Economics, Nitrogen Use Efficiency, and Effects of Nitrogen and Sulfur Fertilizer Level Combinations Applied to Spring Wheat in Minnesota

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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 the net return on the farmer's investment on sulfur fertilizer?

Results

Grain yield and protein content were assessed in response to N and S rates, and the effect of their interaction was analyzed at several locations. From the analysis of variance (ANOVA), there was no interaction between N and S rates for yield and protein. Sulfur application in 2016 had no statistically significant effect on grain yield and protein of wheat at Ada (Table 1), and Red Lake Falls (RLF) (Table 2). At Thief River Falls (TRF), yield responded significantly to S *($p<0.05$)* but not protein (Table 3). Averaged across N rates, grain yield at TRF increased by a significant 5.4 and 6.4 bu/a for the 10 and 20 lbs of S treatments, respectively, when compared to the S control (0 lbs S added) treatment. The neutral detergent fiber (NDF) of the grain, whose level in livestock ration influences their intake, was significantly increased with S at 20 lbs, compared to the check. Nitrogen rates had significant impact on yields and protein at each site. At Ada, 180 lbs of N produced significantly higher yields (80 bu/ac) than the lower N rates (Table 1). At RLF, 60 lbs N produced the highest yield (87 bu/a). But the control produced just 7 bu less, and with statistically similar yields compared to 120, 180 and 240 lbs N. High N mineralization (3.6% SOM) in 2016 probably explains the high yields with no added N. The N mineralized was however, not enough to meet the level of protein produced with fertilizer N at higher rates. At TRF, 120 lbs N produced the highest yield and protein (Table 3). There was no obvious explanation why the protein at 240 lbs N was significantly lower than the other treatments (Table 3), despite producing similar yields as the lower N fertilizer rates. As expected, the strongest response to S and N was at Ada and TRF, where the soils had lower clay content (sandy loam soils) compared to the loam soil of RLF. The average yield and protein response across Ada and TRF, for the 2015 and 2016 growing seasons showed that S improved yields (Figure 1) and grain protein (Figure 2).

Flag leaf N and S showed significant interaction between S and N rates. Nitrogen accumulation in flag leaf (table 3) suggests that when N fertilizer is applied N accumulation is favored when S is applied. But when N is no applied, and probably very deficient, N uptake in plant is not improved by S. The interaction between S and N on flag leaf S suggests that S accumulation increased with application of higher rates of N.

Based on the method (see materials and methods section) used to determine net gain or loss in income, when S was applied in 2016, the farmer would have incurred a net loss of income at almost every N treatment level used, other than at 120 lbs N at RLF and TRF. The highest net revenue was recorded at TRF, where $84/ac was estimated at 120 lbs N and 10 lbs S, followed by $66/ac at 20 lbs of S, compared to $39 at 0 lbs added S (Figure 3). The net return at RLF was $5 at 10 lbs S, but with a net loss of $8 at 20 lbs S. At Ada, there was a surprising net loss of $43/ac with 10 lbs added S, meanwhile a net gain of $10 was recorded without S or with S at 20 lbs. Grain N removed has not yet been determined for 2016. In 2015, grain N removed, and averaged across N rates was, 116 lbs/a without S, 122 lbs at 10 lbs S, and 120 lbs N, at 20 lbs S.

This study supports the recommendation that wheat is more likely to respond to S, on lighter soils, and for soils with low SOM (typically less than 3.5%) content. Application of S at about 10 lbs or less would probably justify the cost than rates above 10 lbs. This is supported by inconsistent responses where, at Ada (2016), yield and protein response was weak whereas in 2015, both yield and protein showed strong response to S and N. In 2015 at TRF, wheat yield did not respond to S and N, contrary to 2016. showed significant response to S was if S is to be applied annually. from this study were that, S increased grain yields and protein in 2015 and 2016 at Ada and TRF with sandy loam soils. The economic impact of S fertilizer application, can be significantly affected by the farmer's decision on how much N fertilizer to use. Our results showed that the farmer has a better chance of a net positive return on S application if they are using the state N recommendation for their respective locations. There was a higher N removed by the grain with application of S.

Application/Use

When farmers apply sulfur to their wheat crop, it is important that they consider factors such as soil type, soil organic matter, and market price. The main determinant of wheat yield and quality is N, but S will often enhance yield and protein in sandy/lighter soils and in soils where SOM is low. Since soil test for sulfur is not well predictive of crop response, annual S application must be weighed against the cost, considering that most of the soil S is present in the organic form that, under suitable soil conditions (warm

spring, adequate soil moisture), will supply the crop needs. Determining the magnitude of yield or protein increase due to S, can serve the farmer well if the impact of S on yields and quality over a period of several years is inconsistent and shows that N fertility and other essential nutrients should be the primary concern.

