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Timing and Positioning of Simulated Hail Damage Effects on Wheat Yield in Kansas: 2015–2016 and 2016–2017 Growing Seasons

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

A. de Oliveira Silva
Kansas State University, adeolive@ksu.edu

R. E. Maeoka
Kansas State University, maeoka@ksu.edu

G. P. Bavia
Kansas State University

See next page for additional authors

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Keywords
wheat hail damage, Kansas wheat, Agronomy field research

Authors
R. P. Lollato, A. de Oliveira Silva, R. E. Maeoka, G. P. Bavia, L. Bonassi, and B. R. Jaenisch

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Hail events often decrease wheat yields in Kansas; however, estimates of yield loss due to hail event timing and position relative to the flag leaf are only available for older varieties. Our objectives were to quantify wheat yield losses as affected by timing of hail event relative to the crop development and positioning of the damage relative to the flag leaf. A total of 14 hail damage treatments including seven different timings during the growing season (boot, anthesis, watery ripe, milk, soft dough, hard dough, and ripe) and two different positions relative to the flag leaf (above or below) were evaluated in a trial conducted in Manhattan, KS, during the 2015–2016 and 2016–2017 growing seasons. Hail damage was simulated by bending 100% of the stems within each plot, which averaged approximately 15 bu/a both growing seasons across treatments, ranging from non-significant to 20.4 bu/a. The lowest grain yield (or highest grain yield loss) due to simulated hail occurred when treatments were imposed during milk stage or anthesis (above and below flag leaf) and during soft dough stage below flag leaf in 2015–2016. Delaying treatment to hard dough, when most of the photosynthates have already been translocated to the grain, also decreased grain yields when compared to the control both years, especially when stem bending occurred below the flag leaf. More years of research are needed to achieve robust estimates of wheat yield loss due to hail damage, but these preliminary data indicate that wheat grain yield is more sensitive to hail damage during the interval between anthesis and the milk stage of grain development.

Introduction

Winter wheat in Kansas is sown mid-September to mid-October, and often harvested as late as July. Thus, it is exposed to weather-related yield-limiting factors for nine to ten months out of the year. These environmental yield-reducing events include:

- Drought conditions - common during the majority of the growing seasons especially in western Kansas;
- Winterkill - might occur in particular years mostly due to lack of snow cover or abrupt shifts in air temperature especially in late-sown fields;

- Spring freeze - often causes some level of yield loss in different portions of the state; and
- Heat stress during grain development - often reduces the duration of the grain filling phase and reduces grain yield.

Still, one of the most devastating weather events to wheat grain yield is hail. Hail damage might fully compromise a particular field's productivity, and accurate estimations of yield losses due to hail damage can help producers and crop insurance agencies make better decisions on whether to maintain a hail-damaged field for grain yield. The objectives of this project were to understand the wheat yield losses associated with stem positioning and timing of stem bending to simulate hail damage, and to ultimately improve the yield loss estimates performed when assessing hail-damaged wheat fields.

Procedures

One experiment was conducted at the Kansas State University Agronomy North Farm in Manhattan, KS, during two growing seasons (2015–2016 and 2016–2017). The experiment was conducted in an incomplete factorial treatment structure established in a randomized complete block design with six replications. One variety (WB Cedar) was exposed to six different timings of stem bending in the first year, and seven timings in the second year, at two different positions in regard to the flag leaf (Table 1). Stem bending timing treatments were at the following stages of wheat development: boot, anthesis, watery ripe (2016–2017 only), milk, soft dough, hard dough, and ripe. Position of stem bending was above or below the flag leaf (either in the peduncle or in the internode immediately below it, respectively). One hundred percent of the stems in the plot were bent at treatment application.

The trial was sown October 20, 2015, and October 17, 2016, in a continuous wheat field under conventional tillage in a Smolan silty clay loam soil. Plots were seven 7.5-inch row spacing rows wide × 8-ft long in the first year and by 10-ft long in the second year. Nitrogen (N) fertilization was performed with a yield goal of 75 bu/a, based on soil nitrate-N content. Initial soil fertility is shown in Table 2 for the two years of the study. Weeds and foliar diseases were controlled at both years so these were not confounding factors. Measurements included grain yield, grain moisture content, 1000-kernel weight, grain test weight, and grain protein concentration. Plots were harvested using a small plot combine. Moisture and test weight were measured in the lab immediately following wheat harvest, and grain yield was corrected for 13.5% moisture content. Statistical analyses were performed considering a one-way treatment structure, and orthogonal contrasts were built on variables of interest: hail vs. non-hail, above vs. below flag leaf, and between each timing of treatment application pooled across bending positions. Analyses of variance were performed using PROC GLIMMIX on SAS and considering treatment as fixed effect and replication as random effect.

