH.

Results and Discussion

Part 1: soil testing methodologies

Although each of the extraction and detection methods resulted in an increase in extractable S with S addition, the 0.01 *M* $CaCl_2$ extraction with ICP-AES detection of S in solution showed the most promise as a soil test for S: this method was best correlated with S added across all four soils and showed the greatest increase in soil test S per lb of S applied (Fig. 1), and it was the only test that showed good consistency between the two detection methods (Fig. 2).

Part 2: Alfalfa response to S addition

Of the eight sites, four (sites 1, 2, 5, and 8) had a relative yield less than 95% and a significant yield response to S fertilization during the 2008 growing season (Table 1). Averaged across these four locations, S fertilization increased yield by 17%. The highest yield and the greatest response to S were measured in central NY (site 5). This was also the only location where residual S resulted in a significant yield increase (a 25% increase) in 2009.

Excluding sites 6 and 7, two locations with a suboptimal pH and high field variability, yield and tissue data from 2008 indicate a critical tissue S level of 0.27% S is needed to produce a 95% relative yield (Fig. 3A), similar to the 0.25% S critical value commonly reported.

Initial soil test S concentrations at the 8 test sites ranged from 3 to 26 ppm S (Fig. 3B). Sulfur fertilization increased the average soil test S (all locations) from 8 to 27 ppm S measured at 3rd cutting. Excluding the two locations with suboptimal pH (sites 6 and 7), the critical soil test S level needed to produce 95% relative yield without S fertilization was 8 ppm CaCl2 extractable S (Fig. 3B).