Material and Methods

The trial was conducted for the second year, on three framers' fields located at Ada, Red Lake Falls (RLF), and Thief River Falls (TRF) in the Red River Valley Area of Minnesota. At Ada, the soil type was a Ulen Sandy loam (2.4% SOM), planted to the variety, Faller on April 13th. Faller was also planted on April 13th at RLF on a Wheatville loam containing 3.6% SOM. At TRF, the variety Prosper was planted on a Foxhome sandy loam soil containing 2.6% SOM. This trial evaluated the response of spring wheat to S at different levels of N. The fertilizer treatments were five levels of N, including a control, at 0, 60, 120, 180, and 240 lbs N. Three S treatment levels were, 0, 10, and 20 lbs imposed in a RCBD within each N treatment, in a split-plot arrangement where, N levels were whole plots and S levels as sub-plots. Each treatment was replicated four times. Flag leaf samples were collected and grain samples sent for S and N analysis, and biomass at Ada (not yet available). Net economic return was calculated using the price of grain at 14% protein at $4.91/bu, with premium above 14% protein and equal to 15% every 0.2% given at $0.06/bu, premium > 15 and equal to 16% protein every 0.2% at $0.02/bu, and discount down between 14 and 11% at every 0.2% reduction at $0.06/bu. The recommended N rate for each site was determined from the University of MN N fertilizer recommendation calculator, using a yield goal of 80 bushels at Ada and RLF, and 70 bushels at TRF. Grain was used was $4.55/bu (also using previous crop N credit of 20 lbs following soybeans, and residual soil test). The net returns were calculated by taking the difference from the baseline N recommended rate calculated above without S applied, and the protein and yields were estimated for this baseline from the regression equations for respective site in 2016. Revenues did not include other variable cost of production besides fertilizer cost and application cost. Data were subjected to analysis of variance (ANOVA) using the Mixed Model analysis in SAS. S rates were analyzed as fixed effects, and the replicate x N rates as random effects.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

The economic impact of S fertilizer application, can be significantly affected by the farmer's decision on how much N fertilizer to use. Our results showed that farmers have a better chance of a net positive return on S application if they are using the state N recommendation for a given location. A dollar lost/ac is $500 for 500 acres. From the TRF results, $45 gain over the control, at 10 lbs S and N rate of 120 lbs/ac would mean an increase in income of almost $22,500/ year

Related Research

This research was in its second year. Results from 2015 study were presented at the 2015 Prairie Grains Conference, and available at: http://smallgrains.org/wp-content/uploads/2015/12/2015TebohSulfur.pdf

Other research work trials to be continued in 2017, will be quantifying the relative contribution of S, P, and K. The first year (2016) study showed S increased wheat yield by three bushels, P, by a bushel, and no increase with potassium applied. How each of these elements affects the impact of the other in single or multiple combination, is to be verified at two locations.

Recommended Future Research

The far reaching implication of lost income by the farmer, due to inadequate management of S or N can have significant implications on their farm business. Our observations from these results need to be verified with more research data for, consistency. Another year of funding will help advance our understanding, to support the fertilizer recommendations used by the farmers.

References

Fertilizer Recommendations for Agronomic Crops in Minnesota:
http://www.extension.umn.edu/agriculture/nutrient-management/nutrient-lime-guidelines/fertilizer-recommendations-for-agronomic-crops-in-minnesota/wheat/#table-1

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Table 1. Effect of N and S, on wheat grain yield and quality (Ada, MN, 2016)

	Yield	Protein	Ash	Fiber	Starch
Lb/a	bu/a	%	%	%	%
N Rate (N)					
0	60c	11.54b	1.46	2.786	83.1a
60	80b	11.74b	1.46	2.808	83.0a
120	77b	13.04a	1.49	2.793	82.1b
180	87a	13.32a	1.50	2.816	81.9bc
240	83ab	13.6a	1.51	2.813	81.5c
Mean	77	12.66	1.48	2.80	82.33
S Rate (S)					
0	78	12.65	1.48	2.796	82.3
10	77	12.60	1.48	2.808	82.5
20	77	12.73	1.49	2.806	82.2
Mean	77	12.66	1.48	2.80	82.33
ANOVA	----------P-Values----------				
N Rate (N)	**<.0001**	**<.0001**	**0.0234**	*2.796*	**<.0001**
S Rate (S)	*0.6094*	*0.831*	*0.3565*	*2.808*	*0.4417*
N x S	*0.5705*	*0.7063*	*0.9936*	*2.806*	*0.3331*

