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Keywords

Triticum aestivum L., wheat, nitrogen, wheat varieties

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Abstract
Nitrogen management in wheat can result in positive impacts on grain yield and grain protein concentration (GPC) if addressed correctly. The aim of this study was to compare whether different varieties responded differently in terms of grain yield and GPC to management of nitrogen (N) rate across different environments. Factorial field experiments were carried out in a split-plot design in four different Kansas locations to evaluate the combination of four N rates (whole plot, 0, 40, 80, and 120 lb N/a) and fourteen different commercially available winter wheat varieties (sub-plots). Grain yield and GPC were measured at harvest maturity. The grain yield average across all treatments at all locations was 50.3 bushels per acre, ranging from 33.6 to 84.9 bu/a depending on treatment and location. Mean GPC across all site-treatment combinations was 11.3%. There were significant interactions between environment and variety, and between environment and N rate for both grain yield and GPC, but not variety by N rate interaction. Different varieties provided to the highest yield and protein groups depending on location. Yield response to N was location-specific due to different amounts of soil NO_3-N in the profile. In general, the highest GPC were obtained with the highest N rates in all locations except for one study site where 80 lb N/a sufficed. Results suggest that variety performance and optimum N rate that maximizes yield changed within the different environments, but the same N rate regime should be adopted across varieties.

Introduction
Nitrogen plays an important role in plant physiology, as part of essential structural and metabolic proteins that are essential for plant growth and development. This macronutrient is often considered one of the most scarce resources that limit plant growth (de Oliveira Silva et al., 2020a; Hawkesford, 2014). Therefore, numerous attempts have been made to identify potential genetic and management traits to improve N efficiency in wheat crops (de Oliveira Silva et al., 2020b).

The mid-season N rate can determine grain yield and grain protein concentration in environments where N availability is limiting (Lollato et al., 2019a, 2021). Nitrogen fertilization is a common practice in wheat crops in the state of Kansas (Lollato et al., 2019b) and has the potential to improve profitability and reduce environmental impacts if addressed correctly. Sustainable improvements in wheat yield are often accompanied by deteriorating wheat grain quality through protein dilution (Lollato and Edwards, 2015). Grain protein concentration is an essential parameter of milling quality (Blandino et al., 2015) that can determine the end-use market of the wheat produced (Lollato et al., 2020). Genotype selection is one of the leading aspects that determine the existing yield gaps (Lollato et al., 2019b), but little is known about the response to N of current genotypes grown in Kansas. Because variety selection sets the genetic potential as well as the protein concentration of a given field, our objective was to highlight the relevance of N rate and wheat variety selection, as well as their potential interaction, in determining grain yields and grain protein concentration across several Kansas locations.

Methods

One experiment was conducted in four different locations in the state of Kansas: Ashland Bottoms (Belvue silt loam); Great Bend (Taver loam); Hutchinson (Ost loam); and Sumner County (Nalim loam). The compared treatments represented a complete factorial combination of fourteen wheat varieties and four N rates with four replicates established in a split-plot design. Nitrogen fertilizer rates (0, 40, 80, and 120 lb/a) were applied as granulated urea (46-0-0) broadcasted at Feekes 3 growing stage in early spring. Trials were sown within the first two weeks of October at 1.2 million seeds per acre. Diammonium phosphate (18-46-0) was applied at 50 lb/a in-furrow at sowing. A total of 20 lb S/a was applied to the entire experiment on the same day of N treatment application to avoid the well-known interactions within N produced by S deficiency (Jaenisch et al., 2019, 2020). Standard weed, insect, and disease management practices were carried out following the recommendations given by nearby farmers. Plots were harvested using a Massey Ferguson 8XP small plot, self-propelled combine.

Soil samples were collected to determine texture and chemical properties in the 0–6 and 6–24 inch soil layers. Soil NO_3-N measurements at sowing in the 0–24 inch profile were 26, 24, 172, and 110 lb N/a at Ashland Bottoms, Conway Springs, Hutchinson, and Great Bend.

