Nitrogen Fertilization and Wheat Variety Interact with Environment Independently to Determine Wheat Yield in Kansas

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Summary
Both nitrogen (N) management and variety selection are crucial elements that influence wheat yield; however, there is limited research exploring whether wheat varieties differ in their response to N rate. Thus, our objectives were to determine potential variety by N rate interactions among modern winter wheat varieties. Factorial field experiments were established in four Kansas locations during the 2020–2021 growing season, including two fields near Ashland Bottoms, one field near Hutchinson, and one near Manhattan. Whole plot treatments were four N rates (0, 40, 80, and 120 lb N/a) applied in the spring and subplots were 14 commercially available winter wheat varieties. Initial soil NO_3-N in the 0- to 24-in. soil profile at sowing ranged from 45 to 67 lb N/a. The weather conditions were overall favorable for crop yields across all studied environments. Wheat grain yield response to the spring-applied N fertilizer depended on location, ranging from 0.1 to 0.5 bushel per lb of N applied, with greater responses to the first 40 to 80 pounds of N per acre in three out of four environments. Likewise, variety grain yield depended on location, and varieties ranking changed accordingly. However, there was no variety by nitrogen interaction, suggesting that all varieties responded similarly to the applied N.

Introduction
Nitrogen is one of the largest yield-limiting factors for wheat produced in U.S. central Great Plains, not only in small plot research (Lollato et al., 2019a; 2021), but also in commercial wheat fields, as indicated by a recent survey of management practices in central Kansas (Lollato et al., 2019b; Jaenisch et al., 2021). Nitrogen management impacts not only the yield produced by wheat but also milling and baking quality attributes (Lollato et al., 2021). Thus, the consequences of suboptimal management of N fertilizer can cascade down the entire wheat product chain.

Another important factor determining wheat yield in the U.S. central Great Plains is wheat variety selection and the inherent traits of each variety that make it more or less adapted to a given production system and region (Munaro et al., 2020; Jaenisch et al., 2022). While there are variety differences in nitrogen-related traits, such as N uptake at maturity and N utilization efficiency (de Oliveira Silva et al., 2020a, b), there is very little information about whether current varieties respond differently to N management, which is true for many other agronomic practices (Munaro et al., 2020). Still, understanding how the different N fertilization rates interact with genotype and environment is crucial to maximize overall efficiency of the wheat cropping systems (Lollato et al., 2021). Thus, our aim was to quantify potential variety by environment interactions as they pertain to N availability in terms of grain yield.

Procedures

Field experiments were conducted during the 2020–2021 cropping season in four locations across Kansas, namely two fields near Ashland Bottoms (one Belvue silt loam and a second Bismarck grove silt loam), one field near Manhattan (Kahola silt loam), and a fourth field near Hutchinson (Ost loam). Soil characteristics are provided in Table 1. Treatment structure consisted of two-way factorial combination of N rates and varieties arranged in a split-plot design with three or four replications depending on the location. Four N rates were the whole plot, applied as granulated urea (46-0-0) during early spring at Feekes 3 growing stage at a rate of 0, 40, 80, and 120 lb/a. Fourteen commercial winter wheat varieties were the sub-plots. To avoid interacting effects between N and sulfur, all plots received 20 lb/a of sulfur in the form of gypsum fertilizer together with N application. All plots were harvested with a Massey Ferguson 8XP small plot combine.

Crop husbandry operations were common across all locations. Winter wheat was sown during the last two weeks of October 2020, at a rate of 1.2 million seeds per acre with 7.5 inches row spacing with a Great Plains 506 no-till drill. All plots received at sowing 50 lb/a of DAP fertilizer, which added about 9 lb/a of N fertilizer to all treatments. Adequate weed control was performed to ensure this was not a limiting factor. At the stage of anthesis (Feekes 10.5.1), foliar fungicide was applied to all plots as a tank mix of carboxamide and propiconazole so that fungal diseases were not a limiting factor. Soil samples were collected at each location before planting from the 0 to 6 in. and from the 6 to 24 in. layers (Table 1). Statistical analysis was performed in R Studio using linear mixed-effects models from *lme4* package.