Means within each column and treatment with different letters are significant (P <0.05) according to the Tukey's HSD test. P-values < 0.05 indicate the treatment had significant effect on the measured variable

Table 2. Effect of N and S, on wheat grain yield and quality (Red Lake Falls, MN, 2016)

	Yield	Protein	TWT	NDVI	Fiber	Starch	Ash	NDF
Lbs/a	bu/a	%	lb/bu	%	%	%	%	%
N rate (N)								
0	80b	10.28c	56.4ab	0.857b	2.98a	81.62b	1.419c	8.908a
60	87a	12.34b	57.20a	0.881a	2.92b	82.10a	1.464b	7.897bc
120	87a	13.30a	55.3a	0.886a	2.93ab	81.51b	1.477b	7.753c
180	86ab	13.72a	54.5b	0.889a	2.96ab	80.85c	1.486ab	7.974bc
240	86ab	13.99a	54.5b	0.887a	2.92b	80.73c	1.516a	8.505ab
Mean	85	12.73	55.60	0.880	2.94	81.4	1.472	8.207
S Rate (S)								
0	86	12.74	55.6	0.878	2.95	81.5	1.465	7.881b
10	84	12.72	55.5	0.882	2.93	81.3	1.474	8.363ab
20	85	12.72	55.6	0.881	2.94	81.3	1.479	8.378a
Means	85	12.73	55.582	0.880	2.94	81.362	1.472	8.207
ANOVA	----------*P-Values*----------							
N Rate (N)	***0.0275***	***<.0001***	***0.0134***	***<.0001***	***0.0105***	***<.0001***	***<.0001***	***0.0002***
S Rate (S)	*0.4412*	*0.9974*	*0.9732*	*0.3552*	*0.5051*	*0.2025*	*0.2955*	***0.0263***
N x S	*0.6314*	*0.3255*	*0.6938*	*0.4488*	*0.3909*	*.06024*	*0.4313*	*0.9510*

Means within each column and treatment with different letters are significant (P < 0.05) according to the Tukey's HSD test. P-values < 0.05 indicate the treatment had significant effect on the measured variable

Table 3. Effect of N and S, on wheat grain yield and quality (TRF, 2016)

	Yield	Protein	NDVI	Flag leaf S	Flag leaf N	N:S
Lb/ac	**bu/a**	**%**		**%**	**%**	
N Rate				3.58c	17.31b	3.58c
0	40.18b	15.34a	0.746b	4.16b	18.04ab	4.16b
60	49.62ab	15.58a	0.85a	4.33ab	18.18ab	4.33ab
120	63.12a	16.00a	0.878a	4.39ab	19.27a	4.39ab
180	54.4a	15.26a	0.854a	4.54a	18.97a	4.54a
240	57.08a	14.06b	0.832a	4.20	18.35	4.20
Mean	52.9	15.25	0.83	%	%	%
S Rate						
0	48.95	15.23	0.816b	0.265b	4.18b	20.71a
10	54.41	15.30	0.837a	.	.	.
20	55.28	15.21	0.844a	0.203a	4.22a	15.99b
Mean	52.88	15.25	0.832	0.234	4.18	
ANOVA	***----------P-Values----------***					
N Rate	***0.0030***	***<.0001***	***0.0001***	*0.0018*	*<.0001*	*0.0246*
S Rate	***<.0001***	*0.5785*	***<.0001***	*<.0001*	*0.209*	*<.0001*
N x S Rate	*0.1908*	*0.1645*	*0.08*	***<.0001***	***0.0305***	***<.0001***

Means within each column and treatment with different letters are significant (P < 0.05) according to the Tukey's HSD test
P-values < 0.05 indicate the treatment had significant effect on the measured variable

Fig 1. Grain protein response of wheat to S at different N rates averaged across Ada and TRF and across years (2015, 2016)

