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L. O. Pradella
Kansas State University, pradella@k-state.edu

R. P. Lollato
Kansas State University, lollato@ksu.edu

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Tillering Potential and Stability of Winter Wheat Varieties Commonly Grown in Kansas

L.O. Pradella and R.P. Lollato

Summary
The tillering potential and stability of winter wheat (*Triticum aestivum* L.) can be positive traits by conferring adaptation to distinct production environments. The literature demonstrates a high correlation between the tillering potential and many yield components. However, the actual impact of tillering potential on grain yield is not clear. Our goal was to quantify the tillering potential and stability of a range of winter wheat varieties. Field experiments were conducted in six locations in the state of Kansas during the 2021–2022 season. A complete factorial treatment structure of twenty-five winter wheat varieties by two seeding rates (400,000 seeds per acre and 1.2 million seeds per acre) was established in a randomized complete block design with three or four blocks. We measured the stand count (twenty days after sowing) and the number of stems at the growth stage Feekes 6 in 3 ¼ row-feet in each plot. Tillers per plant were modeled as a function of plants per square feet by replication within the environment using non-linear models. Overall, fall precipitation and temperature accumulation partially regulated tiller production, but the major determinant of tillers per plant was the number of plants per area. Different seeding rates led to large differences in population and tiller components, which in compensation only resulted in modest grain yield changes. With few exceptions, varieties tended to be stable in their ranking as a function of the environment; thus, varieties with high tillering potential can be an option to reduce seed costs.

Introduction
Winter wheat responses to seeding rate are inconsistent (Bastos et al., 2020; Evans and Fischer, 1999; Jaenisch et al., 2022; Lollato et al., 2019a). Some studies suggest that grain yield responses to population depend on environmental yield potential, which ultimately would occur due to resource availability (Bastos et al., 2020). Wheat yield and its relationships with population were measured in a dataset of commercial fields entered in the Kansas Wheat Yield Contest. The results suggested that populations as low as 400,000 plants per acre were sufficient to maximize yields, as long as fields had substantial resources (Lollato et al., 2019b). Environmental resources (including moisture and temperature) needed to ensure proper wheat tiller production and maintenance during the fall may not always be available in areas with highly variable weather such as Kansas (Lollato and Edwards, 2015; Lollato et al., 2017, 2020; Sciarresi et al., 2019). When wheat sowing dates are delayed to follow a summer crop, low wheat populations can be challenging (Munaro et al., 2020; Jaenisch et al., 2021).

In addition, the literature demonstrates a high correlation between the tillering production and many yield components (Bastos et al., 2020; Jaenisch et al., 2022; Sadras and Rebetzke, 2013). The number of tillers usually associates with the number of spikes; thus, the higher tiller production can help maximize wheat yields when seeding rates are reduced (Bastos et al., 2020). This indicates that winter wheat tillering potential and stability can be positive traits by conferring adaptation to distinct production environments. However, a trait's actual impact on grain yield is not clear, requiring a better understanding of the correlation between grain yield, environments, and varieties.

We used the concept of tillering potential (TP, the number of tillers developed per plant) and tillering stability (i.e., the genotype's ability to produce a predetermined phenotype) to explore genotype by environment interactions. The objective of this work was to quantify the tillering potential and stability of a range of winter wheat varieties.

Procedures

Treatments, Experimental Design, and Management

Six field experiments were conducted in the state of Kansas. Sites were near Belleville, Great Bend, Hays, Leoti, and there were two experiments with contrasting sowing dates near Hutchinson. This research was conducted during the winter wheat seasons of 2021–2022. Across locations, the different cropping systems ensured different tillering potentials resulting from planting dates and conditions. For example, cropping systems ranged from wheat sown at the optimal time after a fallow period, to wheat sown late following the harvest of a summer crop. These different planting times allow us to explore the effects of fall weather on early crop growth. Seeds were treated with thiamethoxam, difenoconazole, and mefenoxam for protection against early-season diseases and insects. Diammonium phosphate (DAP 18-46-0) was used as starter fertilizer at a rate of 50 lb/a. Management factors such as foliar fungicide (Cruppe et al., 2017, 2021), topdressing fertilizer (Lollato et al., 2019c, 2021), weed management, and insect control were carried out to ensure that these were not limiting factors to wheat yield at all sites by using prophylactic pesticide applications.

