Variation in Response to Sulfur Among Spring Wheat Genotypes

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Research Questions

1) Does the application of sulfur (S) increase grain yield and grain protein concentration of hard red spring wheat, and if so, what is the optimal application rate for S?

2) Can plant tissue analysis be used to determine whether hard red spring wheat varieties differ in their potential response to S fertilizer?

3) Can S increase the baking quality of break made from hard red spring wheat and is there an impact of S nutrition on the potential production of acrylamide during baking?

Results

The field sites were selected to represent differing conditions that may affect response to S (Table 1). The site at Crookston included a soil with poor drainage and a relatively high concentration of soil organic matter at the soil surface. Past research funded from 2008 to 2009 by the Minnesota Wheat growers found no impact of S on a single variety, Glenn, grown, in Northwest Minnesota. Kimball represented a site with a medium surface soil texture over gravelly subsoil. This site, while higher in organic matter, should have a greater potential to leach sulfate. However, the total amount of sulfate-S in the top two feet was the greatest at Kimball (Table 2). Increased sulfate-s could be due to previous manure application at this site. Kimball was not irrigated thus there were not incidental application of sulfate-S through irrigation water. Staples was irrigated and had the lowest concentration of soil organic matter in the top six inches of soil. Past research with corn has shown that response to S can greatly be affected by the amount of sulfate-S applied with irrigation water. It was found that as much as 10-15 lbs of S, as sulfate, could be applied on an annual basis depending on the amount of irrigation water applied over the growing season. Increased rainfall in June (Table 1) decreased the need for irrigation until late in the growing season. This could potentially increase the response to fertilizer S at this location. Currently, S fertilizer is only recommended for sandy soils with low concentration of organic matter in the surface soils.

Statistical significance, by location, for spring wheat grain yield, grain protein concentration, and the total amount of protein produced per acre is summarized in Table 3. As expected, yield differed consistently among the varieties. Faller produced the greatest yield across sites followed by RBO7, Mayville, Glenn, Vantage, and lastly, Select. The only surprise out of the ranking was Glenn which was one of the top yielding varieties at two locations (Crookston and Staples). Grain protein concentration was greatest for Vantage and Glenn while Faller producing the least. Total protein produced per acre was greatest for the top yielding variety, Faller, and the varieties with the greatest protein (Glenn and Vantage). The only surprise in the site data was the high protein concentrations measured at Staples. We are in the process of analyzing the grain for total nitrogen to determine if the levels produced were as high as measured on the NIR. Higher levels might be expected if nitrate levels in the irrigation water were high enough to continually feed nitrate in the plant at or post anthesis.

The varieties were selected based on flag leaf tissue data collected from the variety trials at anthesis during 2011 and 2012. Selections were made based on varieties that tended to have increased concentration in S at sites were S availability appeared to be greater (RB07 and Mayville), varieties that appeared to respond no better or worse than others [average varieties (Select and Glenn)], and varieties that appeared to respond less to increased availability of S (Faller and Vantage). The sets were designed to compare varieties that were higher yield, low protein, and low yield high protein. We quested whether the flag leaf tissue concentration would indicate that a variety is more or less responsive to S.

There was no detectable increase in yield at the Crookston and Kimball locations. Yield data for these locations was analyzed together. Data from Staples were analyzed separately as S increased yield only at Staples. Figure 1 summarizes yield data from Crookston and Kimball while Staples is summarized in Figure 2. We were interested whether an interaction between S and variety would occur across sites to determine if varieties responded differently to fertilizer application. The interaction was highly insignificant for all of the locations which indicate that the varieties studied had a similar grain yield response to S at all of the locations. When averaged across varieties, grain yield was increased by 6 bushels per acre (Figure 3) by the lowest rate of S applied (7.5 lbs per acre) which is surprising as our current suggestions for similar soil types is nearly three times that rate. Grain yield was similar between the 7.5 and 15 lb S application rates. One piece of data that has not been considered is the amount of S applied in the irrigation water. A sample has been submitted for analysis but we have not received the data at this time. Once the data is available it may provide information on why a response only occurred to the lowest rate of S. Since irrigation did not begin until July, the amount of S needed to increase yield may have been small since the amount taken up is low early in the growing season.