Results

Growing Season Weather

The weather in Manhattan was characterized by a warm and moist fall, and a cool and moist spring for both growing seasons (Table 3). The winter was considerably different between seasons, with 2015–2016 characterized by dry conditions while 2016–2017 had plenty of precipitation during March (Table 3). Growing season precipitation total was 24.4 in. in 2015–2016 and 17.9 in. in 2016–2017. Despite the high precipitation total, cumulative solar radiation during the growing season was well above 3,000 MJ m^{-2} both seasons, indicating that lack of solar radiation should not have been a yield-limiting factor.

Grain Yield

The yield of the control treatment was similar both growing seasons, 65 bu/a, and there was a significant treatment effect on wheat grain yield (Figure 1). The control treatment had the highest grain yield among all treatments and was only statistically similar to treatment imposed at soft or hard dough above the flag leaf for both growing seasons (56.9 and 58.8 bu/a in 2015–2016 and 59.6 and 65.6 bu/a in 2016–2017, respectively (Figure 1). The lowest grain yield (or highest grain yield loss) due to simulated hail occurred when treatments were imposed during milk stage or anthesis (above and below flag leaf) and during soft dough stage below flag leaf in 2015–2016 (Figure 1). In the first year of the study (2015–2016), stem bending before anthesis (i.e. boot stage) yielded slightly higher than the aforementioned treatments, most likely because of new heads that emerged from secondary tillers to compensate for tiller loss due to stem bending. In 2016–2017, the lowest grain yields were measured in the treatments imposed at boot stage, anthesis, and watery ripe below the flag leaf (Figure 1). During 2016–2017, we did not observe the same development of later tillers as previously mentioned, likely due to less precipitation during the spring (Table 3, 8.8 vs. 15.2 in.).

Delaying treatment to hard dough, when most of the photosynthates have already been translocated to the grain, also decreased grain yields when compared to the control both years, especially when stem bending occurred below the flag leaf (Figure 1). Similarly, treatments imposed at harvest maturity (i.e. “Ripe”) decreased grain yield when compared to the control for both studied growing seasons, possibly due to increased pre-harvest shattering due to an upside-down head positioning which may have increased the tendency of wheat grains to fall off the head. Analyses of the orthogonal contrasts indicated that there was a significant difference between treatments that received simulated hail damage vs. the control, with the control resulting in higher yields (14.7 and 15.0 bu/a difference in 2015–2016 and 2016–2017, respectively, Table 4). Similarly, orthogonal contrasts indicated that yield losses were greater when the breakpoint was below the flag (4.4 and 0.5 bu/a) as compared to above the flag leaf. Pooling results across stem bending positions and analyzing the stage of growth when bending occurred indicated that stem bending resulted in similar yield loss (not significant orthogonal contrast) for both growing seasons when it occurred at i) boot or anthesis, ii) soft dough or ripe, and iii) hard dough or ripe (Table 4). Harsher yield losses occurred both growing seasons when bending occurred at milk as compared to boot (8.0 and 8.1 bu/a), anthesis as compared to hard dough (8.2 and 15.3 bu/a), or ripe (6.7 and 11.3 bu/a), and milk as compared to soft dough (8.0 and 11.6 bu/a), hard dough (14.6 and 12.2 bu/a), or ripe (13.1 and 8.3 bu/a, Table 4).

Interestingly, the extent of the yield loss as compared to the control treatment differed between growing seasons (Figure 2). The largest difference between seasons was with the treatment applied at boot stage, likely due to the secondary tillers that emerged in 2015–2016 and helped compensate for main tiller loss as opposed to the 2016–2017 season. Similarly, treatments applied at soft dough had a much more detrimental effect on grain yield in 2015–2016 (i.e. less than 70% of control yield) compared to 2016–2017 (i.e., more than 80% of the control yield, Figure 2). Yield loss when treatments were imposed during the anthesis, milk interval, were similar between growing seasons, with treatments yielding about 60-75% of the untreated control. Another similarity between seasons was that treatments imposed below the flag leaf tended to cause greater yield loss than treatments imposed above the flag leaf (Figure 2).