Treatments were arranged in a randomized complete block design (RCBD). Each block received twenty-five winter wheat varieties which were sown in two seeding rates: either 400,000 seeds per acre, or 1,200,000 seeds per acre. These sowing rates were considered as treatments of lower and higher seeding rate, respectively. The rates were defined based on preliminary data suggesting that optimum grain yields could be attained at 400,000 seeds per acre (Lollato et al., 2019b). Thus, the trial had a total of 50 treatments.

We demarked a 3.28-ft row to measure stand count (SC) between 3 and 4 weeks after sowing, and the tiller number (TN) after the winter when the plants were around the jointing stage of development (Feekes 6). Finally, grain yield was measured at physiological maturity by harvesting the entire plot and adjusting for 13% moisture.

The Kansas Mesonet system was used to provide weather data, including precipitation, and maximum and minimum temperature.

Statistical Analyses

The number of tillers per plant was correlated by a linear model with fall cumulative precipitation and fall growing degrees per day. The main response variables of population, tillers per area, tillers per plant, and grain yield were grouped by Tukey's test at $P < 0.05$ within location to explore effects of the treatments. A non-linear regression model was fitted to tillers per plant as a function of plants per area by replication within the environment. The residuals of the above relation were ordered by location to show the response of varieties within the environment. The lowest and highest tillering production environments were selected to illustrate and simplify the interpretation of the results.

Results

Fall Weather Conditions

Tillers per plant tended ($P < 0.32$) to increase with increases in precipitation and growing degree days accumulated from the sowing date until December 31st across the six locations studied (Figure 1). Growing degree days had a greater impact ($r^2 = 0.51$) than precipitation ($r^2 = 0.23$) on tillers per plant.

Grain Yield

Increasing seeding rates increased the plants per area two-fold and tillers per area by 15% while reducing tillers per plant by 43% (Table 1). Increases in grain yield were significant but modest (mean: 6%). Interestingly, the reduced crop density increased the tillering production and decreased the number of tillers per area. In spite of the buffer effect from the tillering production, the grain yield was reduced as well. TThis aligns with previous findings (Jaenisch et al., 2022; Lloveras et al., 2004), however here exploring a larger quantity of varieties and environments.

Tillering Potential

Tillers per plant decreased exponentially with increases in the plants per area (Figure 2). The wheat varieties evaluated had different tillering potentials (Table 2). While a few varieties switched ranking between environments markedly, the majority of the varieties maintained their ranking tendency (above or below average). Interestingly, the hierarchical order which was established for the lowest tillering production environments appears to be pretty similar to that resulting from the highest tillering production environments (Table 2). This demonstrates a predominance of the genotype's response to the environment in the tillering potential trait in most of the varieties. Grouping the tillering potential values by Tukey's test at $P < 0.05$ resulted in only two main groups, and in all environments more than 80% of the varieties belonged to the same group. This fact can indicate a difficulty and/or issues in classifying winter wheat varieties by a precise scale by means of their tillering potential traits.

Preliminary Conclusions

This study identified that precipitation and temperature accumulation between sowing and the onset of winter partially regulated tiller production, but the major determinant of tillers per plant was the plant density (plants per area). Different seeding rates led to large differences in population and tiller components, which in compensation only resulted in modest yield changes.

With few exceptions, varieties tended to be stable in their ranking regarding tillering potential as a function of the environment. Thus, varieties with high tillering potential may be an option to reduce seed costs across environments.

Acknowledgments

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Table 1. Mean population, tillers produced per area, tillers produced per plant, and grain yield across varieties for the different environments and plant populations studied

		Population mean (per square ft)		Tillers mean (per square ft)		Tillers per plant		Grain yield mean (bu/a)	
Location	**Environ.**	**Target 400,000 seeds/a**	**Target 1,200,000 seeds/a**	**Target 400,000 seeds/a**	**Target 1,200,000 seeds/a**	**Target 400,000 seeds/a**	**Target 1,200,000 seeds/a**	**Target 400,000 seeds/a**	**Target 1,200,000 seeds/a**
Belleville	BES	11.5b	28.1a	63.6a	65.4a	5.7a	2.4b	77.3b	83.3a
Great Bend	GB	11.0b	24.0a	75.6b	98.4a	7.1a	4.4b	34.2b	35.7a
Hays	HAY	8.4b	18.0a	77.2b	94.7a	9.7a	5.6b	41.6b	44.6a
Hutchinson	HUT-LAT	10.4b	20.1a	50.4b	62.9a	5.3a	3.5b	35.7b	38.7a
Hutchinson	HUT-OPT	6.8b	13.0a	105.4a	110.6a	17.1a	9.3b	58.0b	62.5a
Leoti	LEO	9.1b	17.9a	111.6b	123.5a	13.0a	7.3b	50.6b	55.0a
Mean		9.3b	19.7a	81.6b	93.5a	9.9a	5.6b	49.1b	52.0a

Different letters suggest that means were not similar by Tukey's test at $P < 0.05$.