Grain protein concentration was not affected at any location while the total amount of protein produced was increased by S applied at Staples due to the increase in grain yield (data are not shown). The fact that grain protein concentration was not affect is not surprising as it confirms previously collected data. The total concentration of protein is typically affected by nitrogen and not S. We have seen instances where the type of protein in the grain may change due to an application of S but the total concentration remains unchanged. For instance, S containing proteins such as cysteine and methionine can be increased when S is applied relative to other non-S containing proteins. While S can impact nitrogen utilization in plants the lack of nitrogen deficiency in this study (nitrogen was kept at non-limiting levels) resulted in a low chance for S to affect nitrogen nutrition in the plant. There is no evidence that farmers growing hard red spring wheat should be concerned that S may be limiting protein levels.

Baking quality, amino acid concentration in grain, and grain and flag leaf S concentration measurements were planned for this research. While the data have been collected we still are waiting on analysis to be conducted since most of this work will be funded by in-kind work. A supplemental report will be provided including this data once it is made available for analysis. We anticipated that only the yield and grain protein concentration would be available for the year-end report for the initial funding request.

Application/Use

The data from the first year of this project indicate that some changes may be required to the current fertilizer guidelines for wheat. Changes were made when the Fertilizer Guidelines for Wheat in Minnesota publication was updated in 2012. Some changes included a general framework of S guidelines for eroded low organic matter soils (less than2.0% organic matter in the top six inches). An addition year of data would be beneficial to compare the response that occurred at the Staples location to determine if our current suggestion of 25 lbs of S may be greater than what is required to grow wheat on irrigated sandy soils in Minnesota.

There may be some benefit in baking quality with S. However, until protein premium/discounts reflect quality over the quantity there may be a limited impact to the bottom line of a wheat grower. Since this work was being conducted in-kind at the USDA grain quality lab there was no cost for this work included in the budget of this grant. Previous research has demonstrated benefits of S on baking quality. This study provides a better comparison as it includes multiple varieties.

Our goal for comparing the varieties was to determine if tissue sampling could be used to determine responsiveness of varieties to S. Since there was no evidence that a variety by S interaction occurred, it is unlikely that the tissue data had much value in determining whether S would benefit one variety over another. One caution about this work is that since yield was only affected at one location it is hard to draw hard conclusions unless the effect can be replicated. More locations and one or two additional years of funding would greatly benefit this project to determine if similar effect can be replicated across sites and years. Overall, our data from this study and past research indicated that significant caution should be taken when using plant tissue samples for guiding fertilizer application.

Material and Methods

Small plot S fertilization studies will be established alongside selecting spring wheat variety trials. Three locations were studies. Sites at Crookston Kimball were non-irrigated and an irrigated site was established at Staples. Six wheat varieties will be selected using the stability analysis conducted for spring wheat flag leaf tissue among varieties in 2011 and 2012 at 17 locations. Two varieties will be selected that were considered in the high, average, and low response to S categories and that vary in protein and yield potential. The varieties preliminarily selected are Faller, Vantage, Select, Glenn, Mayville, and RB07. Sulfur rates used will be a non-fertilized control (0 lbs S per acre) and rates of 7.5 and 15 lbs of S per acre. Sulfur was applied to the soil surface at seeding. The source of S was granular ammonium sulfate (21-0-0-24). Nitrogen was applied to balance the rate of nitrogen applied with the high rate of ammonium sulfate. Nitrogen, phosphorus, and potassium were kept at non-limiting rates according to current recommendations. Blanket N was split applied at Staples with half of the N applied after seeding prior to emergence and the remaining applied near the boot stage. All S, P and K were applied as a single application prior to or at-seeding (S treatments).

Grain yield was measured for all plots and a sub-sample of grain was collected and will be analyzed for protein, nitrogen, and S concentration. Baking quality and amino acid concentration (asparagine) will be measured to determine potential for acrylamide formation. Acrylamide concentration will not be directly measured. Grain cysteine and methionine may also be measured to compare with total S uptake. Due to the difficulty of analysis, the amino acid concentration and baking quality data may not be available for the November 15 reporting. The data will be made available to the Minnesota Wheat Research and Communication Council as a supplementary report when fully analyzed.

