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Wheat Variety Yield Response to Nitrogen and Sulfur Rates During the 2019–2020 Growing Season

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Cover Page Footnote

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Abstract
Early spring visual sulfur (S) deficiency symptoms are increasingly a concern for Kansas wheat growers, but the extent of yield limitation due to S deficiencies and its interaction with nitrogen (N) supply is not well quantified in this environment. Our objective was to evaluate the responses of three wheat varieties to the interaction of N and S rates. The experiment was conducted in four Kansas locations during the 2019–2020 winter wheat growing season: Ashland Bottoms, Argonia, Belleville, and Hutchinson. These locations were selected to provide a range in soil textures and organic matter content, as these variables might impact the crop's response to the S rate. All results are discussed, but only those for Ashland Bottoms and Belleville, the most contrasting sites in terms of yield potential and soil organic matter content, are shown. Treatments were arranged as a complete factorial structure with a split-split-plot design. Variety was the whole plot, N was the sub-plot, and S was the sub-sub plot. Nitrogen rates were 50, 100, and 150% of the Kansas State University Soil Testing Lab recommendations for a 60 bushel per acre yield, and S rates were 0, 10, 20, and 40 pounds of S per acre. Wheat varieties evaluated were Zenda, SY Monument, and LCS Mint. Increasing N rates improved grain yield at all locations. The yield increase depended on the S rate at Ashland Bottoms (i.e., treatments not receiving S were non-responsive to N) but not at the remaining locations. Wheat varieties differed in grain yield at all locations regardless of N rate except for Argonia, where Zenda increased yields linearly with increases in N rate, whereas the remaining varieties showed a linear-plateau response. Increases in N rate also increased protein concentration at all locations, and this increase depended on S rate at three locations. Varieties differed in protein concentration at all locations, and this difference depended on the N rate in Argonia. Our results suggest that winter wheat response to the interaction between N and S fertilizer rates is location-specific, with greater chances of response in soils with sandier texture and lower organic matter contents.

Introduction
Sulfur is mostly supplied to plants through rainfall, mineralization of the soil's organic matter and crop residue, or as part of fertilizers. The Clean Air Act has reduced atmospheric S deposition from about 13 to approximately 3.5 pounds of sulfur per acre per year (Sullivan et al., 2018). This reduction, coupled with increased crop removal, has increased S deficiency in many wheat-growing regions (Kaiser et al., 2019). Particularly in Kansas, where winter wheat planted after soybeans has become the preferred crop

rotation in recent years (Lollato et al., 2019a), the issue seems to be severe. The high removal of S by soybeans (Lamond, 1997) coupled with lower organic matter mineralization in the spring and reduced S deposition in the rainfall, resulted in increasingly common symptoms of S deficiency in wheat. While the S requirements of wheat are generally no more than ~22 pounds of S in an 80 bu/a crop (Lamond, 1997), recent evidence suggests that depending on the S content of the soil, wheat can be S-limited at these yield levels when mineral fertilizer is not supplied (Jaenisch et al., 2019a; 2020).

Because N and S can interact to explain wheat yield and protein responses (Salvagiotti et al., 2009), it is important to study S effects within the context of N fertility. Proper N fertilization ensures a high tiller number and grain yield in wheat (Lollato et al., 2019a; 2021), which is generally sink-limited, and kernels per foot acts as a coarse regulator of grain yield (Jaenisch et al., 2019b, Lollato and Edwards, 2015). Potential kernels/ft is determined by jointing, and N deficiency at this time will result in decreased yield potential. Thus, matching N application with this critical growth stage is important for maximizing kernels/ft (de Oliveira Silva et al., 2020a). Likewise, N concentration within the plant changes throughout the growing season according to biomass levels (Lollato et al., 2021); thus, N dilution curves help determine N deficiencies in crops (de Oliveira Silva et al., 2020b). Research is needed to determine the optimal N concentration and N:S ratios in plant tissue to maximize grain yield and quality in Kansas. Our objectives were to evaluate the effects of S and N fertility and their interactions with winter wheat variety on grain yield and grain protein concentration.

Materials and Methods

The experiment was established near Ashland Bottoms (Belvue silt loam, 1.8% organic matter), Argonia (Nalim loam, 1.6% organic matter), Belleville (Crete silt loam, 3.5% organic matter), and Hutchinson (Ost loam, 2.8% organic matter). Only data from Ashland Bottoms and Belleville, the most contrasting locations, are shown in this report.

A three-way factorial experiment was arranged in a split-split-plot design with four replicates. The varieties SY Monument, LCS Mint, and Zenda were the whole plot, three N rates (i.e., 50, 100, and 150% of the N needed for a 60 bu/a yield goal) were the sub-plot [applied as urea ammonium nitrate (UAN, 28-0-0)], and four S rates (0, 10, 20, and 40 lb S/a) applied as ammonium thiosulfate (12-0-0-26S) were the sub-sub-plot. A pressurized CO_2 backpack sprayer with a three-nozzle spray boom was used to apply the treatments, which occurred at Feekes 4.