Results

Environments Description

The 2020–2021 season was characterized by a cold start of the growing season, coupled with low rainfalls during the fall, and with below-normal February temperatures across all locations (Fig. 1). The latter contributed to negative impacts on tiller winter survival. During the winter, available water for the crop was enough to meet the atmospheric demand (Fig. 2). The spring started with adequate precipitation, with colder temperatures that were extended throughout the grain filling period contributing to higher-than normal yields in our evaluated locations, contrasting with the typical harsh weather in Kansas (Lollato et al., 2020).

From the initial soil test analysis, available N-NO_3 at sowing was 44.8, 48.4, 64.5, and 66.5 lb per acre for Ashland Bottoms Belvue silt loam and Bismarckgrove silt loam fields, Hutchinson, and Manhattan, respectively (Table 1). Moreover, Manhattan started with a considerably greater amount of available N-NH_4 at sowing of 82 lb per acre, as compared with the other locations which on average had 45 lb of N-NH_4 per acre. Noticeably, Manhattan also was the site with higher soil organic matter (OM) percentage on the top soil layer (3.9%), while other locations had on average 2.2% OM.

Grain Yield

In all sites, grain yield increased significantly with increasing N rates, however the response to N rate varied significantly depending on location ($P < 0.001$) (Table 2, Figure 3). The greatest yield increases per unit of applied N resulted from the single application of 40 lb N/a in two out of four sites, and from the 80 lb N/a application rate in a third site. As expected, N response decreased with increasing N rates in all sites except Manhattan, which was equal across all N rates, accounting for 0.2 bu/lb N. The previously described soil characteristics can partially explain why yield response to N was lower in Manhattan as compared to the rest of the sites. Current research may determine why we observe an unsaturated response to N under particular environmental conditions.

There was no significant variety by nitrogen interaction, suggesting that all varieties responded similarly to N rates (Table 2). However, the different varieties showed contrasting performance on the different sites, with a significant genotype × environment interaction ($P < 0.001$) (Table 2, Figure 4). The top yielding varieties in Ashland Bottoms Belvue silt loam site were WB4303 and Bentley, which yielded on average 80.2 bu/a as compared to the second yielding group which yielded 71.9 bu/a. At Ashland Bottoms Bismarckgrove silt loam soil, the top performing group included Tatanka, WB4303, and WB-Grainfield averaging 73.9 bu/a, representing a 14% yield increase as compared to the environment mean yield. In Hutchinson, the higher yielding varieties were Tatanka, Bentley, SY Monument, WB4303, Bob Dole, WB-Grainfield, and Larry, with an average grain yield of 61.8 bu/a. Manhattan was the lowest yielding site with an average of 46.3 bu/a. The top yielding group included Tatanka, WB Grainfield, Larry, SY Monument, WB4303, LCS Chrome, and WB4269.

Conclusions

Determining an optimum N rate is among the most complex decisions a wheat farmer has to make during the season. Reinforcing this complexity, we showed that the different locations had different responses to the N rates applied, partially attributed to differences in weather and soil conditions. Variety selection is another complex decision due to the number of varieties available. Likewise, different varieties ranked differently depending on environment. However, we showed preliminary data suggesting that these factors (variety and nitrogen rate) did not interact, facilitating—at least to some extent—wheat management on the farm.