Preliminary Conclusions

Results from both growing seasons were consistent in some aspects, while inconsistent in other aspects. For instance, treatment imposed at boot stage resulted in minimal yield loss in 2015–2016 when plentiful spring precipitation allowed for secondary tiller formation and survival; however, it was very detrimental in 2016–2017 when the aforementioned conditions were not observed. Effects of simulated hail damage on grain yield when treatments were applied during soft dough or ripe were also slightly inconsistent between years. Yield losses for treatments applied between anthesis and milk stage of grain development were similar for both seasons and indicate that the most damaging effect of hail damage occurs when hail takes place during the milk stage of grain development. We also show that treatments applied below the flag leaf resulted in greater yield loss as compared to those applied above the flag leaf, for both growing seasons. The caveats of our analysis include: i) our approach accounted only for stem damage, not taking into account any potential yield loss due to foliage removal or head loss which also occurs in hail storms; and ii) we only have two site-years of data, which compromises the applicability of the results outside the studied site-years. More site-years of data are needed to take definite conclusions of the effect of simulated hail damage to wheat yield, especially due to the importance of the weather in dictating the recovery potential after hail of wheat grain yield.

Table 1. Treatment description, stage of treatment establishment, breakpoint regarding the flag leaf, and actual date of treatment application for simulated hail damage trial near Manhattan, KS, during the 2015–2016 and 2016–2017 growing seasons

Treatment	Stage	Breakpoint regarding flag leaf	Date treatment application (2015–2016)	Date treatment application (2016–2017)
1	Control	---		
2	Boot	Below	4/17/2016	4/17/2017
3	Anthesis	Below	4/26/2016	5/4/2017
4	Anthesis	Above	4/26/2016	5/4/2017
5	Watery ripe	Below	---	5/12/2017
6	Watery ripe	Above	---[a]	5/12/2017
7	Milk	Below	5/15/2016	5/17/2017
8	Milk	Above	5/15/2016	5/17/2017
9	Soft dough	Below	5/27/2016	6/1/2017
10	Soft dough	Above	5/27/2016	6/1/2017
11	Hard dough	Below	6/3/2016	6/6/2017
12	Hard dough	Above	6/3/2016	6/6/2017
13	Ripe	Below	6/13/2016	6/12/2017
14	Ripe	Above	6/13/2016	6/12/2017

[a] Treatment not imposed during the 2015–2016 growing season.

Table 2. Initial soil fertility at the study location. Soil samples were collected at planting

	2015–2016		2016–2017	
Nutrient	0–6, in.	6–24, in.	0–6, in.	6–24, in.
pH	5.9	---	6.01	---
NO_3-N (lb N/a)	49.4	93.6	41.5	28.3
Phosphorus (ppm)	15.7	---	16.2	---
Potassium (ppm)	165	---	190	---
Calcium (ppm)	2093	---	193	---
Magnesium (ppm)	328	---	2142	---
Sodium (ppm)	61.3	---	315	---
Organic matter (%)	2.7	---	2.95	---

Table 3. Summary of the observed weather during the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS

	2015–2016			2016–2017		
Season	Average temperature	Precipitation	Solar radiation	Average temperature	Precipitation	Solar radiation
	°F	in.	MJ m^{-2}	°F	in.	MJ m^{-2}
Fall	48.7	8	765	48.6	3.4	883
Winter	40.9	1.3	1041	42.0	5.8	921
Spring	67.3	15.2	1905	64.8	8.8	1629

Average temperature, and cumulative precipitation and solar radiation are shown for the fall (planting – December 31), winter (January 1 – March 31), and spring (April 1 – harvest date) for both growing seasons.

Table 4. Orthogonal contrasts for yield difference during the 2015–2016 and 2016–2017 growing seasons

Orthogonal contrasts	Yield difference			
	2015–2016		2016–2017	
	------ bu/a ------			
Hail vs. no hail	14.7	***	15.0	***
Above vs. below	-4.4	*	-3.8	*
Boot vs. anthesis	1.6	ns	-5.1	ns
Boot vs. watery ripe	-	-	-7.3	*
Boot vs. milk	8.0	*	-8.1	**
Boot vs. soft dough	0.0	ns	-19.8	***
Boot vs. hard dough	-6.6	ns	-20.4	***
Boot vs. ripe	-5.1	ns	-16.4	***
Anthesis vs. watery ripe	-	-	-2.2	ns
Anthesis vs. milk	6.4	*	-3.0	ns
Anthesis vs. soft dough	-1.6	ns	-14.7	***
Anthesis vs. hard dough	-8.2	**	-15.3	***
Anthesis vs. ripe	-6.7	*	-11.3	***
Watery ripe vs. milk	-	-	-0.9	ns
Watery ripe vs. soft dough	-	-	-12.5	***
Watery ripe vs. hard dough	-	-	-13.1	***
Watery ripe vs. ripe	-	-	-9.1	**
Milk vs. soft dough	-8.0	**	-11.6	***
Milk vs. hard dough	-14.6	***	-12.2	**
Milk vs. ripe	-13.1	***	-8.3	**
Soft dough vs. hard dough	-6.6	*	-0.6	ns
Soft dough vs. ripe	-5.1	ns	3.4	ns
Hard dough vs. ripe	1.5	ns	4.0	ns
Anthesis above vs. below	-1.0	ns	-3.2	ns
Watery ripe above vs. below	-	-	-4.1	ns
Milk above vs. below	-1.4	ns	-3.3	ns
Soft dough above vs. below	-14.7	**	-2.3	ns
Hard dough above vs. below	-5.4	ns	-13.1	**
Ripe above vs. below	0.4	ns	3.0	ns

