Kansas Field Research 2018

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

Kansas Field Research 2018

Contents

Contributors

E.A. Adee, Associate Professor, Kansas River Valley Experiment Field, Topeka

R.M. Aiken, Crops Research Scientist, Northwest Research-Extension Center, Colby

T.M. Albuquerque, Visiting Scholar, Dept. of Agronomy, Kansas State University, Manhattan

G.R. Balboa, Doctoral Graduate Student, Dept. of Agronomy, Kansas State University, Manhattan

G.P. Bavia, Visiting Scholar, Dept. of Agronomy, Kansas State University, Manhattan

L. Bonassi, Visiting Scholar, Dept. of Agronomy, Kansas State University, Manhattan

G. Boyer, Agricultural Technician II, Dept. of Agronomy, Kansas State University, Hays

G.I. Carmona, Graduate Student, University of Nebraska-Lincoln, Lincoln, NE

I.A. Ciampitti, Associate Professor, Crop Production and Cropping Systems, Dept. of Agronomy, Kansas State University, Manhattan

R.S. Currie, Weed Scientist, Southwest Research-Extension Center, Garden City

J.M. Davidson, Graduate Research Assistant, Dept. of Agronomy, Kansas State University, Manhattan

A. de Oliveira Silva, Graduate Research Assistant, Dept. of Agronomy, Kansas State University, Manhattan

S. Duncan, Associate Professor and Agronomist, Northeast Area Extension Office, Dept. of Agronomy, Kansas State University, Manhattan

R. Engel, Undergraduate Student, Department of Biological Sciences, Fort Hays State University, Hays

J.M. Enrico, Researcher at INTA Argentina, Dept. of Agronomy, Kansas State University, Manhattan

J.A. Fernandez, Graduate Research Assistant, Dept. of Agronomy, Kansas State University, Manhattan

A.K. Fritz, Professor, Dept. of Agronomy, Kansas State University, Manhattan

D.S.S. Hansel, Doctoral Graduate Student, Dept. of Agronomy, Kansas State University, Manhattan

B.R. Jaenisch, Graduate Research Assistant, Dept. of Agronomy, Kansas State University, Manhattan

J. Kimball, Plant Science Technician, East Central Experiment Field, Ottawa

G.J. Kluitenberg, Professor, Dept. of Agronomy, Kansas State University, Manhattan

V. Kumar, Assistant Professor, Agricultural Research Center, Hays

C.R. Little, Associate Professor, Dept. of Plant Pathology, Kansas State University, Manhattan

R.P. Lollato, Assistant Professor, Wheat and Forages Extension Specialist, Dept. of Agronomy, Kansas State University, Manhattan

R.E. Maeoka, Graduate Research Assistant, Dept. of Agronomy, Kansas State University, Manhattan

D. Min, Assistant Professor, Forage Management, Dept. of Agronomy, Kansas State University, Manhattan

O.A. Ortez, Assistant Scientist, Dept. of Agronomy, Kansas State University, Manhattan

F. Salvagiotti, Researcher at INTA Argentina, Dept. of Agronomy, Kansas State University, Manhattan

M.A. Secchi, Assistant Scientist, Dept. of Agronomy, Kansas State University, Manhattan

D.E. Shoup, Associate Professor, Crops and Soils Specialist, Southeast Area Office, Chanute

P.W. Stahlman, Professor, Weed Scientist, Agricultural Research Center, Hays

S. Tamagno, Doctoral Graduate Student, Dept. of Agronomy, Kansas State University, Manhattan

G. Zhang, Associate Professor, Agricultural Research Center, Hays

Field Station Weather Reports

East Central Kansas Experiment Field

Introduction

The research program at the Kansas State University East Central Kansas Experiment Field is designed to keep area crop producers abreast of technological advances in agronomic agriculture. Specific objectives are to (1) identify top performing varieties and hybrids of wheat, corn, soybean, and grain sorghum; (2) establish the amount of tillage and crop residue cover needed for optimum crop production; (3) evaluate weed and disease control practices using chemical, no chemical, and combination methods; and (4) test fertilizer rates, timing, and application methods for agronomic proficiency and environmental stewardship.

Soil Description

Soils on the field's 160 acres are Woodson. The terrain is upland and level to gently rolling. The surface soil is a dark gray-brown, somewhat poorly drained silt loam to silty clay loam over slowly permeable clay subsoil. The soil is derived from old alluvium. Water intake is slow, averaging less than 0.1 in./hour when saturated. This makes the soil susceptible to water runoff and sheet erosion.

2017 Weather Information

Precipitation during 2017 was above average, with only May under average during the growing season (Table 1). Overall, the 2017 growing season was similar to 2016. The summer of 2017 had 29 days exceeding 90°F and 1 exceeding 100°F, which compares to 37 and 39 days exceeding 90°F, respectively in 2015 and 2016, but none of those days exceeding 100°F. There were only 8 days with low temperatures in the single digits, compared to 14 and 4 days in 2015 and 2016, respectively. The last freezing temperature in the spring was April 7 (average, April 18), and the first killing frost in the fall was October 27 (average, October 21). There were 203 frost-free days, which is more than the long-term average of 185.

The growing conditions were favorable, other than hail storms damaging corn early in the season. The short season and the full season corn hybrid trials averaged 159 and 166 bu/a, respectively. The soybean yields were very good, with the soybean variety trial averaging 72 bu/a, compared to 79 in 2016, 59 in 2015, and 41 in 2014.

Kansas River Valley Experiment Field

Introduction

The Kansas State University Kansas River Valley Experiment Field was established to study management and effective use of irrigation resources for crop production in the Kansas River Valley (KRV). The Paramore Unit consists of 80 acres located 3.5 miles east of Silver Lake on U.S. Highway 24, then 1 mile south of Kiro, and 1.5 miles east on 17th street. The Rossville Unit consists of 80 acres located 1 mile east of Rossville or 4 miles west of Silver Lake on U.S. Highway 24.

Soil Description

Soils on the two fields are predominately in the Eudora series. Small areas of soils in the Sarpy, Kimo, and Wabash series also exist. Except for small areas of Kimo and Wabash soils in low areas, the soils are well drained. Soil texture varies from silt loam to sandy loam, and the soils are subject to wind erosion. Most soils are deep, but texture and surface drainage vary widely.

2017 Weather Information

The year was similar to last year, but not as cold as previous years, with above average rainfall during most of the growing season. The frost-free season was 203 days at the both units (average = 173 days), with 9 days in single digits at both units, with 4 and 5 days below 0 at Paramore and Rossville, respectively. This is similar to last year but compares to 19 and 18 days in single digits in 2015 at Paramore and Rossville, respectively, compared to 30 and 31 days in 2014, respectively. The last spring freeze was April 7 (average = April 21), and the first fall freeze was October 27 (average = October 11). There were 33 and 34 days above 90°F at Paramore and Rossville, respectively, and one of those days above 100°F. Precipitation was just below normal at both fields for the year (Table 1) and was above average for all the months during the growing season except July. Irrigation requirements were just over 6 inches for the corn and 1 inch for the soybeans. The corn performance trials averaged 238 bu/a for the irrigated and 203 bu/a for the dryland. The soybean performance trials averaged 70 bu/a for the irrigated and 83 bu/a for the dryland. The extremes in soil moisture from dry to saturated may have been the major yield-limiting factor early in the growing season, but the cooler August was very favorable for grain fill in both the corn and soybeans. There was very little Sudden Death Syndrome in most fields in 2017, possibly due to soil saturation several times in late April/early May.

Table 1. Precipitation at Ashland Bottoms, Belleville, and Colby

	Ashland Bottoms		Belleville		Colby	
Month	2017	30-year average	2017	30-year average	2017	30-year average
	------------	------------	------------ in.	------------	------------	------------
January	0.98	0.65	1.04	0.61	0.92	0.41
February	0.47	1.07	0.22	0.87	0.00	0.48
March	4.21	2.20	1.26	2.12	2.03	1.12
April	4.99	2.80	3.06	2.87	1.41	2.03
May	3.81	4.48	8.98	4.35	7.96	3.29
June	2.82	5.09	3.47	4.37	2.43	2.54
July	1.28	3.97	2.84	3.97	2.57	3.77
August	6.09	4.28	1.46	3.68	2.67	2.78
September	0.81	3.17	3.21	3.25	3.02	1.45
October	3.66	2.22	1.15	2.37	1.17	1.58
November	0.09	1.60	0.17	1.19	0.17	0.72
December	0.11	1.02	0.11	0.95	0.08	0.48
Annual	29.32	32.55	26.97	30.6	24.43	20.65
Last freeze	4/27/17		4/28/17		5/4/17	
First freeze	10/28/17		10/27/17		10/11/17	
Frost free days	184		182		160	
Days above 90°F	42		43		47	
Days above 100°F	5		10		8	
Days below 10°F	9		16		20	

Table 2. Precipitation at Conway Springs, Ellsworth, and Garden City

	Conway Springs[1]		Ellsworth		Garden City	
Month	2017	30-year average	2017	30-year average	2017	30-year average
	-----------------	-----------------	----------------- in.	-----------------	-----------------	-----------------
January	0.92	0.82	1.94	0.62	0.36	0.47
February	0.00	1.37	0.05	1.06	0.21	0.52
March	2.03	3.06	3.47	2.35	0.43	1.23
April	1.41	3.08	4.38	2.43	6.94	1.74
May	7.96	4.51	9.14	4.50	2.72	3.00
June	2.43	5.17	3.63	3.93	3.15	3.10
July	2.57	3.55	1.15	3.63	3.11	2.80
August	2.67	3.51	1.87	3.94	4.66	2.51
September	3.02	2.69	3.40	3.05	1.29	1.42
October	1.17	2.88	2.03	2.20	0.64	1.22
November	0.17	1.79	0.21	1.11	1.13	0.54
December	0.08	1.14	0.00	0.93	0.38	0.60
Annual	24.43	33.57	31.27	29.75	25.02	19.15
Last freeze			4/28/17		5/4/17	
First freeze			10/28/17		10/11/17	
Frost free days			183		164	
Days above 90°F			64		59	
Days above 100°F			12		12	
Days below 10°F			11		19	

[1]Temperature data are not available for Conway Springs.

Table 3. Precipitation at Hays, Hutchinson, and Manhattan

	Hays		Hutchinson		Manhattan North Farm	
Month	2017	30-year average	2017	30-year average	2017	30-year average
	in.					
January	1.25	0.50	2.37	0.79	1.35	0.63
February	0.10	0.71	0.17	1.25	0.46	1.08
March	1.50	1.81	3.35	2.58	3.96	2.49
April	7.83	2.14	4.16	2.70	4.52	3.17
May	4.58	3.26	5.44	4.68	3.61	5.09
June	3.82	2.83	1.83	4.57	2.93	5.70
July	1.50	3.92	0.61	4.09	1.51	4.42
August	3.08	3.04	2.53	3.36	5.67	4.12
September	2.17	2.05	2.91	2.66	1.30	3.43
October	1.96	1.58	2.14	2.44	2.51	2.69
November	0.24	0.89	0.02	1.32	0.13	1.73
December	0.04	0.72	0.00	1.17	0.11	1.07
Annual	28.07	23.45	25.53	31.61	28.06	35.62
Last freeze	5/1/17		4/28/17		4/11/17	
First freeze	10/11/17		10/27/17		10/27/17	
Frost free days	163		182		199	
Days above 90°F	55		51		49	
Days above 100°F	7		9		6	
Days below 10°F	17		7		9	

Table 4. Precipitation at McPherson, Ottawa, and Scandia

	McPherson		Ottawa		Scandia	
Month	2017	30-year average	2017	30-year average	2017	30-year average
	----------	----------	----------	in. ----------	----------	----------
January	1.72	0.79	0.99	1.03	1.04	0.45
February	0.08	1.19	0.03	1.32	0.18	0.74
March	3.50	2.69	2.56	2.49	1.38	2.12
April	6.77	2.87	6.16	3.50	2.33	2.96
May	3.69	4.98	4.43	5.23	5.16	4.21
June	3.83	4.95	5.48	5.21	3.13	3.81
July	1.82	3.94	3.75	3.37	2.23	4.24
August	2.42	3.60	8.09	3.59	1.88	3.26
September	1.95	2.86	3.12	3.83	2.30	2.84
October	2.13	2.45	3.78	3.43	1.32	2.14
November	0.04	1.43	0.16	2.32	0.08	1.26
December	0.14	1.04	0.31	1.45	0.05	0.79
Annual	28.09	32.79	39.43	36.78	21.08	28.82
Last freeze	4/27/17		4/7/17		4/27/17	
First freeze	10/27/17		10/27/17		10/10/17	
Frost free days	183		185		166	
Days above 90°F	52		29		39	
Days above 100°F	4		1		0	
Days below 10°F	8		8		15	

Table 5. Precipitation at the Kansas River Valley Experiment Fields

	Rossville Unit		Paramore Unit	
Month	2017	30-year average	2017	30-year average
	---------- in. ----------			
January	1.26	3.18	1.14	3.08
February	0.38	4.88	0.32	4.45
March	3.65	5.46	3.75	5.54
April	5.49	3.67	5.21	3.59
May	6.53	3.44	5.51	3.89
June	6.49	4.64	5.42	3.81
July	2.82	2.97	2.57	3.06
August	4.12	1.90	5.79	1.93
September	1.24	1.24	1.21	1.43
October	2.54	0.95	3.37	0.95
November	0.15	0.89	0.09	1.04
December	0.24	2.42	0.27	2.46
Annual	34.91	35.64	34.65	35.23
Last freeze	4/7/17		4/7/17	
First freeze	10/13/16		10/12/16	
Frost free days	203		203	
Days above 90°F	34		33	
Days above 100°F	1		1	
Days below 10°F	9		9	

Effect of Late Nitrogen Applications on Grain Filling in Corn

J.A. Fernandez and I.A. Ciampitti

Summary

In order to evaluate the effect of nitrogen (N) with late-season fertilizer applications in corn, grain yield and grain filling parameters were evaluated for three genotypes under three N levels. Hybrids with different release years (3394, 1990s; P1151, 2000s; and P1197, 2016) and contrasting N application scenarios (zero-N, N at flowering, and N two weeks after flowering) were evaluated in two studies (dryland and irrigated) at the Ashland Bottoms Research Farm, Manhattan, KS, 2017 season. Results showed that under N stress conditions, the absence of N fertilization in corn significantly reduced yields, by affecting both grain number (GN) and grain weight (GW). Regarding genotypes, a positive trend was found between the year of release of the hybrid and yields, with greater yields for the modern hybrid (i.e., 206 bu/a for P1197). In respect to the grain filling process, N fertilization significantly increased the grain filling duration (GFD), without changes in the grain filling rate (GFR). Consequently, increments in GW were more related to changes in GFD rather than on the GFR.

Introduction

In corn, yield improvement across decades was accompanied by an increase in plant nitrogen (N) uptake, with modern hybrids absorbing more N during reproductive stages (Ciampitti and Vyn, 2012; Haegele, 2013), while delaying N remobilization to the grain until later in the growing season. Evaluation on a range of N management is still necessary to understand the optimal approach for simultaneously improving both yields and N use efficiency (NUE).

From a yield component perspective, final grain yield is the result of grain number per unit area (GN) and final grain weight (GW). Although it is accepted that GN is the primary component for grain yield determination (Borrás et al., 2004), GW can be responsible for important variations in final grain yield in corn. However, results on the effect of N supply on grain filling dynamics in corn are still scarce.

Evaluation on the effect of N with late-season applications can increase our understanding on how N is impacting yields: 1) more grains per plant, or 2) more weight of the grains, or via improvement in both plant yield components. Less is known about how N is impacting corn during the grain filling process, from zero weight (lag phase) until final grain weight is achieved (black layer). The objective of this research study was to evaluate grain filling in corn under three contrasting N scenarios (with and without late-season application, and a check with no N application) for three corn hybrids (from distinct decades) with the goal of determining yield response and grain filling rate.

Procedures

Two field experiments were conducted at the Ashland Bottoms Research Farm, Manhattan, KS, 2017 (one under irrigation and one rainfed). Soil analyses were conducted pre-planting to characterize initial conditions. Overall, the area presented pH of 5.9, soil organic matter (SOM) 1.34%, 50 ppm of phosphorus (P) (Mehlich), and 158 ppm of potassium (K) at 6-inch soil depth.

A split-plot design with two factors was evaluated, genotype with three levels in the main plot, and fertilizer N rate with three levels in the sub-plot. For genotype, three hybrids with different release years (3394, 1990s; P1151, 2000s; and P1197, 2016) and three contrasting N scenarios (zero N, N at flowering, and N two weeks after flowering) were evaluated in both studies. The study was planted on May 5, 2017, in plots of 4 rows, 30 in. apart, and size of 10-ft wide × 70-ft long. For the two fertilized treatments, an initial 50 lb/a was added at planting, and a second application was added at V6 growth stage (50 lb/a and 100 lb/a for dryland and irrigated, respectively). Depending on the treatment, the last application (22 lb/a and 44 lb/a for dryland and irrigated, respectively) was performed at silking or two weeks after this growth stage. Total fertilizer N rate applied for the treatments receiving N was 122 lb/a for the rainfed and 194 lb/a for the irrigated condition. The experimental area was kept free of weeds, pests, and diseases during the growing season.

For grain filling determination, since R2 growth stage, one ear was collected every 3 to 4 days from each treatment combination, until harvest. To understand if late-N can still impact final grain weight, ten kernels from the central portion of the ear were sampled to track changes in kernel dry weight and water volume during the entire period.

At the end of the growing season, grain yield was determined with a plot combine (from two center rows that were 70-ft long), while simultaneously four plants per plot were hand harvested for determining yield components (grain number, grain weight, and harvest index).

Results were subjected to an analysis of variance (ANOVA) to test the effect of fertilizer N rates, genotypes, and their interaction in all the measured variables. Grain filling rate (GFR) and grain filling duration (GFD) were estimated fitting a bi-linear model [equations (1) and (2)] with grain dry weight plotted on a day-time basis from silking to harvest maturity:

$$\text{Grain weight (mg/grain)} = a + b \times d \qquad \text{for } d<c \qquad [1]$$
$$\text{Grain weight (mg/grain)} = a + b \times c \qquad \text{for } d>c \qquad [2]$$

where d are the days after silking, a is the y-intercept (mg/grain), b is the GFR (mg/grain d^{-1}), and c is the total GFD (in days).

Results

Grain Yield and Numerical Components

Table 1 summarizes average yields and yield components for fertilizer N rate levels (N) and corn hybrids (H) evaluated in the experiment. Differences in yield were significant between N and H treatments ($P \leq 0.001$ and $P \leq 0.05$, respectively). As expected, fertilized treatments differed from the zero N treatment, while there were no significant differences in average yields between late-N treatments. In respect to genotypes, a positive trend was found between the year of release of the hybrid and yields, from 176 bu/a for 3394 (early 1990s) to 206 bu/a for P1197 (current).

Regarding yield components, significant differences between N levels and genotypes were found for grain number (GN) ($P \leq 0.001$ and $P \leq 0.01$, respectively), and between N treatments for grain weight (GW) ($P \leq 0.001$). Taken as a whole, final GW did not differ between genotypes, reflecting that yield variations among H were primarily driven by the number of grains per ear defined around silking. However, GN and GW were both affected by the absence of N fertilization, suggesting that GW reductions could have a considerable effect on yields particularly in N stress environments.

Across all treatment and hybrid combinations, GN and GW were both positively correlated with final grain yield ($R^2 = 0.58$ and $R^2 = 0.43$, respectively) in agreement with other previous studies (Andrade et al., 1996; Tollenaar et al., 2000) (Figure 1A and B). A linear correspondence between both components was observed ($R^2 = 0.43$) (Figure 2), indicating that the period around flowering is critical for defining grain number per plant and potential grain size.

Grain Filling Rate and Duration

Increments in GW were more related to changes in GFD rather than in the GFR ($r = 0.28$, $p = 0.043$ and $r = 0.18$, $p = 0.187$, respectively). Nitrogen supply significantly increased GFD (Figure 3), whereas no differences were observed for GFR, reflecting that this trait is more genotype-dependent and less sensitive to management changes. Furthermore, GFR was negatively correlated with GFD ($r = -0.55$), with similar rates across H and extended length for the modern genotype (P1197, Table 1). Overall, under N stress conditions, shorter GFD was the primary factor for the reduction in final GW.

References

Andrade, F.H., A. Cirilo, S. Uhart, and M.E. Otegui. (1996). Ecofisiología del cultivo de maíz. Dekalbpress, Buenos Aires, Argentina.

Borrás, L., Slafer, G. A., & Otegui, M. E. (2004). Seed dry weight response to source–sink manipulations in wheat, maize and soybean: a quantitative reappraisal. Field Crops Research, 86(2), 131-146.

Ciampitti, I. A., & Vyn, T. J. (2012). Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: A review. Field Crops Research, 133, 48-67.

Haegele, J. W., Cook, K. A., Nichols, D. M., & Below, F. E. (2013). Changes in nitrogen use traits associated with genetic improvement for grain yield of maize hybrids released in different decades. Crop Science, 53(4), 1256-1268.

Tollenaar, M., L.M. Dwyer, and D.W. Stewarl. (2000). Physiological parameters associated with differences in kernel set among maize hybrids, p.115-130. Jn M.A. Westgate and K.J. Boote (ed.) Physiology and modeling kernel set in maize. CSSA Spec. Publ. 51. CSSA, Madison, WI.

Table 1. Analysis of variance and means for yield (15.5% moisture), grain number, grain weight, grain filling rate, and duration for three nitrogen (N) levels and three hybrids (H)

Factor	Yields	Grain number	Grain weight	Grain filling rate	Grain filling duration
	bu/a	grains/m^2	mg/grain	mg/°d/grain	days
0 (Zero) N	120 b	2927 b	220 b	7.08 a	45 b
N at flowering	234 a	4017 a	277 a	7.3 a	49 a
N 2 weeks after flowering	223 a	4195 a	276 a	7.25 a	49 a
3394	176 b	3285 b	254 a	7.4 a	46 b
P1151	195 ab	4021 a	252 a	7.23 a	47 ab
P1197	206 a	3833 a	266 a	7.01 a	49 a
Sources of variation					
Nitrogen	***	***	***	Ns	**
Hybrid	*	**	Ns	Ns	*
N × H	Ns	Ns	*	**	Ns

Different letters indicate significant differences at $P \leq 0.05$.
+ Significant at $P \leq 0.1$; × significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; *** significant at $P \leq 0.001$, Ns: non-significant.

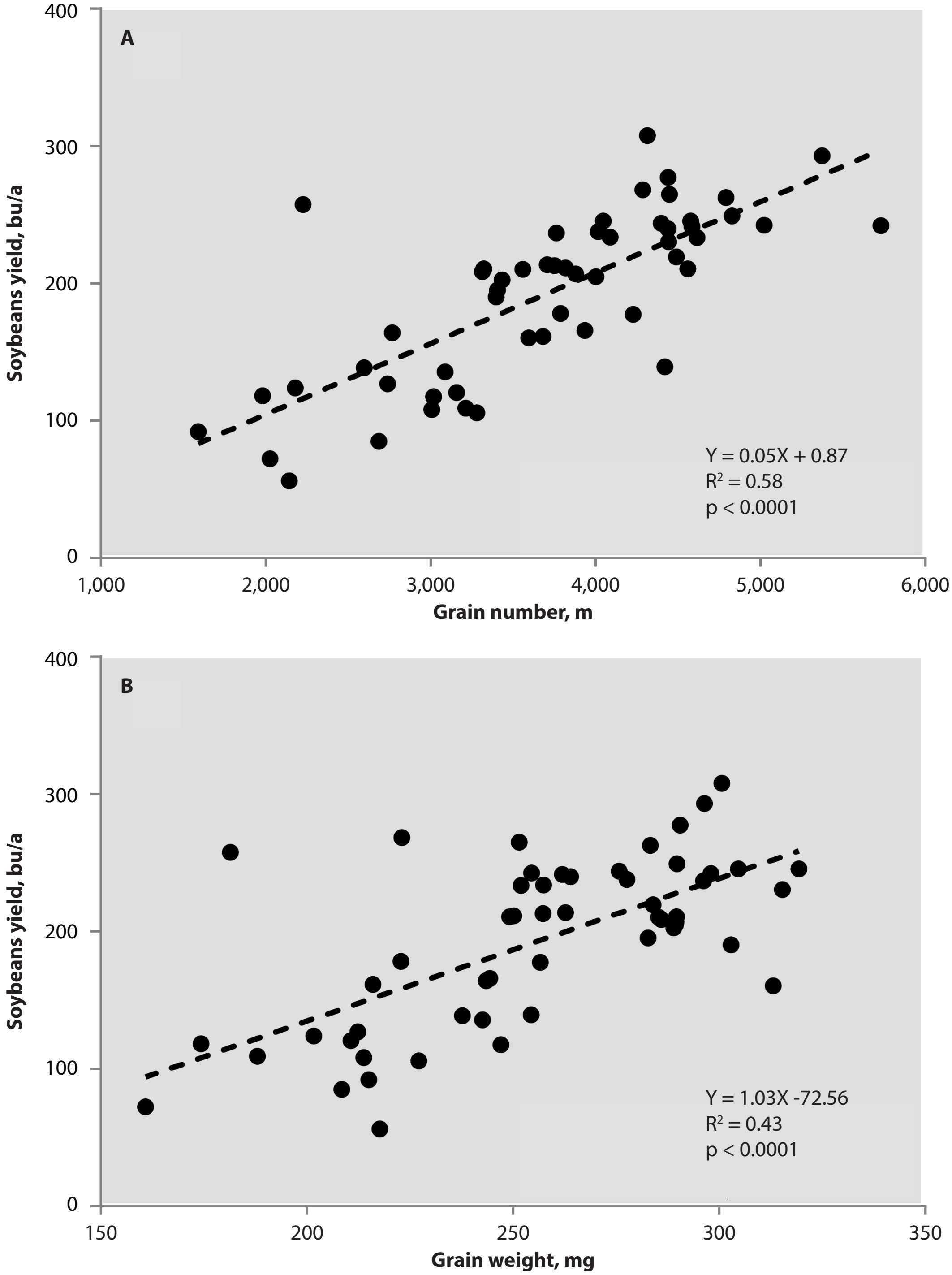

Figure 1. Relationship between grain yield for corn against the number of grains per unit area (A) and final grain weight (B), across all treatments combinations.

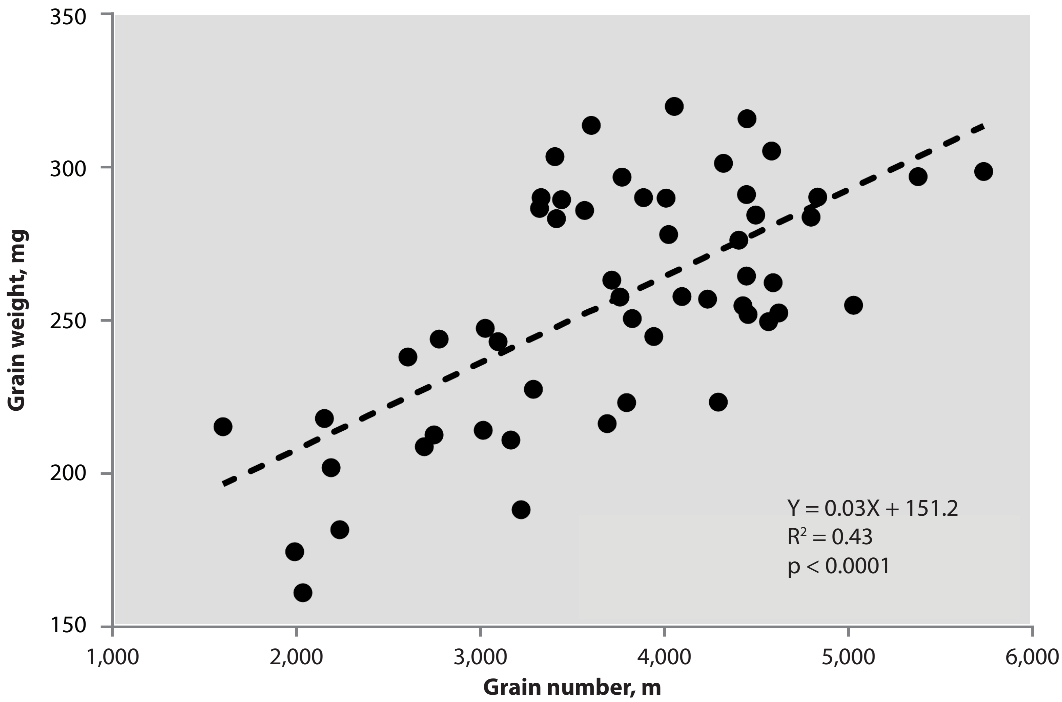

Figure 2. Relationship between final grain weight and number of grains per unit area, across all treatments combinations.

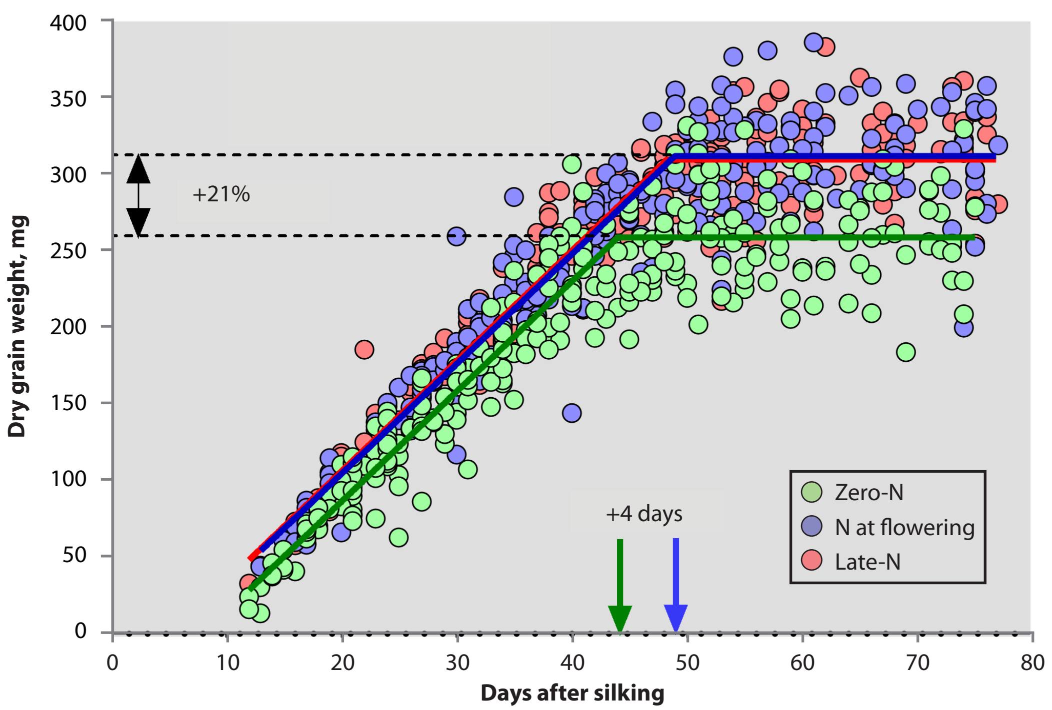

Figure 3. Evolution of grain dry weight on a day-time basis from silking to harvest maturity, sampled from the central portion of the ear, for three nitrogen (N) treatments.

Effect of Fungicides on Southern Rust of Corn

E.A. Adee and S. Duncan

Introduction

The decision to apply fungicides to corn is not an easy decision in Kansas, especially when grain prices are low. Numerous factors determine what diseases are present, and whether the plants will be defoliated enough to reduce yield. Correctly identifying the disease, knowing what environmental conditions favor the development of an epidemic, and knowing the hybrid's resistance to the diseases can be known before making the decision. However, knowing if the conditions will be favorable for the spread of the disease up the plant is very unpredictable. A situation like a 'perfect storm' for foliar diseases defoliating corn occurred in 2017. Southern rust was present at tasseling, much earlier that most years, and it had the ability to spread quickly in the relatively cool (80 to 90°F) and wet conditions that occurred in August. Additionally, many of the corn hybrids didn't have high levels of resistance to southern rust.

Procedures

A fungicide trial that included multiple entries from different companies as well as timing of application on corn was conducted in 2017 at Kansas State University's Kansas River Valley (KRV) experiment fields, near Rossville, KS. The study was under sprinkler irrigation in corn for a third straight year. Nitrogen fertilizer was applied at recommended levels. Pioneer 1192AM (Pioneer Hi-Bred, Johnston, IA) was planted in 30 in. rows at 36,000 seeds/a on April 26. The plots were 10-ft wide (4 rows) × 30-ft long. Twelve rows were left untreated for the check plots. The experimental design was a randomized complete block with at least 4 replications for each treatment. The irrigation scheduling was to promote foliar disease, and was assisted by the KanSched2 irrigation scheduling program, www.bae.ksu.edu/mobileirrigationlab/kansched2.

The fungicide treatments were applied with a CO_2 backpack sprayer equipped with Spraying Systems TJ 8002VS nozzles, 30 psi, 19 gal/a to the middle two rows of a 4-row plot. The fungicides applied included Headline AMP (BASF, Research Triangle Park, NC) at 10 oz/a, and Stratego YLD (Bayer CropScience, Research Triangle Park, NC) at 4 oz/a at tasseling (July 5). There were several other treatments of proprietary fungicides, with strobilurin, strobilurin and conazole, or proprietary combinations included in the trial (data not shown).