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Economic Benefit to a Typical 500 Acre Wheat Enterprise

Assuming a wheat price of $6 per bushel, the response at Staples would result in an additional $36 per acre in added crop value across the varieties. If S cost was $0.50 per lb of S, the rate needed to increase yield (7.5 lb per acre) would cost a grower $3.75 per acre resulting in a net profit of $32.25 per acre and would total $16,125 for a 500 acre operation. The question remains whether the 7.5 lb rate is needed? Since we did not use a smaller rate it is unclear if application of 5 lb of S would result in the same yield. However, the low cost of the treatment relative to the added value of the crop can easily pay for the additional cost of the fertilizer. When S is deficient, application of S is highly profitable for hard red spring wheat.

Even with the low total cost associated with the rate of S needed to increase yield, if a site is not responsive a grower should highly consider using money intended for S for nitrogen especially in years where yield potential and protein discounts are greater. Since there has been no evidence for increased grain protein due to S application in several studies dating back to 2008 S should not play a role in making decisions on fertilizer application for increasing grain protein concentration.

Related Research

A S study was concluded in 2009 which was funded by the Minnesota Wheat Growers that studied the effect of S source, rate, and timing for wheat grown on soils with relatively high concentration of organic matter. This current study provided supporting data for the previous research but focuses on questions received following the previous study on whether we would expect response to S to be greater for varieties which are greater yielding than Glenn which was used in the previous research. We are also following up on information collected in a study funded in 2011 and 2012 that included a survey of flag leaf tissue nutrient concentration. The current research will determine if there is any value in tissue concentration data and whether tissue concentration can help predict a varieties responsiveness to a specific fertilizer.

Recommended Future Research

Since we have not been able to consistently detect significant yield response to S application in hard red spring wheat an additional year or two of follow up research would be beneficial to see if we can replicate responses that occurred at Staples in 2014. In addition, we would like to continue targeting field sites on lower organic matter, eroded, soils to see if we can replicate data collected in corn which suggests soils with less than 3.0% organic matter in the top six inches may be highly responsive to S. Additional years would provide a stronger set of guidelines for when and where to apply S in hard red spring wheat.

Our initial contacts with growers of irrigated wheat also indicate a need to study nitrogen guidelines for irrigated coarse textured soils. While there acreage may be low there is some wheat grown in rotation with other crops on irrigated soils. All of our current research has focused on the primary wheat growing regions in Minnesota which are non-irrigated. A nitrogen study was established at Staples along with the S study in 2014. Additional funding for S research would allow us to also conduct nitrogen studies under irrigation that would provide data for nitrogen guidelines for irrigated wheat.

Publications

Kaiser, D.E., J.J. Wiersma, and J.A. Anderson. 2014. Genotype and Environment Variation in Elemental Concentration of Spring Wheat Flag Leaves. Agron. J. 106:324-336.

**Paper was a summary of work funding by MN wheat for the 2011 and 2012 growing seasons

Appendix

Table 1. Trial location, planting information, and monthly total precipitation for spring wheat S rate studies.

					Monthly Total Precipitation		
Location	County	Soil Type	Soil Texture	Seeding Date	May	June	July
					-----inches-----		
Crookston	Polk	Wheatville	Sandy Loam	17-May	2.6	6.8	2.2
Kimball	Stearns	Fairhaven	Silt Loam	26-Apr	4.4	7.6	1.9
Staples	Wadena	Verndale	Sandy Loam	7-May	3.6	5.9	7.8

Table 2. Spring soil test averages across replications for Spring wheat S trials.

Location	Soil Test (0-6")†				Sulfate-S‡
	P	K	SOM	pH	
	-------ppm-------		---%---		--lb/ac--
Crookston	8	128	4.0	8.0	48
Kimball	98	200	5.1	7.1	76
Staples	46	120	1.9	7.0	52

† P, Bray-P1 phosphorus; K, ammonium acetate potassium; SOM, soil organic matter; pH, soil pH.

