Sustainable Intensification of Winter Wheat for Improved Yield

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Summary

Preliminary evidence suggests that the current wheat grain yield of Kansas farmers is well below the yield potential of current varieties under the typical weather conditions experienced in the region. Consequently, this large yield gap is due to the conservative management of producers. To address whether current yields can be improved via intensive management, and whether such improvement is dependent on variety, we conducted a field study in a complete factorial treatment structure established in a split-plot design across six environments during the 2023–2024 growing season evaluating 10 winter wheat varieties (sub-plot) under two management practices (whole plots), namely intensive and standard. Intensive management included increased seed rate, seed treatment, fungicide application, and enhanced fertilization as compared to standard. Environmental conditions significantly influenced average grain yield, which ranged from 6.6 bushels per acre in Hays to 80.3 bushels per acre in Leoti. There were significant variety by environment and management by environment interactions, suggesting that variety performance and management effectiveness were location-dependent. Here, KS Bill Snyder performed best in Leoti (89.4 bushels per acre) and Phillipsburg (87.7 bushels per acre), while KS Providence excelled in McPherson (66.2 bu/a) and Manhattan (68.1 bu/a). Intensive management boosted average yield in Manhattan (30%), Phillipsburg (12%), and McPherson (11.2%) though the latter was only numerical. These findings emphasize that wheat yield improvement requires site-specific variety selection and management practices, reinforcing the importance of adaptive agronomic strategies to minimize the wheat yield gap in Kansas.

Introduction

Wheat is a cornerstone of food and nutritional security in the world, providing ~20% of all human dietary protein and calories (Shewry and Hey, 2015). In the US, Kansas leads as the nation's largest winter wheat-producing state, producing ~330,000,000 bushels of wheat per year with a 10-yr average yield of 42.9 bushels per acre (USDA, 2023). This yield level, however, falls well behind its potential yield, which is estimated between 74 and 83 bu/a (Couedel et al., 2025; Patrignani et al., 2013; Lollato et al., 2015, 2017, 2019). This significant yield gap (i.e., the difference between actual yield, Ya, and potential yield limited by water, Yw) is critical and can be narrowed with improved wheat management (e.g., Jaenisch et al., 2019, 2022; Raj et al., 2023). The environment to which the crop is exposed — including precipitation amount and distribution, temperatures, and solar radiation — in combination with crop genetics dictate the crop's Yw, while the management adopted by each grower in each field (e.g., crop sequence, sowing dates, in-season management) defines Ya (de Oliveira Silva et al., 2021; Jaenisch et al., 2022; Lollato et al., 2021; Sciarresi et al., 2019).

Kansas has a considerable exploitable yield gap that can be economically reduced through effective management practices. Beres et al. (2020) emphasized the need for innovative management strategies, advocating for the genetics × environment × management (G×E×M) framework to optimize productivity and reduce the yield gap. Adopting improved agronomic practices has contributed to enhancing the actual yield of wheat, thereby slowly narrowing the yield gap (Fischer et al., 2015). In Kansas commercial wheat fields, agronomic management practices that have shown widescale potential to narrow yield gaps include nitrogen (N) management and foliar fungicides (Jaenisch et al., 2021). Furthermore, improved population density (Bastos et al., 2020; Jaenisch et al., 2019; Lollato et al., 2024) and interactions with in-furrow fertilizer applications (Maeoka et al., 2020) and seed treatments (Pinto et al, 2019), could help to narrow the yield gap. The benefits of improved management, however, can be variety-specific (de Oliveira Silva et al., 2020). For example, Giordano et al., (2024) demonstrated that variety-specific N management may be warranted under high-yielding conditions but not under harsh environments. Pradella & Lollato (2023) suggested the need for variety-specific seeding rates. Jaenisch et al. (2019, 2020, 2021) suggested that different varieties may respond differently to the interaction between N and sulfur (S) rates.

The primary objective of the experiment was to determine the yield gains resulting from management intensification using a combination of currently adopted practices, such as seed treatment, fungicide application, fertilization, etc., in ten commercial wheat varieties in field experiments across the state of Kansas.

Procedures

Field experiments were conducted in six environments (E) (Hays, McPherson, Leoti, Manhattan, Phillipsburg, and Hoisington) during the 2023-2024 winter wheat growing seasons in a complete factorial combination of 10 varieties (G) (sub-plot) and two management levels (M) (whole plot) in a split-plot design with three and four replicates depending upon the environment. The winter wheat varieties were Bob Dole, KS Ahearn, KS Big Bow, KS Hamilton, KS Hatchett, KS Providence, KS Territory, KS Mako, KS Bill Snyder, and WB4699, under two wildly divergent management levels, identified as standard and intensive.