Data Collection and Analysis

Foliar disease severity was quantified at R5 (dent), evaluating the severity of foliar disease from 2 leaves below the ear leaf and above as a percent of the leaf area with symptoms in the middle two rows of each plot. Gray leaf spot (GLS), *Cercospora zeae-maydis*, was the predominant leaf disease at ear leaf and below at dent, with some southern rust (*Puccinia polysora*). In subsequent ratings, every 5 to 7 days, southern rust became much more severe as it progressed up to the top leaves. Area Under Disease Progress Curve (AUDPC) was calculated based on the accumulated severity of the disease over time. There were very few plants that expressed symptoms of top dieback, caused by *Colletotrichum graminicola*. The middle two rows of the plots were harvested for yield, and yields were calculated from plot weights adjusted to 15.5% grain moisture.

Results

The level of foliar disease rated at dent stage on August 1 was fairly typical to many fungicide trials for corn at KRV in most years (Table 1). Generally, due to heat and lower humidity typically experienced in Kansas in August, epidemics of foliar disease have difficulty in progressing much above the ear leaf before grain fill is complete at black layer, generally less than 3 weeks after dent. However, the grain fill period in August 2017 was much cooler and wetter than normal (Table 2). A reduced number of Growing Degree Units (GDU) accumulated, which slowed the rate of grain fill and extended the fill period by more than a week. Additionally, August was much wetter that average, and the combination of cooler and wetter weather for Kansas was ideal for southern rust to become established on the upper leaves of the plants. The longer grain fill period is very favorable for higher yields, but there is also more time for a disease to have an impact on the yields.

As a result of the extended grain fill period, 4 disease ratings were taken, compared to 2 for most years. With the conditions very favorable to the development of disease and the presence of abundant southern rust spores, the degree of defoliation of corn reached levels not seen very often in Kansas. The fungicides applied at tasseling (VT) reduced the amount of foliar defoliation, primarily due to southern rust (Table 1). More importantly, yields with the fungicide application at VT increased 7 to 9%, or nearly 20 bu/a. Clearly, the application of fungicide at VT was a good investment in 2017, as the cost of fungicide application is typically covered by a 6 to 8 bu/a yield increase.

Conclusions

1. Foliar diseases, such as southern rust, can defoliate a corn plant relatively quickly, given the right environmental conditions.
2. The combination of cooler and wetter conditions through the later part of the grain fill period contributed to significant yield loss in corn due to defoliation by foliar diseases.
3. The cooler/wetter August is not normal in Kansas. Therefore, scouting fields, knowing the hybrids' resistance to diseases present at tasseling, and observing environmental factors that favor the development of foliar diseases will continue to be necessary to increase the chance that foliar fungicide application on corn is a good investment.

Table 1. Effectiveness of fungicide application on foliar diseases and influence on corn yield at the Kansas River Valley Experiment Field, Rossville in 2017

Treatment	Timing	Foliar disease, August 1[1]	Foliar disease, August 22[2]	AUDPC[3]	Yield
		---------------- %	----------------		bu/a
Headline AMP, 10 oz/a	Tasseling (VT)	1.8 b[4]	24 c	188 b	236 a
Stratego YLD, 4 oz/a	VT	2.3 b	31 c	208 b	238 a
Untreated check		5.2 a	75 a	794 a	217 a

[1]Percent of leaf area defoliated by foliar disease from 2 leaves below the ear leaf and up, primarily gray leaf spot.

[2]Percent of leaf area defoliated by foliar disease from 2 leaves below the ear leaf and up, predominantly southern rust.

[3]Area Under Disease Progress Curve (AUDPC), a unitless number derived from the accumulated disease severity over time.

[4]Means followed by the same letter are not significantly different at alpha = 0.05.

Table 2. Monthly averages for weather 2017 and 30 years at KRV-Rossville[1]

Month	GDU[2]	Average GDU	GDU departure	Rainfall	Average rainfall	Rainfall departure
				--------------------	in.	--------------------
June	708	658	50	6.49	4.64	1.85
July	824	810	15	2.82	2.97	-0.15
August	649	779	-130	4.12	1.90	2.22

[1]Weather data source: Kansas State University Weather Data Library, http://mesonet.k-state.edu/.

[2]Growing degree unit (GDU) for corn.

High Yielding Soybean: Genetic Gain and Nitrogen Limitation

O.A. Ortez, F. Salvagiotti,[1] J.M. Enrico,[1] E.A. Adee, and I.A. Ciampitti

Summary

The United States and Argentina account for more than 50% of the global soybean production. Closing yield gaps (actual on-farm yield vs. genetic yield potential) would require an improvement in the use of the available resources. Overall, 50-60% of soybean nitrogen (N) demand is usually met by the biological nitrogen fixation (BNF) process. A scientific knowledge gap still exists related to the ability of the BNF process to satisfy soybean N demand at varying yield levels. The overall objective of this project is to study the contribution of N via utilization of varying N strategies under historical and modern soybean genotypes. Two field experiments were conducted during the 2016-2017 growing seasons: Rossville, KS (US) and Oliveros, Santa Fe (ARG). However, this report focuses on the 2016 results. Twenty-one historical and modern soybean genotypes were utilized with release decades between 1980s and 2010s. All seeds were inoculated and tested under three N management strategies: S1, non-N applied; S2, all N provided by fertilizer; and S3, late-N applied. The genetic improvement of soybean yield from the 1980s to 2010s was an overall increase of 30%, averaging results from US and ARG. Seed N content (N exported in seed) followed a similar trend for yield, while N concentration in seed was decreased as yields increased. Regarding N management for genotypes from all release decades, S2 (all N provided by fertilizer) generated up to a 20% increase in yields in the US and 5% in ARG. These results suggest that high yielding soybeans could be limited by N under specific growing conditions to express the yield potential.

Introduction

The United States (US) and Argentina (ARG) account for more than 50% of the global soybean production. In the US, more than 85% of the soybean area is located in the Corn Belt region, where corn-soybean rotation (>60%) is the main cropping system. In ARG, soybeans are primarily planted in the Rolling Pampas and Chaco regions, under rain-fed conditions, as monoculture, and in a lesser proportion in rotation with wheat and corn.

Soybean yield potential is genetically determined. Yield potential (Yp) can be attained under ideal conditions (genotype × environment × management practices, G × E × M), assuming no limitations of water and nutrient supply and absence of biotic and abiotic yield-limiting factors. Maximum soybean yields are dependent on a balanced nutrition, with N as one of the limitations for increasing soybean yields.

The main N sources for the soybean plant are the BNF process and the soil (mineral or fertilizer). However, it has been documented that the BNF process is not able to supply the total N requirement of the plant. Overall, only 50 to 60% of soybean N demand is

[1] National Agricultural Technology Institute (INTA), Oliveros, Santa Fe, Argentina.

usually met by the BNF process. In this sense, the ability of the BNF process to supply N to high yield levels is still unknown.

Genetic improvement for soybeans has increased yields in the last 50 years, however, it has been achieved at the expense of the availability of N provided by the soil and the BNF process. If there is a limitation of N, the interaction between genotypes and limitation by N is not yet known. Therefore, it is valid to hypothesize that high-yielding soybean achieved through the process of genetic improvement will require a greater availability of N.

The objectives of this study were to:

1. Evaluate the yield performance and seed N content of historical and modern soybean genotypes released from the 1980s to 2010s.
2. Study the contribution of N under different N nutrition scenarios:
    a. Soybeans planted under normal production conditions, only inoculated;
    b. All N requirement met by N fertilization; and
    c. Inoculated but including an additional application of fertilizer N in reproductive stages.

Procedures

Experimental Sites

The project was conducted in two sites during the 2016-2017 growing seasons: Rossville (Kansas, US) and Oliveros (Santa Fe, Argentina). The current report focuses on the 2016 results.

Experimental Plots

The trials were conducted in experimental plots of 10-ft wide × 30-ft long with a seeding rate of 103,000 seeds/a at Rossville, (US). In Oliveros (ARG), the area of the plots was 8.5-ft wide × 23-ft long and with a seeding rate of 146,000 seeds/a.

Site Characteristics

Soil samples were collected before planting at 6- and 24-in. depths in the US. Parameters analyzed from samples collected at 6-in. depth were pH; Mehlich-P; cation exchange capacity (CEC); organic matter (OM); calcium, magnesium, and potassium availability; and for the soil samples at 24-in. depth, only N-nitrate (N-NO_3) concentration was evaluated. In ARG, all soil samples were collected at an 8-in. depth, parameters analyzed were pH, Bray P-1, OM, and N-NO_3 (Table 1).

Treatments

The treatments evaluated were a combination of three N strategies combined with soybean genotypes from different release decades. The N strategies were: strategy 1 (S1): Non-N as traditional management (control) without application of N, only inoculation; strategy 2 (S2): Full-N with all the N required by the plant was applied as fertilizer (600 lb N/a), the total amount was equally distributed at three times during the growing season: planting, flowering (R1), and pod formation (R3-R4); and strategy 3 (S3): Late-N with a late application of 50 lb N/a at the R3 in Rossville, and at R4 growth stage in Oliveros. Applications were top-dressed to the soil using drop tubes with the liquid source of urea-ammonium nitrate (UAN, 32-0-0). Twenty-one genotypes were evaluated in total with release decades between the 1980s to 2010s. The maturity groups ranged from 3.0 to 4.0 for these two locations. Prior to sowing, all seeds were inoculated with recommended commercial rate.

Results

Yield Gain and Nitrogen Content in Seed as Related to Release Decades

The factors evaluated in this study did not show a statistical significant interaction ($P \leq 0.05$) for any of the evaluated variables, so the results are described according to the main factors–N fertilization and genotypes.

In Rossville (US), seed yields ranged from 33 to 76 bu/a and at Oliveros (ARG) from 40 to 70 bu/a (Figure 2, A and B). In both sites, the modern genotypes released in the 2010 decade recorded the highest production levels compared to those released in the previous decades (1980s, 1990s, and 2000s). When comparing the average yield across all three fertilization strategies for the modern versus the older varieties, yield increased by 33% in Rossville and by 28% in Oliveros.

Regarding the N exported in seeds, the results ranged between 111 and 240 lb N/a in Rossville and 129 to 209 lb N/a in Oliveros (Figure 2, C and D). Nitrogen exported in the seed followed a similar fashion as portrayed by the yield trait, with the largest amount of N removed by the modern genotypes (2010s). An increase of 25% in Rossville and 24% in Oliveros was observed in the N export, when comparing general means of the 2010 decade to the rest and as a general average of the three fertilization treatments.

Nitrogen concentration levels in the seed (as a function of its dry basis) for both locations, as an average for the genotypes grouped according to release decades, and as a general mean of the three fertilization strategies are presented in Figure 2, E and F. In Rossville, seed N concentration ranged between 5.5 and 7.2%. Greater seed N concentration was observed with the genotypes of the 1980s, 1990s and 2000s; while the lowest level was observed with genotypes of the 2010 release decade. For Oliveros, seed N concentration was lower than that observed in Rossville and ranged between 5.1 and 6.4%. The lowest level of seed N concentration was found with the genotypes of the 2000 and 2010 decades.

Yield Gain and Nitrogen Content in Seed as Related to Nitrogen Availability

In general, when averaging the genotypes of all four release decades, the greater availability of N in the cycle through the sequential addition of 600 lb of N/a presented a positive impact on yields in both Rossville and Oliveros ($P \leq 0.05$) locations (Figure 3). In Rossville, the S2 (Full-N, 600 lb) increased seed yield by 20% as compared to S1 (without N fertilization, control). The descending order of yielding results in Rossville was recorded as follows: S2 (Full-N) >> S3 (Late-N) >> S1 (Non-N), with S1 being the strategy that produced the lowest yield levels in this environment. In Oliveros, the positive response in yields to the S2 strategy was 5% increase in yields when compared to the S1 and S3. For this site, S1 and S3 did not result in significant differences between them. In general terms, yield response to full N fertilization was consistent throughout all evaluated genotypes, this indicates the potential N limitation to satisfy plant nutrient demand at both medium (> 45 bu/a) and high (> 67 bu/a) yield levels.

In conclusion, increases in seed yield were documented when comparing the progress of historical genotypes (1980s) to modern genotypes (2010s) in Rossville (+33%) and Oliveros (+28%). Although the seed N concentration with modern genotypes was lower in Rossville and Oliveros (12 and 5%, respectively), the export of N (via seed N removal) per unit area increased (25% in Rossville and 24% in Oliveros), with the increase primarily related to yield improvement. The response of seed yield to the N application, when comparing the extreme conditions of Full-N (without limitation of N) versus the Non-N (control) varied between 20% (Rossville) to 5% (Oliveros). The N strategy utilized in this experiment (i.e. distributed application of a high fertilizer N rate) should help to determine whether the availability of N is a limiting factor at varying yielding conditions in soybean.

Table 1. Soil characterization before planting for the 2016 growing season

	Location	
Soil variable	Rossville, United States	Oliveros, Argentina
pH	6.9	5.5
P Mehlich-3/P Bray-1 (ppm)	21.0	12.0
CEC (meq/100 g)	11.0	---
Organic matter (%)	2.2	2.1
Potassium (ppm)	153	---
Calcium (ppm)	2074	---
Magnesium (ppm)	202	---
$N\text{-}NO_3$ (ppm)	3.0	6.3

CEC = cation exchange capacity.

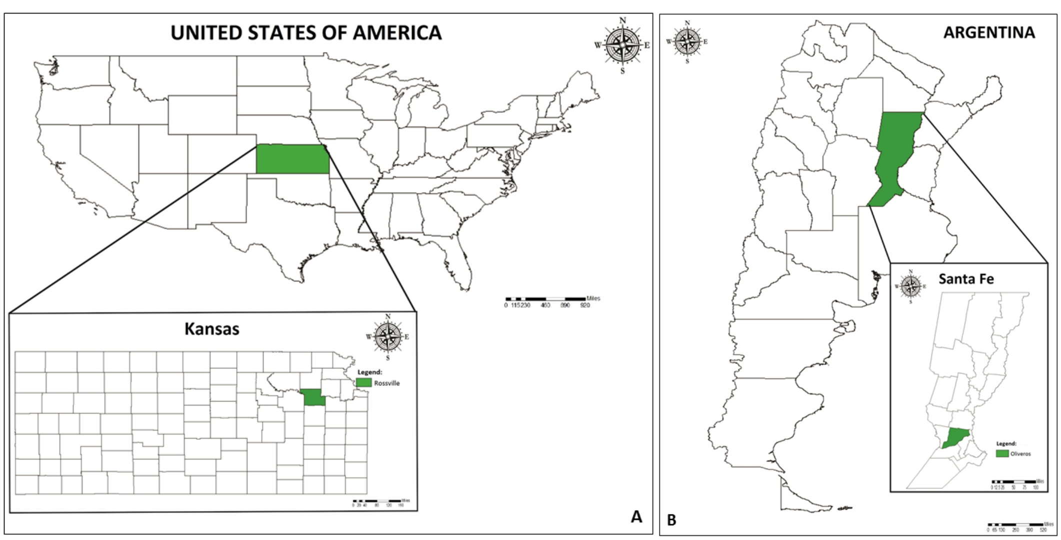

Figure 1. Map highlighting the two sites where the experiment was conducted during 2016-2017 growing seasons: Rossville (Kansas, US) (A) and Oliveros (Santa Fe, ARG) (B).

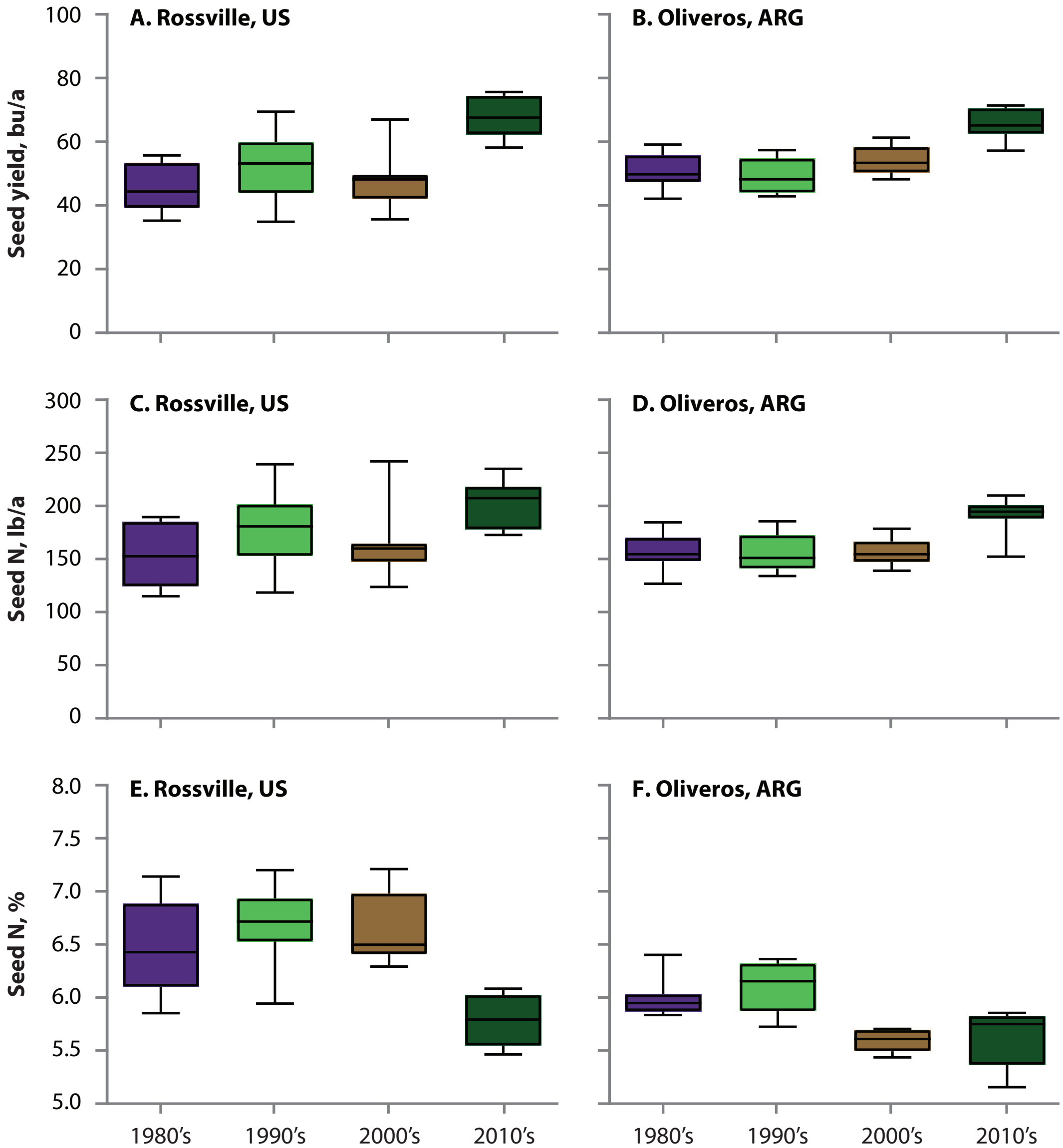

Figure 2. Soybean yield expressed in bushels/a at 13.5% moisture content (A and B), nitrogen (N) exported in seed in lb/a on dry basis (C and D) and N concentration in the seed expressed as a percentage with dry basis (E and F). Different letters indicate significant differences between decades ($P \leq 0.05$).

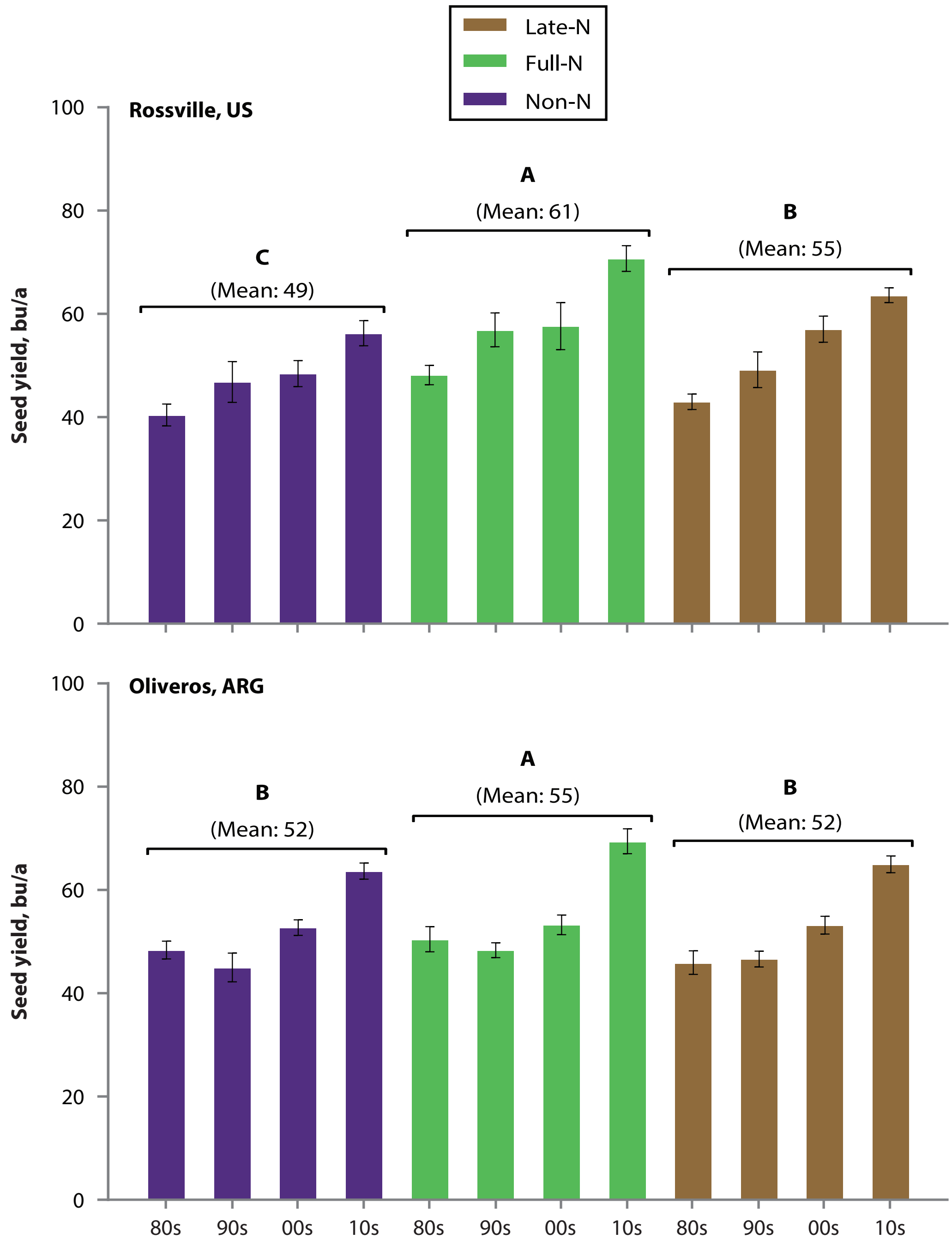

Figure 3. Yield expressed in bushels/a at 13.5% moisture content in soybeans for genotypes released between the 1980s to 2010s and under three management strategies of nitrogen (N) 1) Non-N without N applied; 2) Full-N with 600 lb N/a, and 3) 50 lb N/a applied in the R3 stage at Rossville (US) and R4 stage at Oliveros (ARG) in the 2016 growing season. Different letters indicate significant differences between management strategies of N ($P \leq 0.05$) as general means when pulling together the release decades.

Best Management Systems to Intensify Soybean Production

G.R. Balboa and I.A. Ciampitti

Summary
The aim of this study was to evaluate different management systems to close the yield gap in soybean production. A soybean experiment was established in Scandia, KS, evaluating five management systems under both rainfed and irrigated conditions. For the 2017 season, dryland and irrigated average yields were similar (63–65 bu/a) due to herbicide injury on the irrigated phase. In both water scenarios, intensification (high input) increased yields compared with common practice (low input) systems. Under irrigation, a consistent response to a balanced nutrition program was documented.

Introduction
Yield gap is defined by the difference between potential and actual yield. Management practices such as row spacing, seeding rate, fertilization, pest, and disease control affect the size of the yield gap. A management system is a combination of production practices. The aim of this study was to evaluate the combination of production practices to identify the best management systems (BMSs) for closing soybean yield gaps.

Procedures
A soybean experiment was established during the 2017 season at Scandia, KS. This experiment is part of a long-term corn-soybean rotation. A total of five treatments were established in a randomized completely block design with five replications (Table 1).

Prior to the experiment, soil samples were collected in both water environments and analyzed for organic matter %, pH, and phosphorus (P) content (Table 2).

The weather for the 2017 growing season was compared with the 30 years of data for the Scandia location (Figure 1). Precipitation and mean temperature were below the mean for the April - October period compared to the historical 30-year average. Black dots in Figure 1 represent the precipitation and temperature recorded for the past soybean growing seasons for this study.

Results
Grain Yield
The average yield for the dryland condition was 63 bu/a, ranging from 48 to 76 bu/a (Figure 2). The irrigated soybean average yield was 65 bu/a overall, presenting a range from 48 to 77 bu/a. Seasonal precipitation was 16.3 in. and the irrigated phase received 5.3 in. of water.

Herbicide injury on irrigated plots was assessed on July 27, negatively affecting the final yield (Figure 4). The minimum yield registered for irrigated was 48 bu/a for common practices (CP) and the maximum 77 bu/a for the ecological intensification (EI) treatment. The balanced nutrition program (CF) under irrigated conditions yielded 11 bu/a more over CP. Under both water conditions (dryland and irrigated), treatment EI and advanced plus (AD) showed the greatest yields, without statistically differing between them (Figure 2). The CF and PI treatments yielded more than CP under irrigation (by 11 and 18 bu/a, respectively); while in dryland condition, CF was superior in yield over CP (+3 bu/a) but without statistically differing. Production intensification with balanced nutrition (EI, AD) allowed obtaining 55% and 58% more yield than CP for dryland and irrigated conditions, respectively (Figure 2). After four years of rotation in high yielding environments (irrigated), CP yields statistically differed from the rest of the treatments showing the impact of the lack of a balanced nutrition program.

Long-Term Rotation

To explore the long-term impact of the different treatments under dryland and irrigated conditions, average yields for 2014, 2015, 2016 and 2017 growing seasons were summarized (Figure 3). Narrowing rows and increasing the plant population increased yields (average 62 bu/a). The yield level in the dryland environment did not show response to fertilization over control treatment. For the irrigated scenario, the average of four growing seasons is showing larger yield differences between treatments compared to the 2017 season alone (Figures 2 and 3). For this scenario, a balanced nutrition program (CF) on top of common practices (CP) increased yields over control treatments (+7 bu/a). Ecological intensification and advanced plus were the highest yielding treatments at 81 and 78 bu/a, respectively.

The 4-year summary provides a synthesis on the impact of different management practices and water scenarios on soybean yields, and can help to better understand the interaction of production practices to identify the BMSs to intensify soybean yield environments. Overall, intensified management systems based on seeding rate increase, narrow row spacing and a balanced nutrition program increased yields compared to common practices.

Table 1. Treatment description, Scandia, KS

Treatments	CP	CF	PI	EI	AD
Seeding rate	110,000	110,000	175,000	175,000	175,000
Row spacing (inch)	30	30	15	15	15
Fertilization	No P-K-S	P-K-S	No P-K	P-K-S-N	P-K-S-N
Micronutrients	No	No	No	1× (Fe, Zn, B)	2× (Fe, Zn, B)
Fungicide/insecticide	No	No	No	1×	2×

CP = Common practices, CF = comprehensive fertilization, PI = production intensification, EI = ecological intensification (CF+PI), AD = advanced plus. P = phosphorus, K = potassium, S = sulfur, N = nitrogen, Fe = iron, Zn = zinc, B = boron.

Table 2. Soil characterization before planting time

Soybean studies	Organic matter %	pH	Phosphorus (ppm)
Irrigated	2.2	6.2	11.0
Dryland	2.3	5.4	7.4

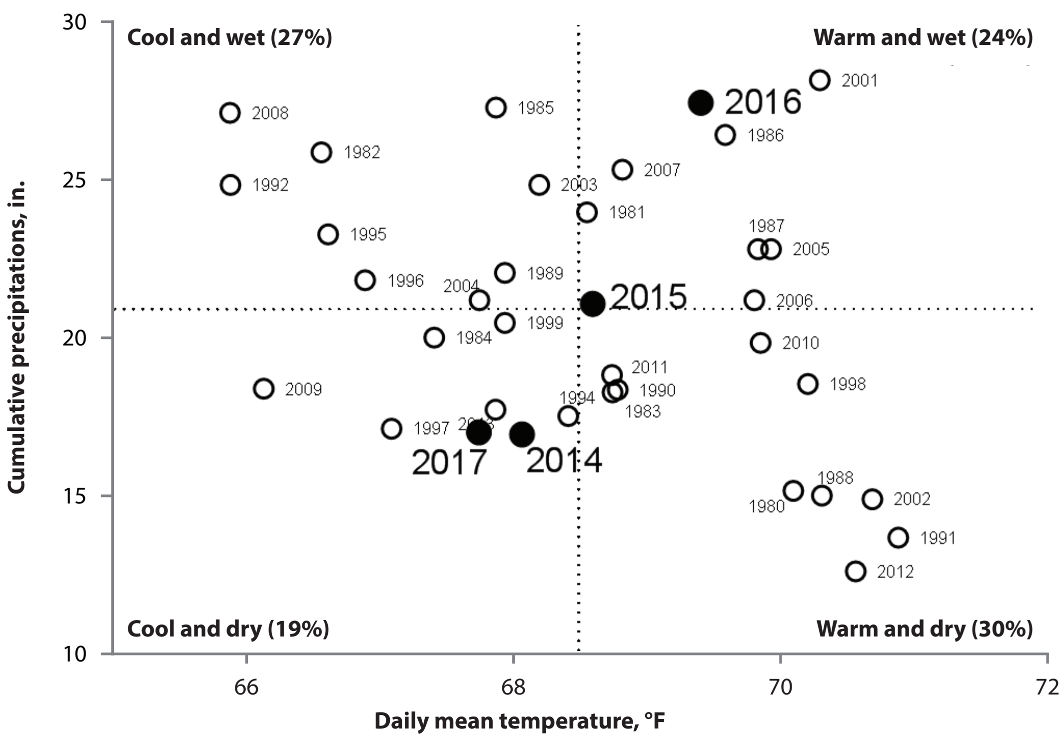

Figure 1. Yearly (1980 – 2016) mean temperature and mean precipitation for the period April – October. Black circles indicate seasons when experimental data were collected. Empty circles indicate years when experimental data were simulated. Dotted vertical and horizontal lines indicate mean temperature (°F) and mean cumulative precipitation (in.) for the period. Percentage of years in each category are listed in parenthesis.

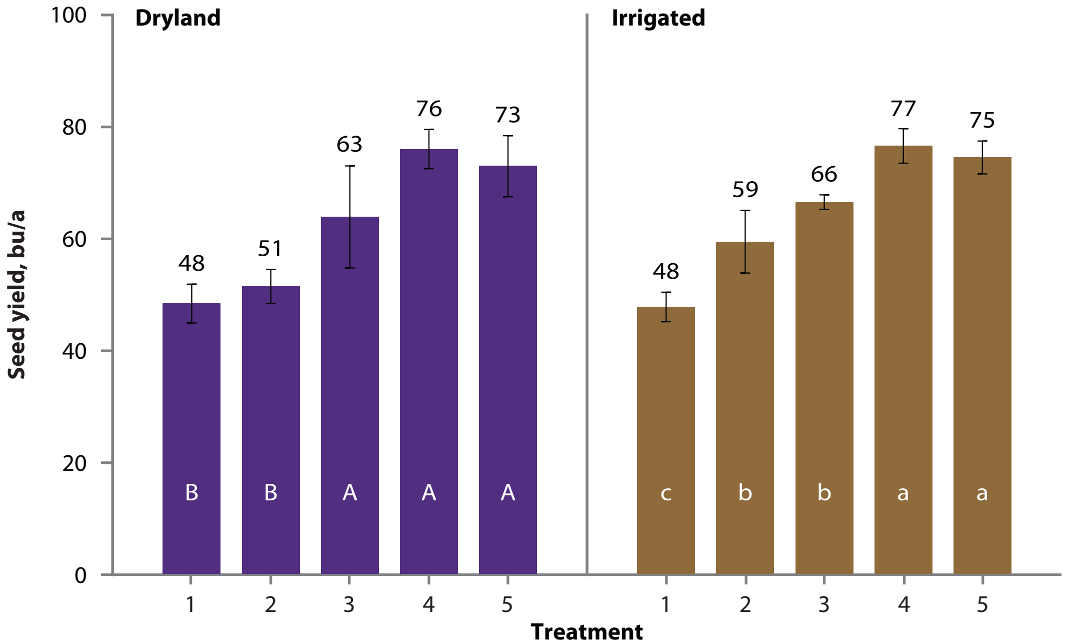

Figure 2. Soybean grain yield by treatment for dryland and irrigated conditions, Scandia, KS, 2017. Different letter shows statistical differences (*P* < 0.05). (1) CP = Common practices, (2) CF = comprehensive fertilization, (3) PI = production intensification, (4) EI = ecological intensification (CF+PI), (5) AD = advanced plus.