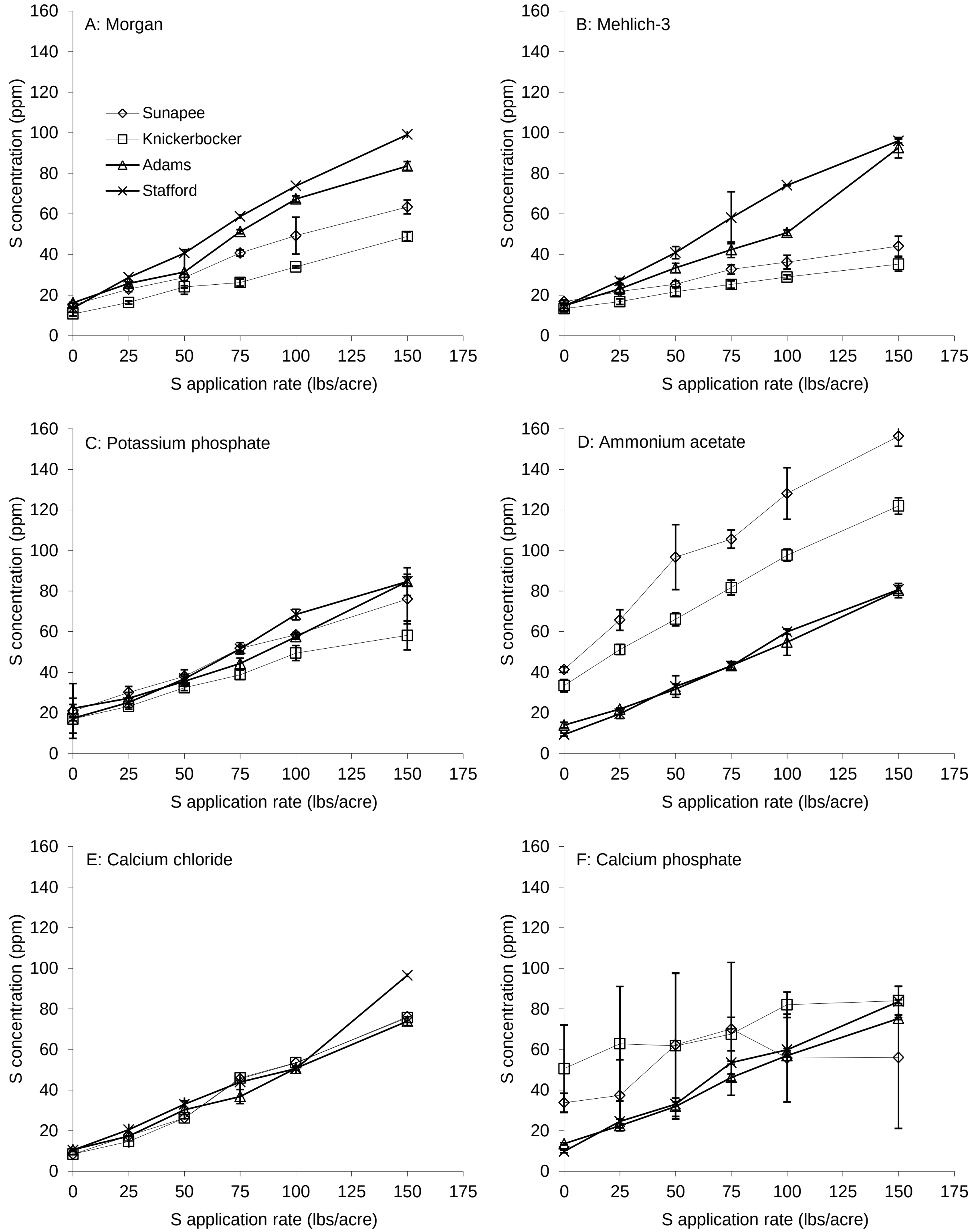


Figure 1: Relationship of the mean and standard deviation (n=4) of S concentration obtained by six different extracting methods with inductively-coupled plasma atomic emission spectroscopy (ICP-AES) detection of S in solution. Sulfur was applied as $CaSO_4$ to four different soils. Adapted from Ketterings et al. (2011).

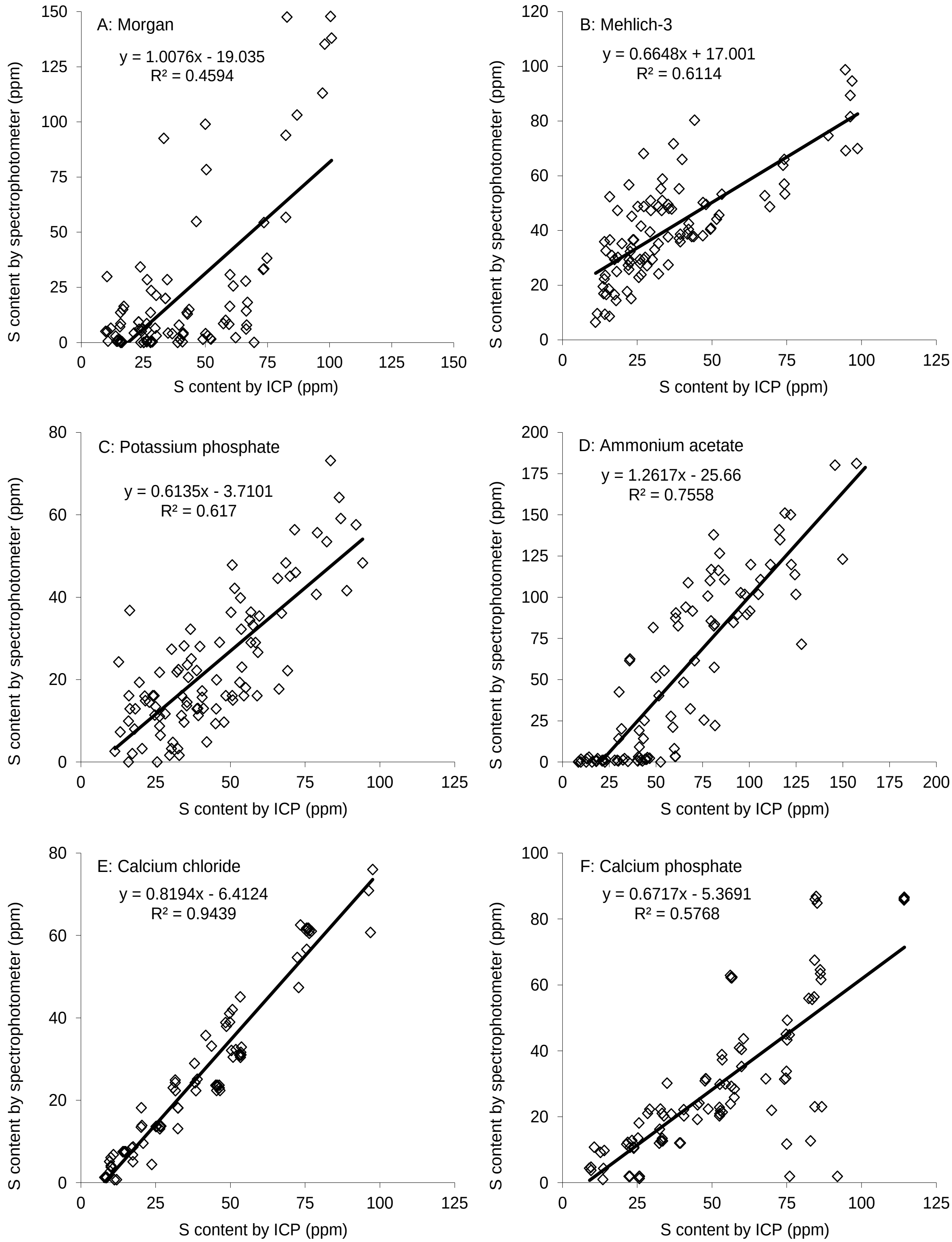
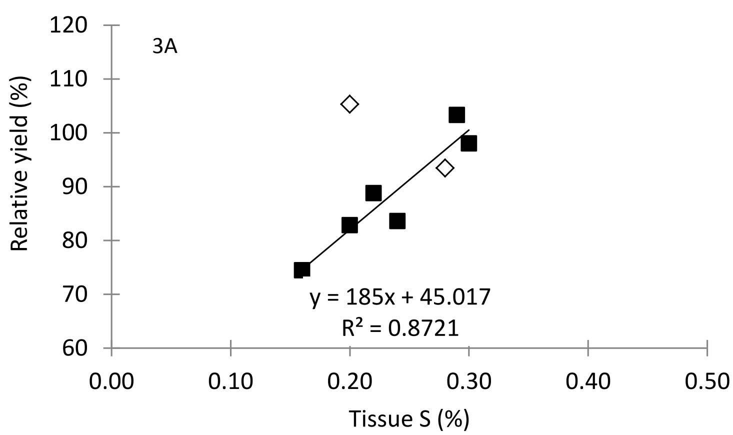