Table 2. Order of varieties per location in terms of tillering potential

Tillering potential	Belleville	Great Bend	Hays	Hutchinson Late	Hutchinson Optimum	Leoti
	------ Variety Name ------					
High	WB4699	WB4699	WB4699	WB4699	WB4699	WB4595
	WB4595	WB4303	WB4269	DoubleStop CL Plus	KS Hamilton	WB4269
	KS Western Star	KS Hamilton	WB4595	WB4269	Larry	Joe
	KS Hamilton	Joe	SY Monument	KS Hatchett	Joe	Larry
	WB4269	Duster	Duster	Duster	KS Hatchett	WB4699
	DoubleStop CL Plus	WB4595	KS Hamilton	SY Wolverine	WB4595	SY Wolverine
	KS Ahearn	WB4269	Joe	Joe	KS Ahearn	Kanmark
	Duster	Showdown	KS Hatchett	Larry	SY Wolverine	KS Hatchett
	WB4792	DoubleStop CL Plus	KS Ahearn	SY Monument	WB4792	KS Providence
	SY Wolverine	KS Ahearn	KS Western Star	KS Ahearn	Duster	SY Monument
	Joe	KS Hatchett	Showdown	KS Hamilton	DoubleStop CL Plus	Showdown
	Bakers Ann	SY Monument	WB4792	WB4595	WB4269	KS Hamilton
Median	Zenda	Zenda	Zenda	Bakers Ann	Zenda	KS Ahearn
	KS Hatchett	WB4401	Larry	WB4792	WB4303	WB4792
	Larry	Bob Dole	SY Wolverine	Showdown	KS Dallas	WB4401
	OK Corral	OK Corral	OK Corral	Zenda	Bob Dole	Duster
	WB4401	KS Providence	Kanmark	Bob Dole	Bakers Ann	Bob Dole
	SY Monument	KS Dallas	Bob Dole	WB4303	KS Western Star	DoubleStop CL Plus
	Smith's Gold	SY Wolverine	KS Providence	KS Dallas	OK Corral	KS Western Star
	KS Dallas	KS Western Star	Bakers Ann	KS Western Star	KS Providence	WB4303
	KS Providence	WB4792	Smith's Gold	KS Providence	SY Monument	Zenda
	WB4303	Larry	WB4303	WB4401	WB4401	OK Corral
	Bob Dole	Smith's Gold	DoubleStop CL Plus	Smith's Gold	Showdown	KS Dallas
	Showdown	Bakers Ann	WB4401	OK Corral	Smith's Gold	Bakers Ann
Low	Kanmark	Kanmark	KS Dallas	Kanmark	Kanmark	Smith's Gold

