Impact of Sulfur, Nitrogen and their Interaction on Grain Yield, Quality and Net Farmer's Income

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Research Questions

1. Does sulfur enhance wheat grain yield and grain protein?
2. Can sulfur impact wheat N use or N removal from soil?
3. How does sulfur application affect net return on the farmer's investment on sulfur fertilizer?

Results

Results of all variables assessed at Ada, are presented in table 1, and at Gentily on table 2. The results include grain yields, protein, test weight (TWT), kernel weight (KWT) of 250 grains, flag leaf N (FLN), flag leaf S (FLS), grain N and grain S concentration, grain N and S uptake (GNUp and GSUp, respectively), and grain relative yield (GRY). The site at Thief River Falls was lost to herbicide damage. Treatment responses were analyzed at 95% confidence level. When a probability (p) value in the ANOVA section of tables 1 and 2 was < 0.05 it means that statistically, we are at least 95% confident that the treatment had a significant effect on the response variable (e.g. yield, grain N) measured. Only then did we test treatment means and used dissimilar letters to indicate significant differences in means, without which differences were not significant.

Ada

In 2017, yield and protein response to N was of statistical significance; meanwhile, the impact of S was not (Table 1), despite higher yields were obtained when Su was applied (Fig 1). When yields were averaged across levels of S, 60lbs N significantly improved yields by 19 bushels from the check (67 bu/ac). Even though yields increase at higher N rates means were not significantly different among N fertilized plots. Grain protein also improved significantly from 0lbs N (2.39%) to 60lbs N (13%), and between 60 and 120lbs N (14.02%). Protein did not differ between 120 and higher N rates. The absence of significant yield and protein response to S, and lack of significant yield differences between treatments that received N fertilizer may be attributed to high N mineralization from organic matter in soil (with only 22 lbs N before treatments were applied). Test weight was enhanced by application of N but not S. Kernel weight was not affected by N or S. Comparing yield and protein results in 2017 to last year and 2015, S had no significant effect on yield or protein in 2016; meanwhile in 2015, S caused significant yield increase of 6 bushels at 10 and 20 lbs S/ac. Results of N use efficiency and net returns are not shown; however, despite improved yields with S as shown on figure 1, yield advantage was not high enough to cover expenses on ammonium sulfate fertilizer applied. Net positive return was observed in 2015 at Ada, and 2016 at Thief River Falls in 2016.

Flag leaf and grain N and S content

Flag leaf N (FLN) was significantly enhanced by N fertilization, increasing with N rates up to 120 lbs N above which, mean differences were not significant. FLN ranged from a minimum at 3.2% to a maximum of 4.9%, and FLS from 0.19 to 0.39%. Interestingly, FLS was not impacted by S application, but instead showed a significant linear response to N fertilization. FLS level was different between the check and the rest of the fertilizer N treatments. Significant FLN differences were observed between the S check (4.24%) and 20 lbs S (4.36%), but not at 10 lbs (4.33). FLS response to N rates may have resulted from N fertilizer enhancement of biomass production causing higher demand and uptake of S than at the 0 lb N check. N:S ration was not different among treatments. It is also probable that the effect of S fertilizer enhanced N uptake earlier in the season before tissue sampling, but not to the extent that these leaf N differences were significant enough to cause yield and protein differences. Grain N and S, and total uptake of N and S by the grain was significantly enhanced by N. Average GNUp ranged between 96 lbs from the N check to 155 lbs N at 240 lbs N rate.

Relationship between flag leaf S, flag leaf N, and relative grain yield

We conducted Pearson correlation analysis to estimate the strength of the relationship between FLS, FLN with grain yield. Correlation analysis indicated a strong association between grain yield and FLS ($r= 0.76$, $p<0.0001$, $n=60$), and between yield and FLN ($r=0.88$, $p<0.0001$, $n =60$). FLS explained 58% in grain S, 54% of variation in grain protein, and 50% in grain N. Yield increased with increasing FLN, probably because photosynthetic rate is positively correlated with FLN. Regression analyses were performed between FLS, FLN and GRY. The GRY was determined by dividing the yield each treatment by the maximum mean yield. We used the best fitted relationship to establish that FLN and GRY were linearly (figure 4). Meanwhile, a quadratic function (Fig. 4) best explained the relationship between relative yield and FLN. From this quadratic relationship, a critical minimum FLS concentration was estimated at 95% of maximum yield. It was estimated that 0.29% was the critical minimum concentration below which S deficiency may cause yield reduction. The weak relationship between relative yield and FLS at Gentilly meant did not permit a critical value to be determined. Dr. Dan Kaiser of University of Minnesota, obtained an estimate of 0.32 in one of his studies.