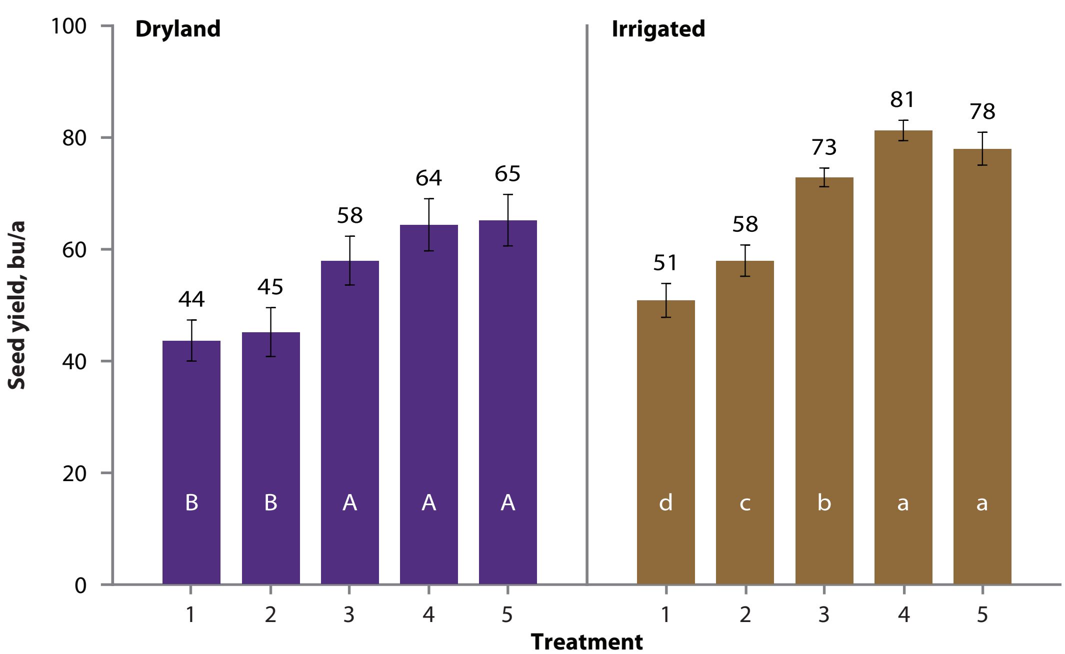

Figure 3. Soybean grain yield by treatment for dryland and irrigated conditions, Scandia, KS, 2014 – 2017. Different letter shows statistical differences (*P* < 0.05). (1) CP = Common practices, (2) CF = comprehensive fertilization, (3) PI = production intensification, (4) EI = ecological intensification (CF+PI), (5) AD = advanced plus.

Figure 4. Crop injury assessed on July 27 with herbicide application on a contiguous soybean field with irrigated plots, Scandia, KS, 2017.

Effect of Management Practices on Double-Crop Soybean Yields

D.S.S. Hansel, J. Kimball, D.E. Shoup, and I.A. Ciampitti

Summary

Double-crop soybean has great potential to increase profits and the use of agricultural land. However, there is a gap between double-crop versus full-season soybean yields. To address this yield difference, a study evaluating different management practices on double-crop soybean was conducted. A four-site-year experiment was conducted at Ottawa, KS, during the 2016 and 2017 growing seasons. In both years, the soybean variety planted was Asgrow 4232 (MG 4.2). The soybean was planted right after two different wheat harvest timings (Study 1, early-wheat harvest 18–20%; and Study 2, conventional-harvest 13–14%). Seven treatments were evaluated in each of the soybean planting dates: 1) common practice; 2) no seed treatment (without seed fungicide+ insecticide treatment); 3) non-stay green (without foliar fungicide + insecticide application); 4) high seeding rate (180,000 seeds/a); 5) wide rows (30-inch row-spacing); 6) nitrogen (N) fixation (without late-fertilizer N application); and 7) kitchen sink (includes all management practices). In the 2017 season, a treatment was added with the purpose of isolating the fertilizer effect, 8) no fertilization (F). Aboveground biomass and yield were recorded. For the 2016 season, there was a different response for early and late planting in relation to yield responses. For the early planting, there were no differences in yield. However, for the late planting, high plant population, wide-rows and kitchen sink showed greater yields. For the early planting, the differences in biomass were not related to differences in yield. For the late planting, greater biomass corresponded to superior yields, except for the kitchen sink treatment that presented low biomass and greater yields, potentially via increasing biomass partitioning to the seed. For the 2017 season, biomass and yield followed the same pattern, yields increased in parallel to biomass. For the early planting, greater yields were observed for the high plant population, no nitrogen applied in reproductive R3, and kitchen sink. There were no significant differences in yield among treatments for the late planting date in 2016. However, in both years yields were lower for late planting dates when compared with the early planting.

Introduction

Double-crop (DC) soybean is cultivated in many regions of United States. In most double-crop systems, soybean is planted immediately after wheat harvest, which increases potential profit where there would be fallow or a non-cash cover crop. Also, soybean can be managed in no-till (NT) systems, reducing costs with less machinery expense after the wheat harvest. Furthermore, NT maintains wheat residue on soil surface, enhancing good soil properties. However, there are many challenges that discourage farmers from planting double-crop soybean. The yield gap between full-season and double-crop soybeans is large, with the high risk of crop failure due to heat and drought during the late summer. To improve yields for DC soybean there are some management practices that should be further investigated: 1) fertilizer application, promoting stronger plant growth and earlier canopy closure to overcome stresses due to a late planting season; 2) ideal row spacing and seeding rate, allowing more plants in the same unit area, potentially suppressing weed establishment and increasing yield; 3) integrated pest management, due to the late planting, the risk of late summer soil and foliar disease and insects could decrease yield; and 4) earlier planting time to lengthen growing season and allow more time for soybean plants to set pods and seed before the first killing frost.

The objective of this study was to improve yields in double-crop soybean planted after wheat harvest and identify the main yield-limiting factors affecting crop productivity from a perspective of environment and management practices.

Procedures

The soil type at the Ottawa location was a Woodson silt loam (Mollisols). Soil samples were taken prior to planting at a depth of 0 to 6 in. Soil chemical parameters analyzed were pH, Melich P, cation exchange capacity (CEC), organic matter (OM), calcium, magnesium, and potassium (K) availability (Table 1).

The studies were arranged in a randomized complete block design with 4 replications. Plot size was 10-ft wide × 60-ft long. The soybean variety utilized was Asgrow 4232, maturity group 4.2. Soybean was planted immediately after wheat harvest of the cultivar WB Cedar. Study 1 (early wheat harvest) was planted on June 10, 2016, and June 13, 2017, and Study 2 (conventional wheat harvest) on June 23, 2016, and June 22, 2017. Seven treatments were evaluated in 2016 season: 1) common practice, CP; 2) no seed treatment, NST; 3) non-stay green, NSG; 4) high plant population (180,000 seeds/a), HP; 5) wide rows, WR (30-in.); 6) N fixation, NF (without late-season fertilizer N); and 7) kitchen sink, KS. In the 2017 season, the same seven treatments from the previous year were evaluated, plus a treatment isolating the effect of fertilization (without fertilization—treatment 8). The specific management practice included for each treatment is listed in Table 2.

The seed treatment was Acceleron Standard (Monsanto Company) which contains a fungicide + insecticide. For the foliar fungicide + insecticide application, the chemicals used were Aproach Prima + Prevathon (6 + 17 fl oz/a) and applied to soybean at the R3-R4 growth stage. Herbicides and hand weeding were used to maintain no weed interference for the entire season. Fertilizer application was performed on treatments 2 to 7 using the formulation 7-7-7-7S-7Cl (chloride). The application rate was 10.93 lb/a of N, phosphorus (P), K, S and Cl. In treatment 2 to 6, late N was applied at a rate of 51 lb/a, in the formulation of 32-0-0 (N-P-K). Biomass was collected in a 12.5 ft^2 area, sampled outside the area collected for yield.

Results

Despite DC soybean usually yielding significantly less than full-season soybean, the 2016 season was a very good year for summer crops, with weather conditions that favored a high-yielding environment. In 2017, the weather conditions were normal. Double-crop soybean yields were lower than in 2016. Yields in 2016 were between 50 and 70 bu/a, and in 2017 ranged between 40 and 60 bu/a.

The accumulated seasonal precipitation was 17.6 in. in 2016, which was 4 inches greater than the 2017 summer growing season, and was well distributed throughout the growing season.

Biomass and Grain Yield

In 2016, in studies 1 and 2, plant biomass was greater for the wide rows, while lower values were recorded for the non-stay green treatment. For seed yield, in Study 1, the N fixation treatment presented the greatest yield at 64 bu/a, while the common practice was the lowest yield level at 58 bu/a (Figure 1). The yield gap between maximum and minimum yield values in this study was approximately 6 bu/a (Figure 1). In Study 2, the common practice yielded the least again in addition to the no seed treatment at 57 bu/a. The yield gap from maximum (wide rows treatment) and minimum yielding (common treatment) treatments was 7.5 bu/a (Figure 1).

In 2017, yields were lower for the late planting compared with the early planting, even with a small difference of 9 days in planting. Late planting did not present any significant differences in yield. However, early planting presented greater yields for the treatments of high population, N fixation, and kitchen sink. The greatest difference in productivity was between high population and common practices, with a 13 bu/a difference in yields.

Conclusions

When planting DC soybean, a higher plant population is required to overcome the stresses of planting out of the ideal timing. Yields were also maximized when all inputs were added. Late planting yielded less than early planting in all four site years. Therefore, anticipating planting of DC soybeans is a strategy that was demonstrated to be efficient for increasing yields. Best management practices for DC soybean can improve overall productivity, increasing yield and biomass. Further evaluation and testing should be performed to better understand and predict the effect of management practices on DC soybean systems.

Table 1. Pre-plant soil characterization at 0- to 6-in. depth at Ottawa, KS, for 2016 and 2017

Soil parameters	2016	2017
pH	5.8	5.7
Mehlich P (ppm)	14.5	19.6
CEC (meq/100 g)	15.4	23.6
Organic matter (%)	2.8	3.0
Potassium (ppm)	79.3	122.9
Calcium (ppm)	2248.7	2447.4
Magnesium (ppm)	303.5	348.7

Table 2. Management practices for treatments imposed on double-crop soybean planted after wheat for the early- and late-planting studies at Ottawa, KS, in 2016 and 2017

Treatment	Description	Seed treatment	Fungicide/ insecticide	Fertility	Population	Rows	Late nitrogen
1	Common practice	No	No	No	140K	30	No
2	No seed treatment	No	Yes	Yes	140K	15	Yes
3	Non-stay green	Yes	No	Yes	140K	15	Yes
4	High population (180K)	Yes	Yes	Yes	180K	15	Yes
5	Wide rows	Yes	Yes	Yes	140K	30	Yes
6	Nitrogen fixation	Yes	Yes	Yes	140K	15	No
7	Kitchen sink	Yes	Yes	Yes	140K	15	Yes
8	No fertilization	Yes	Yes	No	140K	15	Yes

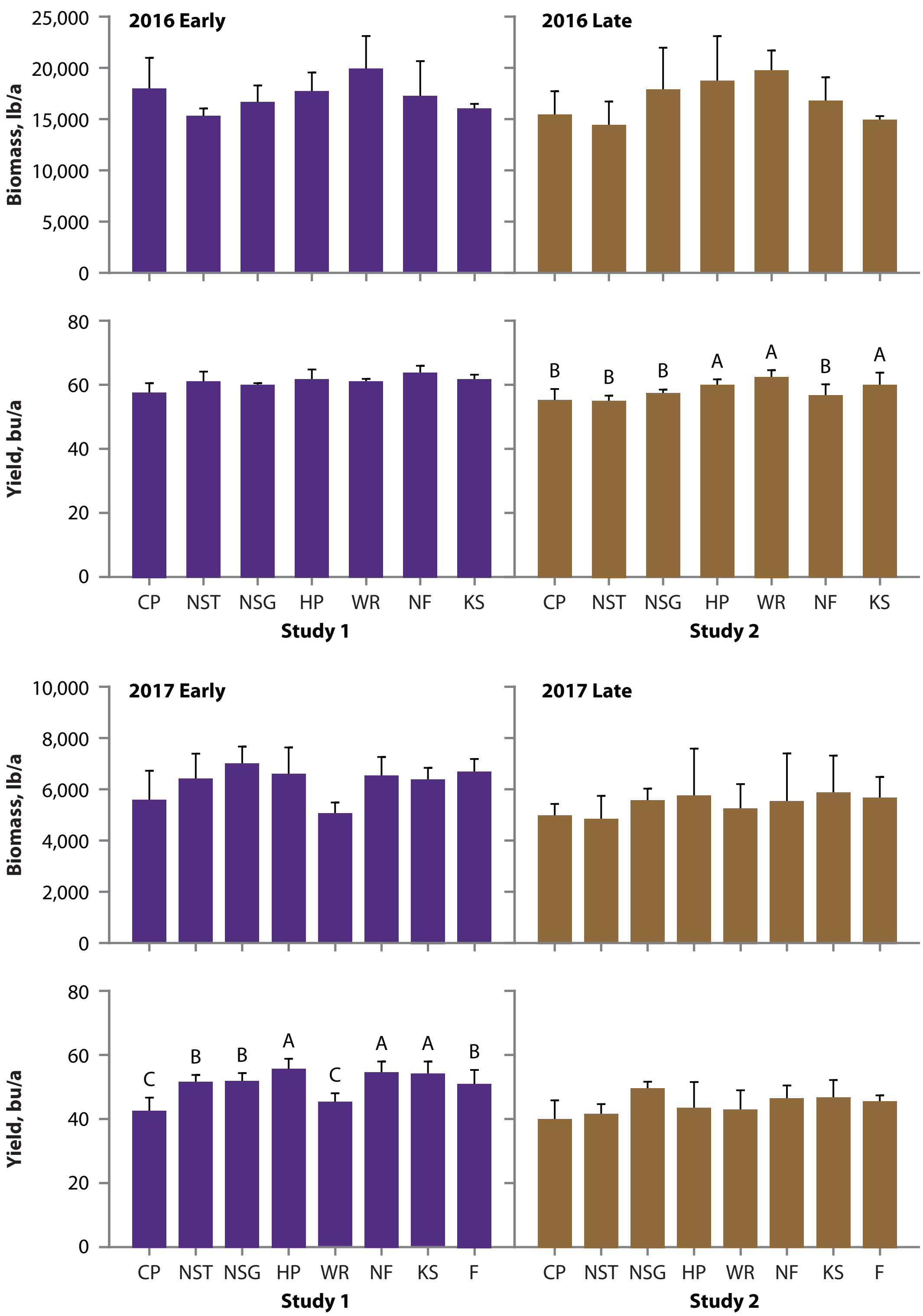

Figure 1. Biomass and yield in studies 1 and 2 for 2016 (upper panels) and 2017 (lower panels) growing seasons, Ottawa, KS. Common practice, CP; no seed treatment, NST; non-stay green, NSG; high population, HP; wide rows, WR; nitrogen fixation, NF; kitchen sink, KS; no fertilizer - F (Table 1). Letters show significance ($P < 0.05$).

Soybean Evaluation of Inoculation: A Three-Year Summary

M.A. Secchi, T.M. Albuquerque, O.A. Ortez, G.I. Carmona, J. Kimball, E.A. Adee, and I.A. Ciampitti

Summary
The relationships between soybean (*Glycine max*) seed yield and response to nitrogen (N) fertilization have received considerable coverage in the scientific literature. This project aims to quantify the response to inoculation for soybean in a field without previous history of this crop (20 years). To address this objective, field studies were conducted during the 2015, 2016, and 2017 growing seasons at the East Central Experiment Field, Ottawa, KS. The treatments consisted of five different N-management approaches: non-inoculated (NI), inoculation at the recommended commercial rate (I1), a double rate of inoculation (I2), a triple rate of inoculation (I3), and non-inoculated but fertilized with 300 lb of N/a (NF). In the 2015 growing season, yields did not statistically differ from one another. In the 2016 growing season, treatment differences were observed and seed yield ranged from 36 to 59 bu/a. In the 2017 growing season, treatments showed significant yield difference, with yields ranging from 23 to 52 bu/a, from the NI to the NF treatment, respectively. Further research should be carried out to understand the impact of the inoculation practice and better understand the best management for N in soybean in newly-planted areas.

Introduction
Soybean seed has a high content of oil and protein in the seeds. The main countries growing soybean are the United States (33%), Brazil (32%) and Argentina (16%) of the estimated global soybean production. Soybean crop, as a legume specie, has the characteristic of fixing N from the atmosphere (biological N fixation, BNF) when a proper symbiosis relationship with specific bacteria has been established. Most of the N required by a soybean plant is supplied via the BNF process. When BNF is adequately established in the host plant, soybean can obtain 50 to 60% of its N from the atmosphere. For high-yielding soybean, the gap between plant N demand and BNF supply becomes larger, and thus, more N might need to be potentially available from the soil to satisfy this demand.

Based on previous studies, inoculation is usually effective when: 1) soybean was never planted before or in the past 3 to 5 years; 2) soil pH is below 6.0 units; 3) soil has a high sand content; 4) in anaerobic conditions, field has been flooded for more than one week when nodulation was supposed to become established; and 5) early-season stress conditions (e.g. heat) affects plant-bacteria establishment.

The inoculation has become a standard practice in soybean fields due to its low cost (as compared to N fertilizer applications) and the critical N need of the plant to successfully achieve seed yields.

The objective of this project was to study the yield response, if any, to variable inoculation rates and the addition of N to a soybean field without history of this crop in the last 20 years.

Procedures

Site Characteristics

The field where the experiment was conducted is an area without history of soybean (20 years). For three years, the experiment was conducted at the East Central Experiment Field, Ottawa, KS, (38.54 N, 95.24 W) (Figure 1). The soil at this location is characterized to be a Woodson silt loam soil series (or Mollisols). Soil samples were collected before planting at a depth of 6 and 24 inches. Soil chemical parameters analyzed with the 6-in. samples were: soil pH, phosphorus (P) levels (Mehlich P), cation exchange capacity (CEC), organic matter (OM), calcium (Ca), magnesium (Mg), and potassium (K). Nitrate analysis (or analyses) were conducted with 24-in. samples (Table 1).

Experimental Design

The study was arranged in a complete randomized block design with six replications. Plot size was 10-ft wide × 60-ft long. The soybean variety was P34T43R2 (Dupont Pioneer), with the RR-2 event; maturity group 3.4.

Treatments

Five treatment combinations were evaluated:

1) non-inoculated (NI),
2) inoculated single-rate (I1),
3) inoculated double-rate (I2),
4) inoculated triple-rate (I3), and
5) non-inoculated but fertilized with 300 lb of N/a (NF).

Nitrogen source utilized was liquid urea ammonium nitrate (UAN), N-P-K, 32-0-0, and was equally split into three applications: at planting, flowering (R1), and pod formation (R3) following the plant N uptake curve for this crop. The inoculant used was VAULT HP plus integral (BASF). Herbicides and hand weeding were used to maintain no weed interference during the entire growing season, and soil nutrient concentrations (other than N) were maintained above the recommended critical levels (through inorganic P and K applications). Seeding rate target was 140,000 seeds per acre.

Measurements

Stand counts were performed measuring 5-ft sections per row, 4 rows in each plot, at the V4 stage (4 full developed trifoliates) in all replications (Table 2). Aboveground biomass samples were collected at the R8 stage, before harvest. Seed harvest index was estimated as the ratio between the grain yield and the aboveground biomass collected at the R8 stage. Yield was collected from the central two rows (5 × 60 ft) and is expressed in bu/a adjusted to 13% of moisture content. Seed number was estimated with the seed weight and yield information.

Weather Information
Maximum and minimum temperatures were recorded and compared to the 30 years of historical information for the region. Seasonal variations in temperature followed a similar trend as the historical. Seasonal precipitation distribution was also recorded and expressed in inches. On average, the amount of precipitation during the growing season was five inches greater than the historical (Figure 2).

Results
Overall seed yield for 2017 averaged 36 bu/a (ranging from 23 to 52 bu/a). Statistically, soybean yields were different for treatment 5 (NF), reaching the maximum yields, although they did not differ from treatment 2 (I1). Final soybean yields averages presented the following trend from high to low: 300 lb of N/a > inoculated 1× > inoculated 2× = inoculated 3× > non-inoculated treatments (Figure 3).

Plant biomass presented an overall value of 4500 lb/a (dry basis). Values greater than 5780 lb of biomass per acre were observed for the single inoculation treatment (I1) (Figure 4). On the other hand, the lowest biomass result was recorded in the non-inoculated (NI) treatment. Seed harvest index (HI) was expressed in relative terms (as percentage) and was similar across all treatments averaging 46%. The treatment with lowest HI was treatment 5 (NF) with 43% (this was the treatment with greatest seed yield); while treatment 4 (I3) achieved the maximum seed HI, with 48% (Figure 4). Overall, maximum yields were attained with biomass playing a major role despite the changes in HI.

Soybean seeds per unit of area did not show statistical differences, but overall followed the same trend as portrayed by final yields with a greater number of seeds per unit of area for the NF treatment, 162 seeds/sq. ft, while the lowest number was found in the NI treatment (control) with 127 seeds/sq. ft (Figure 5).

Yields 2015, 2016, and 2017
Yield response to inoculation and N fertilizer addition in the system were studied for 2015, 2016, and 2017 growing seasons in Ottawa, KS. A summary is presented in Figure 6.

- In 2015, soybean yield treatments were not statistically different.
- In 2016, soybean yields were different for treatment 5 (NF), reaching the maximum yields, while treatments 1 (NI), 2 (I1), and 3 (I2) resulted in the lowest yields levels.
- In 2017, soybean yields were significantly different for treatment 5 (NF) although without differing from treatment 2 (I1). Final soybean yields averages presented the following trend from high to low: 300 lb of N/a > inoculated 1× > inoculated 2× = inoculated 3× > non-inoculated treatments (Figure 6).

Conclusions

- In 2017 (third consecutive year after the first soybean study was planted), the difference between the non-inoculated treatment or control (NI) and the inoculated with recommend rate (I1) was on average 4.7 bu/a, favoring the inoculated condition.
- Across years, treatments with different inoculation rates did not differ in the final yields.
- For 2017, maximum agronomical yield was observed when 300 lb of N/a were applied, even though yields did not differ from the single rate of inoculant treatment. However, the lowest yield was recorded for the control treatment (NI).
- Inoculation is a key piece for enhancing good nodulation in the system, improving N fixation, and helping to ensure stable yields; inoculation practice is relatively inexpensive as compared with other input costs.

In summary, further evaluation and research is needed in order to properly inform our farmers about the best N management approach in soybean grown in a newly-planted area.

Table 1. Pre-plant soil characterization at 0- 6-inch depth, Ottawa, KS

Soil parameters, units	Ottawa
pH	5.8
Mehlich P (ppm)	19
Cation exchange capacity (meq/100 g)	29.7
Organic matter (%)	4.4
Potassium (ppm)	139.5
Calcium (ppm)	3008
Magnesium (ppm)	440
Nitrates (ppm) *	10.24

*Soil samples for nitrate analysis were taken at 24 inches depth.

Table 2. Final stand counts per treatment in the 2017 growing season, Ottawa, KS

Treatments (× 1,000 plants/a)				
Non-inoculation	Inoculation 1	Inoculation 2	Inoculation 3	Fertilizer nitrogen
91	101	97	96	99

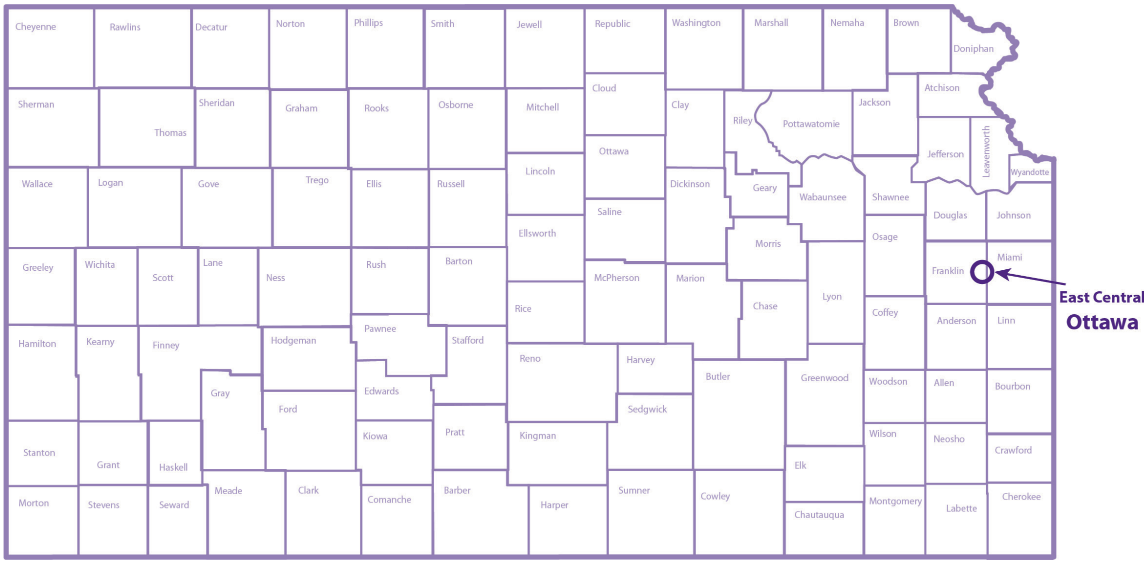

Figure 1. Field location for the soybean inoculation project during the 2015, 2016, and 2017 growing seasons (Ottawa, KS).

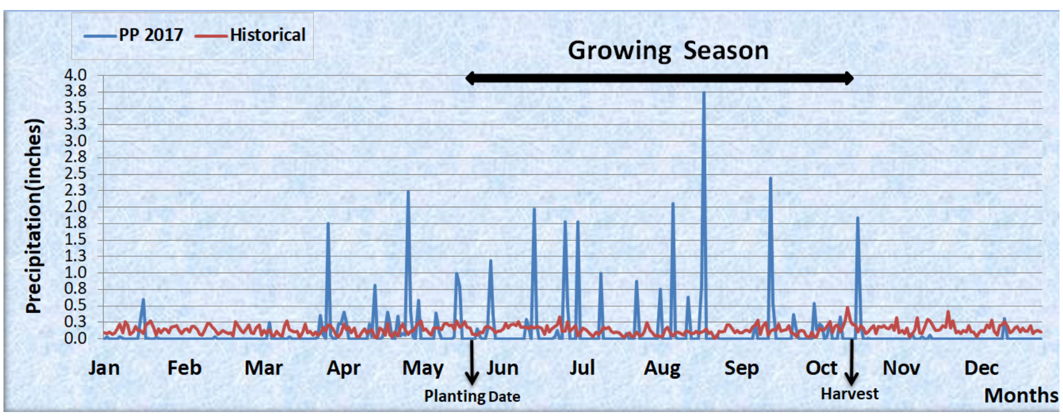

Figure 2. Daily precipitation of 2017 growing season at Ottawa, KS (blue line) and historical means for 30 years (red line). Data from Kansas Mesonet (Historical Weather, http://mesonet.k-state.edu/).

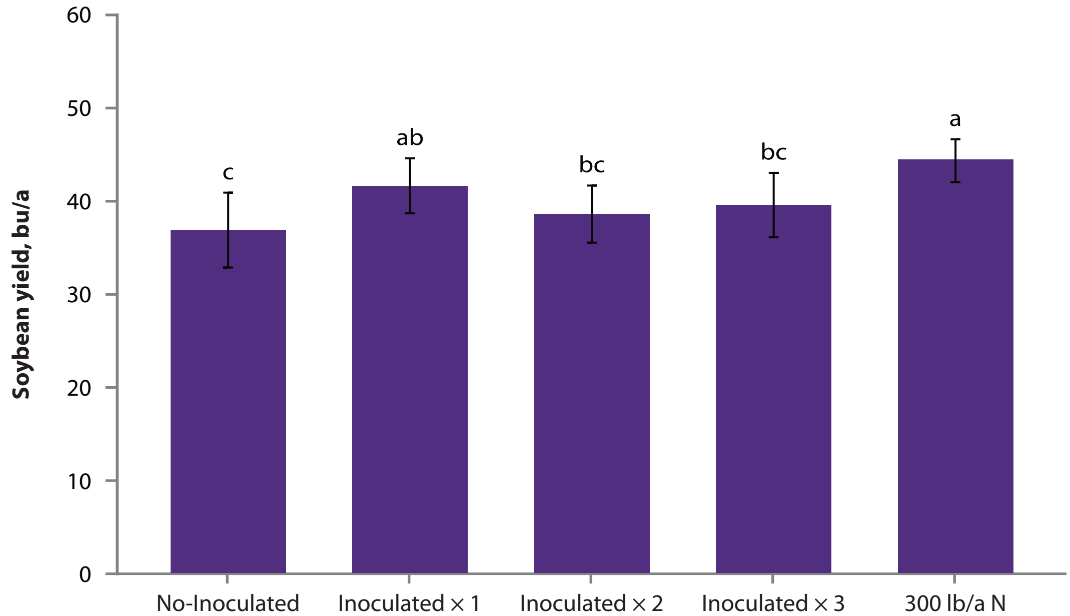

Figure 3. Soybean yield (13% moisture) at Ottawa, KS, for five different treatments during the 2017 season. Whiskers represent standard error of the mean and different letters indicate significant differences at ($P < 0.05$).

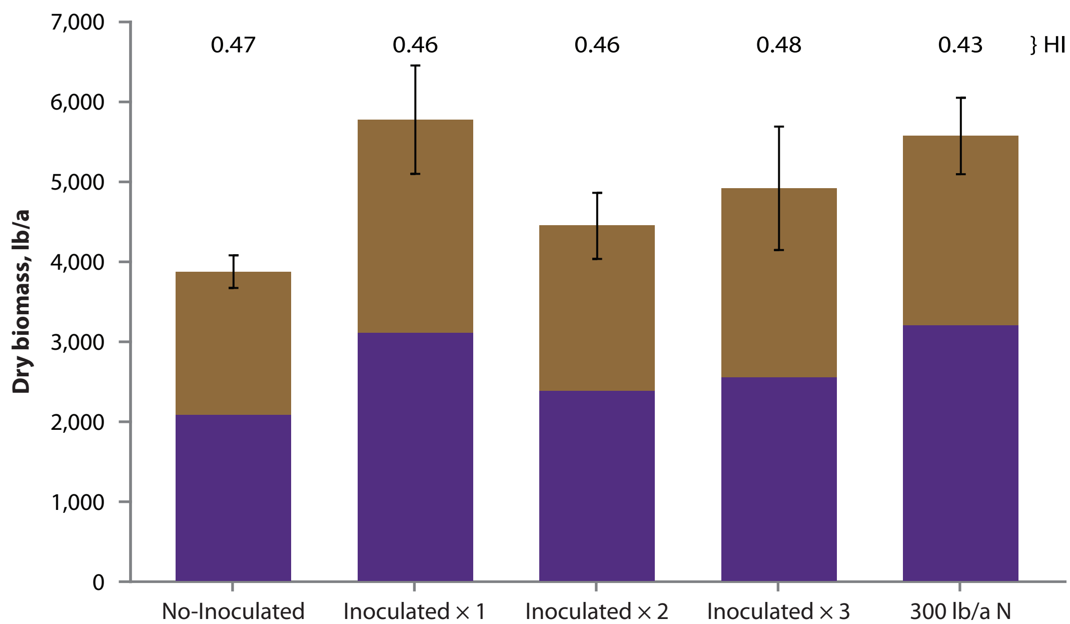

Figure 4. Dry biomass (expressed in lb/a) and seed harvest index (HI, expressed as percentage) at Ottawa, KS, during the 2017 growing season. Whiskers represent the standard error of total dry biomass means. Purple color represents vegetative biomass (non-seed tissues) and brown color represents dry biomass of seeds.

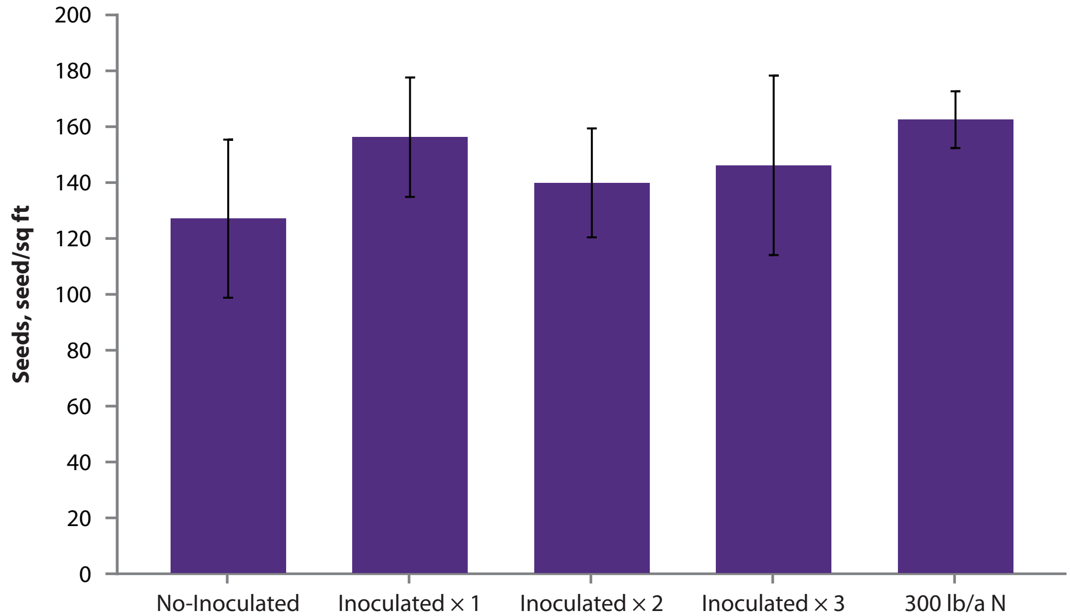

Figure 5. Seed number per unit of area expressed in seeds per square feet at Ottawa, KS, during the 2017 growing season. Whiskers represent the standard error of the mean.