‡ 0 to 2 foot soil sulfate-S

Table 3. Summary of statistical signficance of main effects of variety (V), sulfur rate (S), and their interaction (VxS) for spring wheat grain yield, protein concentration, and total protein produced per acre.

	Grain Yield†			Grain Protein†			Protein Yield†		
Location	V	S	VxS	V	S	VxS	V	S	VxS
	---*P>F*---								
Crookston	<0.001	0.42	0.56	<0.001	0.81	0.82	<0.001	0.85	0.56
Kimball	<0.001	0.52	0.21	<0.001	0.87	0.44	<0.001	0.33	0.28
Staples	<0.001	<0.001	0.28	<0.001	0.34	0.12	0.03	<0.01	0.43

Table 4. Summary of hard red spring wheat grain yield, grain protein concentration, and protein production per acre for individual varieties at Crookston (CR), Kimball (KI), and Staples (ST) Minnesota during 2014. Average values were calculated for data across three sulfur rates and across locations (AVG).

	Grain Yield†				Grain Protein†				Protein Yield†			
	CR	KI	ST	AVG	CR	KI	ST	AVG	CR	KI	ST	AVG
	--------------bushels/ac (@ 13%)---------------				-----------------------%(@ 12%)------------------------				--------------pounds/ac (@ 13%)----------------			
Faller	82a	83a	86a	84a	12.8d	14.4e	17.2d	14.8e	635b	733a	897a	755a
Glenn	84a	60d	79b	74c	14.6a	15.9b	18.8b	16.4b	734a	570c	889a	731ab
Mayville	68c	80a	76bc	75bc	14.4ab	15.3c	18.0c	15.9c	591c	732a	817bc	713b
RB07	75b	80a	79b	78b	13.5c	14.9d	17.8c	15.4d	607bc	709a	843abc	718b
Select	70c	68c	74bc	71d	14.2b	15.5bc	17.8c	15.8c	595c	625b	795c	672c
Vantage	68c	74b	73c	72cd	14.2b	17.1a	20.0a	17.1a	577c	750a	873ab	734ab

† within columns, numbers followed by the same letter are not statistically significant at $P \leq 0.05$ probability level.

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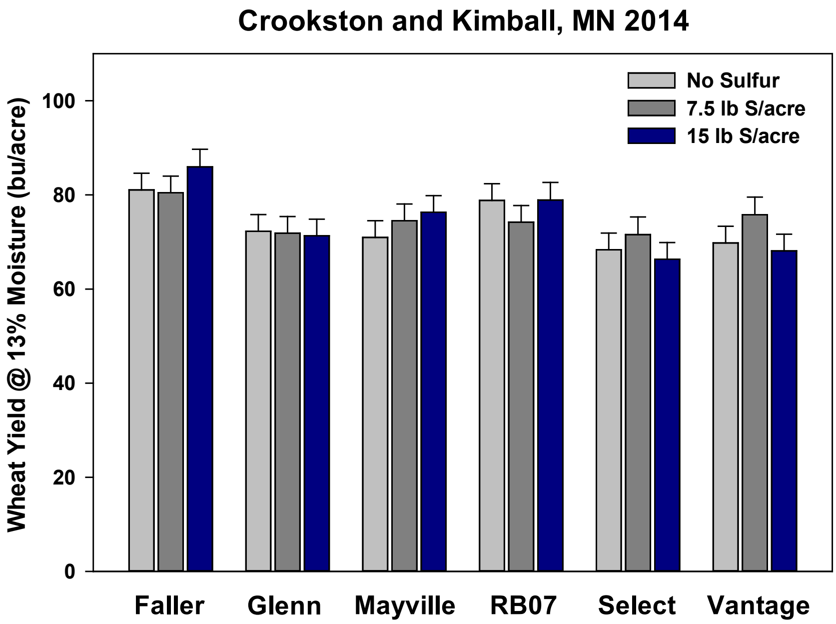

Figure 1. Summary of variety response to sulfur averaged together for the Crookston and Kimball locations studied in 2014.

