Wheat Grain Yield and Protein Concentration Response to Nitrogen and Sulfur Rates

B.R. Jaenisch, T. Wilson, N. Nelson, M. Guttieri, and R.P. Lollato

Summary

Winter wheat is often double-cropped after soybeans in no-tillage systems. The soybean crop removes large quantities of sulfur (S), which might cause S deficiency for the following wheat crop. Our objective was to evaluate the responses of three wheat varieties to three nitrogen (N) and four S fertilizer rates representing a range of N:S ratios. The experiment was conducted near Ashland Bottoms and Hutchinson, KS. 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 university 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 the N rate increased grain yield at both locations. Sulfur increased grain yield at Ashland Bottoms but not at Hutchinson. Nitrogen by S interaction occurred for protein concentration at both locations. At Hutchinson, N rates of 50, 100, and 150% N resulted in grain yield of 62, 73, and 78 bu/a. For the 50% and 100% N rate, protein concentration was 10.8% and 11.3%; however, the 150% N rate with 20 or 40 lb S/a increased protein concentration to 11.8% as compared to 11.5% observed in the 0 or 10 lb S/a treatments. At Ashland Bottoms, N rates of 50, 100, and 150% resulted in grain yield of 56, 69, and 74 bu/a across S treatments. For the 0 pounds of S per acre treatment, though, these N rates resulted in grain yields of 36, 42, and 40 bu/a. The 150% N rate with 20 and 40 lb S/a increased grain yield by 5 bu/a as compared to the 10 lb S/a treatment. At the 50% N rate, protein concentration was 9.7% with an application of S as compared to 10.3% for the 0 lb S/a, which is due to a dilution effect from the increased grain yield. As S application increased, protein concentration decreased at the 100% N rate. However, at the 150% N rate, protein concentrations were 12.2, 11.5, 11.8, and 11.9% for the 0, 10, 20, and 40 lb S/a, respectively. Our results suggest that a balanced fertilization of N and S are essential for improving yield and protein concentration in no-till systems following soybeans, and that initial S in the profile and soil organic matter (OM) play a crucial role in determining the crop's response to the added fertilizers.

Introduction

Sulfur plays many roles within the plant, including the synthesis of amino acids, formation of disulfide linkages, glucoside oils, and chlorophyll (Taiz and Zierger, 2010). Sulfur is supplied to plants through rainfall, mineralization of the soil's OM and crop residue, or as part of organic or mineral fertilizers. The Clean Air Act was successful in decreasing the emission of SO_2 to the atmosphere within the continental USA, which in turn, reduced atmospheric S deposition from about 13 to about 3.5 pounds of sulfur per acre per year (Sullivan et al., 2018). While this is a success story in reducing environmental pollution, rainfall has historically been an important supplier of S to growing crops. The reduction in S deposition in the rainfall, coupled with increased crop removal and other factors (e.g., decreased use of manure as a fertilizer and decreased S content of traditional fertilizers) 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 for many producers (Lollato et al., 2019a), the issue seems to be severe as a 60 bushel per acre grain soybean crop removes approximately 25 pounds of S in the grain and stover (Lamond, 1997). The high removal of S by soybeans, 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 the wheat crop. While the S requirements of wheat are generally low [i.e., an 80 bushel per acre crop needs about 22 pounds of S to complete its cycle, (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., 2019).

Because co-limitation and stoichiometry between N and S can explain the crop responses to both fertilizers (Carciochi et al., 2020), it is important to study S effects on the wheat crop within the context of N fertility. Proper N fertilization ensures a high tiller number and grain yield in wheat (Lollato et al., 2019b), which is generally sink-limited, and kernel per foot acts as coarse regulator of grain yield (Lollato and Edwards, 2015). Potential kernel per foot is determined by Feekes 6 in the winter wheat growing season, 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 per foot (de Oliveira Silva et al., 2020a). Likewise, N concentration within the plant changes throughout the growing season according to biomass levels; 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. Thus, 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.