*,**,*** = significant at $P < 0.05$, 0.01, and 0.001, respectively.

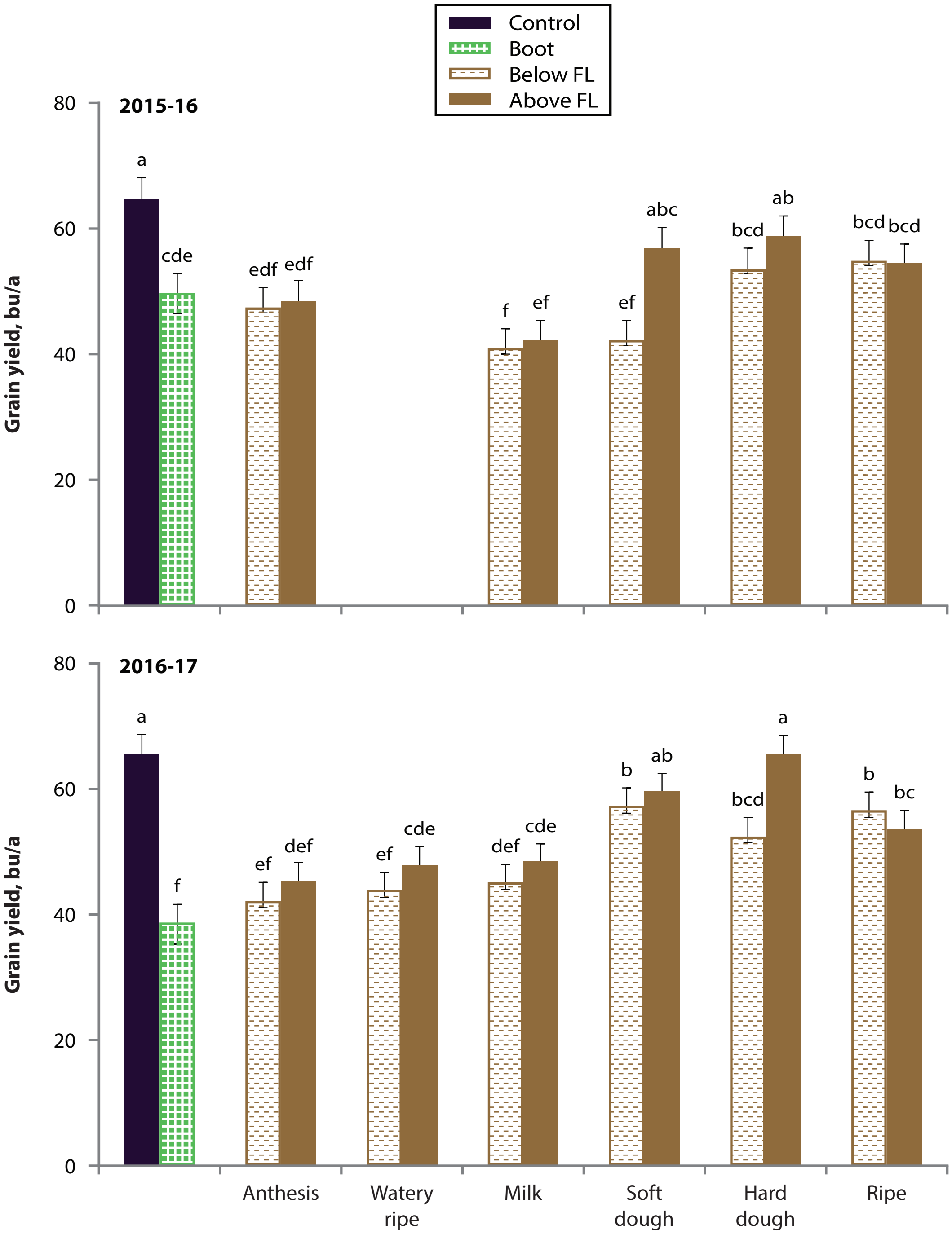

Figure 1. Wheat grain yield as affected by stem bending treatment in Manhattan, KS, during the 2015–2016 (upper panel) and 2016–2017 (lower panel) growing seasons.