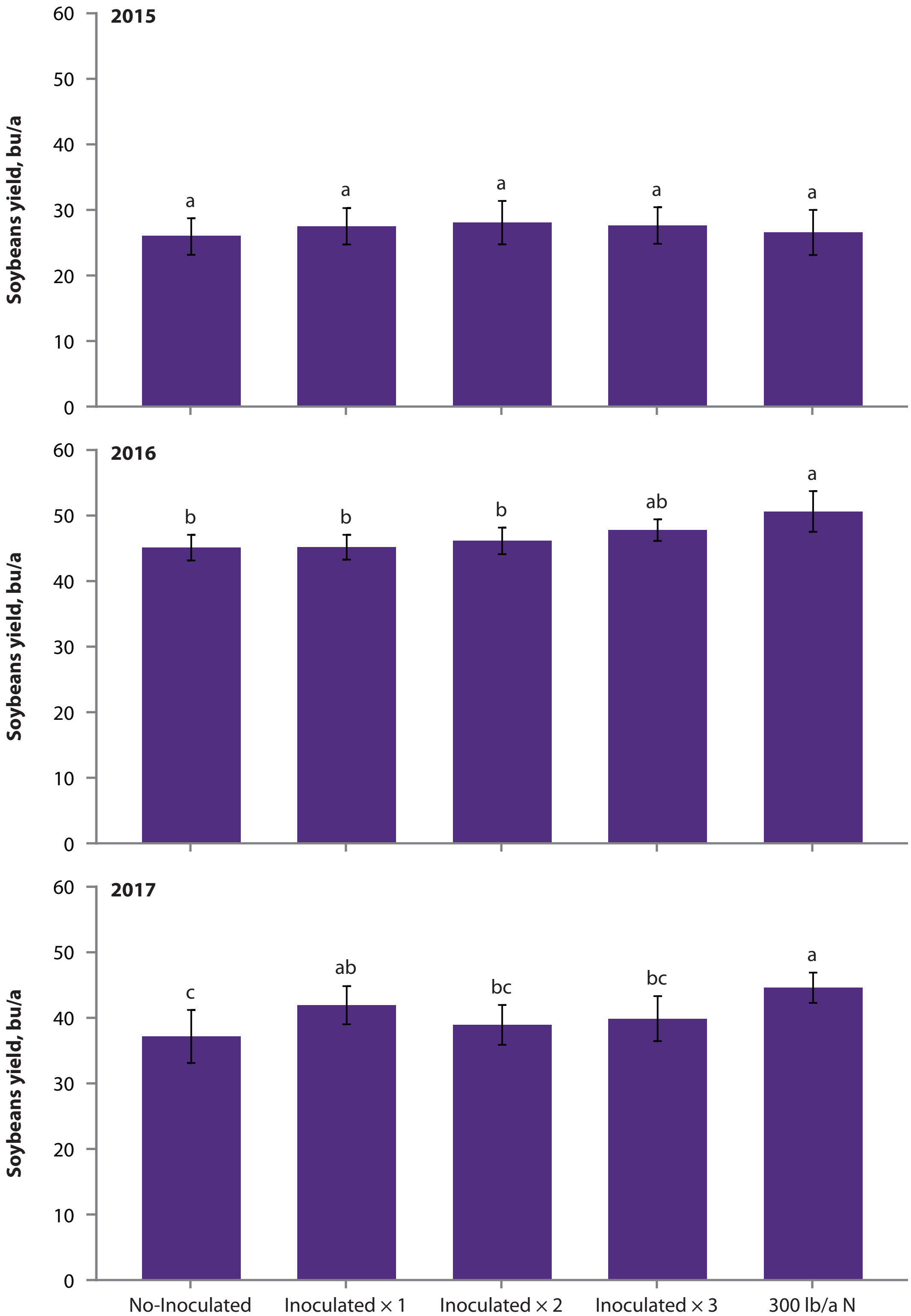

Figure 6. Soybean yield (13% moisture) at Ottawa, KS, for the 2015, 2016, and 2017 growing seasons. Whiskers represent standard error of the mean, and different letters indicate significant differences at ($P < 0.05$).

Effects of Nitrogen in Soybean Seed Quality Definition During Seed-Filling Period

S. Tamagno, E.A. Adee, and I.A. Ciampitti

Introduction

During the seed filling period (SFP), parallel to the seed changes, translocation of assimilates and nutrients takes place from different plant organs to the seed in order to provide sufficient supply for the seed storage components (i.e., starch, oil, and protein) that ultimately will determine the seed quality. There are two processes that define the final seed weight in any crop: 1) the amount of dry mass deposited per unit of time (rate) and 2) the duration of this process from beginning of seed formation to physiological maturity. As seed number is defined, any source limitation during the SFP can affect the final weight and quality of the seeds. This study aims to investigate if nitrogen (N) is limiting potential seed weight and, in consequence, final seed yield as well as the characterization of the deposition of seed components (i.e., oil and protein) that define soybean seed quality among different N conditions and genotypic background.

Procedures

A field study was conducted at the Kansas River Valley research station (Rossville, KS) during the 2016 growing season (Table 1). Experimental layout was a complete randomized block in a split-plot design with seven genotypes (subplots) and two fertilizer N rates (main plots) all replicated three times. For the genotype factor, seven soybean varieties with different years of release were tested (Pioneer). Fertilizer was applied in three timings (i.e., V1, R1, and R3 growth stages). Plot size was 10-ft wide × 50-ft long. For all treatments, seeds were inoculated and plots were maintained weed- and pest-free during the growing season.

Seeds were sampled in all plots at the onset of R5 growth stage (beginning of seed filling) weekly in order to estimate seed filling rate and duration, seed weight and chemical composition (protein and oil content). Protein and oil content (mg/seed) for each seed sample were estimated as the product between individual seed dry weight and component concentration. Protein concentration (%) was estimated as N concentration multiplied by 6.25 using the Kjeldahl method. Oil concentration (%) was determined gravimetrically after extraction with hexane in another 0.5-g subsample.

An analysis of variance was performed to test the effect of genotype, N level, and their interaction in all traits measured. Rate and duration for seed components and seed biomass were determined for each combination of genotype × replication by fitting a bi-linear model (Equations 1 and 2) as in Gambín and Borrás (2011) together with knowledge on heritability estimates and possible trade-off relations among traits. Sixty-five sorghum inbred lines were evaluated for grain filling and other agronomic traits during 2008 and 29 re-evaluated in 2009. Time to anthesis, final grain weight (GW):

Seed weight (mg/seed) = $a + b \times d$ for $d <$ c linear function) [1]

Seed weight (mg/seed) = $a + b \times c$ for $d >$ c plateau function) [2] where *d* are the days after R5, *a* is the y-intercept (mg/seed), *b* is the linear rate of dry mass or seed component accumulation (mg/seed d^{-1}), and *c* is the duration of the SFP (days).

Results

Seed Yield and Numerical Components

Differences for seed yield were significant between genotypes and N levels ($P < 0.01$ and $P < 0.05$, respectively; Table 2). For seed number, modern varieties showed greater values of seed number ($P < 0.001$).

Differences between genotypes and N levels were highly significant for the final seed weight ($P < 0.001$; Table 2). Nitrogen application increased seed weight by extending the duration of the SFP, but without changing the seed growth rate.

Seed Components Accumulation

Large differences between genotypes were reported for oil content ($P < 0.001$; Table 3) and the rate ($P < 0.01$). Oil content varied from 29.8 to 36.2 mg/seed showing the large range of genotypic diversity. As expected, different N levels did not affect the oil content, the rate and duration of this component. The protein content and the duration were primarily affected by N availability ($P < 0.05$). Large differences between genotypes were observed for the genotypes tested and for the rate of protein deposition ($P < 0.05$). However, despite genotypic variability the increase in N availability during the SFP managed to boost the protein content from 48.2 to 55.3 mg/seed.

Conclusions

- This study does not warrant application of N to soybeans, it only demonstrates that the crop can be limited for this nutrient at the end of the growing season. However, for the environment tested there was a positive and significant response in seed yield to N applications in soybean.
- Seed weight was significantly affected by N availability. Larger seed size was explained by changes on duration of the SFP.
- The range of values observed in oil content was due to the genotypic effect rather than higher N during the SFP.
- Nitrogen availability increased the protein content in seeds through longer duration of the SFP.

Reference

Gambín, B.L., Borrás, L., 2011. Genotypic diversity in sorghum inbred lines for grain-filling patterns and other related agronomic traits. Crop Pasture Sci. 62, 1026–1036. doi:10.1071/CP11051

Table 1. Environmental conditions and treatments imposed in the experiment

Location	Rossville, Kansas	
Planting Date	May 12, 2016	
Temperature	73°F	
Precipitation	31 in.	
N Level (lb/a)	0	500
Varieties		
80s	P3981	9391
90s	9392	93B82
00s	93B67	93M90
10s	P35T58R	
Soil (ppm)		
N, P, K	3; 21; 153	

Table 2. Analysis of variance and means for seed yield (13.5% moisture), seed number, seed weight, and seed filling rate and duration for all genotypes and nitrogen (N) levels

Genotype	Release year	N level	Seed yield	Seed number	Seed weight	SFP rate	SFP duration
			bu/a	seed/m²	mg/seed	mg/day/seed	days
P3981	1980		42.7 d	2080 c	148 b	3.81 b	41
9391	1987		51.2 bcd	2636 b	134 c	4.08 ab	35
9392	1991		44.6 cd	2214 bc	133 c	4.34 a	32
93B82	1997		56.2 ab	2583 bc	166 a	4.31 a	40
93B67	2001		44.2 cd	2054 bc	135 c	3.86 b	36
93M90	2003		53.4 bc	2453 bc	151 ab	4.08 ab	39
P35T58R	2013		64.5 a	2664 a	137 c	4.01 b	36
		Zero-N	47.5 b	2270	133 b	4.06	34
		High-N	54.5 a	2469	154 a	4.08	40
Genotype			**	***	***	*	***
N Level			*	ns	***	ns	***
Genotype × N level			ns	ns	ns	ns	*

* Significant at $P \leq 0.05$; *** Significant at $P \leq 0.001$. NS = non-significant. Different letters represent the least significant differences (LSD) between means at $P \leq 0.05$.

Table 3. Analysis of variance and means for oil and protein filling rate, duration and content for all genotypes and nitrogen (N) levels

Genotype	Release year	N level	Oil					Protein				
			Rate	Duration		Content		Rate		Duration		Content	
			mg/day	days		mg/seed		mg/day		days		mg/seed	
P3981	1980		0.93	40	a	32.2	b	1.45	bc	39		52.6	bc
9391	1987		0.94	36	b	29.8	bcd	1.41	bc	38		50.1	cd
9392	1991		1.04	31	c	28.5	cd	1.55	ab	32		48.8	cd
93B82	1997		1.02	39	ab	36.2	a	1.66	a	38		59.8	a
93B67	2001		0.87	36	b	27.6	d	1.4	bc	37		49.6	cd
93M90	2003		0.98	37	ab	32	b	1.5	abc	39		55.1	b
P35T58R	2013		0.97	36	b	30.6	bc	1.34	c	37		46.6	d
		Zero-N	0.92	35		29.3		1.43		35	b	48.2	b
		High-N	1.01	38		32.7		1.51		39	a	55.3	a
Genotype			ns	**		***		*		ns		***	
N Level			ns	ns		ns		ns		*		*	
Genotype × N level			ns	ns		ns		ns		ns		ns	

*Significant at $P \leq 0.05$; *** Significant at $P \leq 0.001$. NS = non-significant. Different letters represent the least significant differences (LSD) between means at $P \leq 0.05$.

Impact on Soybean Yield from Sudden Death Syndrome and Soybean Planting Date

E.A. Adee, C. Little,[1] and I.A. Ciampitti

Summary
Sudden Death Syndrome (SDS) is a disease caused by the soilborne fungus *Fusarium virguliforme*. This fungus prefers wet conditions and thus is usually most severe in irrigated fields. SDS tends to be most severe on well-managed soybeans with a high yield potential. It also tends to be more prevalent on fields that are infested with soybean cyst nematode (SCN) or planted early when soils are wet and cool. Historical yield losses from this disease are generally in the range of 1–25%.

Soybean planting dates have been moving increasingly earlier in much of the soybean growing region, including Kansas. Yield loss of up to 0.5 bushel per day is not uncommon when soybeans are planted after May 10 in many soybean growing regions. However, in the Kansas River Valley, many of the soybeans have been planted after mid-May because of the perennial problem with SDS on soybeans. Later planting has been prescribed as a management practice to help avoid the cooler/wetter soils that can create greater probability of infection by the fungus.

Procedures

Planting Date Study
Two soybean planting date studies evaluating the severity of SDS and soybean yield were conducted at the Kansas River Valley experiment fields in Topeka from 2015-2017. One study was specifically looking at SDS by promoting infection (early and greater irrigation volume), and the other was targeting best management practices to minimize SDS. In the study promoting SDS, two soybean varieties of MG 3.5, one SDS susceptible and one SDS tolerant, were planted into fields with a history of SDS in 2015, 2016, and 2017, on average planting dates of May 3 and 20, and June 8 and 22. The soil was Eudora silt loam and the previous crop was corn. Both studies had foliar symptoms of SDS develop during the growing season. Foliar symptoms of SDS were rated weekly starting July 29, 2015, at R3 (beginning pods); August 8, 2016, at R4 (full-length pods); and August 25, 2017, at R5 (beginning seed); until R6 (full seed) for all planting dates. Ratings were based on incidence and severity of symptoms resulting in percent defoliation. Harvest was completed by October 13 for all three study years.

Best Management Practice Study
Management practices to reduce or avoid SDS were implemented in this study. These include treating the seed with ILeVO (Bayer) at 35 mL/unit of seed to protect against SDS, and withholding irrigation until the crop was getting close to moisture stress (September 1, 2015, August 10, 2016, and July 16, 2017) with less than 3 inches each year. Three soybean varieties of differing maturity group (MG) were planted on three different dates. Soil type, rainfall, and herbicide programs were the same as with the

[1]Department of Plant Pathology, Kansas State University, Manhattan, KS.

SDS Planting Date Study. Also, SDS ratings and harvest were the same dates as the SDS Planting Date Study.

Results

The severity of SDS was greatest with the early planting dates in both studies (Figures 1 and 3), decreasing to very little SDS for the June planting dates with the varieties having average or below-average tolerance to SDS. Overall, SDS foliar symptoms developed later in 2016 and 2017 than in 2015, resulting in a lower severity of SDS. However, the effect of planting date on SDS was consistent with all studies, confirming that earlier planting dates can result in more severe symptoms of SDS.

The yields were also the greatest with the earlier planting dates in both studies (Figures 2 and 4) except for the susceptible variety (Figure 2). Generally, there is a negative relationship between SDS and yield at each planting date (i.e. the greater the SDS, the lower the yield). However, in these experiments, the increased yield potential with the earlier planting dates was partially realized with the more tolerant varieties despite the yield loss due to SDS.

The greatest benefit to early planting was with the SDS tolerant MG 3.5 variety in the SDS Planting Date Study, showing a 0.3 bushel per day yield increase for planting in early May versus mid-May. In the Best Management Practice Study, the MG 4.0 varieties averaged 0.33 bushels per day for the early May planting date versus mid-May. The tolerant varieties were able to realize some of the increased yield potential with the earlier planting. The SDS susceptible variety of similar maturity responded with essentially no yield increase when planted in early May versus early June. While the severity of SDS was greater at the earlier planting dates, the tolerant varieties were able to respond with increased yield, showing the importance of selecting varieties with better tolerance to SDS and incorporating other measures to reduce SDS.

Summary

Based on three years of data from two experiments, SDS is favored by earlier planting, as well as yield. It will be interesting to see in a year when the SDS is more severe whether the yield potential for early planting date is greatly reduced or if a yield benefit will still be realized. It could be that with more severe SDS, the yield response to earlier planting date may look more like that of a very susceptible variety (no change in yield unless planting date is very late).

These studies show that by choosing the more SDS tolerant varieties and taking measures to reduce SDS, that there is a very positive benefit for earlier planting dates of soybeans in the Kansas River Valley.

Acknowledgment

This research was funded in part by the Kansas Soybean Commission.

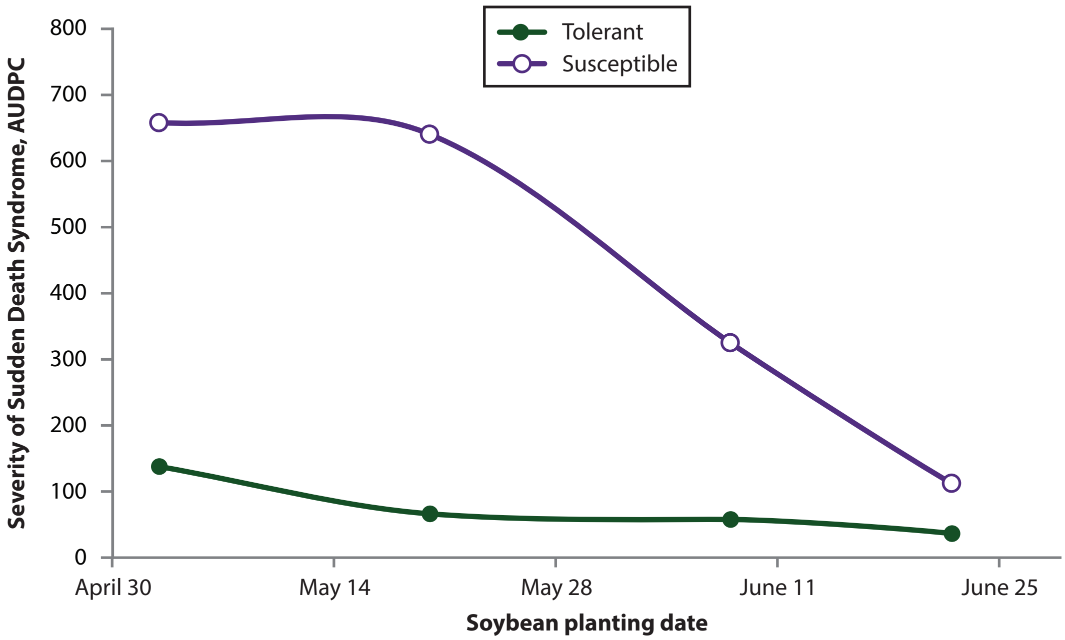

Figure 1. Effect of planting date for two soybean varieties on severity of sudden death syndrome (SDS) measured as area under disease progress curve (AUDPC), Kansas River Valley experiment fields, 2015, 2016, and 2017 averages.

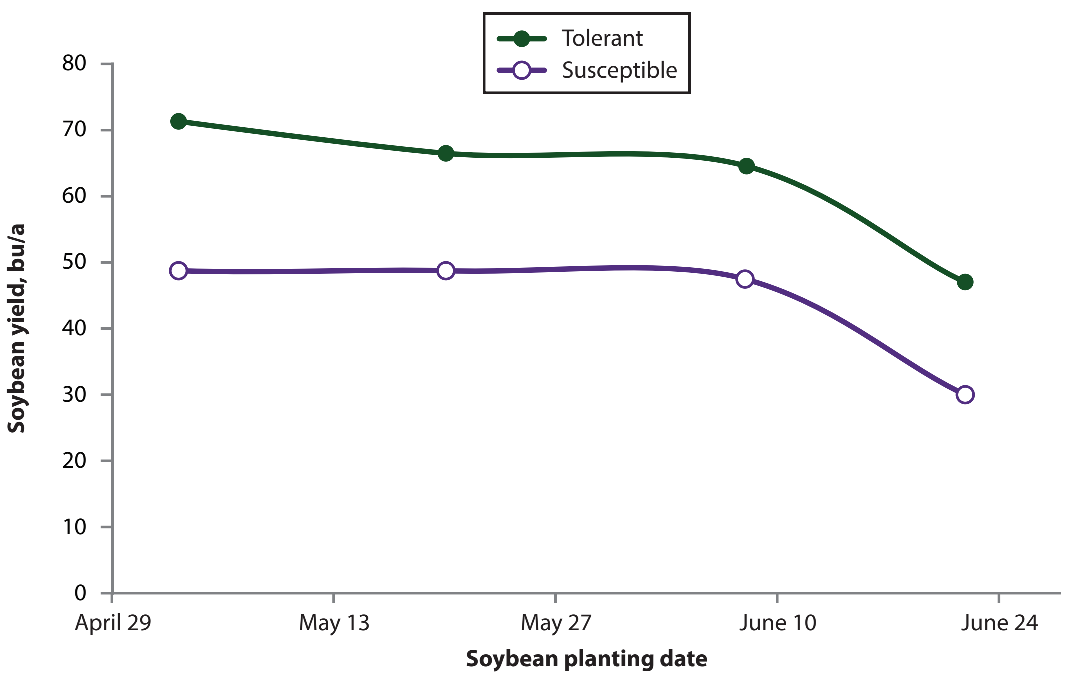

Figure 2. Effect of planting date on yield for two soybean varieties with different levels of susceptibility to sudden death syndrome (SDS), Kansas River Valley experiment fields, 2015, 2016, and 2017 averages.

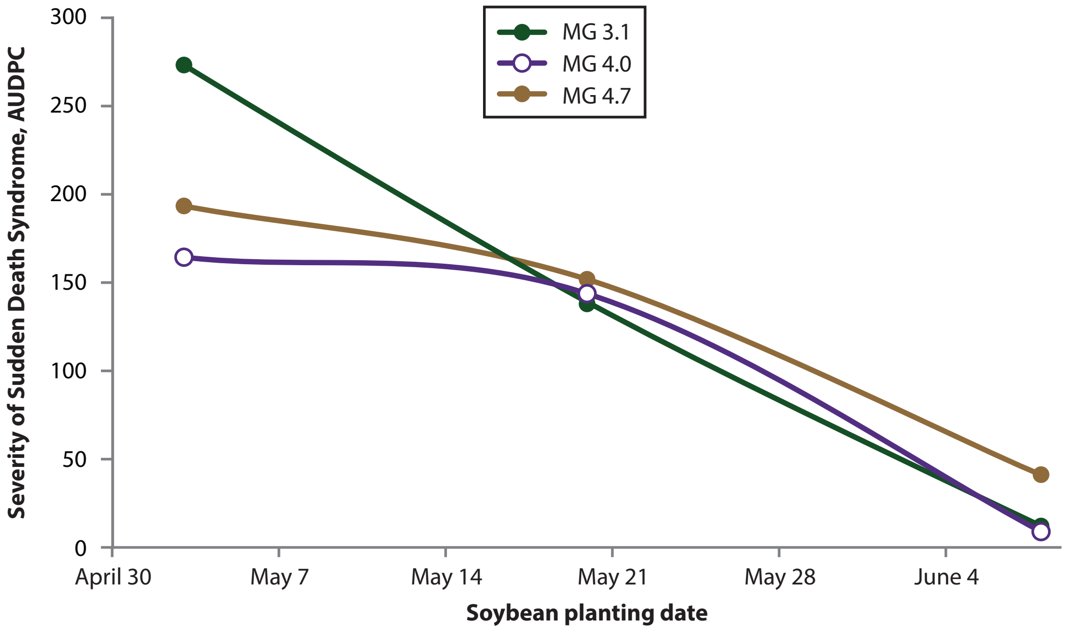

Figure 3. Effect of planting date on severity of sudden death syndrome (SDS) measured as area under disease progress curve (AUDPC) in soybean varieties of different maturity groups (MG) treated with ILeVO, Kansas River Valley experiment fields, 2015, 2016, and 2017 averages.

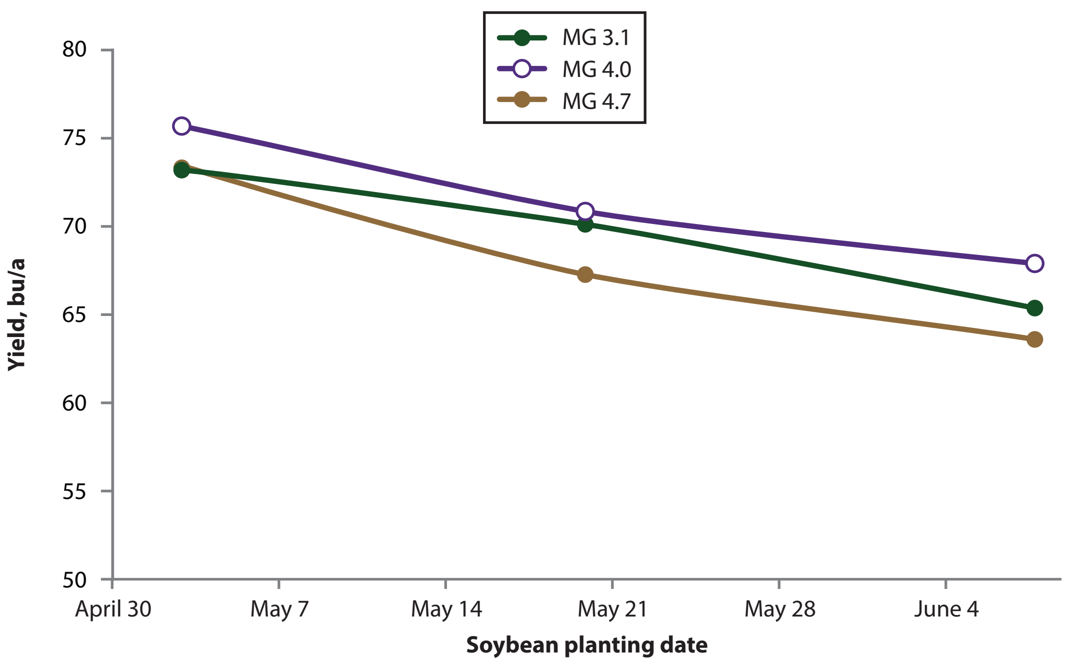

Figure 4. Effect of planting date on yield of soybean varieties of different maturity groups (MG), Kansas River Valley experiment fields, 2015, 2016, and 2017 averages.

Figure 5. Sudden death syndrome.

Palmer Amaranth Populations from Kansas with Multiple Resistance to Glyphosate, Chlorsulfuron, Mesotrione, and Atrazine

V. Kumar, P.W. Stahlman, and G. Boyer

Summary

Multiple herbicide-resistant (MHR) Palmer amaranth poses a serious management concern for growers across the United States. Since 2014, several Palmer amaranth populations with suspected resistance to most commonly used herbicides were collected in random field surveys across Kansas. This study aimed to characterize the resistance levels to glyphosate (EPSPS inhibitor), mesotrione (HPPD inhibitor), chlorsulfuron (ALS inhibitor), and atrazine (PS II inhibitor) in three suspected MHR Palmer amaranth populations (KW2, PR8, and BT12) compared to a known herbicide-susceptible (SUS) population. Dose-response studies revealed that PR8 and BT12 populations had 7- to 14-fold level resistance to glyphosate, and up to 12-fold level of resistance to chlorsulfuron (Glean herbicide) on the basis of visible control (LD_{50} values) and shoot dry weight response (GR_{50} values). The KW2, PR8, and BT12 populations also showed 2- to 4-fold resistance to mesotrione (Callisto herbicide) relative to SUS population. Based on plant dry weight response (GR_{50} values), the KW2 and BT12 populations showed 5- and 16-fold resistance to atrazine (AAtrex 4L herbicide), respectively, compared with the SUS population. These results confirm the first report on the evolution of a Palmer amaranth population (BT12) with multiple resistance to glyphosate (12 to 14 fold), chlorsulfuron (11 fold), mesotrione (2 to 4 fold), and atrazine (16 fold) in Kansas. Further studies are in progress to investigate the response of these MHR populations to fomesafen (PPO inhibitor); 2,4-D; and dicamba (synthetic auxins) herbicides.

Introduction

Palmer amaranth (*Amaranthus palmeri*) is the most troublesome broadleaf weed species in the United States, including Kansas (Wychen, 2017). Palmer amaranth possesses several unique traits, including extended period of emergence, fast growth habit, and high seed production potential. A single female plant of Palmer amaranth can produce up to 600,000 seeds and can cause heavy infestation in field crops (Burke et al., 2007; Keeley et al., 1987). Season-long competition from Palmer amaranth at densities of 10 plants m^{-1} row of soybean was found to cause up to 68% yield reduction (Klingaman and Oliver, 1994).

In recent years, multiple herbicide-resistant (MHR) Palmer amaranth populations have become an increasing management concern for Kansas growers. Palmer amaranth's resistance to sulfonylurea (ALS inhibitors) and atrazine (PS II inhibitor) has been reported in Kansas since the early and mid-90s, respectively (Heap, 2018). Glyphosate-resistant (GR) Palmer amaranth was confirmed in Kansas in 2011. A Palmer amaranth population resistant to multiple herbicide modes of action, including mesotrione (HPPD inhibitor), atrazine (PS II inhibitor), and chlorsulfuron (ALS inhibitor) has previously been reported in Kansas (Nakka, 2016). Since 2014, state-wide random field surveys have monitored the distribution, frequency, and resistance levels of MHR Palmer amaranth populations across the Kansas cropping systems. The main objective of this research was to investigate suspected MHR Palmer amaranth populations for resistance to multiple herbicide modes of action (glyphosate, chlorsulfuron, mesotrione, and atrazine) relative to a known susceptible population.

Procedures

Fully-matured seeds of suspected MHR Palmer amaranth populations (40 to 50 plants per field) were originally collected from Barton (BT12), Kiowa (KW2), and Pratt (PR8) counties in Kansas. Seeds of a known herbicide-susceptible (SUS) Palmer amaranth population were collected from the Kansas State University Ashland Bottoms research fields in Riley County, KS, and were used previously in various greenhouse and laboratory studies. Dose-response experiments were conducted by sowing seeds of each MHR and SUS population on the surface of germination trays filled with commercial potting mix. Later on, seedlings of each Palmer amaranth population were transplanted in 4 × 4-inch plastic pots containing commercial potting mixture under greenhouse conditions at the Kansas State University Agricultural Research Center near Hays, KS. For each herbicide tested, the study was set up in a randomized complete block design (blocked by population) with 6 to 8 replications. Actively growing seedlings (3- to 4-inch tall) from each population were sprayed with Roundup PowerMax (glyphosate) at doses of 0, 2, 4, 8, 16, 32, 64, 128, 256, and 512 fluid oz/a. Ammonium sulfate at 2% (wt/v) was included with all glyphosate treatments. Doses for Callisto (mesotrione) herbicide along with 1% v/v of crop oil concentrate (COC) and 2.5% v/v of urea ammonium nitrate (UAN, 28%) included: 0, 0.187, 0.375, 0.75, 1.5, 3, 6, 12, 24, and 48 oz/a. Doses for Glean (chlorsulfuron) herbicide along with 0.25% v/v of nonionic surfactant (NIS) included: 0, 0.0625, 0.125, 0.25, 0.5, 1, 2, 4, 8, and 16 oz/a. Doses for AAtrex (atrazine) herbicide along with 1% v/v of Agri-Dex crop oil concentrate (COC) included: 0, 2, 4, 8, 16, 32, 64, 128, 256, and 512 fl oz/a. Herbicide applications were made using a cabinet spray chamber equipped with an even flat-fan nozzle tip (TeeJet 8001EXR) calibrated to deliver 10 gallons per acre of spray solution at 40 psi. Herbicide-treated plants were returned to the greenhouse and watered and fertilized as needed. Data on percent visible control (0 = no control, 100 = dead plant) were visually assessed at 7, 14, and 21 days after treatment (DAT) of each herbicide. Shoot dry weights were also determined at 21 DAT. For each dose-response experiment, data were analyzed using a 3-parameter log-logistic model in *R* software using the following equation (Ritz et al. 2015):

$$y = \{d/1+\exp [b (\log x - \log e)]\} \qquad [1]$$

where y refers to the response variable (% visible control or shoot dry weight), d is the upper limit, b is the slope of each curve, *e* is the herbicide dose required to cause 50% control or 50% shoot dry weight reduction (referred to as LD_{50} or GR_{50}), and x is the herbicide dose. Nonlinear regression parameter estimates and standard errors for each population were determined using the *drc* package in R software. Resistance level (referred as R/S ratio) to a particular herbicide was estimated by dividing the LD_{50} or GR_{50} value of each MHR population by the LD_{50} or GR_{50} value of the susceptible population.

Results

Resistance to Glyphosate

Based on the dose-response curves for visual control (%) data, the LD_{50} (effective dose of Roundup PowerMax required to obtain 50% control) values of PR8 and BT12 Palmer amaranth populations were 59 and 79 fl oz/a, respectively, and were greater than the 5.7 fl oz/a value obtained for the SUS population (Table 1). Based on the LD_{50} values, the PR8, and BT12 populations exhibited 10- and 14-fold level resistance to glyphosate (Table 1; Figure 1A). Similarly, the PR8 and BT12 populations had GR_{50} values (effective dose of Roundup PowerMax required to cause 50% reduction in shoot dry weights) of 39 and 66 fl oz/a, respectively, which were higher than the 5.5 fl oz/a rate for the SUS population (Table 1). Based on the shoot dry weight response, the PR8 and BT12 populations showed 7- and 12-fold level of resistance to glyphosate (Table 1; Figure 1B). Visual control and shoot dry weight response of the KW2 population to various doses of Roundup PowerMax herbicide were more or less similar to the SUS population (Table 1; Figure 1). Thus, both the visual and dry weight assessments indicated the PR8 and BT12 populations were highly resistant to glyphosate.