Procedures

The experiment was established at the South-Central Experiment Field in Hutchinson (fine-loamy, Ost loam) and the Agronomy Farm in Ashland Bottoms, KS. Both locations were managed under rainfed conditions and were chosen as no-till wheat is commonly sown into soybean stubble. A three-way factorial experiment was arranged in a split-split-plot design with four replications. The varieties SY Monument, LCS Mint, and Zenda, selected for their differences in N use efficiency, were the whole plot. Three

N rates (i.e., 50, 100, and 150% of the N needed for a 60 bushel per acre yield goal considering the soil N profile analyses for each location) were the sub-plot and were applied using urea ammonium nitrate (UAN, 28-0-0). The N rates for 50, 100, and 150% of the yield goal were 66, 127, and 189 lb N/a and 52, 102, and 153 lb N/a for Ashland and Hutchinson, respectively. Four S rates were the sub-sub-plot, in which S was applied as ammonium thiosulfate (12-0-0-26S) at 0, 10, 20, and 40 lb S/a. A pressurized CO_2 back sprayer with a three-nozzle spray boom applied both the N and S. The specific streamer nozzles (SJ3-02-VP - SJ3-05-VP) varied due to the change in N and S rates. The N and S were applied in combination for specific treatments and application occurred at Feekes 4. The UAN rates were adjusted to balance the N application for treatments receiving ammonium thiosulfate.

Wheat was sown no-till into soybean stubble directly after harvest with a Great Plains 506 no-till drill (7 rows spaced at 7.5 inches) with plot dimensions of 4.375-ft wide × 30-ft long at all locations. Seed was treated with 5 oz Sativa IMF Max across the whole study so neither fungicide nor insecticide were a limiting factor. Likewise, the three varieties were sown at 1.5 million seeds/a due to the later sowing date. Soil samples were collected at sowing at each location for soil nutrient analysis at two depths i.e., 0–6 in. and 6–24 in. (Table 1). A total of 15 cores were pulled per depth and combined to represent a composite sample at each location. Weeds were controlled to ensure they were not limiting factors by a pre- and post-emergence herbicide application. Insect pressure was not experienced in 2018–2019.

Results

Weather

The 2018–2019 winter wheat growing season had a cold and wet winter, a cold and wet early spring, and a cool and wet late spring/early summer. The wet and cool temperatures kept the wheat crop dormant until late April. Likewise, the cool spring and increased rainfall reduced spring tillering but incorporated the applied fertilizer. Grain harvest occurred very late due to the cool and wet weather. These conditions resulted in above-average grain yields at both Ashland Bottoms and Hutchinson.

Initial Soil Profile

Initial soil test results varied greatly for Ashland Bottoms and Hutchinson (Table 1). The soil at Ashland Bottoms had lower organic matter content and sulfate-S as compared to Hutchinson. A significant amount of sulfate-S comes from OM mineralization and this mineralization can be sufficient enough to avoid yield losses from S deficiencies. Based on the soil test results, Ashland Bottoms and Hutchinson had a supply of 10 and 17 lb of S/a, respectively. Thus, while Ashland Bottoms was severely deficient in S; Hutchinson had sufficient S depending on the yield level of the crop.

Wheat Grain Yield

Across locations, increasing N rates increased wheat grain yield (Figure 1). At Hutchinson, N rate was the only significant effect and N rates of 50, 100, 150% N resulted in grain yield of 62, 73, and 78 bu/a, respectively (Figure 1). Grain yield did not respond to S application at Hutchinson. At Ashland Bottoms, there was a significant N by S interaction—the absence of S resulted in grain yields of about 40 bushels per acre, regardless of N rate. However, when S fertilizer was applied, grain yield increased to the 60–85 bushels per acre range and became responsive to N. Interestingly, when 10 pounds of S per acre was provided, wheat grain yield increased from 50 to 100% N, and plateaued afterwards. Nonetheless, providing 20 or 40 pounds of S per acre allowed grain yields to respond linearly to increases in N rates to as much as 150% N. At this rate, 20 and 40 pounds of S per acre increased grain yield by 5 bu/a as compared to the 10 pounds of S per acre.