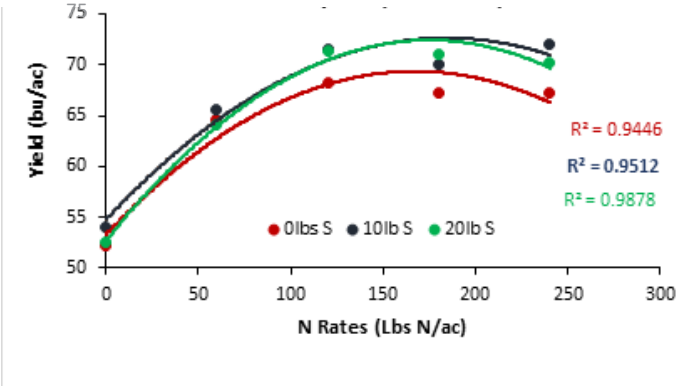

Fig 2. Grain protein response of wheat to S at different N rates averaged across Ada and TRF and across years (2015, 2016)

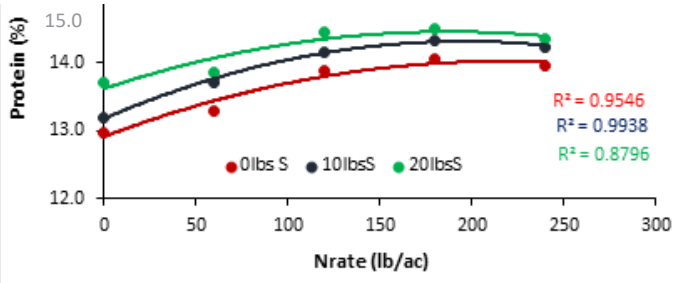

Fig 3. Net revenue from S and N application to wheat. Estimated by sbtracting revenue of each treatment from that of the baseline (x-axis) recmmended N (135 lbs N) at 0 lbs S, at TRF

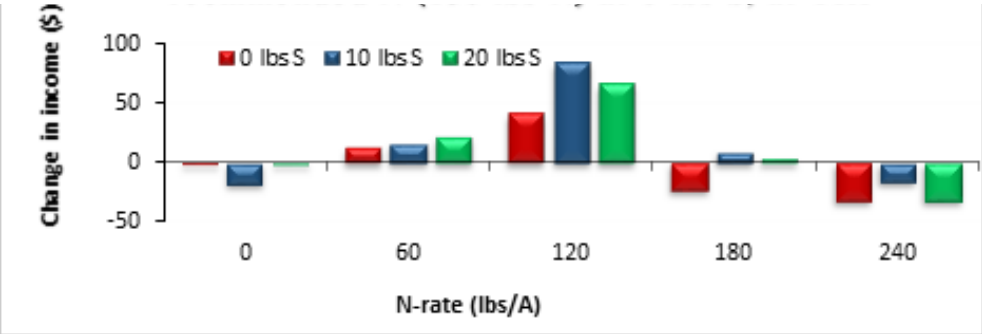

Fig 4. Net revenue from S and N application to wheat. Estimated by sbtracting revenue of each treatment from that of the baseline (recommended N of 130 lbs at 0 lbs S, RLF

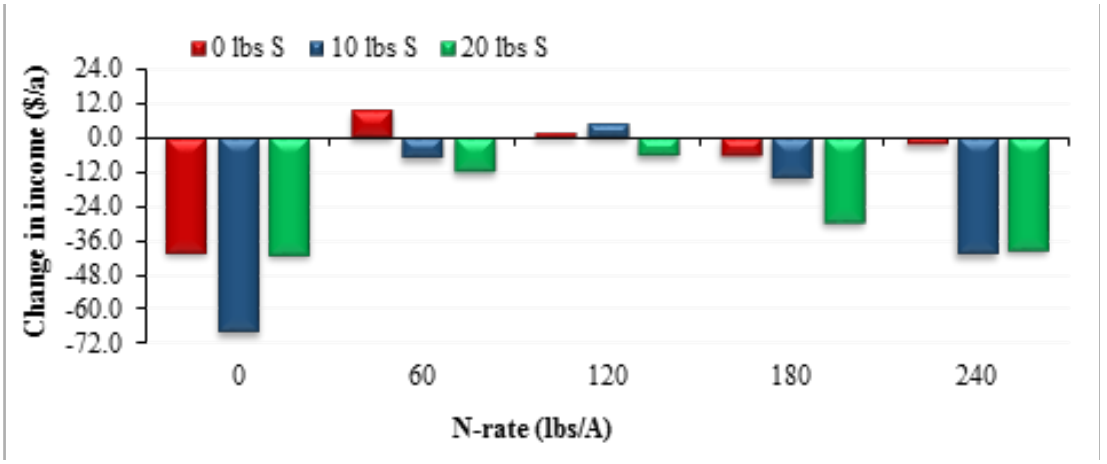

Fig 5. Grain N removed in wheat in response to S applied and averaged across N rates (Ada, 2015)