Resistance to HPPD Inhibitors

The confirmed glyphosate-resistant Palmer amaranth populations (PR8 and BT12) also had at least 2- and 4-fold resistance to mesotrione (Callisto) herbicide on the basis of visible control data (LD_{50} values) (Table 2; Figure 2). In addition, the KW2 population also exhibited at least 3-fold resistance to mesotrione based on LD_{50} values. Based on shoot dry weight response (GR_{50} values), the KW2 and BT12 populations exhibited 3- and 2-fold level of resistance to mesotrione herbicide (Table 2; Figure 2). However, the shoot dry weight response of the PR8 population with various doses of mesotrione did not differ from SUS population (Table 2). These results indicated that all tested MHR populations in this study had evolved low level of resistance to mesotrione.

Resistance to ALS Inhibitors

A whole plant dose-response study indicated that all three suspected MHR Palmer amaranth populations viz., KW2, PR8, and BT12 had at least 2-, 12-, and 11-fold resistance to chlorsulfuron (Glean XP) herbicide, respectively, compared to the SUS population on the basis of percent visible control rating (LD_{50} values) (Table 3; Figure 3). The shoot dry weight response of these populations to chlorsulfuron also showed similar results (data not shown). In comparison to a previous report on ALS-resistant Palmer amaranth from Kansas (Nakka, 2016), the selected MHR populations in this study showed both low and high level of resistance to chlorsulfuron.

Resistance to PS II Inhibitors

Based on plant dry weight response (GR_{50} values), the two tested MHR Palmer amaranth populations viz., KW2 and BT12 showed at least 5- and 16-fold resistance to atrazine (AAtrex 4L herbicide) compared to the SUS population. These results indicated that both populations had developed moderate to high level resistance to atrazine (Table 4; Figure 4).

Conclusions and Implications

This research confirms the first case of a Palmer amaranth population (BT12) with multiple resistance to glyphosate (EPSPS inhibitor), mesotrione (HPPD inhibitor), chlorsulfuron (ALS inhibitor), and atrazine (PS II inhibitor) in Kansas. Increasing reports of MHR Palmer amaranth populations are of great concern as these herbicide chemistries are commonly used in Kansas cropping systems. Growers should adopt integrated weed management programs by incorporating effective and alternate herbicide modes of action and nonchemical based approaches (such as diversifying crop rotations, growing cover crops, tillage, cuttings, mowing, etc.) together on their production fields. Future studies will determine the sensitivity of these confirmed MHR Palmer amaranth populations to other herbicide modes of action, including synthetic auxins (2,4-D and dicamba), PPO inhibitors (Flexstar and Cobra herbicides) and will investigate the underlying mechanism(s) of these multiple herbicide resistance traits.

References

Burke IC, Schroeder M, Thomas WE, Wilcut JW (2007) Palmer amaranth interference and seed production in peanut. Weed Technol 21:367–371

Heap IM (2018) The International Survey of Herbicide Resistant Weeds. Accessed on February 11, 2018. Available www.weedscience.org

Keeley PE, Carter CH, Thullen RJ (1987) Influence of planting date on growth of Palmer amaranth (*Amaranthus palmeri*). Weed Sci 35:199–204

Klingaman TE, Oliver LR (1994) Palmer amaranth (*Amaranthus palmeri*) interference in soybeans (*Glycine max*). Weed Sci 42:523–527

Nakka S (2016) Physiological, biochemical and molecular characterization of multiple herbicide resistance in Palmer amaranth (*Amaranthus palmeri*). Ph.D. dissertation. Manhattan, KS: Kansas State University.

Ritz C, Baty F, Streibig JC, Gerhard D (2015) Dose-response analysis using R. PLoS One 10:e0146021

Van Wychen L (2017) 2017 Survey of the most common and troublesome weeds in grass crops, pasture and turf in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Available: http://wssa.net/wp-content/uploads/2017-Weed-Survey_Grass-crops.xlsx.

Table 1. Regression parameter (equation 1) estimates for whole plant dose response of Palmer amaranth populations from Kansas treated with Roundup PowerMax (glyphosate) herbicide

Population[a]	d (± SE)	b (± SE)	LD_{50} or GR_{50} (± SE)	R/S[b]
Based on % visible control				
SUS	99.2 (1.9)	-5.1 (0.7)	5.7 (0.3)	-
KW2	99.1 (1.9)	-3.4 (0.4)	8.4 (0.4)	1
PR8	82.2 (2.9)	-2.1 (0.3)	59.1 (4.5)	10
BT12	82.1 (2.6)	-3.5 (0.7)	79.1 (4.4)	14
Based on shoot dry weight				
SUS	94.4 (5.1)	5.6 (2.1)	5.5 (0.6)	-
KW2	96.2 (4.7)	7.1 (3.1)	6.1 (0.7)	1
PR8	103.1 (5.1)	1.9 (0.3)	39.2 (4.5)	7
BT12	94.3 (4.6)	2.5 (0.8)	66.0 (8.3)	12

[a]Abbreviations: d, upper limit; b, slope of each curve; SUS, herbicide susceptible population from Ashland Bottoms research fields, Riley, KS; KW2, suspected multiple herbicide-resistant (MHR) population from Kiowa County, KS; PR8, suspected MHR population from Pratt County, KS; BT12, suspected MHR population from Barton County, KS; LD_{50} and GR_{50} are effective doses (fl oz/a) of Roundup PowerMax required for 50% control and shoot dry weight reduction, respectively.
[b] R/S is calculated as a ratio of LD_{50} or GR_{50} of an MHR population to LD_{50} or GR_{50} of the SUS population.

Table 2. Regression parameter (equation 1) estimates for whole plant dose-response of Palmer amaranth populations from Kansas treated with Callisto (mesotrione) herbicide

Population[a]	d (± SE)	b (± SE)	LD_{50} or GR_{50} (± SE)	R/S[b]
Based on % visible control				
SUS	99.3 (3.2)	-1.9 (0.3)	0.4 (0.03)	-
KW2	89.4 (3.3)	-1.7 (0.3)	1.5 (0.15)	3
PR8	98.1 (2.1)	-4.4 (1.7)	0.8 (0.03)	2
BT12	92.3 (3.8)	-1.4 (0.2)	1.9 (0.13)	4
Based on shoot dry weight				
SUS	100.1 (5.1)	3.2 (0.9)	0.22 (0.01)	-
KW2	99.9 (5.3)	1.3 (0.3)	0.65 (0.03)	3
PR8	100.1 (4.9)	0.7 (0.2)	0.25 (0.01)	1
BT12	99.9 (4.3)	1.1 (0.2)	0.58 (0.04)	2

[a]Abbreviations: d, upper limit; b, slope of each curve; SUS, herbicide susceptible population from Ashland Bottoms research fields in Riley County, KS; KW2, suspected multiple herbicide-resistant (MHR) population from Kiowa County, KS; PR8, suspected MHR population from Pratt County, KS; BT12, suspected MHR population from Barton County, KS; LD_{50} and GR_{50} are effective doses (fl oz/a) of Callisto herbicide required for 50% control and shoot dry weight reduction, respectively.
[b] R/S is calculated as a ratio of LD_{50} or GR_{50} of an MHR population to LD_{50} or GR_{50} of the SUS population.

Table 3. Regression parameter (equation 1) estimates for whole plant dose response of Palmer amaranth populations from Kansas treated with Glean XP (chlorsulfuron) herbicide

Population[a]	d (± SE)	b (± SE)	LD_{50} (± SE)	R/S[b]
Based on % visible injury				
SUS	99.9 (3.3)	-1.2 (0.5)	0.03 (0.001)	-
KW2	86.9 (1.7)	-6.9 (2.2)	0.06 (0.001)	2
PR8	98.8 (4.8)	-0.6 (0.1)	0.38 (0.01)	12
BT12	57.4 (2.4)	-1.6 (0.4)	0.34 (0.04)	11

[a]Abbreviations: d, upper limit; b, slope of each curve; SUS, herbicide susceptible population from Ashland Bottoms research fields in Riley County, KS; KW2, suspected multiple herbicide-resistant (MHR) population from Kiowa County, KS; PR8, suspected MHR population from Pratt County, KS; BT12, suspected MHR population from Barton County, KS; LD_{50} are effective doses (oz/a) of Glean herbicide required for 50% control of each population, respectively.
[b]R/S is calculated as a ratio of LD_{50} of an MHR population to LD_{50} of the SUS population.

Table 4. Regression parameter (equation 1) estimates for whole plant dose response of Palmer amaranth populations from Kansas treated with AAtrex 4L (atrazine) herbicide

Population [a]	d (± SE)	b (± SE)	GR_{50} (± SE)	R/S[b]
Based on shoot dry weights				
SUS	100.1 (5.5)	0.7 (0.05)	0.31 (0.06)	-
KW2	100.6 (4.6)	0.4 (0.07)	1.74 (0.08)	5
BT12	101.8 (5.4)	1.0 (0.16)	5.2 (0.09)	16

[a]Abbreviations: d, upper limit; b, slope of each curve; SUS, herbicide susceptible population from Ashland Bottoms research fields in Riley County, KS; KW2, suspected multiple herbicide-resistant (MHR) population from Kiowa County, KS; BT12, suspected MHR population from Barton County, KS; GR_{50} are effective doses (fl oz/a) of AAtrex 4L herbicide required for 50% shoot dry weight reduction of each population, respectively.
[b]R/S is calculated as a ratio of GR_{50} of an MHR population to GR_{50} of the SUS population.

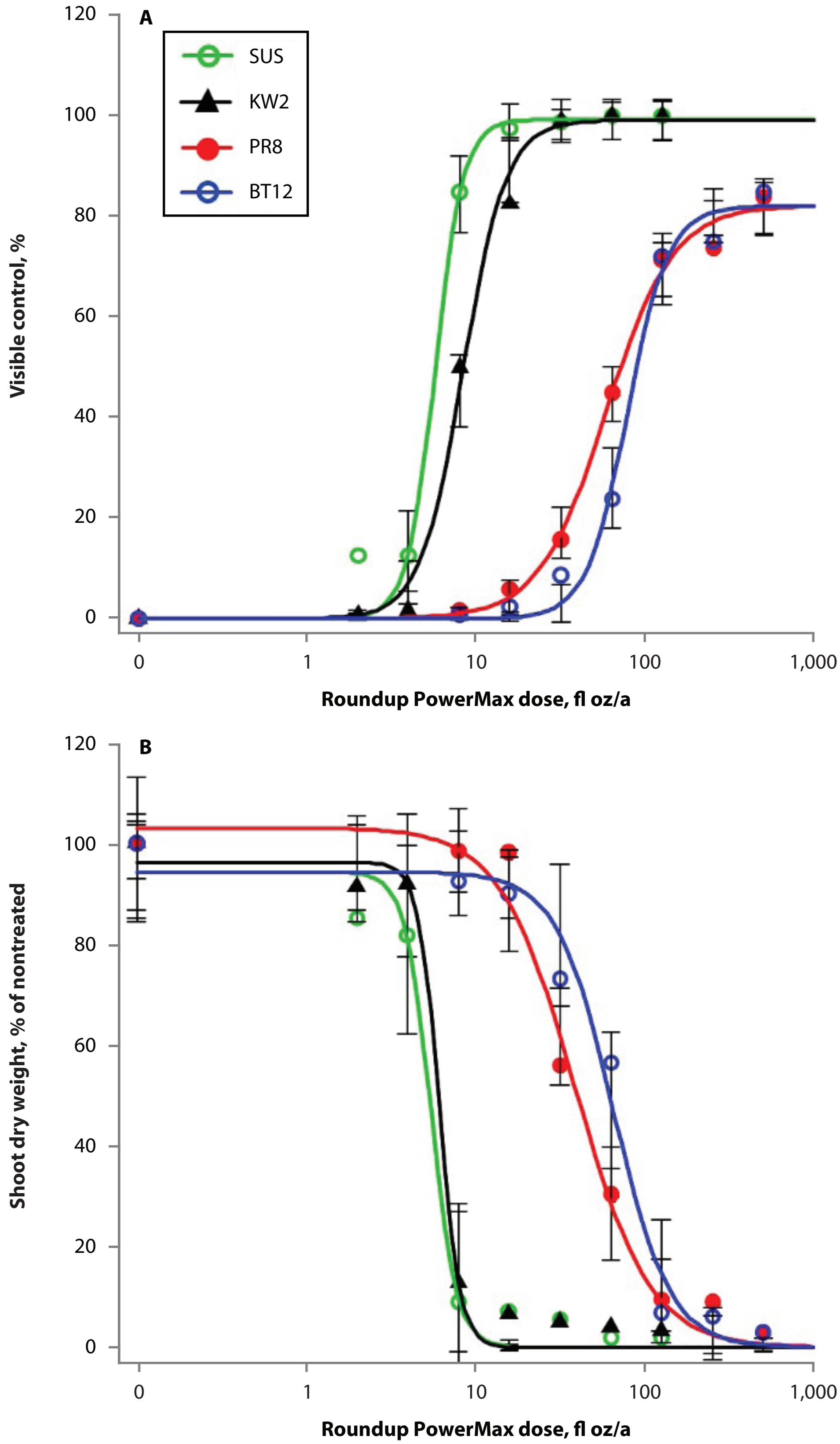

Figure 1. Visible control (%) (A) and shoot dry weight (B) response of three MHR Palmer amaranth populations (KW2, PR8, and BT12) and an herbicide-susceptible population (SUS) in a whole plant dose–response experiment with Roundup PowerMax (glyphosate) herbicide.

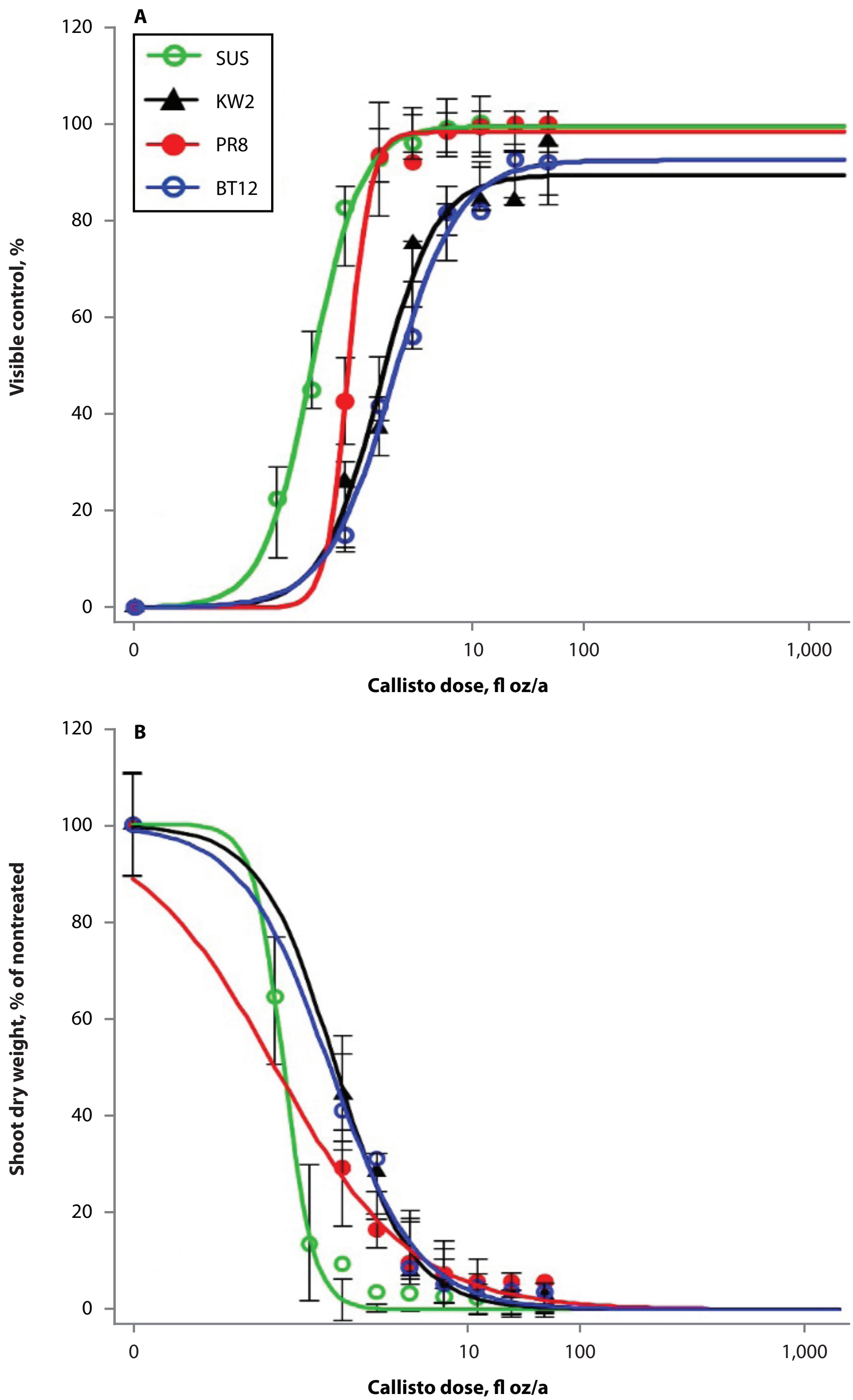

Figure 2. Visible control (%) (A) and shoot dry weight (B) response of three MHR Palmer amaranth populations (KW2, PR8, and BT12) and an herbicide-susceptible population (SUS) in a whole plant dose–response experiment with Callisto (mesotrione) herbicide.

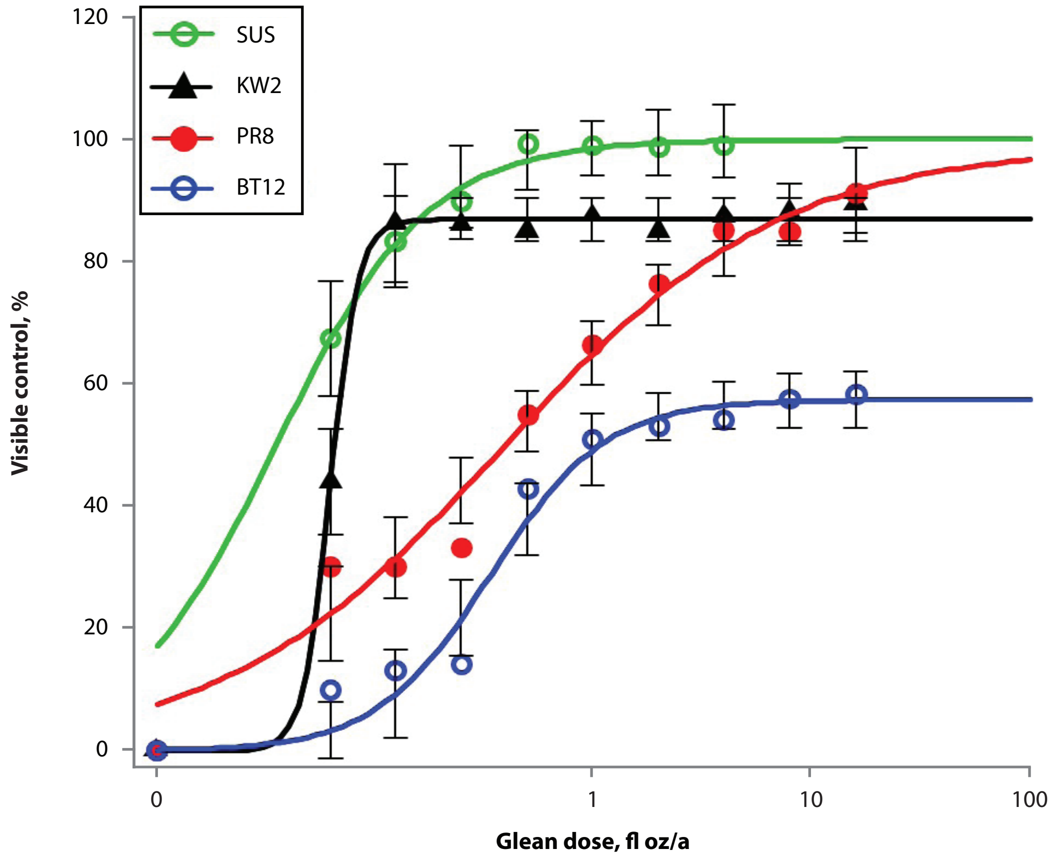

Figure 3. Visible control (%) response of three MHR Palmer amaranth populations (KW2, PR8, and BT12) and an herbicide-susceptible (SUS) population in a whole plant dose–response experiment with Glean (chlorsulfuron) herbicide.

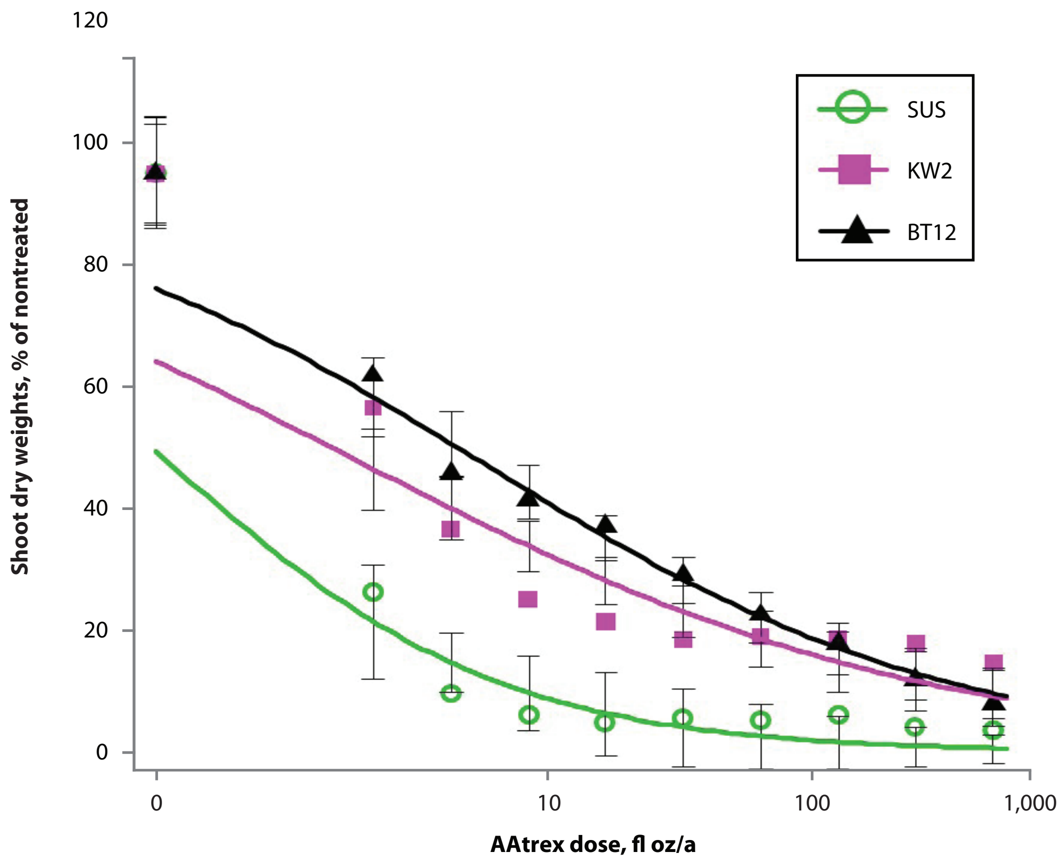

Figure 4. Shoot dry weight response of two MHR Palmer amaranth populations (KW2 and BT12) and an herbicide-susceptible population (SUS) in a whole plant dose–response experiment with AAtrex 4L (atrazine) herbicide.

Variable Response of Kochia Accessions to Dicamba and Fluroxypyr in Western Kansas

V. Kumar, P.W. Stahlman, R.S. Currie, R. Engel, and G. Boyer

Summary

The rapid development of glyphosate resistance in kochia has increased the use of auxinic herbicides (dicamba and fluroxypyr) in the US Great Plains, including Kansas. Increasing reliance on auxinic herbicides for controlling glyphosate-resistant (GR) kochia may also enhance the evolution of resistance to these herbicide chemistries. The main objectives of this research were to (1) investigate the variation in kochia response to dicamba and fluroxypyr, and (2) characterize the dicamba resistance levels among progeny of kochia accessions collected from western Kansas. Greenhouse experiments were conducted at the Kansas State University Agricultural Research Center near Hays, KS. Discriminate-dose studies with field-use rates of Clarity (dicamba) (16 fl oz/a) and Starane Ultra (fluroxypyr) (9.6 fl oz/a) indicated that progeny from individual kochia plants (accessions) collected near Garden City, KS, had 78 to 100% and 85 to 100% survivors when treated with dicamba and fluroxypyr herbicides, respectively, at 28 days after treatment (DAT). In separate dicamba dose-response experiments, two putative dicamba-resistant (DR) kochia accessions viz., DR-110 and DR-113 collected near Hays, KS, had about 5- and 3-fold resistance to dicamba, respectively, based on fresh weight reduction (I_{50}) compared to a dicamba-susceptible (DS) accession. Based on plant dry weight response, the DR-110 and DR-113 accessions showed 9- and 6-fold resistance to dicamba, respectively. These results confirm the co-evolution of cross-resistance to dicamba and fluroxypyr in kochia accessions from Garden City, and moderate to high level resistance to dicamba in the Hays accessions. Growers should adopt stewardship programs for auxinic herbicides and utilize all available weed control tactics to prevent further evolution of auxinic resistance in kochia populations.

Introduction

Kochia (*Kochia scoparia* L.) is a problematic summer annual broadleaf weed species that has spread across the Great Plains states, including Kansas. Kochia emergence initiates early in the spring (February - March) continuing in flushes through late spring (late May to early June), then slows with occasional plant emergence into summer months. Kochia is a fast growing weed species and produces enormous numbers of seeds (>100,000 seeds/plant) (Kumar and Jha 2015). Kochia manifests the unique way of spreading seeds to long distances, i.e. "tumbling mechanism." Season-long infestation of kochia at higher densities is known to cause significant crop yield reductions.

The evolution of kochia populations with resistance to herbicides is a tremendous challenge for growers across western Kansas and other US Great Plains states. Currently, kochia resistant to sulfonylurea (ALS inhibitors), atrazine (photosystem II inhibitors), dicamba (synthetic auxins), and glyphosate has been reported (Heap, 2018). GR kochia was first confirmed in crop production fields in Kansas in 2007 and is now fairly common throughout the central and northern Great Plains. With the increasing spread of GR kochia, growers are relying heavily on preemergence (PRE) and postemergence

(POST) dicamba applications. This increasing reliance on dicamba applications for controlling GR kochia may also escalate the risk of widespread evolution of DR kochia. The main objective of this study was to investigate the response of selected kochia accessions from western Kansas to POST dicamba and fluroxypyr herbicides.

Procedures

Fully-matured seeds were collected from individual plants that survived a 16 oz/a rate of Clarity (dicamba) herbicide POST application in research plots at the Kansas State University Agricultural Research Center near Hays, KS. These were designated as accessions, i.e. DR-104, DR-107, DR-110, and DR-113.The sampled field was historically under a continuous wheat–sorghum–fallow rotation and had received frequent dicamba applications in glyphosate-based burndown treatments. In addition, seeds of a dicamba-susceptible (DS) kochia accession were collected from pasture land with no previous history of dicamba use, located approximately 2 km from the cultivated field. Similarly, seeds of individual kochia plants surviving two applications of Starane Ultra (fluroxypyr) herbicide at field-use rate (6.4 fl oz/a) were collected from two different corn fields (designated as KS-4 and KS-10) near Garden City, KS. The sampled fields were under a wheat–fallow–wheat rotation for >6 years followed by corn (for KS-4 accession) or a wheat–corn–fallow rotation (for KS-10 accession) with frequent use of dicamba and fluroxypyr herbicides. Kochia seedlings from each accession were grown in a greenhouse at the Kansas State University Agricultural Research Center near Hays, KS. Discriminate-dose experiments with Clarity (16 fl oz/a) and Starane Ultra (9.6 fl oz/a) were conducted using progeny seeds of each selected kochia accession (about 100 seedlings per herbicide). Dose-response experiments were also conducted to further characterize the response of DR-110, DR-113, and DS accessions to dicamba POST applications. Dose-response studies were conducted in a randomized complete block design, with 12 replications (1 plant/pot) and repeated twice. Doses of Clarity (dicamba) herbicide used were 0, 8, 16, 32, 48, 64, and 80 fluid oz/a. Data on visual control (on a scale of 0 to 100; 0 being no injury and 100 being dead plant) were recorded at 14 and 28 days after treatment (DAT), and individual plants were harvested to determine the fresh and shoot dry weight at 28 DAT. Data were analyzed using a three parameter log-logistic model in *R* software using following equation (Ritz et al., 2015):

$$y = \{d/1+\exp[b(\log x - \log e)]\} \qquad [1]$$

where y refers to the response variable (fresh or shoot dry weight), d is the upper limit, b is the slope of each curve, *e* is the herbicide dose required to cause 50% reductions in fresh and shoot dry weight (referred to as I_{50} or GR_{50}), and x is the herbicide dose. Nonlinear regression parameter estimates and standard errors for each accession were determined using the *drc* package in R software. Resistance factor (referred as R/S ratio) to dicamba was estimated by dividing the I_{50} or GR_{50} value of each DR accession by the I_{50} or GR_{50} value of DS accession.

Results

Discriminate-Dose Study

Results from single-dose experiments with dicamba indicated that DR-113, DR-104, DR-107, and DR-110 kochia accessions collected near Hays, KS, had 88, 97, 98, and

100% survivors at 28 DAT, respectively (data not shown). Similarly, progeny seedlings from the two Garden City, KS, accessions had 78 to 100% and 85 to 100% survivors with discriminate doses of Clarity and Starane Ultra herbicides, respectively, at 28 DAT (Table 1, Figure 1). In contrast, seedlings of the DS accession did not survive the discriminate dose of either Clarity or Starane Ultra herbicide at 28 DAT (data not shown).

Dicamba Dose-Response Study

Results from dicamba dose-response experiments indicated that about 5- and 3-fold higher dicamba dose was required to obtain 50% fresh weight reduction (I_{50}) of DR-110 and DR-113 accessions, respectively, relative to the DS accession (Table 2; Figure 2). Furthermore, about 38 and 24 fl oz/a of Clarity (dicamba) was needed to achieve a 50% dry weight reduction (GR_{50}) in DR-110 and DR-113 accessions, respectively. Based on shoot dry weight response (GR_{50} values), the DR-110 and DR-113 accessions showed approximately 9- and 6-fold resistance to dicamba, respectively (Table 2; Figure 2). These results are in agreement with Brachtenbach (2015), who reported at least 8-fold difference among 11 kochia populations in susceptibility to POST dicamba. Thus, both tested accessions in the current study had developed moderate to high level resistance to dicamba herbicide.

Practical Implications

These results confirm the evolution of kochia accessions with resistance to auxinic herbicides (dicamba and fluroxypyr) in western Kansas. The continuous and sole reliance on these herbicide chemistries for controlling kochia may further escalate the evolution and spread of auxinic herbicide resistance trait among field populations. Additionally, the rapid adoption of newly-developed dicamba-tolerant crops may further exacerbate the problem of auxinic herbicide resistance in kochia populations. Growers are advised to adopt dicamba and fluroxypyr use stewardship programs and are encouraged to utilize multiple modes of action herbicides in conjunction with other cultural and mechanical approaches to prevent evolution of auxinic-resistant kochia on their production fields. Further studies will focus on characterizing the resistance levels to fluroxypyr in those confirmed kochia accessions. In addition, the response of DR kochia to PRE applications of dicamba will also be investigated under field conditions.

References

Brachtenbach DA (2015) *Kochia scoparia* response to dicamba and effective management practices for soybeans. MS Thesis. Kansas State University, Manhattan, KS.

Heap IM (2018) The International Survey of Herbicide Resistant Weeds. Accessed on March 16, 2018. Available www.weedscience.org

Kumar V, Jha P (2015) Influence of glyphosate timing on *Kochia scoparia* demographics in glyphosate-resistant sugar beet. Crop Prot 76:39–45

Ritz C, Baty F, Streibig JC, Gerhard D (2015) Dose-response analysis using R. PLoS One 10:e0146021

Table 1. Percent survivors from progeny seeds of individual kochia plants (accessions KS-4 and KS-10) from Garden City, KS, treated with discriminate-doses of Clarity (16 oz/a) or Starane Ultra (9.6 fl oz/a) herbicides at 28 days after treatment

	% Survivors			% Survivors	
Kochia plant	Clarity	Starane Ultra	Kochia plant	Clarity	Starane Ultra
KS-4A	96	98	KS-10A	98	100
KS-4B	80	100	KS-10B	87	100
KS-4C	80	85	KS-10C	97	94
KS-4D	78	94	KS-10D	94	92
KS-4E	98	90	KS-10E	100	100
KS-4F	96	89	KS-10F	97	100
KS-4G	100	90	KS-10G	95	96
KS-4H	83	98	KS-10H	98	100

Table 2. Regression parameter (equation 1) estimates for whole plant dose response of kochia accessions from Hays, KS, treated with Clarity (dicamba) herbicide

	Regression parameters (±SE) [b]				
Accession[a]	d	b	I_{50} or GR_{50}	95% CI	R/S
Based on fresh weight					
DS	40.2 (1.1)	1.1 (0.1)	12	10–14	-
DR-110	39.4 (1.0)	1.4 (0.2)	66	58–74	5.5
DR-113	39.9 (1.1)	0.9 (0.1)	38	32–44	3.1
Based on dry weight					
DS	10.2 (0.3)	0.5 (0.01)	4	2–6	-
DR-110	10.0 (0.3)	1.0 (0.1)	38	31–45	9.5
DR-113	10.4 (0.2)	0.8 (0.01)	24	19–29	6.0

d = upper limit. b = slope of each curve.