Grain Protein Concentration

There was a significant N by S interaction on grain protein concentration, as well as a significant variety effect, at both locations. First, there was an overarching trend of increased protein concentrations with increased N rates at both locations. At Ashland Bottoms, the significant interaction resulted from the tendency to stabilize protein concentrations for N rates beyond 100% for the 0 and 10 pounds of S per acre treatments, while 20 and 40 pounds of S per acre allowed protein concentrations to continue to increase with increases in N rate. Specifically, at the 50% N rate, protein concentration was 9.7% with an application of S (regardless of S rate) as compared to 10.3% for the 0 lb of S. As sulfur application increased, protein concentration decreased at the 100% N rate. However, at the 150% N rate, protein concentration was 12.2, 11.5, 11.8, and 11.9% for the 0, 10, 20, and 40 pounds of S per acre. Zenda had a protein concentration of 11.4%, which was greater than SY Monument and LCS Mint. At Hutchinson, the trends were not as clear as at Ashland Bottoms, but likewise, protein concentrations increased with N rates, and the 20 and 40 pounds of S per acre resulted in the highest protein concentrations at high N rates. Specifically, at the 50% and 100% N rate, protein concentration was 10.8% and 11.3%, respectively. However, the 150% N rate with 20 or 40 lb S/a increased protein concentration to 11.8% as compared to 11.5% for the 0 or 10 lb S/a. Following the same trend as that measured at Ashland Bottoms, Zenda had protein concentration of 11.8%, which was greater than SY Monument and LCS Mint.

Preliminary Conclusions

Due to limitations of sites and years, it is difficult to make strong conclusions out of a single year of data. However, the significant N by S rate interactions for both grain yield and protein concentration suggest that a balanced nutrition is needed for both nutrients to produce high yields. One trend that surfaced was that increasing N increased grain yield and protein concentration, suggesting that N rates can be further increased to maximize yield (depending on yield potential). Increasing the S rate to 20 lb per acre maximized wheat yield at Ashland Bottoms; however, no grain yield response to S rate was measured at Hutchinson. Thus, these results suggest that soil profile S plays an important role in maximizing wheat yield, as the soil at Ashland Bottoms was at deficient levels as compared to the soil at Hutchinson. We will evaluate the plants' tissue nutrient concentration for co-limitations and stoichiometry to further decipher this interaction of N by S within wheat plants.

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Table 1. Initial soil fertility levels at Ashland Bottoms and Hutchinson, KS, for the 2018–2019 growing season

Location	Depth	pH	P	K	Ca	Mg	Na	NH_4-N	NO_3-N	Cl^-	SO_4-S	OM	CEC
	inches	---					ppm	---				%	Meq 100 g^{-1}
Ashland Bottoms	0–6	6.2	45	179	1129	138	9	2.6	3.3	4.1	2.5	1.5	10
	6–24	6.6	27	116	1284	144	8	2.6	1.3	3.1	1	1.5	8
Hutchinson	0–6	5.3	50	228	1018	185	8	3.3	9.7	3.7	3.5	1.8	17
	6–24	6.4	11	151	1920	330	17	3	3.2	4.6	2	1.8	16

Fertility levels include soil pH, buffer pH, Mehlich-3 extractable phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), ammonium- (NH_4-N) and nitrate-nitrogen (NO_3-N), chloride (Cl), sulfate-sulfur (SO_4-S), organic matter (OM), and cation exchange capacity (CEC). Sampling depths were 0–6 in. and 6–24 in.

Table 2. Treatment description of three winter wheat varieties (Sy Monument, LCS Mint, and Zenda), three nitrogen rates based on a yield goal of 60 bu/a (50, 100, and 150%), and four sulfur rates (0, 10, 20, and 40 lb S/a) at Ashland Bottoms and Hutchinson, KS, in 2019

Winter wheat varieties	Nitrogen rate based on a yield goal of 60 bu/a	Sulfur rate
SY Monument	50%	0 lb S/a
LCS Mint	100%	10 lb S/a
Zenda	150%	20 lb S/a
		40 lb S/a