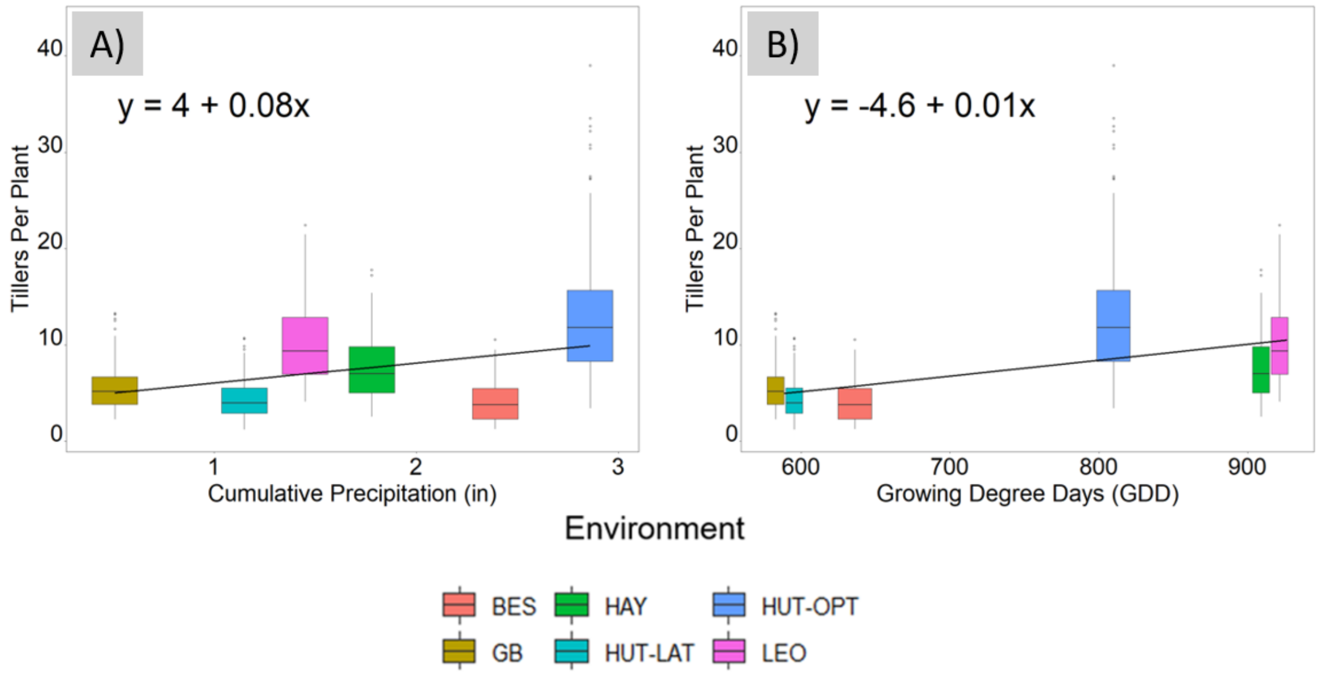

Figure 1. Tillers per plant tended to increase as function of precipitation (A) and growing degree days (B) accumulated from the sowing date until December 31 ("Fall") across the six environments evaluated.

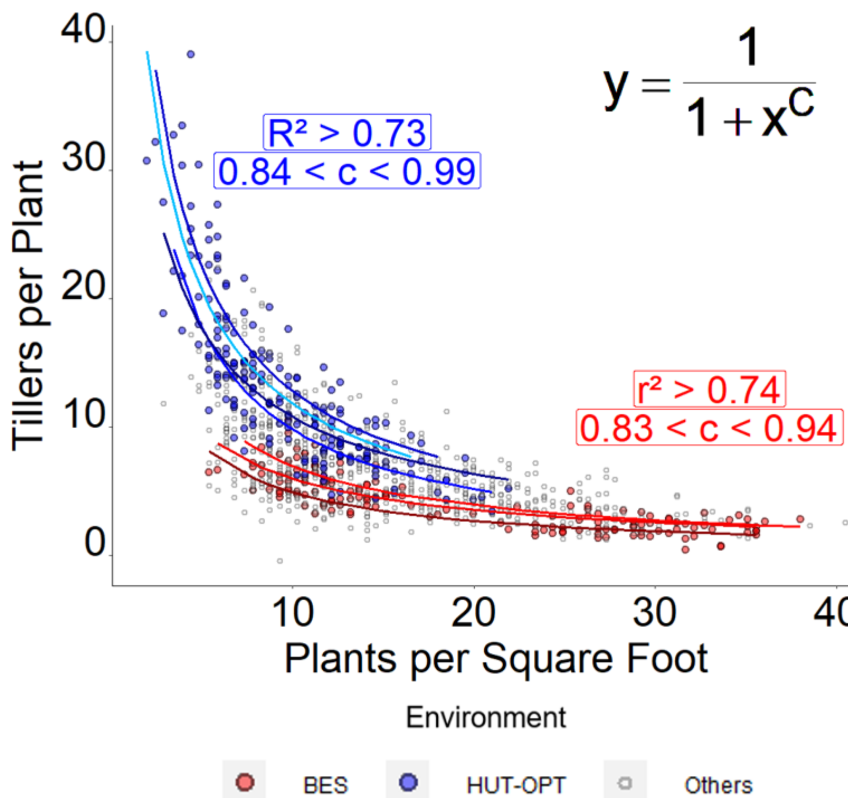

Figure 2. Tillers per plant decreased exponentially with increases in plants per area. Lines show regressions for each block in blue for the highest tillering environment (Hutchinson sown at the optimum time) and red for the lowest tillering environment (Belleville sown late after soybeans).