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Table 1. Soil characteristics for the topsoil (0–6 inches) and subsoil (6–24 inches) layers for the different sites of the study

Location	pH	Depth	CEC	K	Mg	Ca	P Mehlich	Na	N-NO_3	N-NH_4	OM
		inches	meq $100g^{-1}$	----------------------		ppm	----------------------		lb/a		%
Ashland 2A2	6.1	0 - 6	23.17	345.2	266.3	2,524	32.8	10	13.9	14.2	2.5
Ashland 2A2	6.4	6 - 24	23.45	314.9	299.1	2,834	20	12.4	30.7	38.8	2.3
Ashland M3	5.5	0 - 6	14.63	224.4	145.1	1,313	30.2	9.8	22.5	11.5	1.8
Ashland M3	6.3	6 - 24	11.83	175.7	150.5	1,465	13.4	10.2	25.8	24.0	1.3
Hutchinson	5.9	0 - 6	19.28	226.8	171.7	1,774	71.1	11.5	24.4	14.2	2.2
Hutchinson	6.9	6 - 24	25.73	228.2	217.6	3,969	34.5	21.8	40.0	33.3	2.1
Manhattan	7.4	0 - 6	34.05	347.4	229.9	6,064	16.2	14	15.4	23.8	3.9
Manhattan	7.4	6 - 24	34.89	328.9	225.1	6,227	12.7	15.1	51.1	58.5	3.7

Table 2. Significance of location, N rate variety and their interactions for grain yield, during the 2020–2021 growing season

Effect	Df	Grain yield significance
(Intercept)	1	>0.001
Location (L)	3	0.59
Variety (V)	13	>0.001
N rate (N)	3	>0.001
L × V	39	>0.001
L × N	9	>0.001
V × N	39	0.90
L × V × N	117	0.99

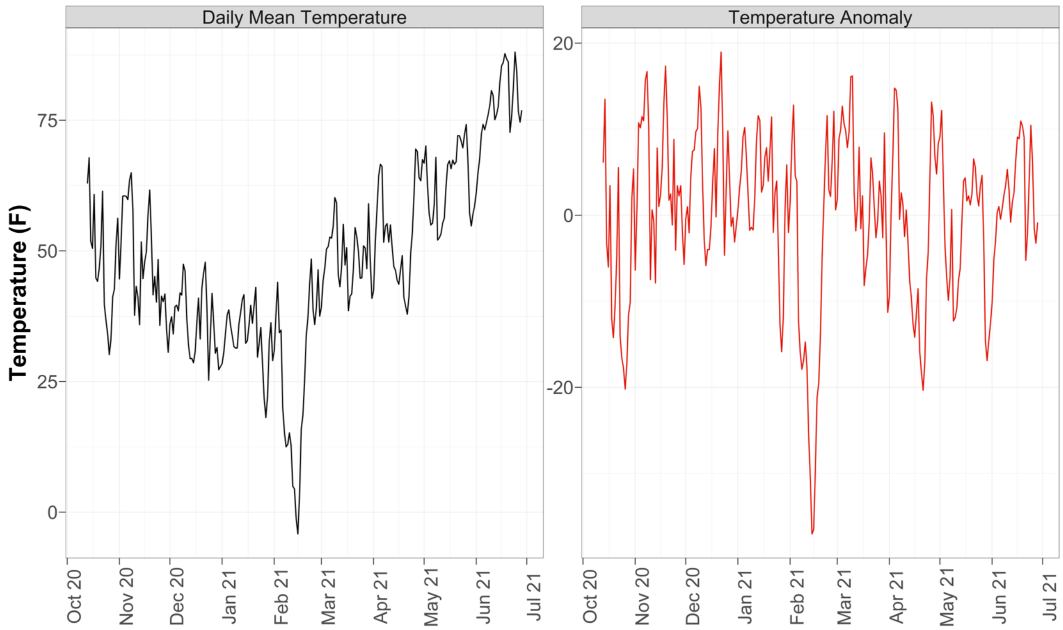

Figure 1. Daily mean temperature and daily mean temperature anomaly during the 2020–2021 growing season averaged across the four locations. Anomalies were calculated comparing the current growing season with the most-recent 20-year average.