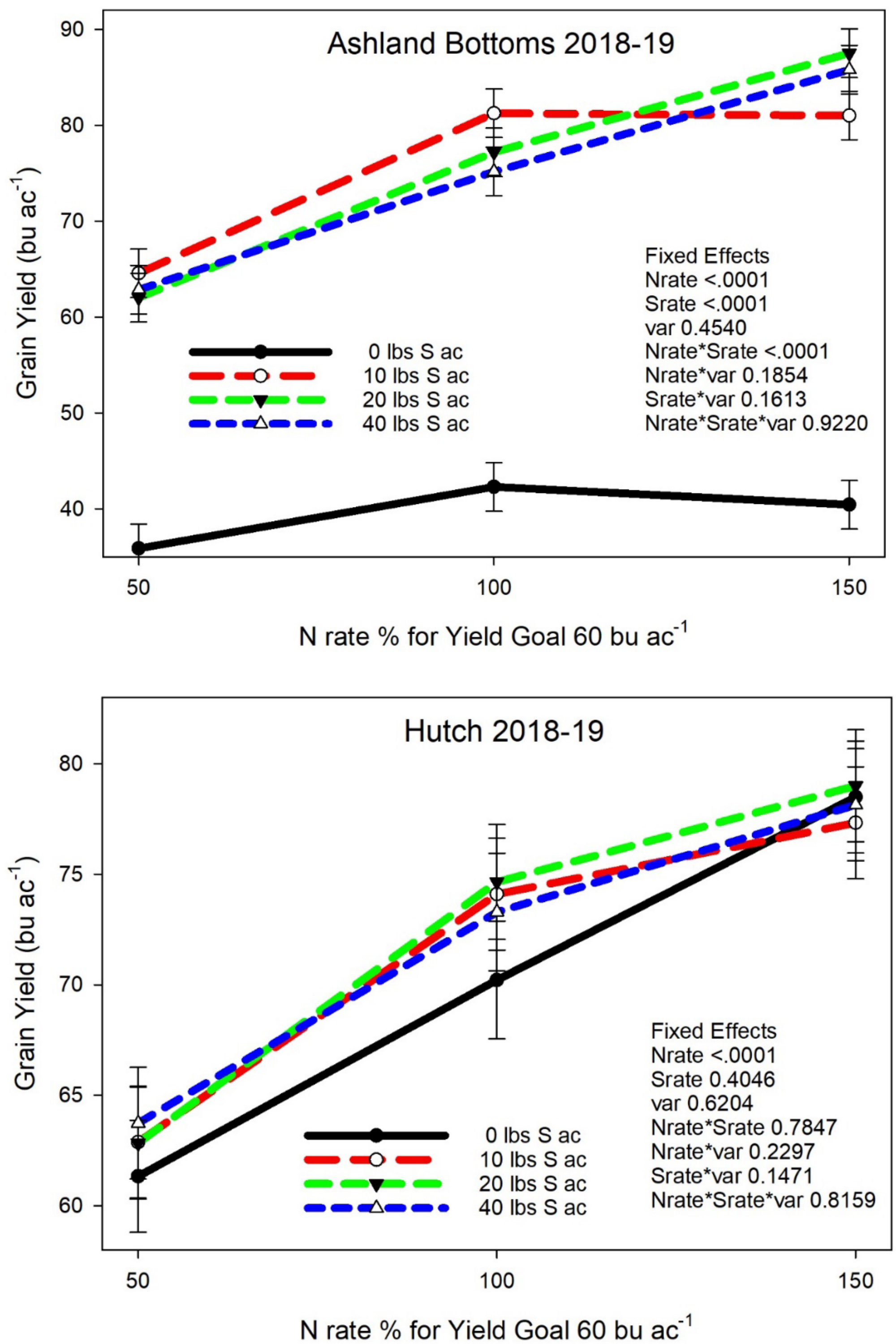


Figure 1. Average wheat grain yield (bu/a) response to three nitrogen (N) (50, 100, and 150 %) and four sulfur (S) (0, 10, 20, and 40 lb S/a) rates across all winter wheat varieties for Ashland Bottoms and Hutchinson, KS, during the 2018–2019 growing season.

