SULFUR FERTILITY FOR KENTUCKY AGRICULTURE

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Abstract

Sulfur (S) fertility concerns are becoming more common in Kentucky due to the reduction in atmospheric deposition resulting from more stringent air quality concerns. The most likely crops where S deficiency would first occur are winter wheat and alfalfa, due to mineralization rates or high removal rates. Currently few, if any, fields in Kentucky show consistent S deficiency problems. Tissue surveys were conducted in alfalfa fields during 2013 and 2014 to assess S status in alfalfa. Twenty-one percent of the fields sampled in 2013 were below the reported sufficiency range for S. Twenty-five percent of the fields sampled in 2014 were below the reported sufficiency range of S. In 2014, response trials were conducted in five of the six fields that were below the S sufficiency range in 2013. One field had a positive response to S additions at the third cutting in 2014; conversely one field had a negative response to S additions for the third cutting. When the second and third harvest was combined, no significant response was observed. The lack of yield response to S applications could be due to either sufficient S present in the soil or that tissue S sufficiency ranges are not well defined and vary with environmental conditions. Based on this and previous research, sulfur fertility does not currently appear to limit crop yields in Kentucky.

Introduction

The reduction in atmospheric deposition of S due to the utilization of low sulfur coal, diesel, and fuel oil, coupled with more stringent air quality regulations has caused concern for sulfur fertility in agricultural crops. For the past 100 years, ample S was deposited from the burning of fossil fuels in the US, but more stringent regulations have reduced the amount of S that can be released into the air. In 1985, Kentucky received between 16 to 24 lb S/A from atmospheric deposition, which was reduced to 11 to 19 lb S/A by 2008, and is currently less than 10 lb S/A (National Atmospheric Deposition Program, 2014). Sulfate sulfur, a divalent anion, is somewhat mobile in the soil profile and subject to leaching, but typically does not leach out of the rooting zone of most Kentucky soils due to adsorption by clay in the subsoil (Jones, 2001). Soil organic matter (SOM) contains a large portion of S in most soils and is considered a "storehouse" for S deposited in the past. The S contained in SOM must mineralize to the sulfate form prior to crop utilization, but only 1 to 3% of the total organic S is expected to mineralize in a given year. High crop yields coupled with less atmospheric deposition and low mineralization rates have raised concern with some Kentucky producers.

The crops in Kentucky where S deficiency would likely first appear are: winter wheat, due to low mineralization rates during winter; alfalfa, due to high total biomass removal coupled with high protein content of the tissue; and silage crops where the majority of the aboveground portion of the plant is removed (Schwab, 2008). In 2011, Ritchey et al. (2011) conducted a wheat tissue survey in 15 western Kentucky counties and sampled 29 fields. No fields were found to be below the reported sufficiency range for S in 2011. The wheat survey was repeated in 2012 by Ritchey and Gray, and 40 fields in 16 western Kentucky counties were sampled. In 2012, one field had tissue samples that were below the sufficiency range. This was a rather large field (approximately 100 acres) that had 3 to 4 small areas (50 to 100 ft^2) within the field that showed visible signs of S deficiency; two areas were confirmed by tissue testing. This field had historical oil production and areas that had brush cleared, piled, burned, and then buried prior to the current landowner purchasing the property. Further, soil pH, Mg, Zn, and B in the soil samples were not typical and varied considerably from other parts of the field. It was not known if the soil disturbance caused the S deficiency or if it was a true deficiency, but it was suspected that the S deficiency was related to some other cause than a true deficiency for this field.