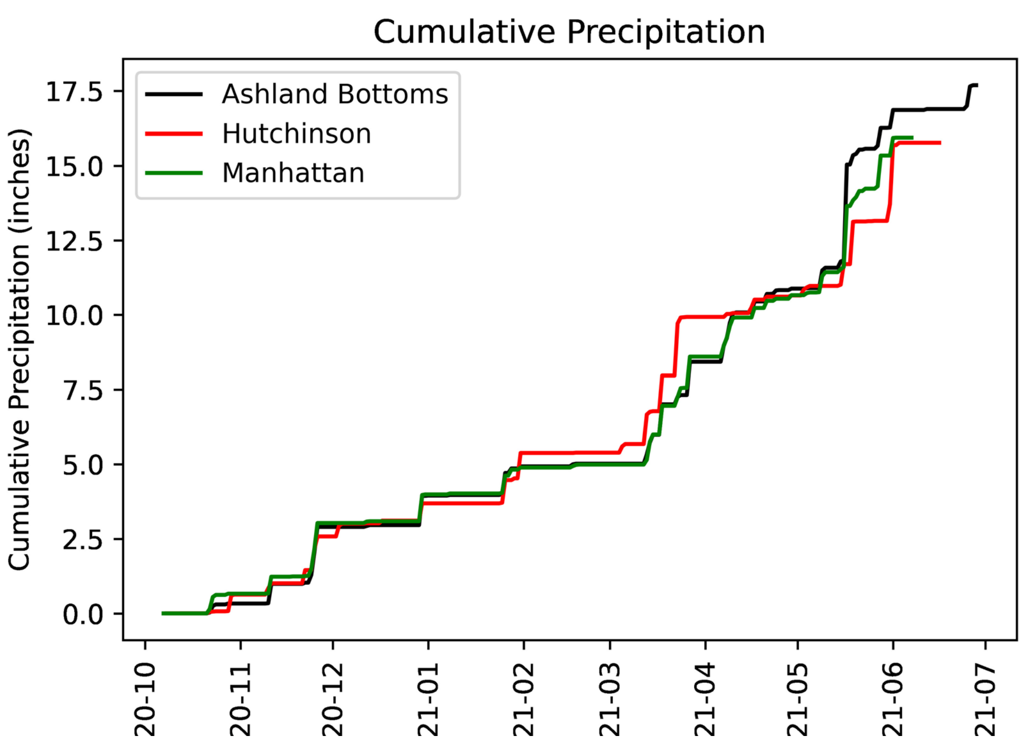

Figure 2. Cumulative precipitation for the different locations in which the trials were placed. Ashland Bottoms summarizes both fields 2A2 and M3.