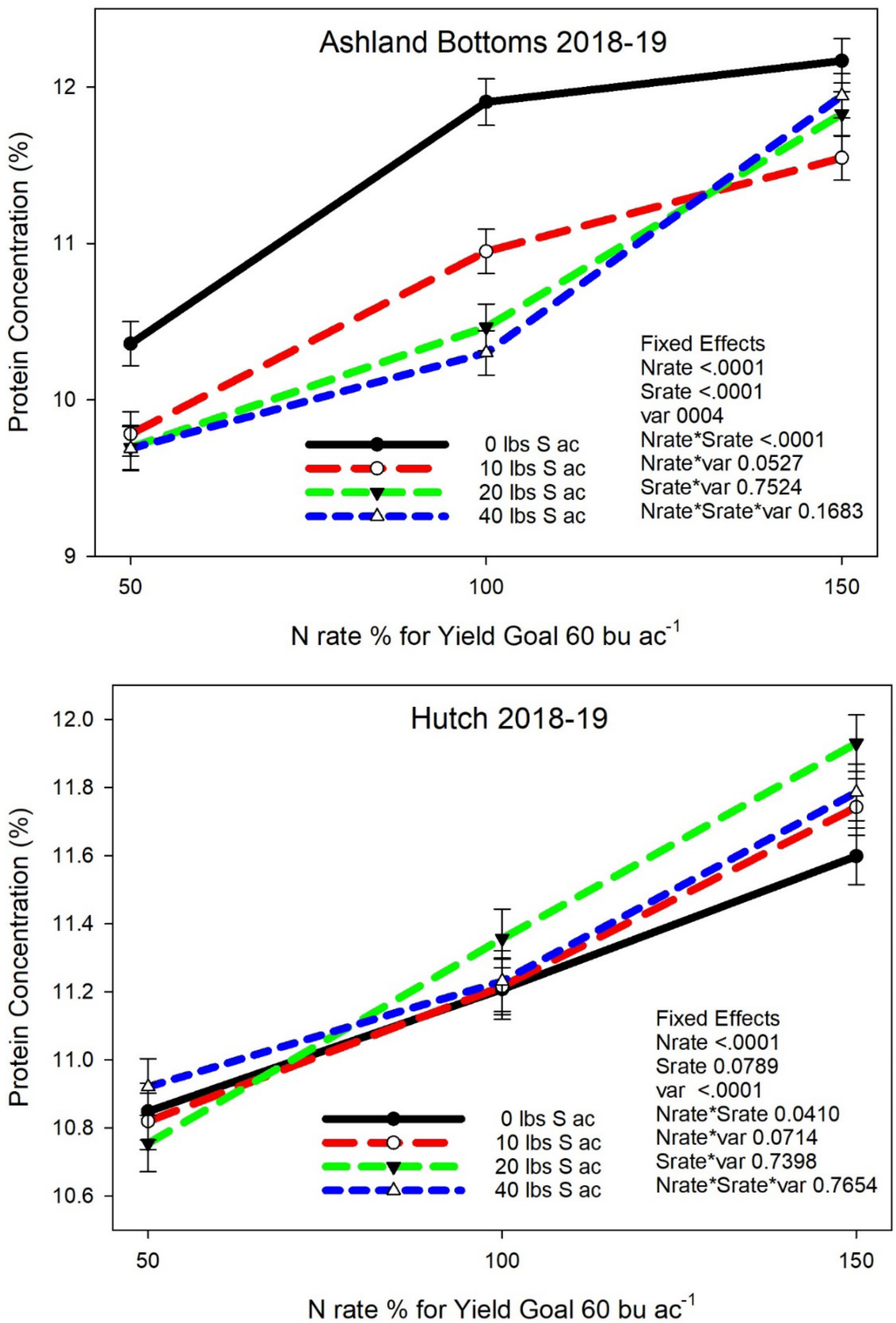
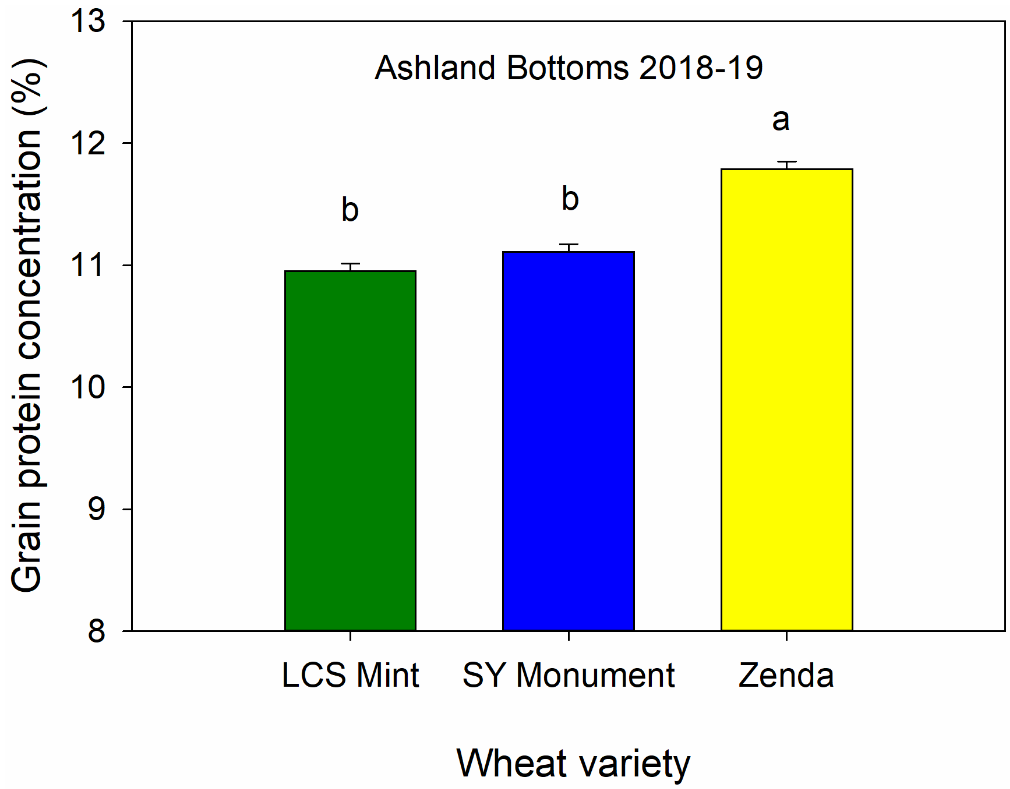