Gentilly

Sulfur had limited impact on all measured variables. N fertilizer caused significant yield and protein response, among other variables measured (table 2). However, due to N contribution from soil through mineralization, significant differences were observed only between the N check and at 240 lbs N. Grain protein was significantly different between the check and N fertilizer rates. The highest grain protein was produced at 180 lbs N (14.45%). Only 39% of the GRY yield was explained by FLN. Because FLS and relative yield were related by a linear function, rather than a quadratic function, a critical value for FLS could not be obtained. Flag leaf N was significantly different between N fertilized plots compared to the check. FLN ranged from a minimum at 3.7 to a maximum at 4.6%, and FLS S ranged from 3.7 to 4.6%. Differences in response to S at Ada versus Gentilly was not surprising in in view of a higher organic matter content (>3% at Gentilly), compared to 2% at Ada.

Application/Use

When farmers apply sulfur to their wheat crop, it is important to consider soil texture, soil organic matter, fertilizer and grain prices because of inconsistent crop response to S. At least 90% of soil S is present in the soil organic form. of SOM The main determinant of wheat yield and quality is N, but S will often enhance yield and protein in sandy/lighter soils, where soil organic matter is low. Out of eight site years of data, two showed significant contribution of S to wheat yields and or grain protein. Two of the five sites used for this multiyear study showed that responses were observed for some years on fields where SOM was less than 2.7%, and soil was sandy loam or lighter. Three of the five sites that did not respond to S, had SOM>3%, and were loam or clay loam. Flag leaf sampling and analysis has been suggested as a means to assess crop S status. Maintaining practices that enhance SOM buildup will help minimize S requirements. Reduction of S fertilizer rates to 10 lbs or below will likely be economical for the farmers in soils less susceptible to sulfate (S) and N leaching.

Material and Methods

The trial will be conducted at three locations in the Red River Valley area. Two field locations have already been identified at Ada and Thief River Falls (TRF), where nutrient leaching is more likely, SOM content is usually less than 3%, and clay content is below 30% (sandy loam). A third site will be located in or near Red Lake falls, MN, where SOM (>3%) and/or clay content is relatively high (loam to clay loam). Five N rates in 60 lbs/ac increments including a control (0 lb/ac), will constitute the main treatment plots, and three S rates (0, 10, 20 lbs/ac) as sub-plot treatments to be imposed within every N main plot treatment. The treatments will be applied following a split-plot arrangement within a randomized complete block design, using four replicates. There will be a total of 15 treatments at each site. Recommended Minnesota state agronomic practices will be followed, such as for herbicide and pesticide application, and deficient soil nutrient application. Data will be collected mid-season to assess tissue N and S levels of flag leaves before anthesis, to determine if S content is limiting, and if N:S ratio is related to final yield or protein in response to S.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

This study, and previous studies have shown, and confirmed that farmers applying over 10 lbs of S are likely to get less return. Long term economic losses could be quite high if producers apply annual S rates above 10 lbs S for the soil types used in these studies (medium to heavier soils). Nitrogen fertilizer application above 180 lbs was a sure rate to maximize yields and grain quality, plus soil N credit and previous crop credit. In some years, 60 lbs of N was not different from 180 lbs. farmers have interest in clean groundwater and less risk of groundwater pollution. Aggregation of small savings by reducing N and S fertilizer rates on a 500-acre field will go a long way to reduce risk of groundwater pollution especially where yield benefits are not consistent with high N fertilization.

Related Research

This was the final of three year's research on S and N. Results from 2016 study was presented at the 2016 Prairie Grains Conference, and the 2015 results available http://smallgrains.org/wp-content/uploads/2015/12/2015TebohSulfur.pdf

Other planned research trials for 2018 will aim at quantifying the amount of N removed in the grain, aboveground biomass, and what stays in the soil, as residual N to assess risk of ground water contamination.

Recommended Future Research

Assess split and N rates of fertilizer contamination risk of residual N leaching to ground water, and crop use.

Publications

Jasper M Teboh, Joel Ransom, Szilvia Yuja. 2017. Effect of sulfur fertilization on nitrogen use efficiency of spring wheat and corn in ND and MN. 15th Annual Nitrogen Use Efficiency Conference. August 7-9. Baton Rouge, Louisiana.