The University of Kentucky currently does not have a valid soil test for S, critical soil test S levels have not been established, a soil sampling protocol has not been developed, and fertilizer S rate recommendations have not been determined. However, many private labs provide S recommendations that are based on a 0 to 4 or 0 to 6 inch sample depth. The Mehlich 3 extractant is currently used by many soil test labs, including University of Kentucky Regulatory Services. The use of Mehlich 3 is questionable for S determination (Rao and Sharma, 1997). It has been suggested that soil texture and SOM content may be a better method to determine S need than soil test extractants (Rhem, 2000; Wortman et al., 2009). The University of Kentucky Cooperative Extension Service currently recommends soil sample depths of 0 to 4 inches for NT fields, which includes pastures and hayfields, and 0 to 6 inches for tilled fields (Murdock and Ritchey, 2014). Since a large portion of S may be present below the 4 inch depth that is available for crop uptake, a deeper sample may be required to adequately assess S fertility status. The University of Kentucky Cooperative Extension Service provides fertilizer recommendations based on response trials at known levels of the specific nutrient in question. To date, Kentucky has very few fields have shown S deficiency adequate to conduct these response trials so that a given amount of S can be recommended or determine what critical threshold will produce an economic response. The remainder of the paper will discuss the current state of knowledge and the direction for Kentucky S fertility research.

Materials and Methods

Alfalfa Tissue Survey Sampling Protocol

County agents were contacted in 2013 and 2014 and asked to identify alfalfa fields that were produced using good management practices, including regular soil sampling. Once a field was identified, tissue and soil samples were collected in a 100 by 100 ft area from the second cutting of alfalfa. The top 6 inches of 50 plants in the identified areas were collected when alfalfa was at approximately 10% bloom. Tissue samples, free of soil contaminants, were placed in a paper bag to air dry. Samples were then oven dried at 120 F and ground to pass a 18 mesh screen prior to analysis. The sufficiency range for alfalfa is 0.25 to 0.50% for the top 6 inches of alfalfa at 10% bloom (Schwab et al., 2007). Soil samples were collected from 0 to 4 inches and from 0 to 12 inches (when possible) in the same area. Tissue and soil samples were submitted to Waters Agricultural Laboratory for nutrient determination. Plant tissue concentrations were compared to sufficiency ranges reported in University of Kentucky Cooperative Extension Publication AGR-92: Sampling Plant Tissue for Nutrient Analysis (Schwab et al., 2007). No critical value has been determined for soil test S in Kentucky to date. In 2013, 28 tissue samples were received from eight counties and 21 tissue samples were received from 10 counties in 2014.

Alfalfa Sulfur Response Trials

County agents were contacted in 2014 for those samples that were below the S sufficiency range to arrange S response trials on the areas that were below the sufficiency range in 2013. Five locations were used for response trials. Plots were established on the same locations in the fields that were sampled in 2013 and deemed below the sufficiency range. Plots were established in a randomized complete block design with 4 replications, after the first alfalfa cutting was removed. Plots were 5 ft wide by 10 ft long and were randomly assigned rates of 0, 25, or 50 lb/A of S as gypsum ($CaSO_4$). Soil samples were collected in each plot to a depth of 0 to 4 inches and 0 to 12 inches prior to application of gypsum. Two samples in each plot were collected for biomass determination for the second and third harvests. Separate tissue samples were collected from each plot at harvest for tissue nutrient concentration determination.

Results and Discussion

Alfalfa Tissue Survey

The previous tissue surveys in wheat by Ritchey and associates in 2011 and 2012 did not indicate that currently there was a great concern for S fertility in Kentucky, although many producers make applications based on private soil test recommendations or the perceived need for some other reason. Some alfalfa producers routinely make S applications in this manner. Of the 28 samples collected in 2013, six were below the sufficiency range of 0.25 to 0.50 (Table 1). Five out of 20 tissue samples were below the sufficiency range in 2014 (Table 2). Rainfall during the growing season of 2013 was near optimal, very little drought stress occurred across most of the state. However, in 2014, the western part of the state received below average rainfall which might be responsible for the some of the tissue samples being below the sufficient range.

Tissue concentrations were compared against soil test S and SOM at the 0 to 4 inch sample depth (Figure 1). Soil test S explained 21% of the variation in tissue S in 2013, but this relationship was not evident in 2014 (Figure 2). Tissue concentrations were also compared against SOM in 2013 and 2014, but no relationship was evident. Neither soil test S nor SOM appear to be good predictors of alfalfa tissue S content based on this limited data set. Pumphrey and Moore (1965) indicated that a N:S ratio above 11 would positively respond to S fertility. In our survey, this was not tested since treatments were not applied, but 26 of the 28 samples were above the N:S ratio they deemed critical. Based on this critical ratio, it would seem that this is not a good method to determine S fertility needs for alfalfa production.