Wheat was sown under no-till conditions into soybean stubble, which represents one of the predominant rotations in central Kansas (Lollato et al., 2019b). Plots were sown using a Great Plains 606 no-till drill (7 rows spaced at 7.5 inches) with plot dimensions of 4.4-ft wide × 30 ft long. Seed was treated with 5 oz Sativa IMF Max. The three varieties were sown at 1.5 million seeds per acre to compensate for later sowing dates (Bastos et al., 2020). Composite soil samples (15 cores) were collected at sowing for soil nutrient analysis at two depths i.e., 0–6 in. and 6–24 in. (Table 1). Weeds and diseases were controlled, and insect pressure was not experienced.

Results

Weather Conditions

Growing season precipitation ranged from 12.5 inches in Belleville to 24.2 inches in Ashland Bottoms, while the atmospheric water demand (i.e., reference grass evapotranspiration) ranged from 30.3 to 35.9 inches (Table 2). The corresponding balance between water supply (precipitation) and water demand (reference evapotranspiration) ranged from 0.40 to 0.80. The growing conditions at Ashland Bottoms were the most favorable for high yields, as the crop was exposed to heat stress near the time of grain filling in the other three locations due to late sowing dates, typical for systems in which wheat follows soybeans.

Wheat Grain Yield

At all locations, increases in N rate increased grain yield, but this yield increase depended on S rate in Ashland Bottoms (Figure 1) and on variety in Argonia (data not shown). In Ashland Bottoms, an increase in N rate from 50% to 150% resulted in no yield gain in the zero S treatment. Once S was provided; regardless of the rate, grain yield increased until the N rate reached 100% and then plateaued afterwards. In Argonia, all varieties had the same yield at the lowest N rate, but responded differently to increases in N rate, with LCS Mint yielding more than SY Monument, which yielded more than Zenda at the two highest N rates. In Belleville (Figure 2) and Hutchinson, (data not shown), grain yield increased linearly with increases in N rate. The performance of the different varieties also depended on location, with LCS Mint resulting in the greatest yield in Belleville (Figure 2); SY Monument resulting in the greatest yield in Hutchinson (data not shown); and both SY Monument and LCS Mint having the greatest yield in Ashland Bottoms (Figure 1).

Grain Protein Concentration

Grain protein concentration was affected by the interaction of N and S rates in Ashland Bottoms (Figure 1), Hutchinson, and Argonia (data not shown), and by N rate in Belleville (Figure 2). Likewise, wheat variety significantly impacted grain protein concentration in Ashland Bottoms (Figure 1), Belleville (Figure 2), and Hutchinson (data not shown), with a significant interaction between variety and N rate in Argonia (data not shown). In Ashland Bottoms, the zero S rate resulted in the highest protein concentration (Figure 1), likely due to the strong dilution from yield increases when S was applied. For treatments receiving S, increases in N rate also increased protein concentration. In Belleville, increases in N rate resulted in increased grain protein concentration (Figure 2). At both locations, Zenda had the highest protein concentration as compared to LCS Mint and SY Monument (Figures 1 and 2), which was also true in Argonia and Hutchinson (data not shown).

Preliminary Conclusions

The significant N × S rate interactions for both grain yield and protein concentration at Ashland Bottoms (low organic matter site) suggested that under these S-limited conditions, there were no benefits from increases in N rate unless S was also provided, highlighting the interaction between both nutrients. However, we also showed that in conditions under which S is not limiting (Belleville, higher organic matter site), there was virtually no benefit from applying S to the crop. The varieties LCS Mint and SY Monument consistently outperformed Zenda in terms of yield, and these results were inversed in terms of protein. The site-specific nature of the results from this research reinforce the benefits of soil sampling for informed decisions about N and S management for wheat in Kansas.

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We would like to thank Keith Thompson and Dustan Ridder for helping us with project establishment, management, and harvest at the experiment fields. We would also like to thank the Kansas Wheat Commission for the funding to allow us to conduct this research.

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Table 1. Soil chemical and physical properties at the four study locations during the 2019–2020 winter wheat growing season

		Ashland Bottoms		Argonia		Belleville		Hutchinson	
Analysis	Unit	0–6 in.	6–24 in.	0–6 in.	6–24 in.	0–6 in.	6–24 in.	0–6 in.	6–24 in.
CEC	meq/100 g	13.05	10.22	19.92	18.99	22.88	26.59	24.18	25.99
OM	%	1.8	1.4	1.6	1.6	3.5	2.9	2.8	2.2
pH		5.9	6.8	5.1	5.4	5.5	5.9	5.4	6.2
NO_3-N	ppm	6.4	3.3	2.9	3.5	9.9	6.5	7.8	5.8
NH_4-N	ppm	3.8	2.5	1.4	2.4	5.5	2.4	4.1	4.9
P	ppm	45.8	21.5	62	48.2	73.4	48.4	88.6	45.5
K	ppm	262.9	181	157.1	139.9	602.6	615.9	425.5	368.9
Ca	ppm	1,279	1,675	891	1,152	1,876	2,741	1,959	2,779
Mg	ppm	141.1	161	265.7	337	236.8	367.7	348.3	505.7
S	ppm	0.6	1.2	2	2	2.3	2.2	4.2	4.9
Mn	ppm	11.4	6.3	28.3	21.7	31.5	21.5	25	17.1
Na	ppm	9.3	10.4	16.4	30	12.8	24.2	8.8	14.5
Cu	ppm	0.6	0.5	0.8	0.8	1.7	2.1	1.2	1
Zn	ppm	0.8	0.4	0.4	0.4	1.7	1.2	0.5	0.3
Fe	ppm	50.1	29.9	70.1	65	134.1	103.6	87	58.5
Cl	ppm	3	2.6	4.6	6.7	6.1	9.2	3.9	4
Sand	%	34	26	48		14		28	26
Silt	%	54	60	30		64		44	40
Clay	%	12	14	22		22		28	34