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Table 1. Effect of N and S, on wheat grain yield and qualityn N and S grain uptake (ADA, 2017)

Fertilizer rates	Yield	Protein	TWT	KWT 250	Flag Leaf N	Flag Leaf S	Flg leaf N:S	Grain N	Grain S	Grain N:S	Relative Yield	Protein Yield	Grain N uptake	Grain S uptake
N (lb/ac)	bu/a	%	lb/bu	g	——%——			——lbs/ac——			%	————lbs/ac————		
0	67b	12.39c	61.7b	9.94	3.5c	0.23b	15.5	2.4d	0.13b	18.2	73b	505c	96c	5.3b
60	86a	13.03b	62.2ab	10.00	4.3b	0.29a	15.1	2.5c	0.15a	17.6	93a	684b	131b	7.5a
120	88a	14.02a	62.3ab	9.88	4.5a	0.3a	15.4	2.7b	0.15a	18.6	96a	755ab	143ab	7.8a
180	92a	14.35a	62.8a	9.88	4.6a	0.3a	15.6	2.8ab	0.15a	18.6	100a	808a	154a	8.3a
240	92a	14.47a	62.3ab	9.94	4.6a	0.31a	14.9	2.8a	0.15a	18.7	100a	813a	155a	8.4a
S (lb/ac)														
0	82	13.66	62.2	9.98	4.2b	0.27	15.8	2.6	0.14	18.7	89	691	131	7.1
10	86	13.69	62.0	9.98	4.3ab	0.29	15.3	2.7	0.14	18.5	94	726	138	7.5
20	86	13.61	62.5	9.82	4.4a	0.30	14.8	2.6	0.15	17.8	94	722	137	7.8
	ANOVA (P-Values)													
N Rate	**<.0001**	**<.0001**	**0.004**	0.887	**<.0001**	**<.0001**	0.8554	**<.0001**	**<.0001**	0.271	**<.0001**	**<.0001**	**<.0001**	**<.0001**
S Rate	0.1454	0.8393	0.098	0.208	**0.029**	0.1401	0.2615	0.7654	0.0702	0.085	0.1455	0.1959	0.1509	0.0566
N x S	0.448	0.1946	0.183	0.225	0.6614	0.9474	0.9566	0.3366	0.1433	0.607	0.4422	0.2884	0.2759	0.3832

Identical letters within column indicate no significant differences. Means were not separated by letters if a treatment did not have signifcant effect, implying the P value was not less than 0.05. KWT= Kernel weight (250 grains)

Table 2. Effect of N and S, on wheat grain yield and qualityn N and S grain uptake (Gentily, 2017)

Fertilizer rates	Yield	Protein	TWT	KWT 250	Flag Leaf N	Flag Leaf S	Flg leaf N:S	Grain N	Grain S	Grain N:S	Relative Yield	Protein Yield	Grain N uptake	Grain S uptake
N (lb/ac)	bu/a	%	lb/bu	g	---------%-------			-------lbs/ac----			%	------------lbs/ac---------		
0	69b	13.34c	59.9	9.1842	3.79b	0.293	13.32	2.62	0.145	18.12	75b	559b	107b	6.0b
60	78ab	13.95b	60.2	9.4207	4.17a	0.329	13.36	2.63	0.148	17.73	85ab	659a	122ab	6.9ab
120	78ab	14.33ab	60.1	9.3083	4.23a	0.314	13.51	2.68	0.142	18.90	85ab	677a	123a	6.6ab
180	79ab	14.45a	59.8	9.2967	4.29a	0.330	13.05	2.63	0.143	18.46	86ab	688a	125a	6.6ab
240	81a	14.37ab	59.6	9.2483	4.33a	0.316	13.79	2.68	0.145	16.93	88a	702a	128a	7.0a
S Rate (Lb/a)														
0	77	14.08	59.9	9.3169	4.17	0.306	14.07	2.66	0.143	18.68	84	661	122	6.60
10	77	14.13	60.1	9.3005	4.13	0.320	13.10	2.65	0.147	18.00	83	656	121	6.74
20	77	14.06	59.8	9.2575	4.19	0.323	13.05	2.64	0.144	17.40	79	655	120	6.59
	ANOVA *(P-Values)*													
N Rate	**0.022**	**<.0001**	0.469	0.483	**<.0001**	0.2106	0.9516	0.762	0.7502	0.3781	**0.019**	**<.0001**	**0.0056**	**0.0438**
S Rate	0.959	0.8238	0.338	0.8128	0.491	0.3964	0.2742	0.709	0.4920	0.3172	0.969	0.9445	0.8197	0.8382
N x S	0.901	0.9274	0.294	0.1711	0.991	0.9971	0.9331	0.235	0.8596	0.8327	0.8967	0.8461	0.9254	0.841

Identical letters within column indicate no significant differences. Means were not separated by letters if a treatment did not have signifcant effect, implying the P value was not less than 0.05. KWT=Kernel weight (250 grains)