At one site from the tissue survey in 2014, a soil sampled was collected to a depth of 24 inches (Table 3). This site had been in alfalfa for 7 years prior to one year of soybean production and the seeded in spring of 2014 back to alfalfa. Phosphorus, K, and S were stratified but opposite in their occurrence (Table 3). Both P and K were substantially higher in the 0 to 4 inch depth than either the 0 to 12 or 0 to 24 inch depth. Sulfur concentration was much greater at the 0 to 24 inch depth. It is interesting to note that although 106 lb S/A was present at the 0 to 24 inch depth; this was one of the samples that was below the sufficiency range for S. It may be that the low soil pH of 5.1 was responsible for less root exploration and thus S uptake, environmental conditions influenced sample results, or critical tissue concentrations are not well defined.

Alfalfa Response Trials

Response trials were conducted in 2014 on five of the six fields that were determined to be below the sufficiency range in 2013. None of the samples collected at either harvest time or S rate were below the sufficient range in 2014 (Table 4). This occurrence leads one to conclude that environmental conditions influence tissue nutrient content. Most locations showed an increase in tissue S content at 25 lb S/A, but not at 50 lb S/A. The tendency for increased tissue concentration rarely resulted in a yield increase of harvested biomass. Additions of greater than 25 lb S/A were not beneficial. One of five sites showed a statistical increase in yield with the third harvest, but conversely, one of the sites actually showed a statistical decrease in yield at the third harvest. No site responded to an S addition for the second harvest. Since a fertilizer addition is expected to increase yield over the entire season, the harvest was totaled from the second and third harvest. No statistical increase in yield was observed for the "total" harvest. The yield data collected was extremely variable, but in general no benefit was observed by the addition of S.

The lack of S response can be attributed to several reasons, although none are conclusive at this point. The most obvious reason is that S is adequate in the sampled fields and currently not limiting alfalfa yields in Kentucky, despite reduced atmospheric deposition in recent years. Sufficient S may be available for optimal crop growth from mineralization of SOM, S present in the subsoil, and atmospheric deposition. Alfalfa is a deep rooted crop that can extract nutrients at much greater depths than represented by the 0 to 4 or 0 to 12 inch sample depth. Finally, the reported sufficiency range might not be refined to the extent that definite yield limitations are detected. The most likely occurrence of S deficiency will be in coarse textured soils, low in OM, in seasons with low mineralization rates. The S status of Kentucky will continue to be monitored so that S fertility recommendations can be made with confidence.

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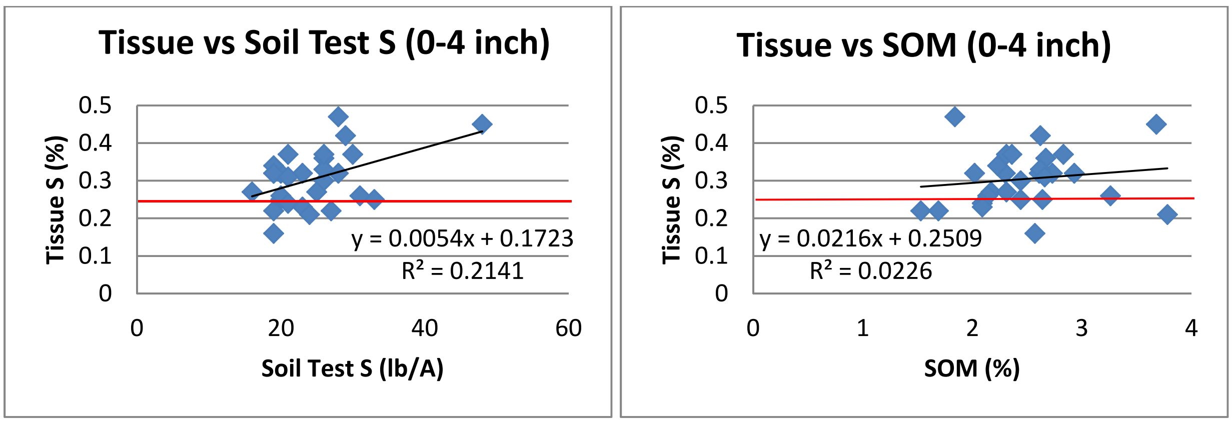