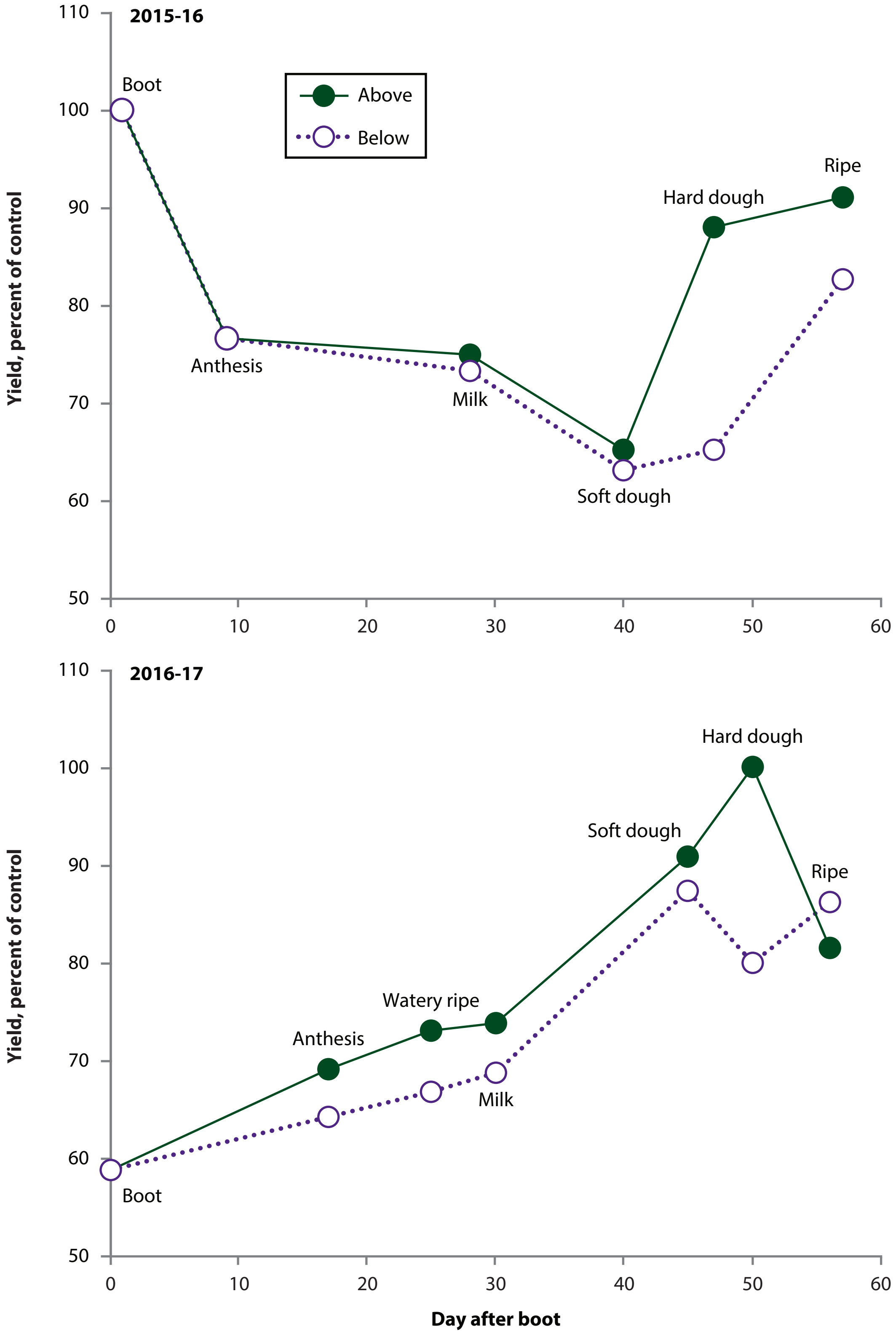

Figure 2. Grain yield, expressed as percent of the control treatment, as affected by breakpoint in reference to the flag leaf (above, solid circles; below, open circles) and by number of days after boot (e.g. date of first treatment application) during the 2015–2016 (upper panel) and 2016–2017 (lower panel) growing seasons.