[a]Abbreviations: DS, dicamba susceptible kochia accession from a disturbed area in a pasture near Hays, KS; DR-110 and DR-113, putative dicamba-resistant kochia accessions from research plots in a fallow field near Hays, KS.

[b] I_{50} or GR_{50} is effective dose (fl oz/acre) of Clarity for 50% fresh and shoot dry weight reduction, respectively; [b] R/S (resistance factor) is the ratio of I_{50} or GR_{50} of a dicamba-resistant to I_{50} or GR_{50} of the DS kochia accession.

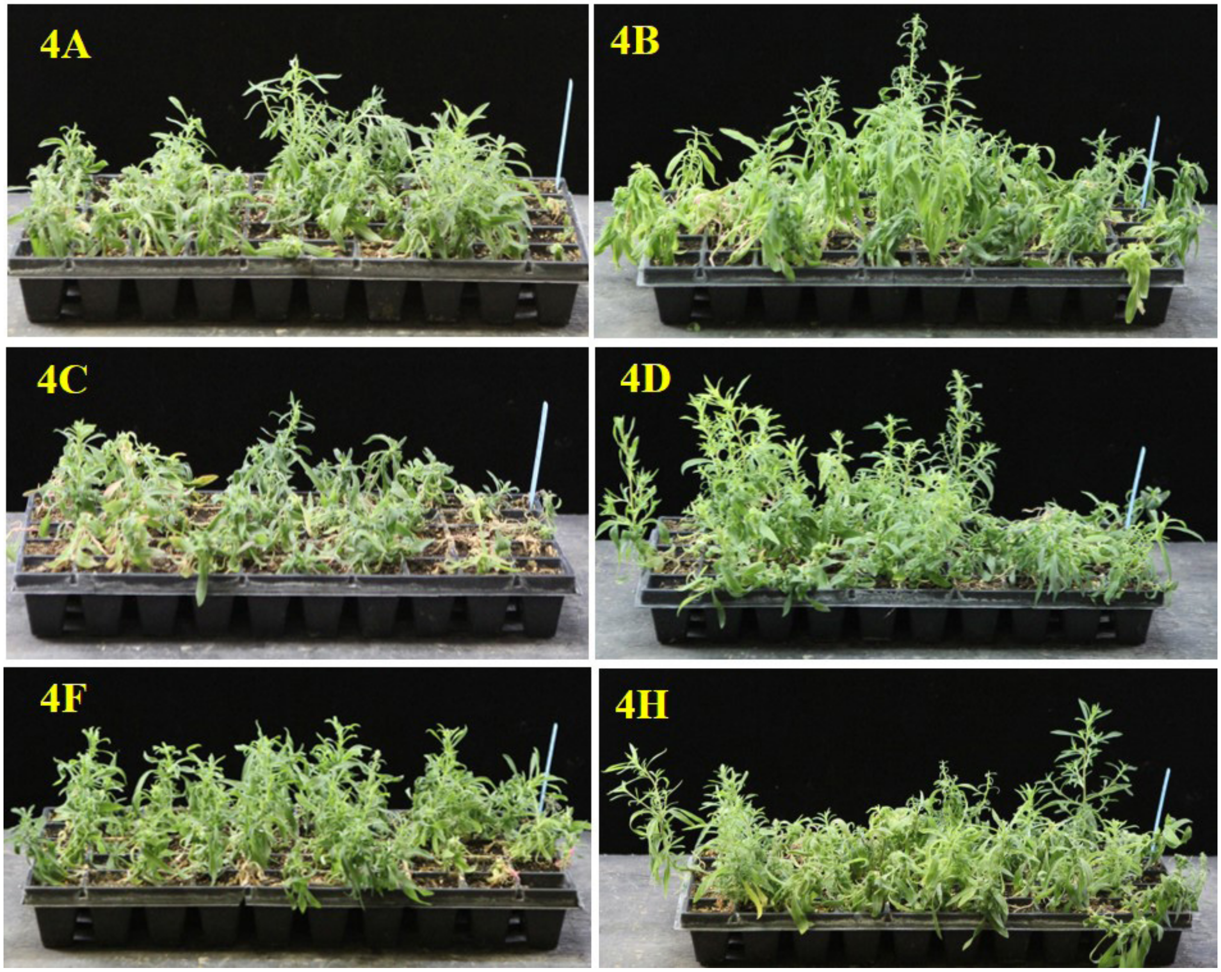

Figure 1. Percent survivors from progeny seedlings of individual kochia plants (accession KS-4) from Garden City, KS, treated with discriminate-dose of Starane Ultra (9.6 fl oz/a) herbicide at 28 days after treatment.

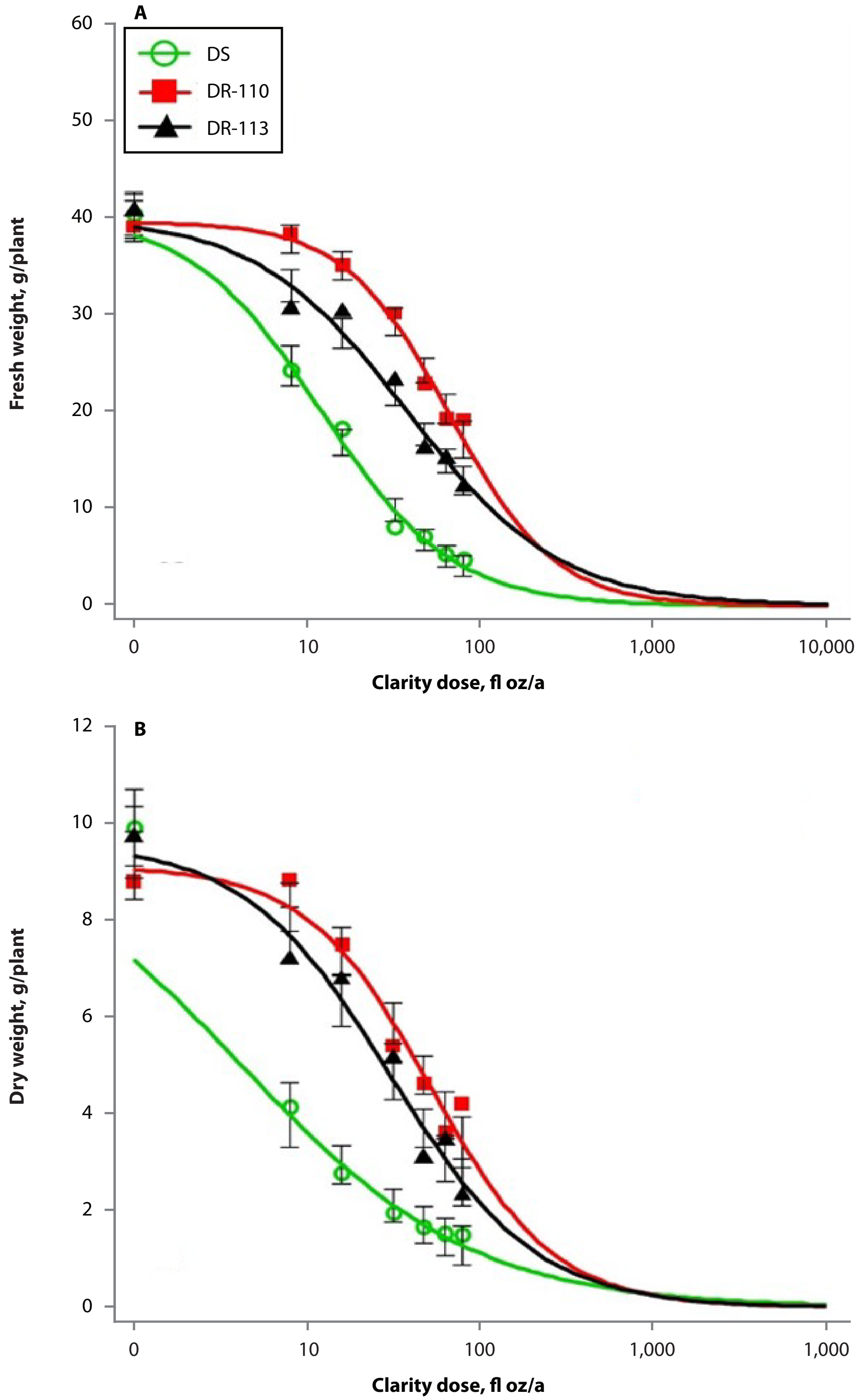

Figure 2. Fresh (A) and shoot dry weight (B) response of two putative dicamba-resistant (DR) kochia accessions (DR-110 and DR-113) and one dicamba-susceptible (DS) accession in a whole plant dose–response experiment with Clarity (dicamba) herbicide.

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

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

Abstract
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.

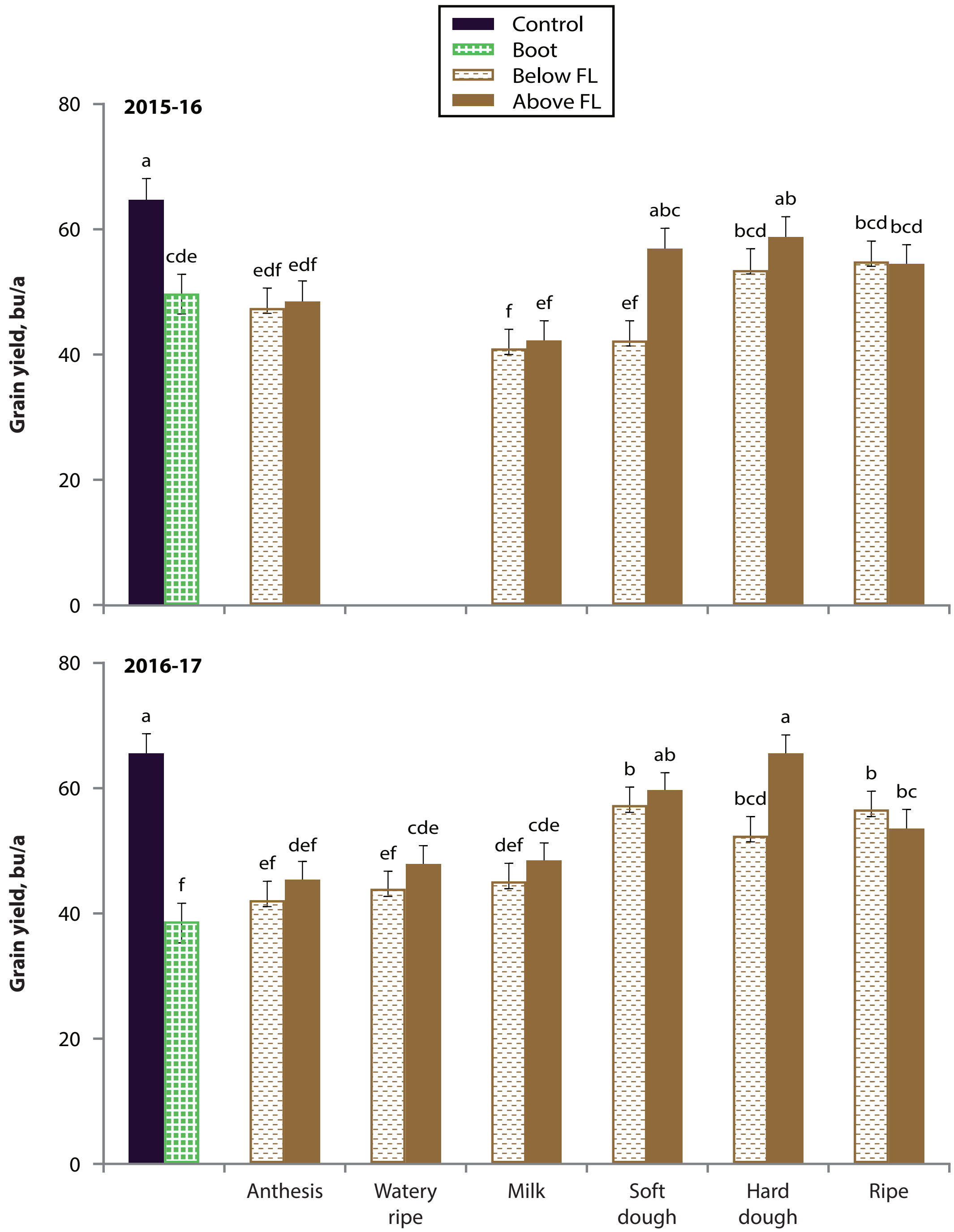

Figure 1. Wheat grain yield as affected by stem bending treatment in Manhattan, KS, during the 2015–2016 (upper panel) and 2016–2017 (lower panel) growing seasons.

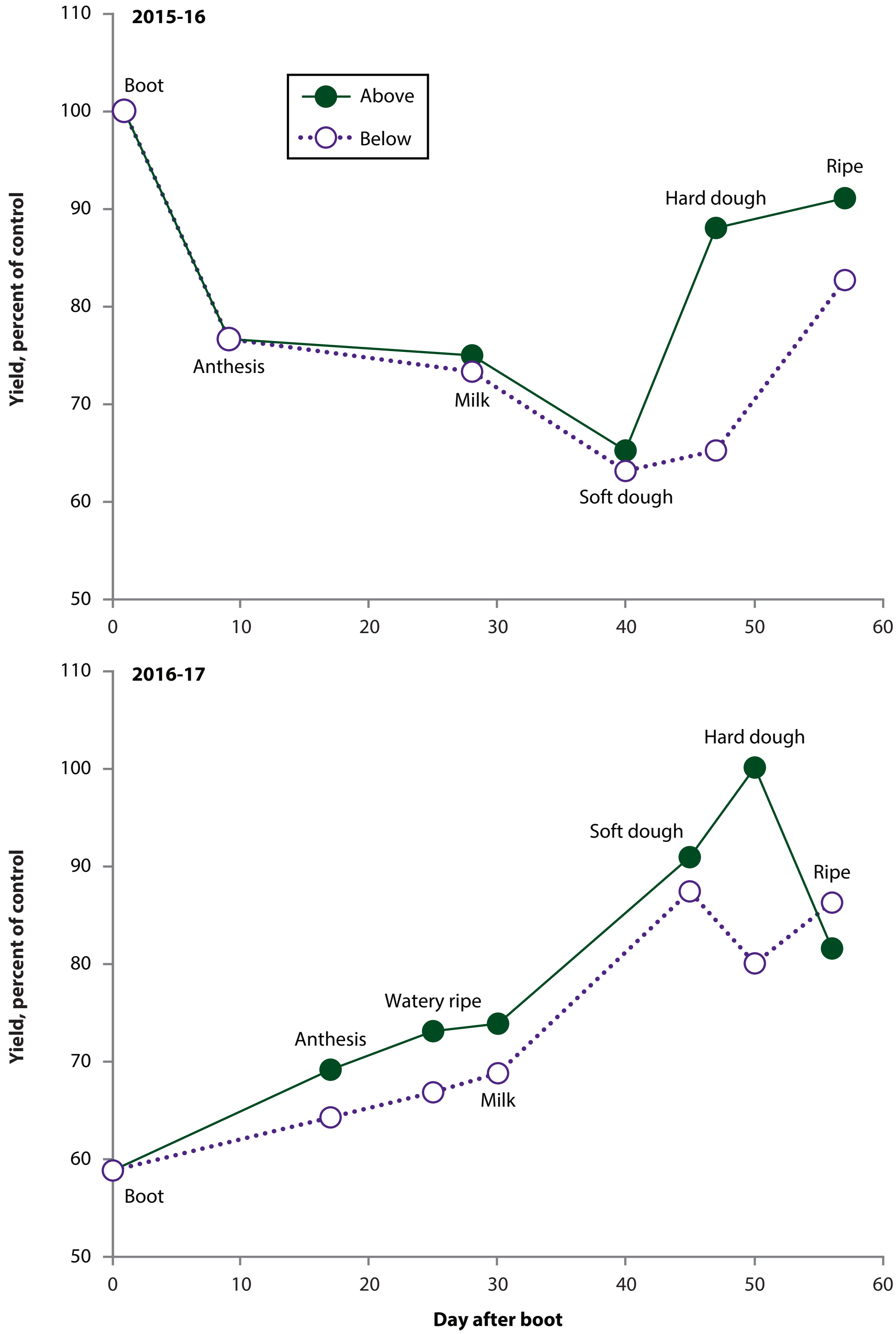

Figure 2. Grain yield, expressed as percent of the control treatment, as affected by break-point in reference to the flag leaf (above, solid circles; below, open circles) and by number of days after boot (e.g. date of first treatment application) during the 2015–2016 (upper panel) and 2016–2017 (lower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

Wheat Variety Response to Seeding Rate in Kansas During the 2015–2016 and 2016–2017 Growing Seasons

R.P. Lollato, G. Zhang, B.R. Jaenisch, R.E. Maeoka, L. Bonassi, and A. Fritz

Abstract

Plant density is among the major factors determining a crop's ability to capture resources such as water, nutrients, and solar radiation; therefore, different wheat varieties might require different seeding densities to maximize yield. The objective of this project was to better understand the response of different wheat varieties to seeding rate. Two field experiments were conducted during 2015–2016 and repeated during 2016–2017, evaluating seven wheat varieties subjected to five different seeding rates (0.6, 0.95, 1.3, 1.65, and 2.0 million seeds/a). Crop was managed for a 70 bu/a yield goal and pests were controlled using commercially available pesticides. Final stand and grain yield were measured, and all statistical analyses were performed for relating emerged plants per acre to grain yield. At each individual environment and across varieties, grain yield usually was maximized at approximately 0.9 million emerged plants per acre. There were significant differences among varieties in grain yield, with Joe and Tatanka usually outperforming the remaining tested varieties. Across environments, grain yield usually was maximized at populations between 0.6 and 0.7 million plants per acre for less responsive varieties (1863, Everest, and Tatanka), at approximately 0.9 million plants per acre for average responsive varieties (Joe, Bob Dole, KanMark, and Zenda), and more than 1.05 million emerged plants per acre for more responsive varieties (Larry and AG Icon). These preliminary data suggest that there is the potential to manage each wheat variety according to its individual tillering potential; however, more data are needed to make definite conclusions about each variety's optimum seeding rate. Thus, this experiment is currently being conducted at five sites during the 2017–2018 growing season.

Introduction

Plant density is among the major factors determining the crop's ability to capture resources such as water, nutrients, and solar radiation (Satorre and Slafer, 1999). The response of wheat to plant density is largely determined by competition for resources with neighboring plants, and increased competition can result in reduced survival, dry matter production, and grain yield of individual wheat plants (Satorre, 1988). Wheat plants subjected to high density generally have fewer tillers and grains than widely spaced plants (Rana et al., 1995). On the other hand, too widely spaced plants can result in few plants per unit area and consequently less grains per unit area, explaining the typical parabolic response of grain yield to plant density (Holliday, 1960). Consequently, appropriate management of population density may allow maximum yields per unit area to be achieved (Satorre and Slafer, 1999). Given the difference in wheat varieties regarding their ability to tiller as well as their response to intra-canopy competition for resources, it is possible that different varieties require different seeding densities to maximize yield. Therefore, the main objective of this project was to better understand the response of different wheat varieties to seeding rate.

Procedures

One experiment was conducted at four site-years: at the South Central Experiment Field near Hutchinson, KS, during 2015–2016 and 2016–2017; at the Agronomy North Farm in Manhattan, KS, during 2015–2016; and at the North Central Experiment Field in Belleville, KS, during 2016–2017. Trials were established in a randomized complete block design with four replications. Seven varieties (i.e. Everest, KanMark, 1863, Larry, Zenda, Tatanka, and Joe during 2015–2016; and KanMark, Larry, Zenda, Tatanka, Joe, Bob Dole, and AG Icon in 2016–2017) and five seeding rates (0.6, 0.95, 1.3, 1.65, and 2 million seeds/a) were tested, for a total of 35 treatments and 140 plots per location. Plots were 7 rows wide at a 7.5-in. row spacing in Manhattan and at both locations during the 2016–2017 growing season, and 6 rows wide at a 10-in. row spacing in Hutchinson. The harvestable portion of the plots was approximately 20-ft long at all locations.

Management practices adopted at all locations are described in Table 1 and initial soil fertility is listed in Table 2. Nitrogen (N) fertilization at all locations was performed with a yield goal of approximately 70 bu/a. Weeds and foliar diseases were controlled at both locations. Agronomic measurements included stand count approximately 3–4 weeks after planting, percent canopy cover measured several times during the growing season using digital imagery, and a 1-meter row subsample clipped from each plot at harvest time for biomass, harvest index, head count, average grain weight, and head size. The latter samples were still being processed at the time this report was prepared, therefore, results are not shown in the current report. Plots were harvested using a small plot combine at all locations, and grain yield was adjusted to a 13% moisture basis.

Results

Growing Season Weather

The weather during the 2015–2016 growing season was characterized by a warm and moist fall, followed by a dry and mild winter and a cool and moist spring (Table 3). Meanwhile, the 2016–2017 growing season started with a drier fall with similar temperature totals, received earlier moisture during the winter, and had a similar spring to that observed during the previous season, with plenty of precipitation and below-average temperatures (Table 3). Growing season precipitation total was 20.5 in. in Hutchinson and 24.4 in. in Manhattan (2015–2016), and 18.2 in. in Hutchinson and 14.8 in. in Belleville (2016–2017). Despite the high precipitation totals, cumulative solar radiation during the growing season was well above 3,000 MJ m^{-2} at all studied site-years, indicating that solar radiation should not have been a yield-limiting factor in this study.

Stand Establishment

The trials were sown into adequate moisture at all locations, which ensured good germination and stand establishment. Average percent establishment (final stand over targeted seeding rate) was 72% in 2015–2016 and 92% in 2016–2017. At all site-years, increasing seeding rate increased the final stand count for all varieties at all locations (Figure 1).

Wheat Grain Yield: Individual Site-Year Analysis

There was a great difference in yield potential among study-locations, with average yield across all varieties and plant population densities ranging from 44 bu/a in Manhattan 2015–2016, 78 bu/a at both Hutchinson 2015–2016 and Belleville 2016–2017, and 101 bu/a in Hutchinson 2016–2017 (Figure 2). Yields were normally distributed across all locations. At all individual studied locations, grain yield was significantly affected by variety and by planting density, but there was no significant interaction (Table 4). In other words, there were grain yield differences among varieties and among population densities; however, the different varietal responses to planting density were not captured in each individual site-year analysis (all varieties responded similarly to the change in population density in each individual location). At all locations and years, wheat grain yield response averaged across varieties was well represented by an exponential rise to the maximum on a non-linear regression model, with wheat grain yields reaching 95% of the asymptotic maximum at approximately 890,000–911,000 emerged plants per acre in three out of four sites (Figure 3). The only exception was Hutchinson during 2015–2016, when grain yields maximized at 530,000 plants per acre. The lowest population density treatment at each location, which ranged from 445,000 to 721,000 plants per acre depending on site-year, resulted in grain yields statistically similar to the very next plant population density at all site-years, but had lower yields than the following greater population density treatments (greater than approximately 850,000 to 1,000,000 plants per acre, Figure 3).

Wheat Grain Yield: Analysis Pooled Across Site Years

The pooled analysis of variance was first performed over the entire dataset using raw yield data. Subsequently, due to the differences in yield environment among the four site-years in this study (Figure 2), the analysis was performed using relative yields. Relative yields were calculated for each variety at each site-year using the highest yielding plot for a particular variety as the denominator for all plots for that same variety. Wheat varieties behaved differently at each location and year, but some trends were observed. Grain yield averaged across seeding rates for each variety is shown in Figure 4. In Hutchinson, Larry, Joe, Tatanka, and KanMark were in the highest yielding group for both growing seasons; as well as 1863 and Bob Dole during the 2015–2016 and 2016–2017 growing seasons, respectively. In Manhattan 2015–2016 and Belleville 2016–2017, Joe had the highest grain yield as compared to the other varieties (Figure 4).

The initial analysis using the raw yield data allowed us to screen for varieties more responsive to plant population (i.e. varieties that showed large yield increases at higher stands), average responsive varieties, and less responsive varieties (varieties that tended to maximize yields at very low seeding rates). Among varieties that maximized yields at low seeding rates were Tatanka, Everest, and 1863, all of which maximized yields between 650,000 and 695,000 plants per acre (Figure 5). It is important to highlight that Everest and 1863 were only tested during 2015–2016 and thus reflect only one year's data, which gives us less confidence in the results. Tatanka has now a total of two years of data, providing greater strength to assume its good performance under low population densities. The majority of the varieties belonged to the average response group, including Joe, KanMark, Zenda, and Bob Dole – the latter only evaluated in one year of the experiment. This group maximized yields between 785,000 and 900,000 plants per acre (Figure 5). Varieties that required more plants to maximize yields included Larry and AG Icon (single year of data for the latter one), which required 1,080,000 to 1,060,000 plants per acre to maximize yields (Figure 5).

The previous results were later confirmed by the subsequent analysis, which discriminated among varieties but evaluated relative rather than raw grain yield. In the relative grain yield analysis pooled across site-years, Joe, KanMark, and Zenda again maximized yields between 775,000 and 870,000 plants per acre, which reflects the average response group (Figure 6); Larry and AG Icon maximized yields at populations beyond 950,000 plants per acre (more responsive varieties; Figures 6 and 7); and Tatanka, Bob Dole, Everest, and 1863 maximized yields at populations less than 690,000 plants per acre (less responsive varieties; Figures 6 and 7). Everest and 1863 showed no significant response to plant densities (Figure 7). Bob Dole was the only variety that showed discrepant results between the relative yield and raw yield data analyses, as it was categorized as an average responsive variety using the raw data and a less responsive variety using the relative yield data. Results for Everest, 1863, Bob Dole, and AG Icon should be interpreted with more caution than the remaining ones because they only reflected one year's data, and more tests are needed to increase the power of the analysis.

Preliminary Conclusions

With four site-years of data, we start gathering firm conclusions about each variety's response to plant population. Zenda, KanMark, and Joe seem to have an intermediate response to seeding rate and maximize yields around 800,000 to 900,000 plants per acre. Tatanka seems to be less responsive to plant population, maximizing yields with populations as low as 565,000 to 660,000 plants per acre. Larry has shown greater response to plant population, and yield was only maximized at populations above 1,060,000 plants per acre. While preliminary data suggest Everest and 1863 are not responsive to plant population, Bob Dole is intermediate, and AG Icon is more responsive, the limited number of observations (two site-years of data only) limit the power of this analysis and the breadth of these conclusions, not allowing for broader implications from the data. This study is currently being conducted at five locations during the 2017–2018 growing season so that more definite recommendations can be drawn for each variety.

References

Holliday, R. 1960. Plant population and crop yield. Field Crop Abstracts 13(3):159-167.

Rana, D.S., S. Ganga, and D.K. Pachauri. 1995. Response of wheat seeding rates and row spacing under dryland conditions. Annals of Agricultural Research 16:339-342.

Satorre, E.H. 1988. The competitive ability of spring cereals. PhD Thesis, University of Reading, UK.

Satorre, E.H., and G.A. Slafer. 1999. Wheat: ecology and physiology of yield determination. Food Products Press, Binghamton, NY. pp. 503

Table 1. Location (latitude, longitude, and elevation), soil type, and management practices adopted at all study locations during the 2015–2016 and 2016–2017 growing seasons

	2015–2016		2016–2017	
	Hutchinson	Manhattan	Hutchinson	Belleville
Latitude	37.9313°N	39.2181°N	37.927501°N	39.81841°N
Longitude	98.0246°W	96.5907°W	98.026516°W	97.671968°W
Elevation	1535 ft	1020 ft	1535 ft	1545 ft
Soil type	Ost loam	Kahola silt loam	Ost loam	Crete silt loam
Tillage	Conventional till	No-till	Conventional till	Conventional till
Previous crop	Wheat	Corn	Wheat	Wheat
Planting date	10/07/2015	10/08/2015	10/13/2016	10/03/2016
Row spacing	10 in.	7.5 in.	7.5 in.	7.5 in.
Topdress N rate	107 lb N/a	99 lb N/a	113 lb N/a	75 and 35 lb N/a
Topdress N date	02/19/2016	02/28/2016	2/21/2017	9/24/2016 and 2/17/2017
Herbicide rate	Powerflex – 2 oz/a MCPE – 1 pt/a AMS 2.8 lb / 100 gal mix	Harmony Extra – 0.7 oz/a MCPA Ester – 16 oz/a NCIS – 16 oz / 100 gal mix	Powerflex 2 oz/a + MCPA ester 1.5 pt/a 15 gal water/a	0.4 oz of Affinity BroadSpec, 0.75 pt Sword (MCPA), 1 qt/100 gal NIS
Herbicide date	02/19/2016	03/10/2016	11/15/2016	11/14/2016
Fungicide rate	Quilt Xcel 12 fl. oz/a	Quilt Xcel – 14 fl. oz/a	Aproach Prima 6.8 oz/a	Aproach Prima 6.8 oz/a
Fungicide date	4/25/2016	04/22/2016	4/26/2017	5/10/2017
Harvest date	06/16/2016	06/24/2016	6/20/2017	6/28/2017

Table 2. Initial soil fertility at both study locations

	2015–2016				2016–2017			
	Hutchinson		Manhattan		Hutchinson		Belleville	
Nutrient	0–6 in.	6–24 in.	0–6 in.	6–24 in.	0–6 in.	6–24 in.	0–6 in.	6–24 in.
pH	4.9	6.3	6.6	7.0	7.86	7	5.9	5.9
NO_3-N (lb/a)	20.6	33.6	19.4	21	25.4	26.9	9.1	11.4
Phosphorus (ppm)	74.7	21.4	39.8	15.3	63.3	---	41.7	11.6
Potassium (ppm)	238	170	210	227	201	---	474	224
Calcium (ppm)	1379	2976	4045	5383	2172	---	1532	2005
Magnesium (ppm)	231	293	311	279	181	---	202	245
Sodium (ppm)	17.9	42.7	22.8	23.9	12.8	---	13.3	18.7
SO_4-S (ppm)	7.9	7.4	7	4.4	7.8	---	2.9	2.5
Chlorine (ppm)	9	4.8	4.8	3.3	4.8	---	5.0	3.3
CEC (meq/100 g)	15	17.4	26.8	23.1	12.9	---	21.1	23.5
Organic matter (%)	2.2	---	3.9	---	1.9	---	3.0	---

Soil samples were collected at sowing.

Table 3. Summary of the observed weather during the 2015–2016 (Manhattan and Hutchinson) and 2016–2017 (Hutchinson and Belleville) growing seasons

	2015–2016					
	Hutchinson			Manhattan		
Season	Average temperature	Precipitation	Solar radiation	Average temperature	Precipitation	Solar radiation
	°F	in.	MJ m^{-2}	°F	in.	MJ m^{-2}
Fall	47.9	7.2	837	48.7	8	765
Winter	41	2.2	1156	40.9	1.3	1041
Spring	62.9	11.1	1578	67.3	15.2	1905
	2016–2017					
	Hutchinson			Belleville		
Fall	46.6	1.6	768	44.8	3.6	841
Winter	44.1	5.8	943	38.6	2.6	992
Spring	64.2	10.8	1640	62.4	8.6	1888

Average temperature, and cumulative precipitation and solar radiation are shown for the fall (planting – December 31), winter (Jan 1 – March 31), and spring (April 1 – harvest date) for all locations.

Table 4. Significance of the source of variation on wheat grain yield in Hutchinson, Manhattan, and Belleville, KS, during the 2015–2016 and 2016–2017 growing seasons

	2015–2016		2016–2017	
Source of variation	Hutchinson	Manhattan	Hutchinson	Belleville
Variety	***	***	***	***
Plant population	*	***	***	***
Variety × Plant population	ns	ns	ns	ns

*, *** = significant at $P < 0.05$ and 0.001, respectively.
ns = not significant.