Grain weight and moisture were measured at harvest maturity. Grain protein concentration (GPC) was determined by NIR spectroscopy. A single moisture basis of 13% was used for adjusting grain yield and GPC. Data analysis was performed using InfoStat statistical software. Mean comparisons were performed using the Fischer test of least significant differences.

Results

Grain Yield

Grain yield averaged 50.3 bu/a for all site-treatment combinations. The highest yielding location was Hutchinson with an overall mean of 71.6 bu/a. Both N rate and variety effects were location-dependent, evidenced by the significant interaction between variety and location, and between N rate and location. This indicates that there was variability in variety performance as well as in the crop's response to N rate in each studied location, but that all varieties responded similarly to N rate (no significant variety × N rate interaction) (Table 3). The varieties WB-Grainfield, WB4269, SY Monument, Bentley, and Larry, were in the top-yielding group in Ashland Bottoms, achieving an average yield of 50.2 bu/a (Table 1), this represent an 11% yield gain. In Great Bend, varieties WB-Grainfield, WB4269, Bentley, and Larry out-yielded significantly ($P < 0.0001$) the other varieties with an average yield increase of 8% (46.8 bu/a versus 43.5 bu/a yield across all varieties) (Table 1). In Hutchinson, the variety WB4269 was the only one that yielded 19% more than the compared group, representing 13.3 bu/a more than the location mean (Table 1). There were no significant differences within varieties at the Sumner County study site (Table 1). The ANOVA showed that grain yield also responded differently to N rate depending on location (Table 3). For instance, in Hutchinson, there was no effect of N rate on grain yield, likely due to the high N in the profile at sowing (data not shown). At the other locations, grain yield maximized (i.e., showed no further gains with increases in N rate) at 80, 40, and 120 lb of N/a for Ashland Bottoms, Great Bend, and Sumner County (Table 2).

Grain Protein Concentration

Overall across locations, varieties, and N rates, grain protein concentration ranged from 7.4 to 14.8%. Similar to yield, the effects of both N rate and variety on grain protein concentration depended on location as significant interactions were found (Table 3). In Ashland Bottoms, the varieties with the highest grain protein concentration were WB4458, DoubleStop CL Plus, Green Hammer, and LCS Chrome with a GPC average of 12.0% (Table 1). At Great Bend, the variety Green Hammer tested 14.8%, the highest significant GPC value across varieties; and Tatanka the lowest GPC, tested 11.5% (Table 1). In Hutchinson the highest testing varieties were Bob Dole, WB4303, WB4458, DoubleStop CL Plus, Green Hammer, and LCS Chrome, averaging 13.3% (Table 1). The highest testing values obtained in Sumner County were represented by varieties WB4458 (10.2%), DoubleStop CL Plus (9.7%), and Green Hammer (10.0%) (Table 1). Grain protein concentration was also affected by the interaction of nitrogen rate and location (Table 3). In general, the highest grain protein concentration values were obtained with the highest N rates in all locations, except for Great Bend where GPC testing did not significantly differ in between N rates of 80 (13.3%) and 120 lb N/a (13.7%) (Table 2). The lowest GPC testings corresponded with the control (zero N applied) in all situations with the exception of Ashland Bottoms where GPC tested for zero and 40 lb of N/a treatments were not statistically different (Table 2).