The management levels were designed to test technologies already adopted by wheat growers in their commercial fields. Thus, we used the survey data collected by Jaenisch et al. (2021) to develop combinations of management practices that reflected the average Kansas wheat farmer management, and a level of intensification that reflected the 80^{th} percentile grain yield level among the ~700 wheat fields surveyed. Standard management involved a seeding rate of 1 million seeds per acre, no seed treatment, no flag leaf fungicide application, and a nitrogen rate of 80 pounds of N per acre applied as urea during spring green-up. In contrast, the intensive management utilized a higher seed rate of 1.4 million seeds per acre together with 50 pounds of diammonium phosphate (DAP) per acre applied in furrow, fungicide and insecticide seed treatment (Sedaxane, Difenoconazole, Mefenoxam, and Thiamethoxam at 0.03, 0.16, 0.04, and 0.47 oz ai per acre respectively), and flag leaf fungicide application (Benzovindiflupyr, Azoxystrobin, and Propiconazole at 5.0, 2.9, and 2.2 oz ai per acre respectively). Ammonium-sulfate was added to provide 20 pounds of S per acre and reduce the chances that S availability limited grain yield. Total nitrogen rate, including that as applied as ammonium-sulfate plus urea, was 130 pounds of N per acre. A detailed description of the combination of treatment for both management practices is provided in Table 1.

The treatments were implemented either through the manual application of fertilizers or via a CO_2-pressurized backpack sprayer for applying foliar fungicides (Table 1). Plots were harvested using a Massey Ferguson 8XP small plot, self-propelled combine. Parameters such as grain weight, test weight, and moisture content were automatically measured during harvest using the on-board HarvestMaster GrainGage system. Grain yield was adjusted to 13% moisture content. Statistical analysis was conducted employing a three-way analysis of variance with varieties, management, environments, and their interactions treated as fixed effects, and block nested within the environment and management nested within block as random effects. Mean values were distinguished at the significance level of alpha = 0.05 ($p<0.05$).

Results

The locations studied had very contrasting weather conditions, especially considering in-season precipitation that ranged from 11.1 to 27.6 inches. This range in precipitation drove large differences in grain yield among locations. The highest average grain yield was observed in Leoti (80.3 bushels per acre) followed by Philipsburg (74.4 bushels per acre), Manhattan (60.9 bushels per acre), McPherson (59.1 bushels per acre), Hoisington (15.2 bushels per acre), and lastly Hays (6.6 bushels per acre) (Table 2). The low yields measured in Hays and Hoisington were due to a combination of factors including primarily extreme season-long drought conditions and potential cold injury at stem elongation.

There were significant interactions between varieties and environment (G×E), and between environment and management (E×M), suggesting that the performance of different varieties was influenced by environmental conditions, and the effectiveness of management practices was also location-dependent. The variety by location interaction was likely due to all varieties performing similarly in Hays, Hoisington, and Manhattan, but performing differently in McPherson, Leoti, and Phillipsburg. The variety KS Bill Snyder had the greatest yield in Leoti and Phillipsburg, while KS Providence outperformed other varieties in McPherson (Table 2). The interaction between management and environment was portrayed by the intensive management increasing grain yield in Manhattan (21.6 bushels per acre or 30% yield gain) and in Phillipsburg (9.6 bushels per acre or 12% yield gain). However, despite the numerical yield increase in McPherson (6.9 bushels per acre or 11% yield gain), no significant difference in grain yield was noticed for management practices across other locations. We note that there were no significant three-way interactions among varieties, environment, and management (G×E×M).

Conclusion

Environmental conditions were the primary drivers of yield variations, but variety and management also played crucial roles. The significant G × E and E × M interactions indicated variety selection and management strategies should be tailored to specific environments for optimal grain yield. Intensive management improved yields only in specific locations, reinforcing the need for site-specific recommendations to address the yield gap in wheat production.

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Table 1. Combinations of management practices adopted in winter wheat fields based on different yields.

	Across Locations	
Management Practices	**Standard**	**Intensive**
Seeding rate (seeds/a)	1,000,000	1,400,000
Seed treatment	No	Yes
DAP (lb/a)	No	50
N rate (lb N/a)	80	130
S rate (lb S/a)	0	20
Fungicide (Trivapro) (oz/a)	No	13.7
Flag leaf fungicide	No	Yes

Table 2. Grain yield as determined by the interaction between variety and environment, and management and environment.

	Grain Yield (bushels per acre)					
Treatments	Environments					
Varieties	**Hays**	**Hoisington**	**McPherson**	**Leoti**	**Manhattan**	**Phillipsburg**
Bob Dole	6.5	17.8	60.1[ab]	67.8[c]	68.9	63.4[d]
KS Ahearn	6.8	16.1	55.4[ab]	80.7[abc]	60.6	63.2[d]
KS Big Bow	8.3	16.5	62.9[ab]	84.2[ab]	64.9	86.2[a]
KS Bill Snyder	4.6	14.3	60.2[ab]	89.4[a]	54.6	87.7[a]
KS Hamilton	6.0	15.3	55.3[ab]	81.2[ab]	57.5	72.2[bcd]
KS Hatchett	5.6	14.2	53.5[ab]	76.4[abc]	54.8	74.9[abcd]
KS Mako	6.0	16.5	65.1[ab]	83.5[ab]	65.6	80.4[ab]
KS Providence	8.3	15.1	66.2[a]	85.5[ab]	68.2	70.2[bcd]
KS Territory	7.9	13.3	59.9[ab]	73.1[bc]	58.7	79.3[abc]
WB4699	5.6	12.5	52.7[b]	81.1[abc]	55.4	66.7[cd]
Management Practices						
Intensive	7.2	12.4	62.6	79.8	71.7[a]	79.2[a]
Standard	5.9	18.0	55.7	80.8	50.1[b]	69.6[b]

*Letters denote significance at the 0.05 probability level.