Figure 2: Comparison of S concentration in six different extraction solutions determined with inductively-coupled plasma atomic emission spectroscopy (ICP-AES) versus turbidimetric (TS) determination of S in the extraction solution. Adapted from Ketterings et al. (2011).

Table 1: Alfalfa yield as impacted by S addition. The 2008 yields are for 2nd and 3rd cutting only. In 2009, no additional S was applied and yields represent season yields.

Site	Treatment	2008 (sulfur added)	2009 (no additional sulfur)
		----------------- Tons DM/acre	-----------------
1 Essex County	Control	1.37 b	3.15 a
	Plus S	1.72 a	3.54 a
2 St. Lawrence County # 1	Control	2.07 b	2.97 a
	Plus S	2.41 a	3.04 a
3 Lewis County	Control	2.72 a	3.95 a
	Plus S	2.63 a	4.00 a
4 St. Lawrence County # 2	Control	2.50 a	3.21 a
	Plus S	2.55 a	3.49 a
5 Cayuga County	Control	3.79 b	5.68 b
	Plus S	4.44 a	7.08 a
6 Columbia County	Control	3.02 a	4.44 a
	Plus S	2.86 a	4.44 a
7 Steuben County	Control	2.29 a	1.80 a
	Plus S	2.44 a	1.76 a
8 Wayne County	Control	2.67 b	2.26 a
	Plus S	2.97 a	2.14 a



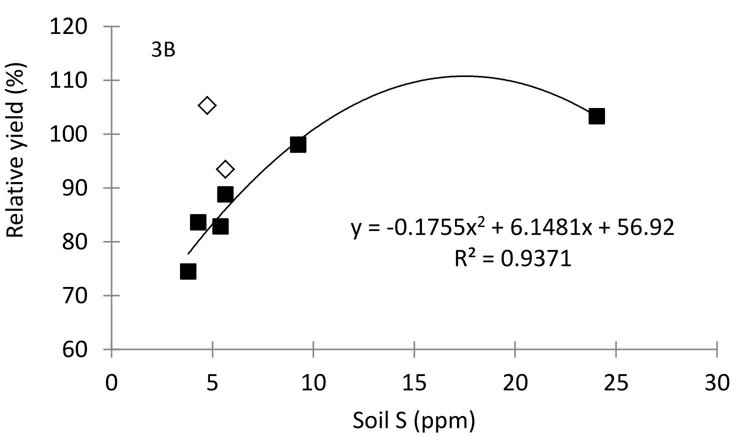


Figure 3: Tissue S content (A) and 0.01 mol L^{-1} $CaCl_2$ extractable soil S (B) as predictors for relative yield of alfalfa (the ratio of yield without and yield with the addition of 150 lbs S/acre). The open diamonds indicate two locations with suboptimal pH (6.2 or lower). Adapted from Ketterings et al. (2012).

An accidental manure application at site 3 resulted in elevated soil test S suggesting manure addition is an effective way to increase S levels. For plots that had been fertilized with S, soil S in the spring of 2009 was 38-85% lower than levels measured at 3rd cutting in 2008, supporting the hypothesis that there is limited carryover of fertilizer S into the following year.

Conclusions

Given the drastic decrease in S deposition since the 1980's, it is not surprising that four of the eight locations in the current study showed a significant yield increase to S fertilization. Most likely candidates for S deficiency are coarse-textured, low organic matter sites with no manure applied in recent years. Both tissue and soil testing for S were effective in predicting an alfalfa yield increase from S fertilization for the sites in this study. The data support a critical tissue S level of 0.27% S for samples taken at the 3rd cutting (top 6 inches of the plant). The soil test data suggest a critical level of 8 ppm S (with 0.01 mol L^{-1} $CaCl_2$ extractable S, 0-8 inch soil samples) with samples taken at 1st cutting. Manured fields are not likely to be S responsive in the year of manure application. Deficiencies could occur if no manure has been applied in the past couple of years. More site-years of S response studies, covering a wider diversity of soils, field histories, and climatic conditions, are needed to fully test the utility of soil and tissue testing for S management of alfalfa.

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