Figure 1. Relationship between tissue sulfur content, soil test sulfur, and soil organic matter at 0-4 inch sample depth for 2013.

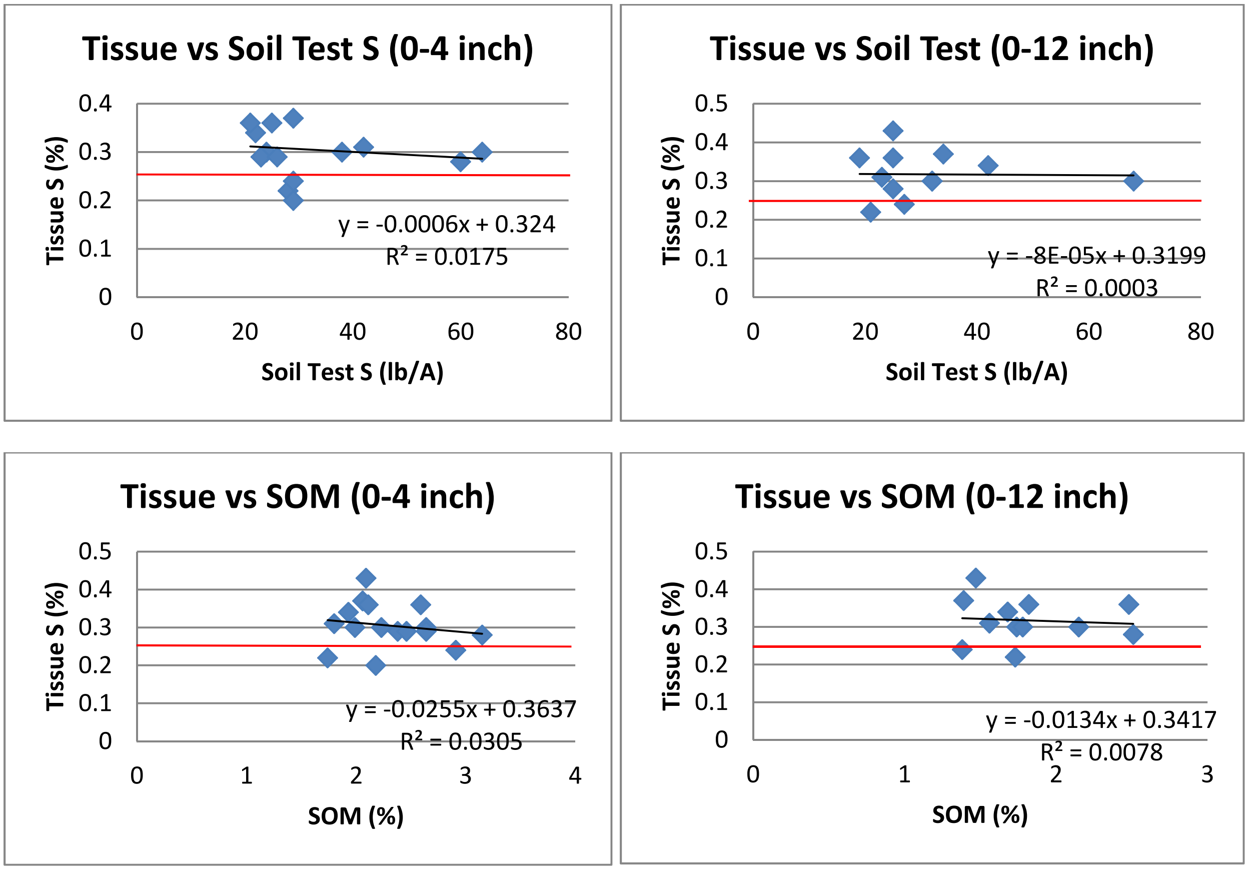

Figure 2. Relationship between tissue sulfur content, soil test sulfur, and soil organic matter at 0-4 and 0-12 inch sample depths for 2014.