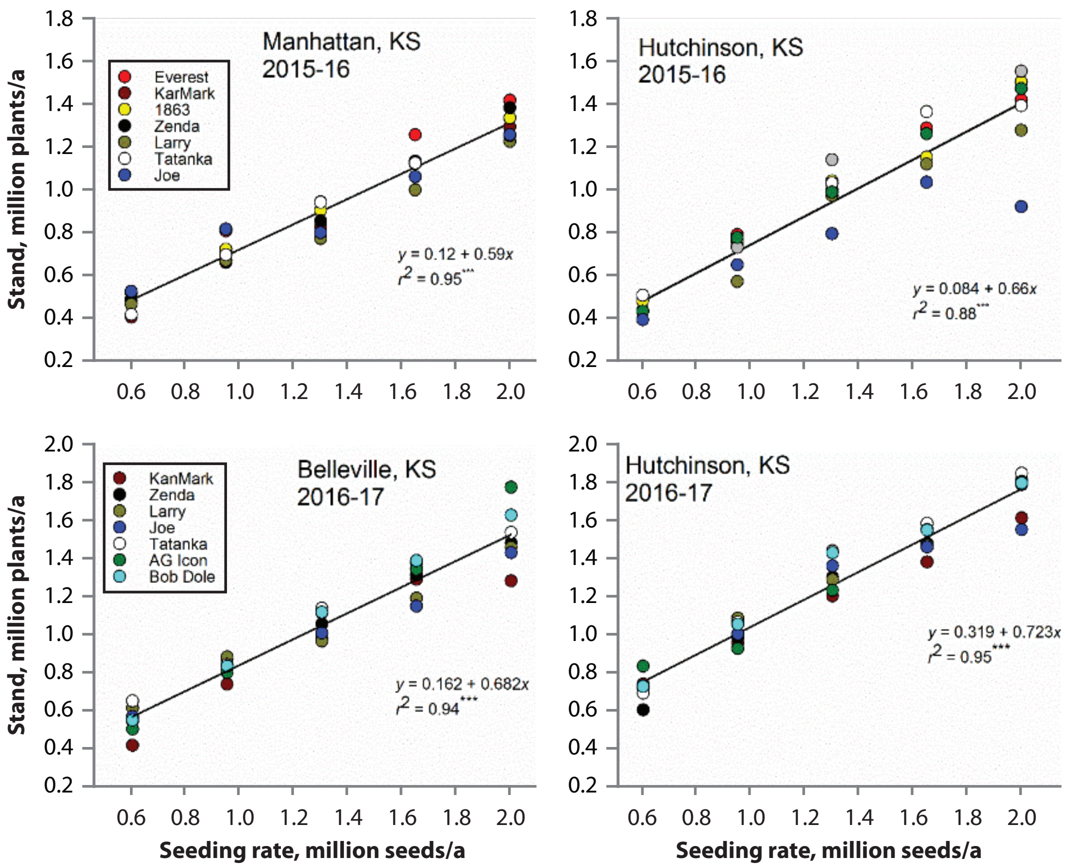

Figure 1. Final plant stand as affected by seeding rate in Hutchinson and Manhattan during the 2015–2016 growing season (upper panels) and Hutchinson and Belleville during the 2016–2017 growing season (lower panels). * Indicates that the regression coefficient was significant at $P < 0.001$.**

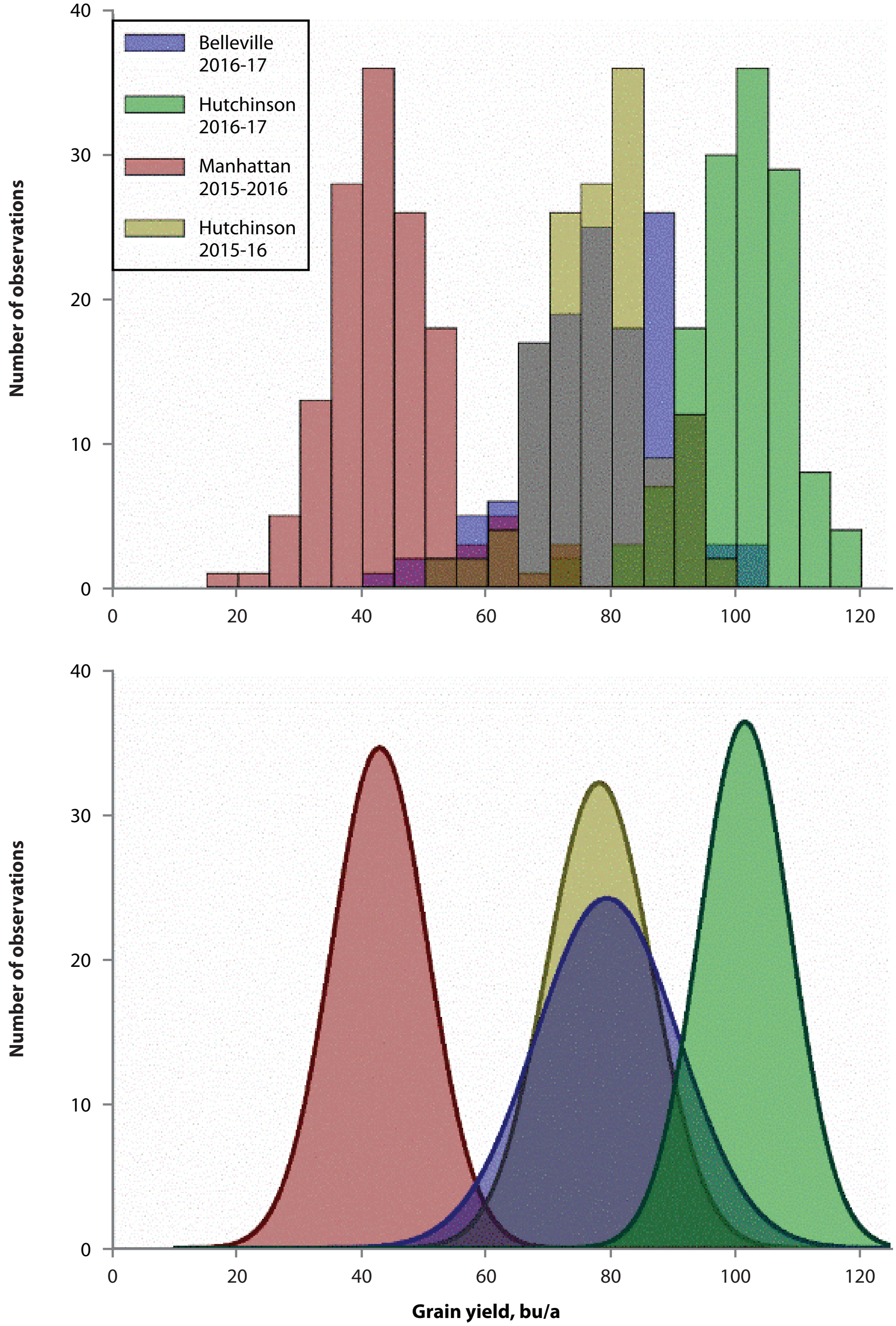

Figure 2. Wheat grain yield distribution across all studied site-years shown as histograms (upper panel) and the Gaussian model fit around each respective histogram (lower panel).

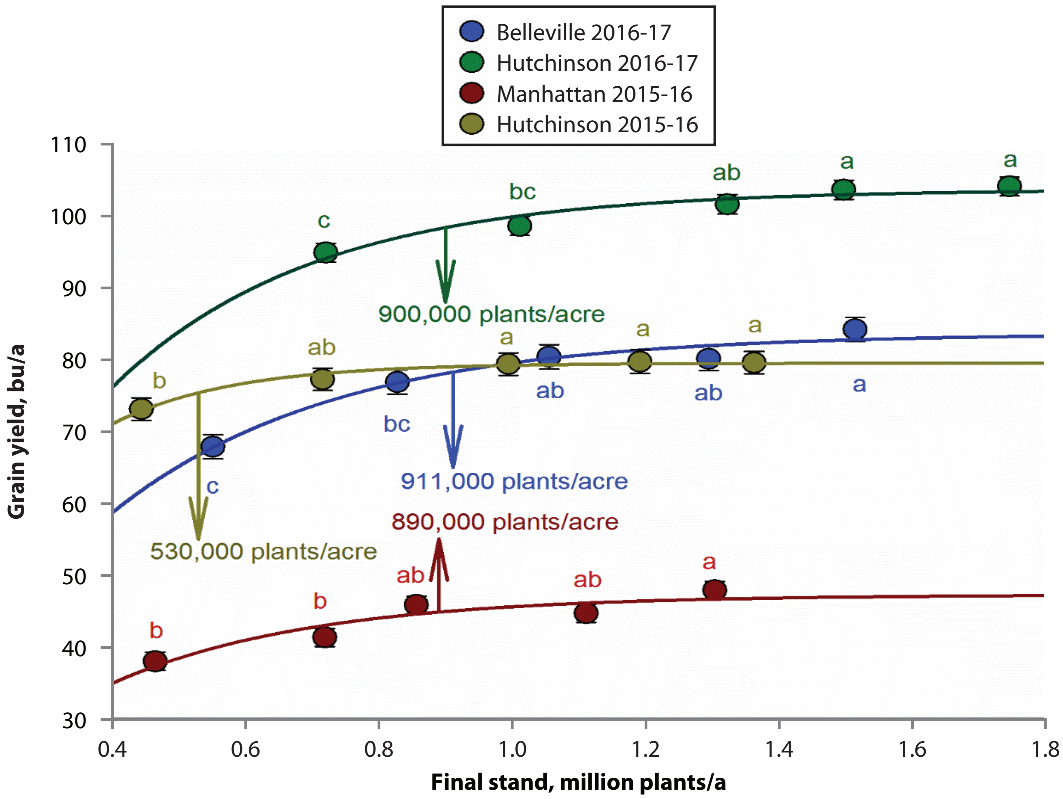

Figure 3. Wheat grain yield response to plant population at the four site-years included in this report. Wheat yields are averages across varieties due to the non-significance of variety × seeding rate interaction.

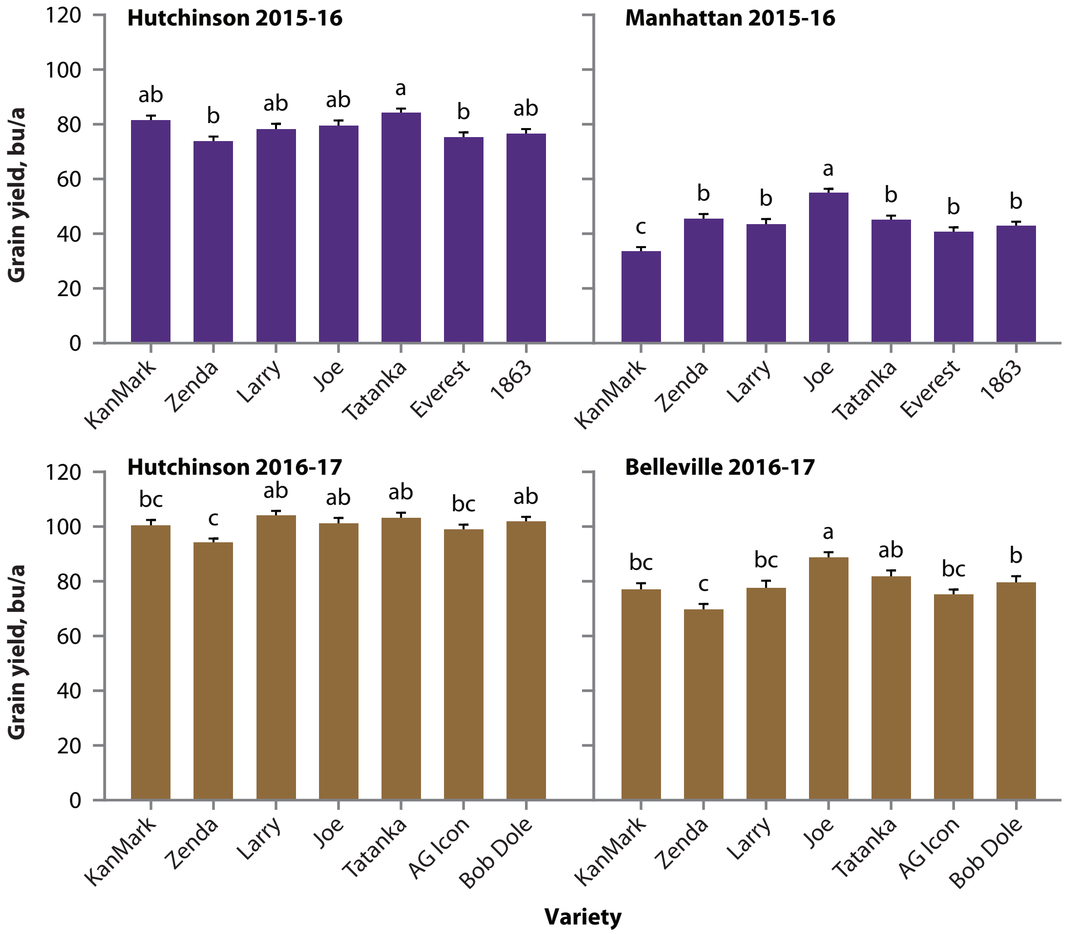

Figure 4. Wheat grain yield as affected by wheat variety and pooled across seeding rates during the 2015–2016 (upper panels) and 2016–2017 (lower panels) growing seasons.

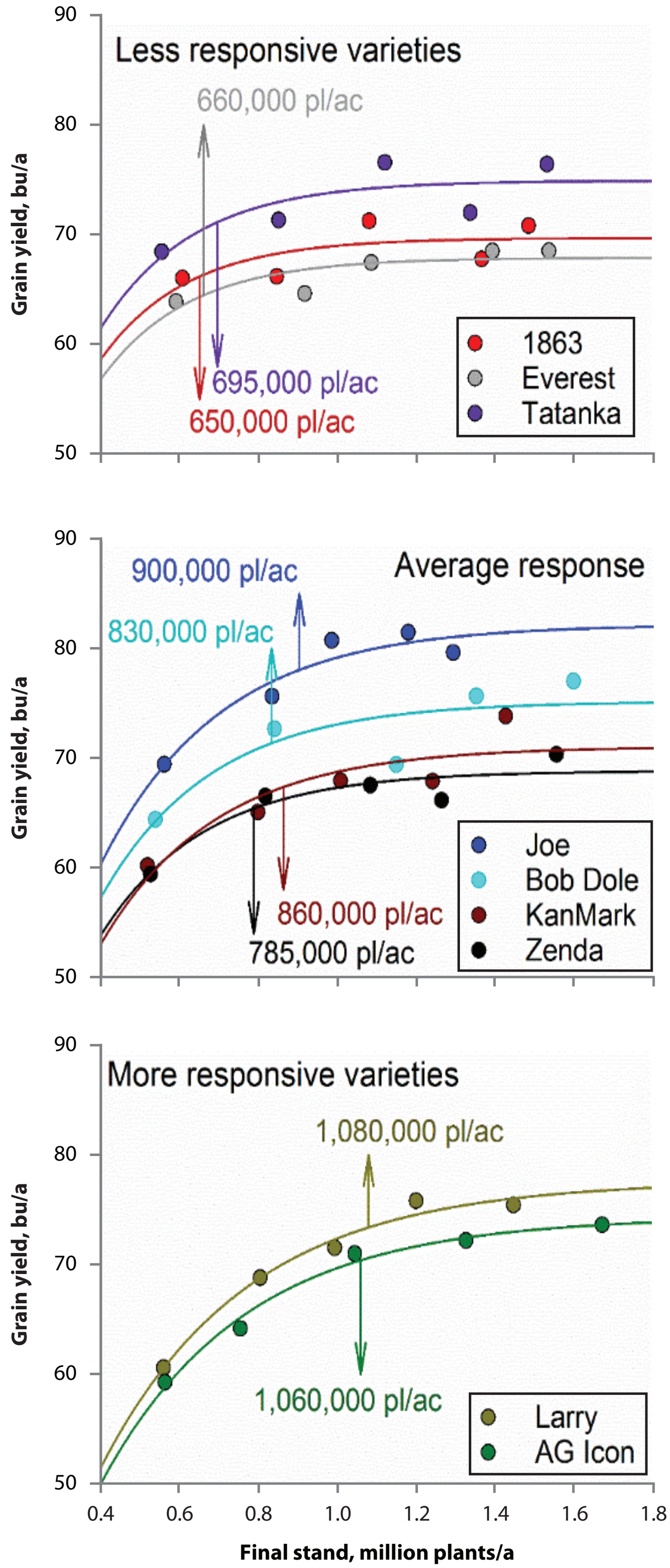

Figure 5. Wheat grain yield as affected by plant population for nine wheat varieties. Data shown are pooled over the entire dataset reflecting four (Larry, Joe, KanMark, Zenda, and Tatanka) and two (AG Icon, Bob Dole, Everest, and 1863) site-years of data.

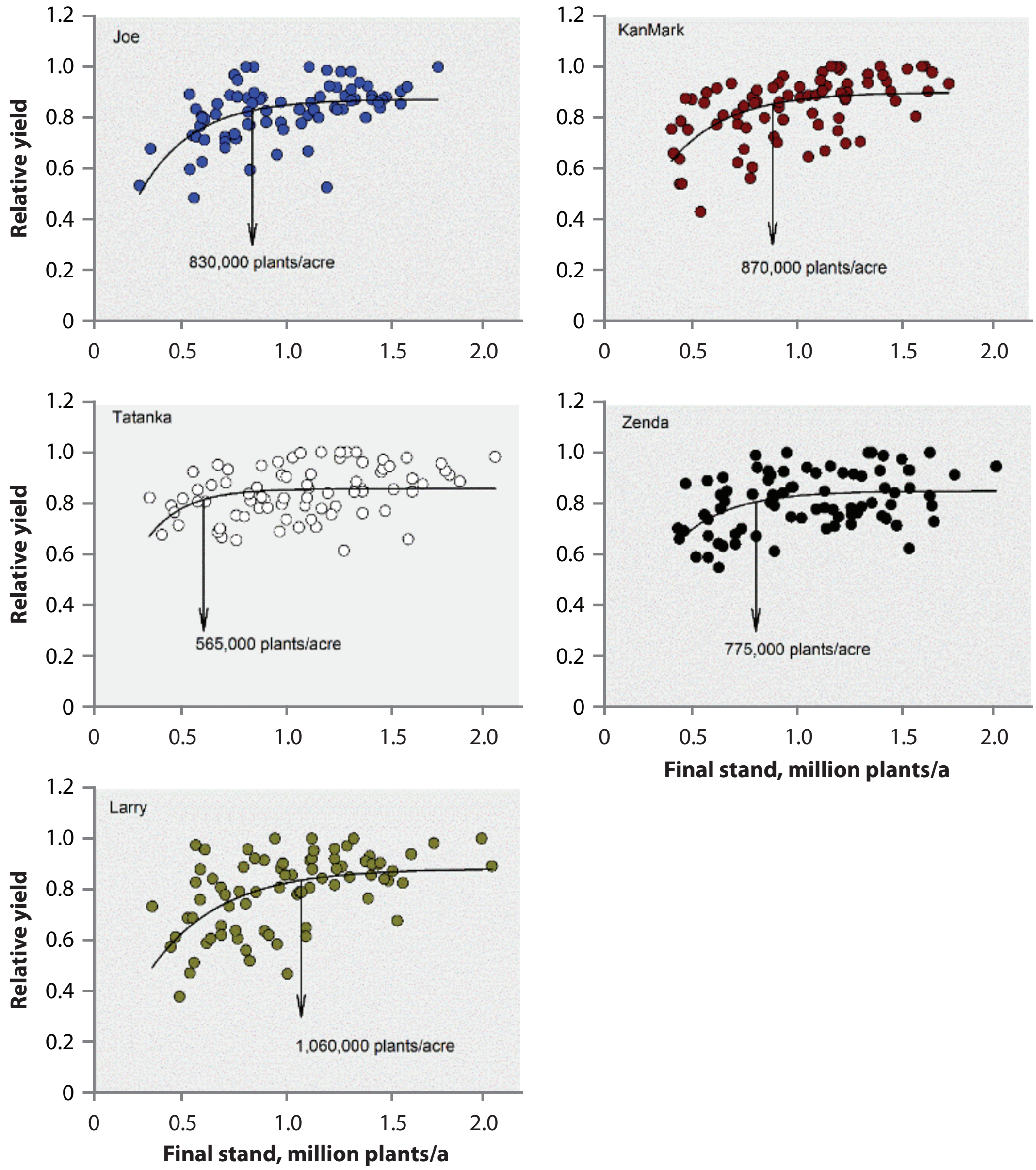

Figure 6. Relative wheat grain yield as affected by plant population for five wheat varieties. Data shown are pooled over the entire dataset reflecting four site-years of data.

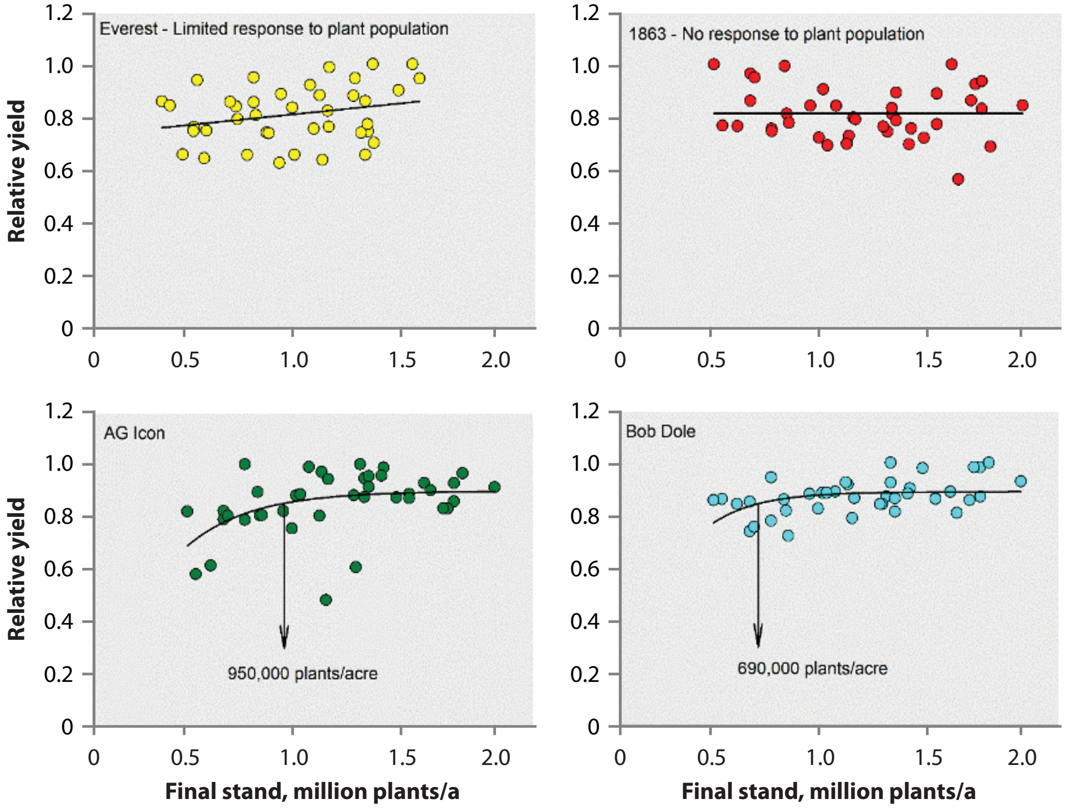

Figure 7. Relative wheat grain yield as affected by plant population for four wheat varieties. Data shown are pooled over the entire dataset, but the selected varieties have only two site-years of data.

Wheat Development and Yield as Affected by Era of Variety Release and In-Furrow Fertilizer

R.E. Maeoka and R.P. Lollato

Summary

Nutrients play a major role in wheat yield determination; however, limited information exists on the differential responses of historical and modern varieties to in-furrow fertilizer. Our objectives were to estimate grain yield and differences in agronomic traits of historical and modern winter wheat varieties as affected by different fertilization programs. Two field trials were established during the growing season 2016–2017 (i.e., Ashland Bottoms and Belleville, KS). Seven winter wheat varieties released between 1920 and 2016–Kharkof (1920), Scout 66 (1966), Karl 92 (1988), Jagalene (2001), Fuller (2006), KanMark (2014), and Larry (2016)–were sown using one of two different fertilizer practices: either the university recommendation or a treatment where 100 lb/a MESZ were applied in-furrow. At both locations, historical varieties were taller and had thinner stems than modern ones. In-furrow fertilizer increased yield of modern varieties relative to no fertilizer treatment in a sandier soil in Ashland Bottoms, while historical varieties showed neutral to negative yield response. In the silt loam soil near Belleville, there was only a significant variety effect but no fertilizer effect, likely due to a greater cation exchange capacity of the studied soil. More site-years of this study are needed to determine whether there is a need for re-evaluation of current fertility recommendations for modern wheat varieties.

Introduction

Kansas is the largest hard red winter wheat producer in the United States. Wheat yield improved over the last few decades due to progress in plant breeding, especially led by the successful introduction of dwarfing genes by breeders that allowed the development of shorter plants and higher yield. Agronomic practices, such as the advent of nitrogen (N) fertilizer, also contributed to increased yields in the state. However, the increased grain yield potential of modern wheat varieties may have had the hidden consequence of a shift in the nutrient requirements of the modern wheat plants. Therefore, current fertilizer recommendations need to be tested to determine whether an update is needed to match nutrient necessities of modern varieties and increase the return over investment. The objectives of this project were to evaluate whether historical and modern winter wheat varieties respond differently to in-furrow fertilizer in high P-level soils and to determine the partial contribution from genetic and agronomic management to wheat yield gain.

Procedures

One field experiment was conducted at two Kansas State University research locations: the Research Farm in Ashland Bottoms, KS; and at the North Central Kansas Experiment Field in Belleville, KS. Both sites were characterized to have more than 40 ppm extractable phosphorus (P), which is double the minimum required by a wheat crop (about 20 ppm). A two-way factorial treatment structure was established in split plot design with four replications, with main plots arranged as randomized complete block design and subplots completely randomized within main plots. Main plots were varieties released in different historical eras and the subplots were two different nutrient fertilization programs. Seven varieties released between 1920 and 2016, were tested, grouped by eras: historical, Kharkof (1920) and Scout 66 (1966); and modern, Karl 92 (1988), Jagalene (2001), Fuller (2006), KanMark (2014), and Larry (2016). Fertilization programs were i) K-State soil fertility recommendation for P and potassium (K), using the nutrient "sufficiency" approach, therefore, no fertilizer was applied; and ii) in-furrow 100 lb/a applied as 12-40-0-10-1.

Wheat was sown October 18, 2016 at Ashland Bottoms and October 3, 2016, at Belleville at a seeding rate of 60 lb/a (approximately 1.28 million seeds/a); all the locations were planted under the conventional tillage method following wheat. Plots were 30-ft long × 4.38-ft wide, with seven 7.5-in. spaced rows. In Ashland Bottoms, 50 lb/a of pre-plant N fertilizer in the form of urea (46-0-0) was applied, and 50 lb/a of N in the form of urea ammonium-nitrate (UAN) (32-0-0) was applied before winter dormancy. In Belleville, high levels (18.47 lb N/a) of inherent soil N was available so no fall N fertilization was necessary. In both locations, topdress N (46-0-0) was applied early spring (Feekes 5-6) with a yield goal of 90 bu/a, and two foliar fungicide applications were performed (Feekes 6-7, Feekes 10.5) to avoid foliar diseases and consequently yield losses. Similarly, commercially available herbicide products were sprayed to ensure weeds were not a limiting factor. No significant insect pressure was observed; therefore, insecticide applications were not warranted. Plots were harvested for grain using a self-propelled small-plot combine. Grain moisture was measured at harvest and grain yield was corrected for 13.5% moisture content. Measurements included percent canopy closure measured at bi-weekly intervals throughout the growing season, stem diameter was measured at Feekes growth stage 11.2 (soft dough stage of kernel development), and plant height was measured at the Feekes growth stage 11.4 (ripening). Analyses of variance considered varieties and fertilization practice as fixed effects, and orthogonal contrasts were developed to evaluate historical varieties versus modern varieties across fertilization programs. Dynamics of canopy cover were modeled by fertilization program and location as a sigmoidal function of growing degree days (GDD) using non-linear regression model:

$$Y = \frac{a}{1+e^{-\left(\frac{t-t0}{b}\right)}} \qquad [1]$$

where *a* is the asymptotic maximum percent canopy cover, *t* is time (GDD), t_o is the inflection point at which the rate in percent canopy cover increase is maximized (GDD), and *b* is a parameter determining the shape of the curve.

Results

Growing Season Weather

The weather in both locations was similar, a fall characterized by warm temperatures and cumulative precipitation below normal, followed by a mild and dry winter during January through the third week of March, and cool and above-average well-distributed precipitation during the spring. Cumulative precipitation of 16.5 in. at Ashland

Bottoms and 16.8 in. at Belleville occurred during the growing season, and mostly concentrated during the spring (more than ½ of the total precipitation).

Canopy Cover

The sigmoidal model in Equation 1 explained dynamics of canopy cover development and indicated that in-furrow fertilizer increased the asymptotic maximum canopy cover (a) from 90.2 to 94.5% at Ashland Bottoms (Figure 1A) and from 89.7 to 91.5% at Belleville (Figure 1B), compared to no fertilizer added. Furthermore, in-furrow fertilizer led to a quicker achievement of maximum rate of canopy cover (t_o) from 1099 GDD to 535 GDD at Ashland Bottoms (Figure 1A) and from 1310 GDD to 1257 GDD at Belleville (Figure 1B), irrespective of era of variety release as both historical and modern varieties presented the same pattern of development.

Plant Height

Variety was the only significant factor affecting plant height at both locations. Overall, plant height was negatively correlated with release year of the varieties, showing a reduction over time. The plant height ranged from 44.88 to 34.98 inches for historical and modern varieties, respectively. Modern varieties had approximately 78% of the plant height of historical varieties (Figures 2A), mainly due to the successful introduction of the dwarfing genes.

Stem Diameter

Similarly, to our measurements of plant height, variety was the only significant factor affecting wheat stem diameter at both locations; however, this followed the opposite trend and was positively correlated with year of release of the varieties, and we measured an increase over time. The stem diameter ranged from 0.113 to 0.121 inches for historical and modern varieties, respectively. Modern varieties had approximately 7% thicker stems relative to historical varieties (Figure 2B). Straw strength is important to avoid lodging, which can be associated with reduced yield.

Grain Yield

Ashland Bottoms

At the Ashland Bottoms field experiment, there was significant interaction between variety and fertilization program on wheat grain yield. Historical varieties showed negative responses to in-furrow fertilizer, on average decreased 5.88 bu/a, and obtained the lowest wheat yields regardless of fertilization practice (Figure 3). On average, modern varieties increased wheat yield under in-furrow fertilizer in 8 bu/a, with the exception of Karl 92 and Fuller in which fertilizer effect was non-significant. The increased grain yield on the other three modern wheat varieties nonetheless was significant. At this field experiment, barley yellow dwarf (BYD) decreased overall location yield.

Belleville

At the Belleville field experiment, there was no significant interaction between variety and fertilization program on wheat grain yield, and statistical difference was obtained only for variety factor. Grain yield ranged from 32.52 to 89.88 bu/a, increasing from Kharkof to KanMark, respectively (Figure 4). The historical varieties averaged 40.62 bu/a, while modern ones averaged 83.76 bu/a. Relative to Kharkof, all modern wheat varieties yielded more than 200%. At this location, bacterial streak was observed late in the growing season and could possibly have affected grain yields.

In-Furrow Fertilizer vs. No Fertilizer, Yields

On average of both sites, an increase in yield was greater when in-furrow fertilizer was applied as compared to no fertilizer (Figure 5), which is indicated by the slope of the relationship between no-fertilizer and in-furrow fertilizer of 1.31, which is greater than one. This relationship also indicates that modern, higher yielding varieties responded more to the in-furrow fertilizer than older, lower yielding varieties, as the low-yielding points are positioned below the 1:1 line.

Acknowledgments

The authors appreciate and acknowledge the Kansas Wheat Commission for providing funds necessary to perform this research, and the Kansas State University Wheat Production Team for the help collecting and processing field data.

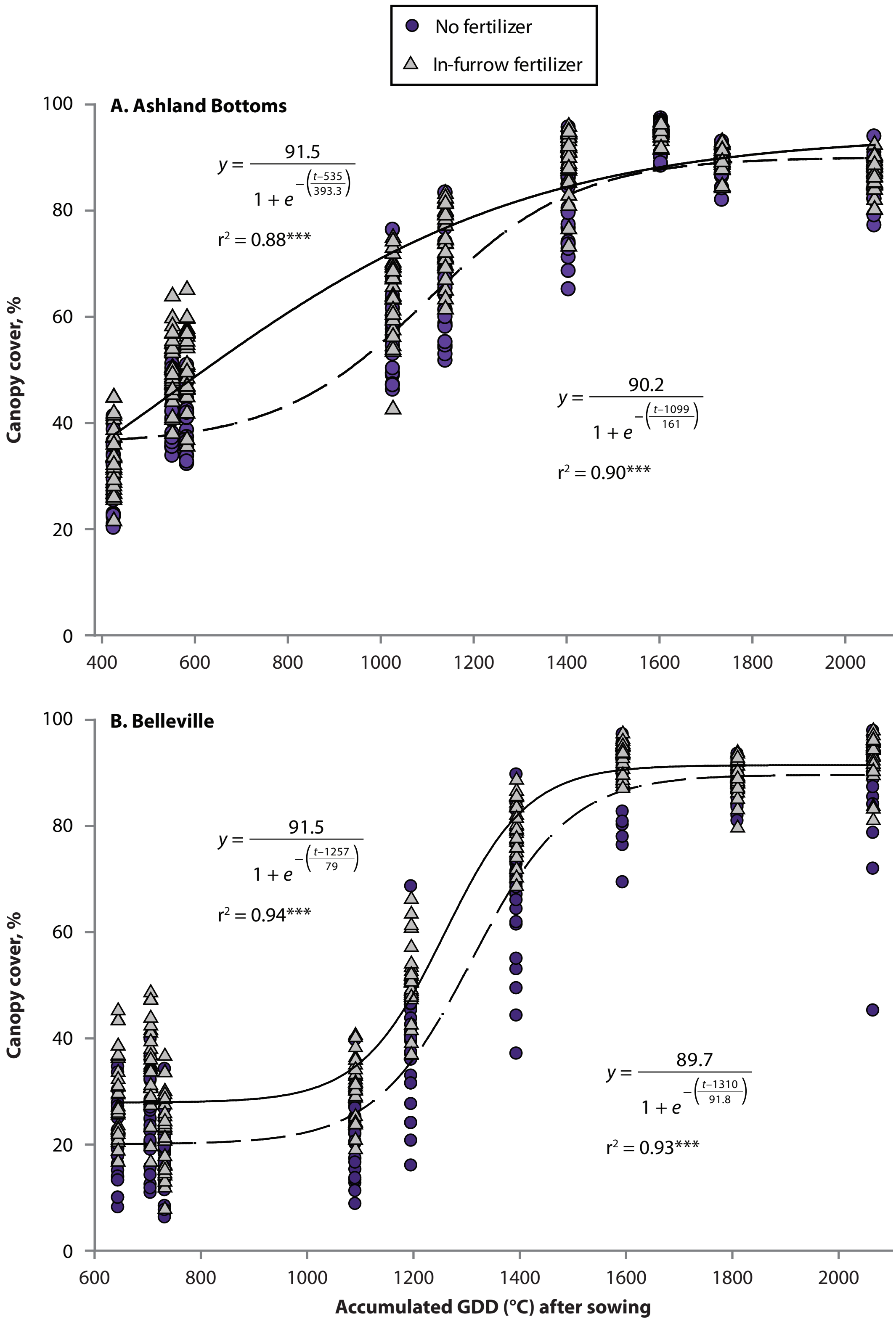

Figure 1. Dynamics of canopy cover development during the growing season 2016–2017 as function of accumulated growing degree days (GDD °C) after sowing, as affected by in-furrow fertilizer.