CEC = cation exchange capacity. OM = organic matter.

Table 2. Average maximum (Tmax) and minimum (Tmin) temperatures, and cumulative precipitation, grass reference evapotranspiration (ETo) and the ratio of water supply (WS) to water demand (WD) during the growing season at the four study locations during 2019–2020

Location	Tmax	Tmin	Precip.	ETo	WS:WD
	--------------- °F	---------------	------------- inches	-------------	
Ashland Bottoms	59.3	37.0	24.2	30.3	0.80
Belleville	57.7	33.7	12.5	31.0	0.40
Conway Springs	61.9	39.4	16.4	35.9	0.46
Hutchinson	59.4	34.6	13.6	30.8	0.44

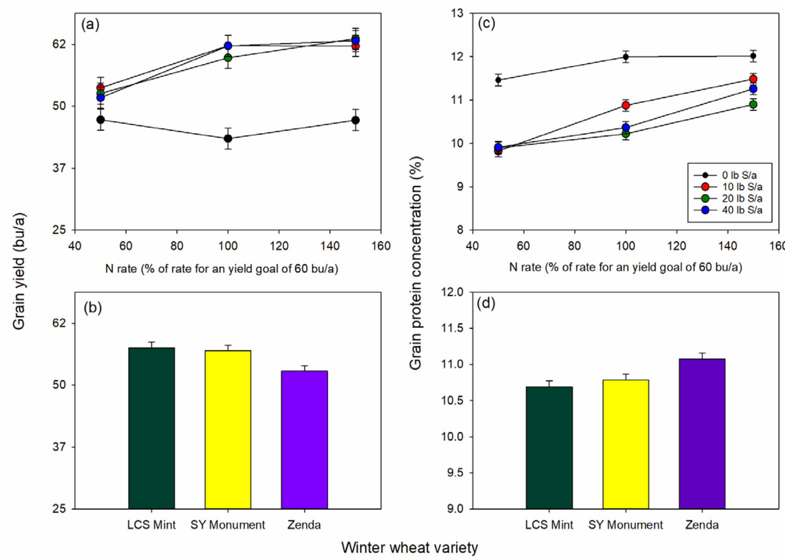

Figure 1. Winter wheat grain yield (a and b) and grain protein concentration (c and d) as affected by the interaction of nitrogen and sulfur rates (a and c) and by variety (b and d) in Ashland Bottoms, KS, during the 2019–2020 winter wheat growing season.

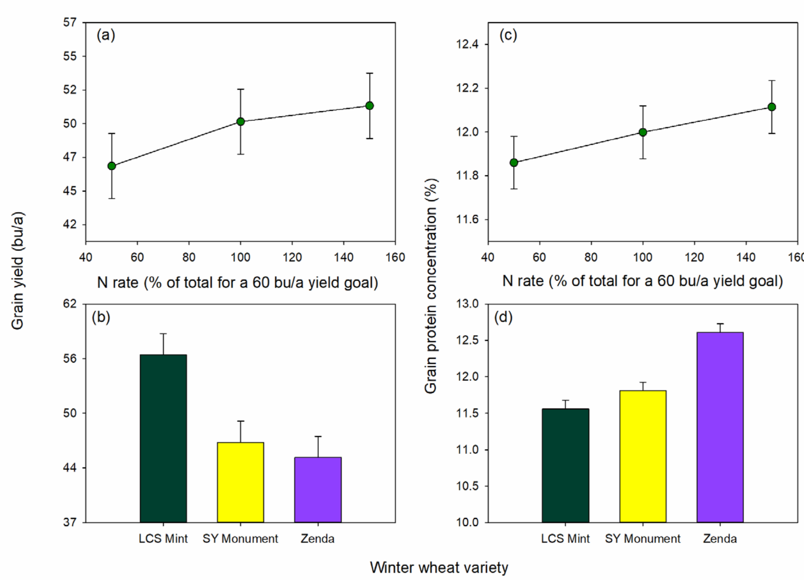

Figure 2. Winter wheat grain yield (a and b) and grain protein concentration (c and d) as affected by nitrogen (a and c) and by variety (b and d) in Belleville, KS, during the 2019–2020 winter wheat growing season.