Table 1. Tissue nutrient values for 28 samples collected in eight counties for 2013 prior to the second harvest at approximately 10% bloom. Samples highlighted in yellow are below the sufficiency range as reported in AGR-92.

	Tissue content			Soil Sample (0-4 inch)			
County	N	S	N/S	S	pH	Buffer pH	SOM
		%		Lb/A	H^+ ion		%
Fleming	4.91	0.42	11.69	29	7.2	7.8	2.62
Fleming	5.18	0.32	16.19	20	6.8	7.6	2.30
Fleming	4.67	0.25	18.68	20	7.1	7.8	2.64
Fleming	5.23	0.37	14.14	21	6.7	7.6	2.31
Fleming	4.74	0.37	12.81	30	7.2	7.8	2.36
Fleming	5.45	0.36	15.14	26	5.7	7.5	2.67
Fleming	4.82	0.32	15.06	19	7.2	7.8	2.93
Fleming	5.01	0.47	10.66	28	7.5	7.8	1.84
Fleming	4.94	0.45	10.98	48	7.3	7.7	3.68
Fleming	4.8	0.34	14.12	19	6.7	7.7	2.23
Madison	5.15	0.32	16.09	19	6.9	7.6	2.73
Madison	5.05	0.32	15.78	23	6.6	7.6	2.61
Lewis	4.36	0.30	14.53	26	6.1	7.7	2.44
Lewis	4.51	0.32	14.09	28	6.2	7.7	2.02
Franklin	4.51	0.25	18.04	33	6.7	7.7	2.44
Franklin	3.93	0.27	14.56	16	6.0	7.5	2.17
Franklin	5.15	0.33	15.61	26	6.5	7.7	2.62
Franklin	4.05	0.26	15.58	20	7.0	7.7	2.14
Casey	3.98	0.26	15.31	31	6.3	7.6	3.26
Casey	4.58	0.24	19.08	21	7.1	7.8	2.09
Casey	4.39	0.23	19.09	23	6.8	7.7	2.09
Ballard	3.78	0.22	17.18	27	5.9	7.7	1.53
Anderson	4.28	0.31	13.81	21	6.8	7.6	2.66
Anderson	3.65	0.22	16.59	19	6.2	7.7	1.69
Anderson	3.25	0.16	20.31	19	6.3	7.5	2.57
Anderson	3.78	0.27	14.00	25	6.8	7.7	2.31
Henry	3.06	0.21	14.57	24	6.7	7.5	3.78
Henry	4.91	0.37	13.27	26	7.0	7.7	2.83

Table 2. Tissue nutrient values for 20 samples collected in 10 counties for 2014 prior to the second harvest at approximately 10% bloom. Samples highlighted in yellow are below the sufficiency range as reported in AGR-92.