Figure 2. Average wheat grain protein concentration (%) response to three nitrogen (N) (50, 100, and 150 %) and four sulfur (S) (0, 10, 20, and 40 lb S/a) rates across all winter wheat varieties for Ashland Bottoms and Hutchinson during the 2018–2019 growing season.



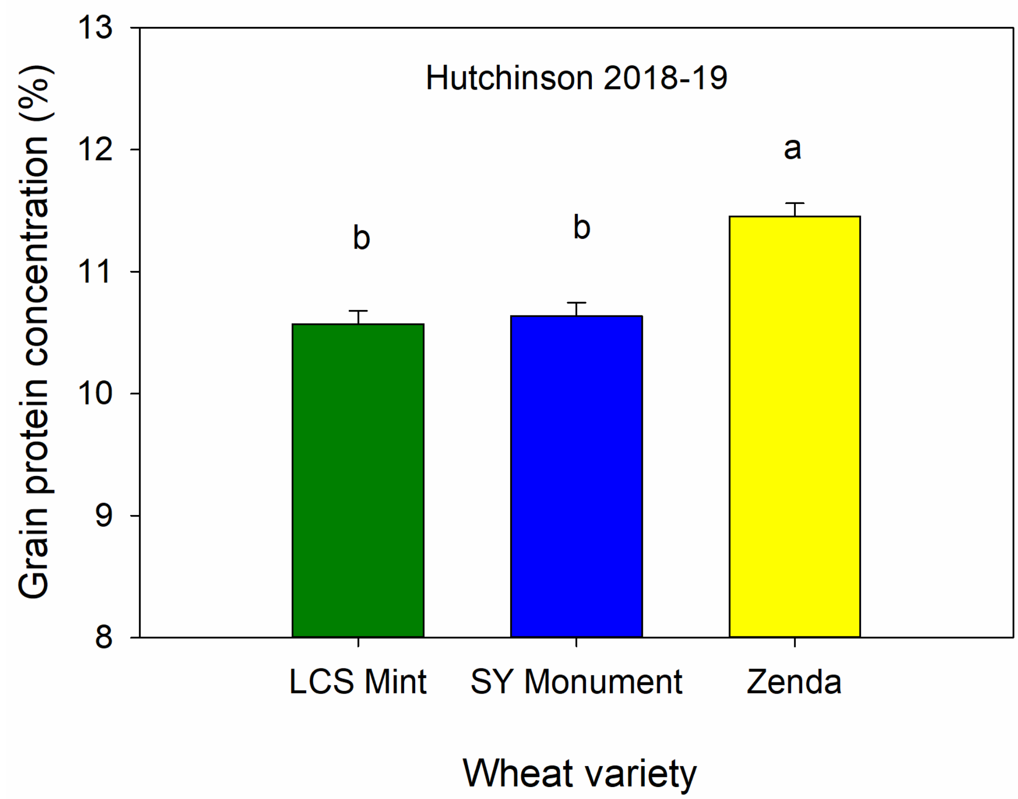


Figure 3. Average wheat grain protein concentration (%) as affected by three winter wheat varieties (LCS Mint, SY Monument, and Zenda) across three nitrogen (N) (50, 100, 150 %) and four sulfur (S) (0, 10, 20, 40 lb S/a) rates for the trials conducted at Ashland Bottoms and Hutchinson during the 2018–2019 growing season. At both locations, Zenda had statistically greater protein concentration than LCS Mint and SY Monument.