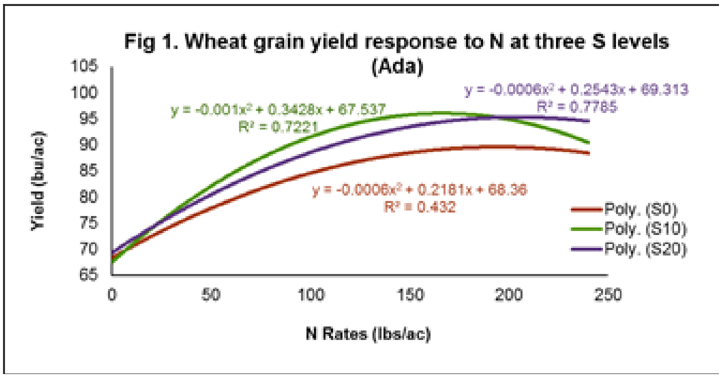
Fig 1. Wheat grain yield response to N at three S levels (Ada)
y = -0.001x² + 0.3428x + 67.537
R² = 0.7221
y = -0.0006x² + 0.2543x + 69.313
R² = 0.7785
y = -0.0006x² + 0.2181x + 68.36
R² = 0.432
Poly. (S0)
Poly. (S10)
Poly. (S20)
Yield (bu/ac)
N Rates (lbs/ac)

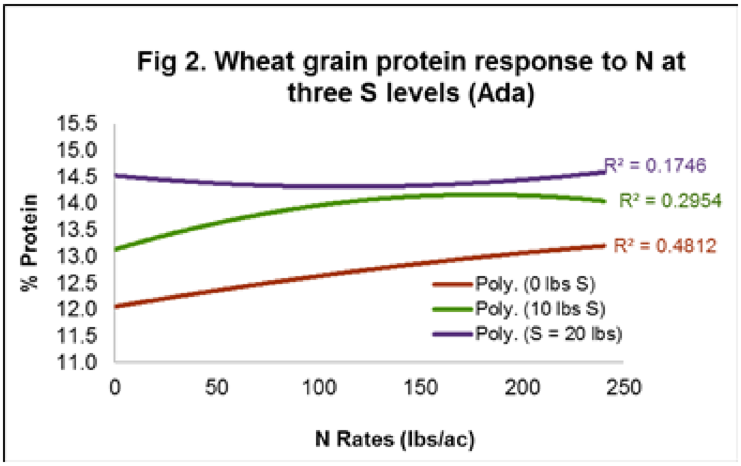
Fig 2. Wheat grain protein response to N at three S levels (Ada)
R² = 0.1746
R² = 0.2954
R² = 0.4812
Poly. (0 lbs S)
Poly. (10 lbs S)
Poly. (S = 20 lbs)
% Protein
N Rates (lbs/ac)

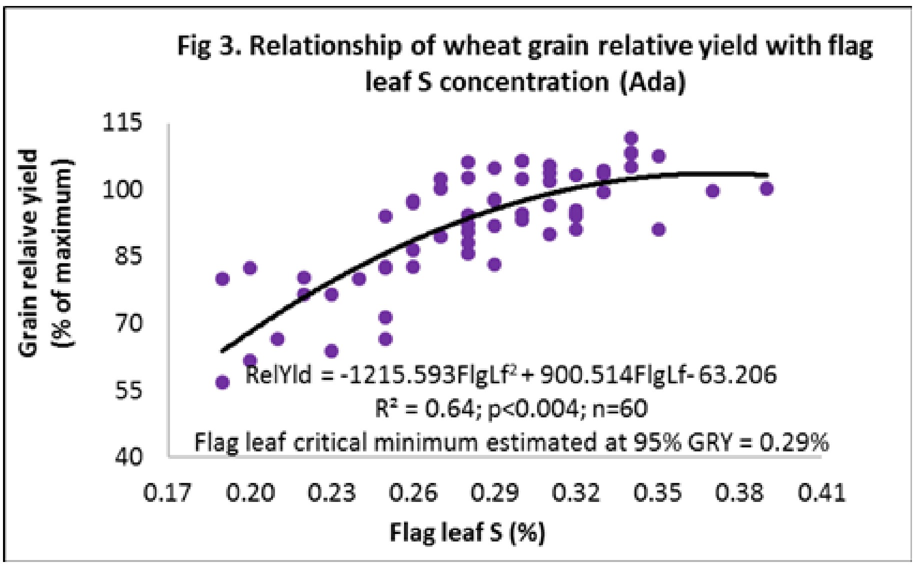
Fig 3. Relationship of wheat grain relative yield with flag leaf S concentration (Ada)
RelYld = -1215.593FlgLf² + 900.514FlgLf- 63.206
R² = 0.64; p<0.004; n=60
Flag leaf critical minimum estimated at 95% GRY = 0.29%
Grain relaive yield (% of maximum)
Flag leaf S (%)