	Tissue content			Soil Sample (0-4 inch)				Soil Sample (0-12 inch)			
County	N	S	N/S	S	pH	Bu pH	SOM	S	pH	Bu pH	SOM
		%		Lb/A	H^+ ion		%	Lb/A	H^+ ion		%
Hopkins	4.46	0.34	13.12	22	6.0	7.7	1.93	42	6.1	7.7	1.68
Caldwell	3.34	0.22	15.18	28	6.8	7.8	1.74	21	7.2	7.7	1.73
Caldwell	3.38	0.20	16.90	29	5.7	7.6	2.18	-	-	-	-
Caldwell	3.88	0.28	13.86	60	6.4	7.6	3.15	25	6.6	7.6	2.51
Caldwell	3.42	0.24	14.25	29	7.1	7.7	2.91	27	6.0	7.5	1.38
Lyon	4.68	0.30	15.60	24	6.5	7.8	1.99	68	6.5	7.6	1.74
Lyon	4.85	0.30	16.17	64	7.0	7.7	2.23	32	6.9	7.8	1.78
Daviess	4.24	0.31	13.68	42	6.8	7.8	1.80	23	6.5	7.7	1.56
Union	4.68	0.37	12.65	29	7.1	7.8	2.06	34	6.6	7.8	1.39
Lewis	4.27	0.36	11.86	21	7.1	7.8	2.59	19	6.9	7.6	2.48
Lewis	4.59	0.30	15.30	38	6.5	7.6	2.64	32	6.1	7.6	2.15
Madison	4.21	0.29	14.52	23	7.2	7.8	2.38	-	-	-	-
Madison	4.16	0.29	14.34	23	6.9	7.7	2.46	-	-	-	-
Madison	4.17	0.29	14.38	26	6.7	7.7	2.64	-	-	-	-
Warren	5.89	0.43	13.70	29	6.8	7.8	2.09	25	6.3	7.7	1.47
Warren	4.87	0.36	13.53	25	6.6	7.6	2.11	25	7.0	7.7	1.82
Bourbon	4.64	0.36	12.89	77	6.8	7.6	-	-	-	-	-
Franklin	4.23	0.24	17.63	18	6.4	7.7	-	-	-	-	-
Franklin	4.78	0.32	14.94	21	6.6	7.6	-	-	-	-	-
Franklin	3.26	0.19	17.16	15	5.9	7.6	-	-	-	-	-

Table 3. Nutrient profile of one sample collected to a depth of 24 inches in Caldwell County, KY in 2014.

Depth (inch)	pH	Bu pH	P	K	S	SOM
	H^+ ion			Lb nutrients/A		%
0-4	7.1	7.7	107	326	29	2.91
0-12	6.0	7.5	12	174	27	1.38
0-24	5.1	7.5	10	170	106	1.0

Table 4. Tissue sulfur content and dry matter yield as influenced by sulfur application in 2014.

Location	Harvest	Treatment	Tissue S (%)	Prob>F	DM Yield (lb/A)	Prob>F
1	Second	0	0.295	0.1097	2974	0.8839
1		25	0.308		2648	
1		50	0.342		2511	
1	Third	0	0.398	0.2623	1517 a	0.0980
1		25	0.425		1783 b	
1		50	0.415		1654 ab	
1	Combined	0	-†	-	4491	0.7578
1		25	-		4432	
1		50	-		4165	
2	Second	0	0.303 a	0.001	2024	0.675
2		25	0.355 b		2211	
2		50	0.348 ab		2212	
2	Third	0	0.335 a	0.037	2247	0.599
2		25	0.383 b		2463	
2		50	0.400 b		2437	
2	Combined	0	-	-	4271	0.462
2		25	-		4674	
2		50	-		4650	
3	Second	0	0.323 a	0.009	3294	0.997
3		25	0.395 b		3274	
3		50	0.393 b		3260	
3	Third	0	0.370	0.130	1520 b	0.051
3		25	0.413		1373 a	
3		50	0.430		1377 a	
3	Combined	0	-	-	4813	0.905
3		25	-		4646	
3		50	-		4637	
4	Second	0	0.300 a	0.001	2358	0.626
4		25	0.420 b		2522	
4		50	0.453 b		2480	
4	Third	0	0.335 a	0.001	2206	0.668
4		25	0.413 b		2375	
4		50	0.435 b		2300	
4	Combined	0	-	-	4564	0.406
4		25	-		4897	
4		50	-		4780	
5	Second	0	0.353 a	0.008	1191	0.726
5		25	0.405 b		1195	
5		50	0.420 b		1272	
5	Third	0	0.303 a	0.073	1691	0.170
5		25	0.330 a		1772	
5		50	0.363 b		1454	
5	Combined	0	-	-	2882	0.606
5		25	-		2966	
5		50	-		2726	

† No data was collected for this variable; only total biomass harvested was collected.

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