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Table 1. Wheat grain yield and grain protein concentration as affected by variety in four sites across Kansas, during the 2019–2020 growing season

	Grain yield (bu/a)				Grain protein concentration (%)			
Variety	Ashland Bottoms	Great Bend	Hutchinson	Sumner County	Ashland Bottoms	Great Bend	Hutchinson	Sumner County
WB-Grainfield	**54.1**	**44.8**	72.4	**44.2**	10.0	12.6	11.9	7.8
WB4269	**51.5**	**48.5**	**84.9**	**42.6**	10.6	12.2	11.7	8.6
SY Monument	**48.9**	44.5	75.2	**44.6**	10.6	12.3	12.2	8.2
Bentley	**48.5**	**45.5**	75.8	**43.6**	10.8	12.5	12.3	8.2
Larry	**47.9**	44.3	71.8	**41.5**	10.6	13.0	12.0	8.1
Tatanka	46.5	**48.4**	71.0	**43.6**	9.6	11.5	11.3	7.4
Bob Dole	45.0	44.2	65.2	**41.6**	11.1	12.7	**13.0**	8.7
WB4303	44.0	43.1	67.9	**42.3**	11.0	13.3	**13.0**	8.5
WB4458	43.0	40.4	65.7	33.6	**12.0**	13.8	**13.2**	**10.2**
DoubleStop CL Plus	42.4	40.6	74.3	**39.2**	**12.3**	13.7	**13.5**	**9.7**
Green Hammer	41.4	36.9	68.3	**37.0**	**12.2**	**14.8**	**13.7**	**10.0**
LCS Chrome	41.2	41.9	68.6	**40.7**	**11.6**	13.7	**13.4**	9.2
Zenda	40.7	42.7	70.2	**37.9**	11.1	12.5	11.2	9.2
Everest	39.6	43.4	70.6	36.4	11.3	12.8	12.1	9.2
Location mean	45.3	43.5	71.6	40.6	11.0	12.9	12.5	8.8
LSD (0.05)	7.4	3.8	4.5	8.0	0.8	0.7	0.8	0.9
CV	23.3	12.6	9.0	28.3	9.9	8.0	9.6	14.1
P-value	**	**	**	0.2	**	**	**	**

Values in bold pertain to the top group within location for yield or protein.

** indicates significant differences at the 0.05 probability level (p-value < 0.05).

Table 2. Wheat grain yield and grain protein concentration as affected by nitrogen (N) rate in four sites across Kansas, during the 2019–2020 growing season

Location	N rate	Grain yield		Grain protein concentration	
	lb/a	bu/a		%	
Ashland Bottoms	0	30.8	a	10.3	a
	40	44.4	b	10.2	a
	80	52.1	c	11.3	b
	120	54.0	c	12.4	c
LSD (0.05)		2.4		0.4	
CV		14.0		8.6	
P-value		**		**	
Great Bend	0	39.9	a	12.0	a
	40	45.2	b	12.8	b
	80	44.8	b	13.3	c
	120	44.2	b	13.7	c
LSD (0.05)		2.1		0.4	
CV		13.2		8.9	
P-value		**		**	
Hutchinson	0	73.7	b	11.7	a
	40	71.6	ab	12.3	b
	80	70.1	b	12.6	b
	120	70.9	ab	13.2	c
LSD (0.05)		2.9		0.5	
CV		11.0		10.4	
P-value		0.1		**	
Sumner County	0	24.5	a	7.5	a
	40	39.1	b	8.1	b
	80	46.6	c	9.2	c
	120	52.4	d	10.5	d
LSD (0.05)		1.9		0.3	
CV		12.4		10.0	
P-value		**		**	

**Indicates significant differences at the 0.05 probability level (*P*-value < 0.05).

Different letters represent statistical differences at LSD = 0.05.

Table 3. Significance of site, nitrogen (N) rate, variety and their interactions on grain protein concentration and grain yield for trial conducted during the 2019–2020 growing season.

Effect	Degrees of freedom	Grain yield	Grain protein concentration
Site (S)	3	<0.0001	<0.0001
N rate (N)	3	<0.0001	<0.0001
Variety (V)	13	<0.0001	<0.0001
S × N	9	<0.0001	<0.0001
S × V	39	<0.0001	<0.0001
N × V	39	0.9471	0.6478
S × N × V	117	0.9948	0.6763