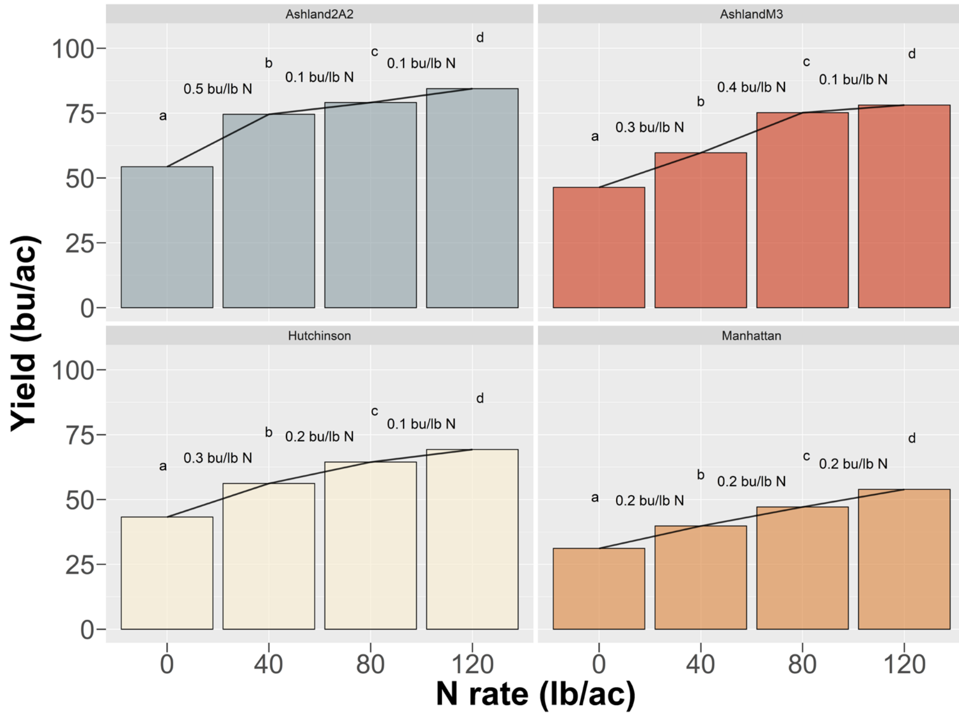

Figure 3. Average grain yield (bu/a) as affected by N rate (lb/a) for trials conducted in Ashland Bottoms 2A2, Ashland Bottoms M3, Hutchinson, and Manhattan. Differences between letters indicate statistically significant differences at $\alpha = 0.05$. Values between columns represent the average yield increase in bushels, per unit applied nitrogen (lb) between two successive N rates tested.

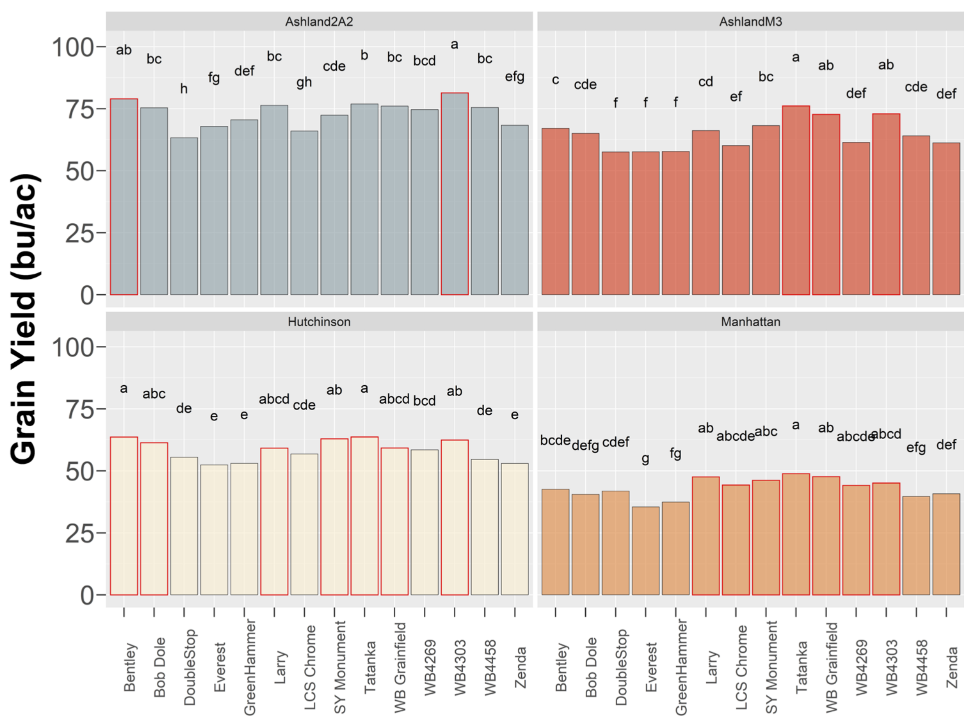

Figure 4. Average grain yield (bu/a) for each of the tested varieties in the four locations. Differences between letters indicate statistically significant differences at $\alpha = 0.05$. Red colored bar-lines represent the top yielding group for each of the locations.