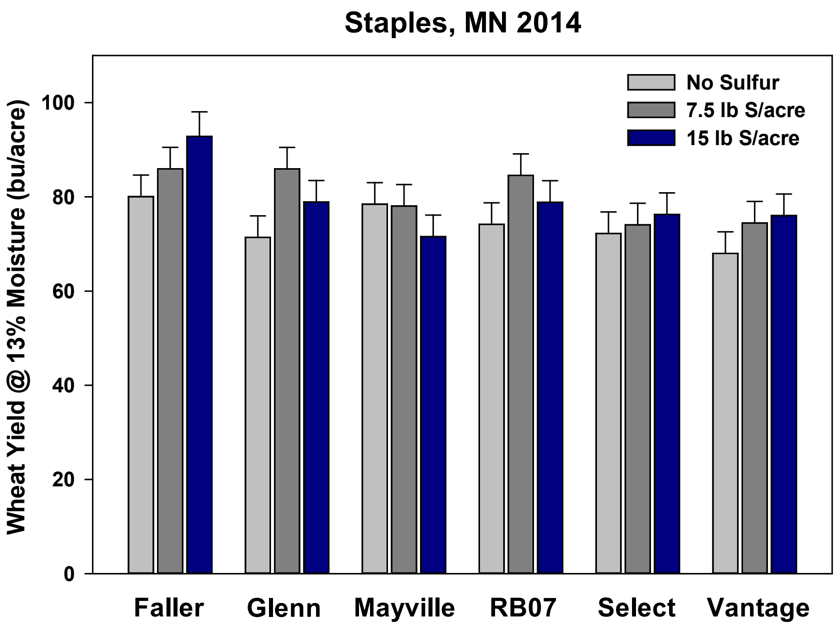

Figure 2. Summary of variety response to sulfur at the Staples, Mn locations studied in 2014.

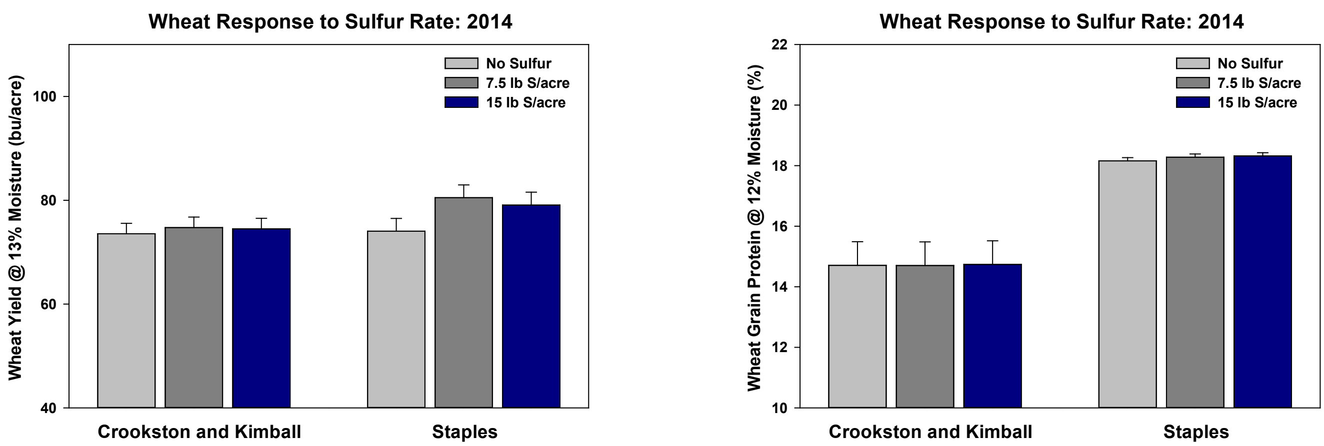

Figure 3. Impact of sulfur rate on hard red spring wheat grain yield and grain protein concentration for Crookston and Kimball (average across location) where sulfur did not increase yield and Staples were an application of 7.5 lbs of S per acre increased yield over the control (no sulfur).