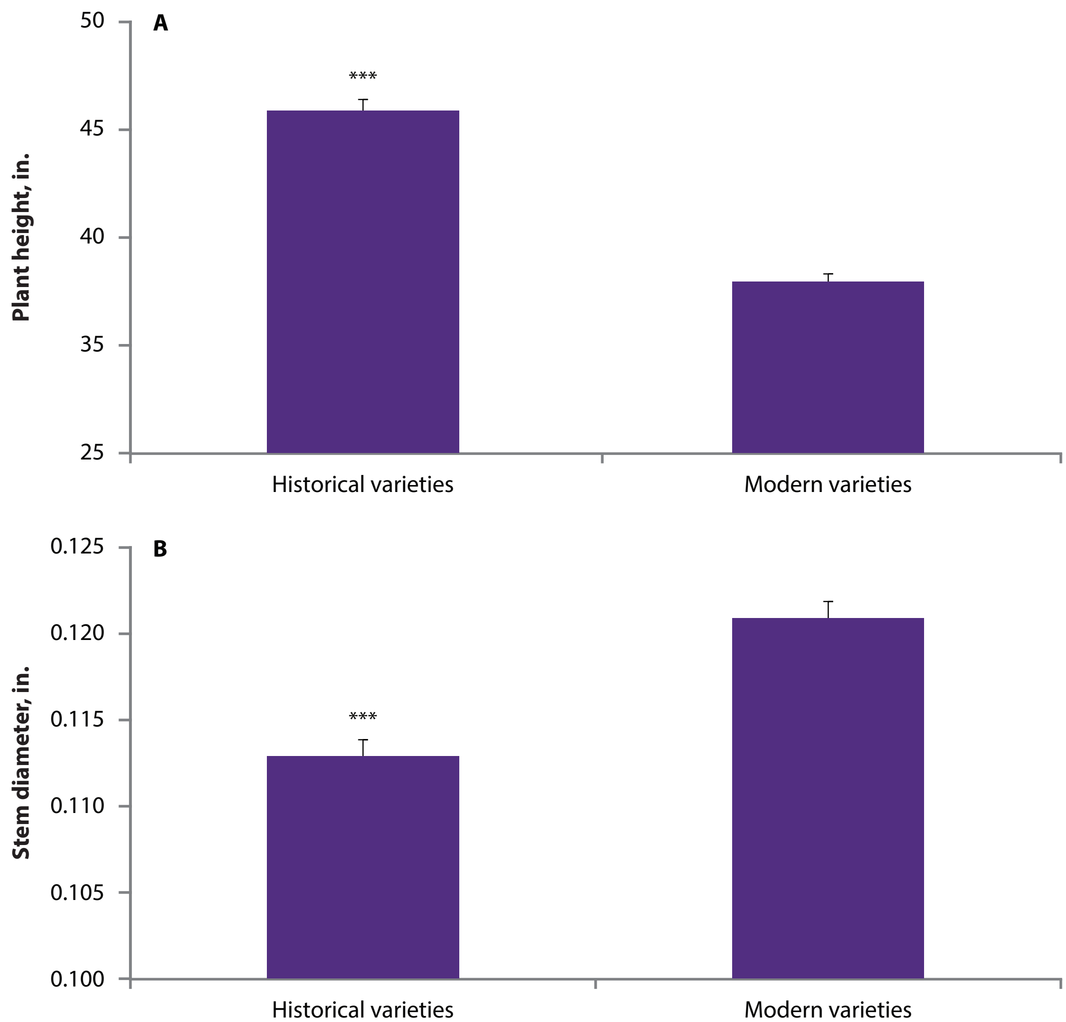

Figure 2. Plant height (A) and stem diameter (B) in historical versus modern varieties irrespective of fertilization program during the growing season 2016–2017.

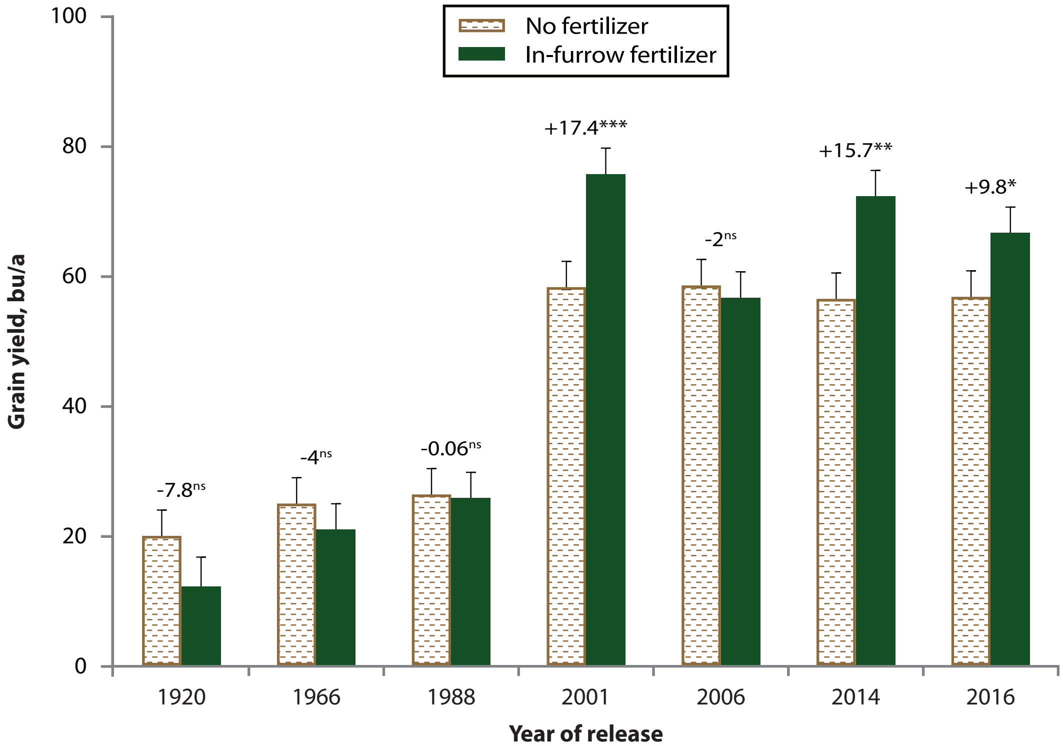

Figure 3. Grain yield of varieties released from 1920 to 2016 as affected by two fertilization programs during the growing season 2016–2017, at the Kansas State University Ashland Bottoms Research Farm and the difference in yield from no fertilizer and in-furrow fertilizer.

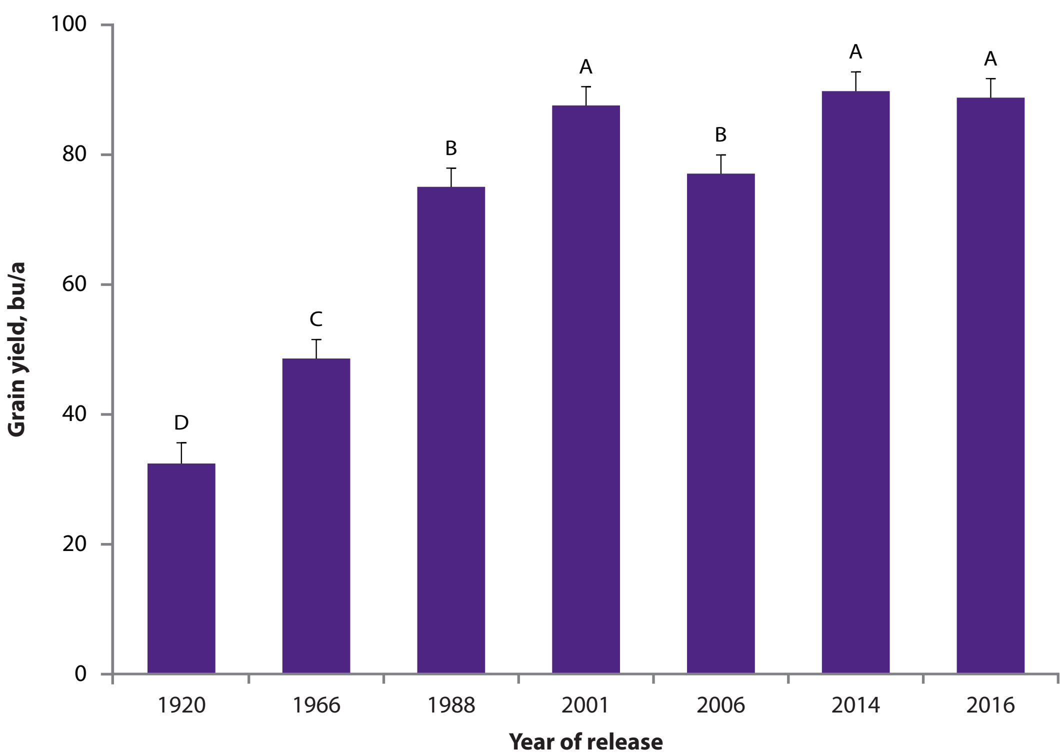

Figure 4. Grain yield of varieties released from 1920 to 2016 during the growing season 2016–2017, Kansas State University North Central Kansas Experiment Field, Belleville.

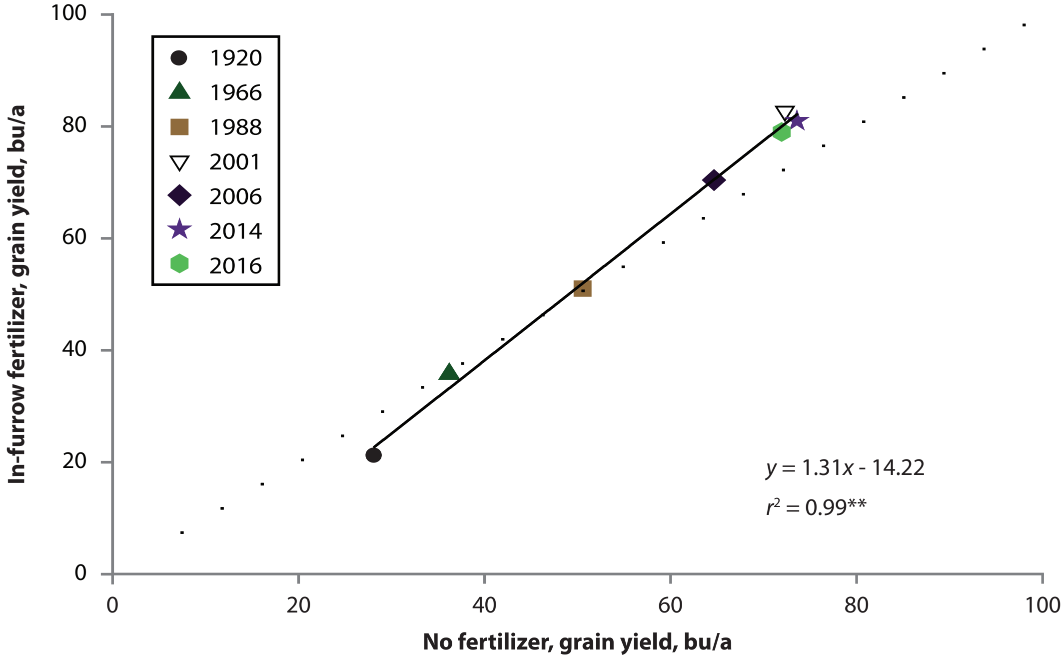

Figure 5. Correlations among grain yield and two fertilization programs during the growing season 2016–2017.

Plant Population and Fungicide Treatment Reduce Winter Wheat Yield Gap in Kansas

B.R. Jaenisch and R.P. Lollato

Abstract
Despite the large winter wheat yield gap in Kansas, limited research is available on integrated agronomic practices to increase grain yield. Our objective was to quantify the contribution of individual and combined management practices to reduce wheat yield gap. An incomplete factorial treatment structure established in a randomized complete block design was conducted in three locations in Kansas during 2016–2017 to evaluate the impacts of 14 treatments on yield and grain protein concentration of the modern wheat variety 'Everest.' We individually added six treatments to a low-input standard control or removed from a high-input intensive control, which received all treatments. Treatments were: additional nitrogen, sulfur or chloride, increased plant population, foliar fungicide, and plant growth regulator. In Manhattan, the intensive control increased grain yield by 6 bu/a as compared to the standard control, mostly led by additional nitrogen, sulfur, increased population, and fungicide (3–6 bu/a). In Belleville and Hutchinson, foliar fungicide increased grain yield on average by 19 bu/a. Additional nitrogen was the only treatment that increased grain protein concentration across all locations. Our results suggest that integrated pest management should be preferred over an intensive program with prophylactic pesticide application.

Introduction
The last two winter wheat growing seasons in Kansas were characterized by above average yields, with 57 and 47 bu/a in 2015–16 and 2016–2017, respectively. However, these yields are below the long-term yield potential of 75 bu/a. Thus, further research is needed to determine which management strategies will help narrow this yield gap. Our hypothesis is that improved management can largely contribute to closing wheat yield gaps in Kansas. Our objectives were to quantify the partial contribution of different management strategies, including fertilization, plant population density, fungicide, and growth regulator applications, all individually or in combination to close the wheat yield gap in central Kansas.

Procedures
Field studies were conducted as a randomized complete block design with an incomplete factorial treatment structure and six replications at three locations during the growing season of 2016–2017. Locations included the North Central Kansas Experiment Field in Belleville, the South Central Experiment Field in Hutchinson, and the North Agronomy Farm in Manhattan, KS. The trial was conducted under rainfed conditions at all locations and sown to the wheat variety Everest. Seed was treated with 5 oz. Sativa IMF Max across the entire study so fungicide or insecticide seed treatment was not a limiting factor. Soil samples were taken for soil nutrient analysis at sowing at each location for the 0–6 and 6–24-in. soil depths, and analyzed by the Kansas State University Soil Testing Laboratory.

The treatment combinations were set up with two control treatments: a standard "farmer practice" and an intensive "kitchen sink" management approach. Yield goals in these treatments were 70 and 120 bu/a, respectively. Agronomic management strategies that were modified from the standard to the intensive treatment and also evaluated individually consisted of high vs. low seeding rate (110 vs. 75 lb/a), nitrogen at planting and top-dressed (Feekes 3-4) vs. additional 100 lb N/a nitrogen applied early spring (Feekes 5-6), sulfur or chloride applied during Feekes 5-6, two foliar fungicide applications (Feekes 6-7, 10.5), and growth regulator (Feekes 6-7). The standard control consisted of: low seeding rate and N applied at planting and top-dressed for a yield goal of 70 bu/a. Next, treatments were added individually to the standard control totaling six low-input treatments plus a control (Table 1). The intensive control consisted of: nitrogen applied at planting and top-dressed similarly to the standard treatment, an additional 100 lb of nitrogen/a at Feekes 6, high seeding rate, sulfur, chloride, two applications of fungicide, and growth regulator. Conversely, treatments were removed individually from the intensive approach for a total of an additional six high-input treatments plus a control (Table 1). A total of 14 treatment combinations was evaluated in this study. Plants were harvested using a small plot combine, and grain moisture was corrected for 13.5% moisture content. Protein content was measured using near-infrared spectrometry. In this report, we discuss the effects of the treatments on wheat grain yield and protein content.

Results

In 2016–2017, all locations received more than 16 inches precipitation during the growing season, which is considered greater than the minimum necessary to maximize wheat yields. In addition, below average temperature during grain fill (May and early June) resulted in grain yields as high as 97, 101, and 84 bu/a at Belleville, Hutchinson, and Manhattan, respectively. Likewise, split nitrogen significantly affected grain protein concentration across all three locations.

Grain Yield

Across all locations, treatment applications resulted in significant differences for grain yield (Table 2). Due to the cool and moist conditions in April and May, stripe rust had high levels of infestation in central Kansas. Thus, foliar fungicide increased grain yield by an average of 19 bu/a in Belleville and Hutchinson. Likewise, the removal of nitrogen from the intensive control resulted in a yield decrease of 11 bu/a. In Belleville, no other treatments significantly increased or decreased yields from their respective control. However, additional nitrogen, sulfur, and plant population significantly affected yields in Manhattan, where the trial was conducted under no-till and had less severe disease pressure.

In Belleville, grain yield for the standard control consisted of 77 bu/a and addition of individual treatments resulted in no significant differences in grain yield. However, the removal of fungicide from the intensive control decreased yield from 90 bu/a to 70 bu/a. Following a similar trend, the standard control yielded 74 bu/a and the addition of fungicide increased yields to 90 bu/a in Hutchinson. The removal of split nitrogen and fungicide from the intensive control decreased yields from 100 bu/a to 90 and 71 bu/a, respectively. Grain yield in Manhattan did not follow the same trend as Belleville and Hutchinson. Increased plant population increased grain yield to 79 bu/a from 73 bu/a for the standard control. However, the removal of additional nitrogen, sulfur, and increased plant population decreased yields from 84 bu/a for the intensive control to 74, 74, 77 bu/a, respectively.

Grain Protein Concentration

Across all locations, additional 100 lb of N/a applied as split nitrogen during Feekes GS 6 was the only treatment that consistently affected grain protein (Table 3). In Belleville, additional nitrogen and fungicide increased grain protein from the standard control of 11.0 to 11.8% and 11.5%, respectively. Likewise, the removal of additional nitrogen and fungicide decreased grain protein to approximately 12.0% as compared to 13.0% for the intensive control. Grain protein concentration in Hutchinson and Manhattan followed a similar trend to those measured in Belleville. Grain protein increased from 9.3 to 11.9% and 9.6% from additional nitrogen and plant growth regulator, respectively in Hutchinson. However, only the removal of additional nitrogen decreased grain protein from 12.3% for the intensive control to 9.3%. Split nitrogen increased grain protein for the standard control from 11.9 to 12.7%, and the removal of additional nitrogen decreased grain protein to 12.2% as compared to 13.1% for the intensive control in Manhattan.

Conclusions

Due to severe stripe rust infestations, foliar fungicide increased grain yield by an average of 19 bu/a at Belleville and Hutchinson. In Manhattan, the no-till conditions resulted in a yield increase resulting from additional nitrogen, sulfur, and increased plant population. Additional nitrogen consistently increased grain protein at all locations. Wheat grain yield was increased by an intensive approach; however, this was not economical. This demonstrates that an integrated approach should be adopted by producers.

Acknowledgments

We acknowledge and appreciate Andrew Esser, Gary Cramer, and Dustin Ridder for helping us with project establishment, production, and harvest at the experiment fields. We also appreciate the Kansas Wheat Commission for the funding to allow us to conduct this research, DuPont for partial funds to support research and for providing the fungicide products Aproach and Aproach Prima used in this study. We also acknowledge Syngenta for providing the Palisade growth regulator used in this study.

Table 1. Standard and intensive treatments were the low and high input controls, respectively

Treatment	Description	Rate
1-Standard	75 lb/a, top-dress N at Feekes GS 3	Yield goal: 70 bu/a
2	+ Split nitrogen at Feekes GS 5	+ 120 lb N/a
3	+ Sulfur at Feekes GS 5	+ 40 lb S/a
4	+ Chloride at Feekes GS 5	+ 40 lb Cl/a
5	+ Plant population	110 lb/a
6	+ Fungicide at Feekes GS 6 and 10.5	+ 2 applications
7	+ Growth regulator at Feekes GS 6	+ 1 application
8- Intensive	All treatments 2-7 combined	Yield goal: 120 bu/a
9	- Split nitrogen	- 120 lb N/a
10	- Sulfur	- 40 lb S/a
11	- Chloride	- 40 lb Cl/a
12	- Plant population	110 lb/a
13	- Fungicide	- 2 applications
14	- Growth regulator	- 1 application

Description of the individual treatment strategy for each addition (+) or removal (-) of an input from the respective control.

Table 2. Average winter wheat grain yield as affected by management strategy and by addition or removal of individual treatments from the standard and intensive controls, respectively, for the 2016–2017 growing seasons in Belleville, Hutchinson, and Manhattan, KS

Treatment		2016–2017		
Management strategy	Exception	Belleville	Hutchinson	Manhattan
		----------	bu/a	----------
Standard	None	77	74	73
Standard	+ Split nitrogen	72	75	72
Standard	+ Sulfur	75	78	74
Standard	+ Chloride	77	78	73
Standard	+ Plant population	82	68	79*
Standard	+ Fungicide	86	90*	73
Standard	+ Plant growth regulator	73	70	68
Intensive	None	90	101	84
Intensive	- Split nitrogen	93	90*	74*
Intensive	- Sulfur	95	102	74*
Intensive	- Chloride	89	99	81
Intensive	- Plant population	83	100	77*
Intensive	- Fungicide	70*	71*	79
Intensive	- Plant growth regulator	97	100	83

*Indicates significance at the 0.05 probability as compared to the respective control ('Standard' or 'Intensive').

Table 3. Average winter wheat grain protein concentration as affected by management strategy and by addition or removal of individual treatments from the standard and intensive, respectively, for the 2016–2017 growing seasons in Belleville, Hutchinson, and Manhattan, KS

Treatment		2016–2017		
Management strategy	Exception	Belleville	Hutchinson	Manhattan
		---------------------------- % ----------------------------		
Standard	None	11.0	9.3	11.9
Standard	+ Split nitrogen	11.8*	11.9*	12.7*
Standard	+ Sulfur	11.2	9.3	11.5
Standard	+ Chloride	11.1	9.3	11.7
Standard	+ Plant population	10.9	9.3	11.6
Standard	+ Fungicide	11.5*	9.3	11.9
Standard	+ Plant growth regulator	11.7	9.6*	11.7
Intensive	None	13.0	12.3	13.1
Intensive	- Split nitrogen	12.0*	9.3*	12.2*
Intensive	- Sulfur	13.1	12.3	13.0
Intensive	- Chloride	13.0	12.4	12.8
Intensive	- Plant population	13.1	12.3	13.2
Intensive	- Fungicide	12.3*	12.0	13.1
Intensive	- Plant growth regulator	12.7	12.2	13.0

*Indicates significance at the 0.05 probability as compared to the respective control (‘standard’ or ‘intensive’).

Reducing the Wheat Yield Gap Through Variety-Specific Management

A. de Oliveira Silva, A.K. Fritz, and R.P. Lollato

Summary
In Kansas, wheat yields have been nearly stagnant at approximately 40 bu/a for the past 30 years, which corresponds to a yield gap (the difference between average producer yield and yield potential) of approximately 35 bu/a relative to the state average yield potential of ~75 bu/a. Our objective was to continue investigation on the influence of varieties with different genetic and agronomic characteristics and management practices on grain yield to demonstrate that appropriate variety-specific management can help producers to achieve long-term profitability in a sustainable manner. The Kansas State University wheat variety performance tests (VPT) evaluate 35–50 varieties in more than 20 locations every year. We have expanded the test to a paired-plot design in three VPT locations (Ellsworth, Conway Springs, and McPherson, KS) in the 2016–2017 growing season, where one plot is managed under standard management practice (SM) based on current farmer's practice of each region with no fungicide application and the adjacent plot with the same variety is enhanced with additional 40 lb of N/a and two fungicide applications hereafter referred to as intensive management (IM). Yield gap between the IM and SM ranged from 7 bu/a in Conway to 10 bu/a in Ellsworth on average of all varieties, mainly due to stripe rust (*Puccinia striiformis* Westend) occurrence in the growing season. Varieties more susceptible to stripe rust had 50% cumulative probability yield gain of 9 bu/a across all locations studied by switching from SM to IM, while resistant varieties gained 7 bu/a. The probability of breakeven was 22% greater in susceptible varieties as compared to resistant varieties. Our results indicate that selecting varieties with resistance to major fungal diseases can narrow the wheat yield gap in most years, reducing the need for additional fungicide. By comparing yield responses of currently-grown and new wheat varieties under farmer's management and intensive management practices, this on-farm research provides science-based information for farmers to maximize profit while protecting natural resources and reducing the wheat yield gap in Kansas.

Introduction
In Kansas, wheat yields have been nearly stagnant at approximately 40 bu/a for the past 30 years, which corresponds to a yield gap (i.e. difference between average producer yield and economical yield potential of the region) of approximately 35 bu/a relative to state average yield potential of ~75 bu/a. A few studies and yield contests have reported average yields of ~110 bu/a, suggesting even larger opportunities for yield improvements in this region during particular growing seasons. It is proposed that the yield gap in the southern Great Plains is possibly due to low-input management practices rather than lack of genetic potential of current varieties. Yield gain from fungicide applications has been inconsistent across production systems as its effectiveness depends on variety resistance, disease pressure, and growing season weather, while split-N application has increased yield, grain protein concentration and N use-efficiency in wheat. Thus, studies evaluating variety-specific crop management are crucial to sustainably improve

yield in different farming systems. Our preliminary data show that the development of variety-based agronomic recommendations can economically enhance yields, but long-term analyses including multiple site-years are needed to understand ways to reduce the environmental footprint in wheat production while increasing producers' profitability. Furthermore, a comprehensive characterization of varieties under a wide range of cropping systems will assist producers to select varieties best suited to their area, and consequently, narrow the yield gap in wheat production through variety selection and variety-specific agronomic management.

Procedures

We conducted rainfed research studies in three production fields in Kansas during the 2016–2017 growing season: Conway Springs (CO), Ellsworth (ELL), and McPherson (MP) (Table 1). Weather data were collected on a daily basis from sowing to harvesting from the Kansas Mesonet Network, which had stations located at the vicinity of the experiment sites (Table 1). The predominant soil type was Bethany silt loam in CO, and Crete silt loam in ELL and MP. At all site-years, the seeding rate was 60 lb/a. We adopted conventional tillage practices at ELL and MP locations, and no-till practices in CO. Wheat field trials were sown with a 6-row Hege small plot cone planter with row spacing of 10 in. and plot length of 15 ft (Table 1). Insect and weed occurrence was minimal, and controlled with commercially available pesticides as needed.

A total of 38 to 48 wheat varieties (both commercially available and experimental lines) were tested at each location as part of the official Kansas State University Wheat Performance tests (Table 2). Varieties differed in year of release, maturity range, disease resistance, responsiveness to nitrogen (N), and yield potential. The experimental design was a strip plot design with variety as the main factor and management practice as the sub-factor. The varieties were arranged in a randomized complete block design with three replications, while the two treatments were non-randomized and applied as strips. The management treatments tested were (i) standard management (SM), with the N rate calculated based on K-State fertilizer recommendations for approximately 70 bu/a yield goal and no fungicide application; and (ii) intensive management (IM), comprising the SM treatment, an additional N rate of 40 lb of N/a applied as urea (46-0-0) at Feekes GS 3 (spring tillering), and two fungicide applications at Feekes GS 6 (jointing) and 10.5 (heading) (Table 2). For the SM treatment, the N rate, source and timing of application slightly varied across locations depending on soil N profile and each farmer's practice (Table 2). Plots were harvested with a small plot combine Wintersteiger Delta and grain yield was adjusted to 12% moisture (Table 1). The average yield recorded by farmers for the past 3–5 years prior the establishment of the field trials in these regions, were 49, 60, 62 bu/a for ELL, CO, and MP, respectively.

Statistical analysis was executed using the R software. The yield differences between management treatments (hereafter referred to as yield gap) were estimated prior to analysis, and used as dependent variable. At each location, the yield gap was estimated as the difference between the yield from the intensive management (IM) and standard management (SM) for each plot. Varieties were grouped into three categories of resistance levels to stripe rust based on K-State wheat variety disease ratings (De Wolf et al., 2017): [i.e., resistant (RES) with ratings score of 1 to 3; intermediate (INT) with ratings score between 4 and 6; and susceptible (SUS) with ratings score of 7 and 9] for the yield gap, cumulative probability of yield gain, and probability of breakeven analyses.

Results

The weather variability during the 2016–2017 growing season led to highly variable yields across the three studied locations. Adequate fall precipitation and temperature increased early vegetative growth of the crop. Dry conditions, few freezing events, and above average temperature (+6 to 10°F) were observed during the winter, which was followed by above average rainfall and cooler temperatures from March to May, which benefited grain development and yield. However, the latter conditions also favored lodging in high yielding environments (e.g. McPherson), and the incidence of the fungal diseases stripe rust (*Puccinia striiformis* Westend) and leaf rust (*Puccinia triticina*).

The average yield across all varieties for each management treatment at each location was 97 bu/a for the IM and 87 bu/a for the SM treatments in ELL, 71 bu/a for the IM and 64 bu/a for the SM in CO, and 77 bu/a for the IM and 68 bu/a for the SM managements in MP (Table 2). The minimum and maximum yield observed when averaged across all varieties and management treatments at each location were 51 and 125 bu/a in ELL, 34 and 92 bu/a in CO, and 40 and 101 bu/a in MP. Grain protein concentration was not nearly as variable as grain yield, with average protein of 10% across management practices and locations (Table 2). The additional N supplied in the intensive management increased protein levels from 9.5–10% in the SM to 10–10.5% in the IM (Table 2).

The large yield variability observed was possibly due to differences in disease pressure across locations, and to variety differences in resistance levels to stripe and leaf rust, consequently affecting the response to the fungicide applications. Additionally, yield differences might also have occurred due to differences in responses to N fertilizer applied (data not shown). Although a trend was observed, yield gap was not statistically different between varieties SUS to stripe rust as compared to the other groups in any of the locations during the 2016–2017 growing season (Figure 1). The lack of difference could be explained by the unbalanced number of varieties tested within each resistance level group, and the consequent lower number of SUS varieties (n = 12) relative to RES (n = 35) and INT (n = 45) varieties across locations.

For each location, the greatest yield gap (i.e., 28 bu/a) was measured in ELL for the SY Flint and WB4269 varieties and average yield for both varieties was ~100 bu/a under the IM (Figure 2). This yield gap was followed by a yield gap of 23 bu/a for the varieties Tatanka in CO and WB4303 in MP, with average yields of 85 and 94 bu/a for the IM, respectively (data not shown). The variety Everest showed a consistent yield gain of approximately 15 bu/a resulting from switching from SM to IM across the three studied locations with average yield of 88 bu/a at IM. Meanwhile, the variety T158 showed a larger yield gap as a result of the yield gain of ~19 bu/a in MP and CO locations, likely due to its susceptibility to stripe rust. Additionally, T158 was severely lodged at harvesting in MP, and showed inconsistent lodging scores in CO and ELL.

Probability of yield gain resulting from the IM treatment was slightly larger for susceptible than for resistant varieties (Figure 3). Susceptible varieties had 50% cumulative probability of yield gain of 9 bu/a across all studied locations in KS by switching from SM to IM, while resistant varieties gained 7 bu/a. On average of the three locations, the probability of breakeven was 22% greater in susceptible varieties as compared to resistant varieties (42 vs. 20%) (Figure 4). Probability of breakeven (%) was estimated using $4/bu for the wheat price, $32/a for fungicide costs and total nitrogen costs of $20/a.

Preliminary Conclusions

Our results indicate that selecting varieties with resistance to major fungal diseases may narrow the wheat yield gap in Kansas, potentially reducing the need for additional fungicide. Intensive management may be a viable alternative for varieties that lack the aforementioned genetic resistance, but long-term analyses including multiple site-years are needed to quantify the most typical response per level of disease resistance. Wheat variety response to N fertilizer rate was related to straw strength, and avoiding over-fertilization in varieties with below-average straw strength can help reduce the environmental footprint in wheat production. This study provides science-based information to farmers on how to maximize profit while protecting natural resources and reducing the wheat yield gap in Kansas.

References

De Wolf, E., R.P. Lollato, and R.J. Whitworth. 2017. Wheat variety disease and insect ratings 2017. Kansas State University Agricultural Experiment Station and Cooperative Extension Service MF991.

Table 1. Site information: plot coordinates, planting and harvesting dates, previous crop, cumulative precipitation (Cum PPT) in inches, and cumulative evapotranspiration (Cum ET) in inches and cumulative growing degree days (Cum GDD) at each location during the 2016–2017 growing season in Kansas

Location	Coordinates	Planting date	Harvesting date	Previous crop	Cum PPT	Cum ET	Cum GDD
					----------- in. -----------		°F
Ellsworth	38°35'37.99" N 98°19'58.18" W	10/7/2016	6/27/2017	wheat	16	554	5380
Conway Springs	37°27'36.7" N 97°37'48.3" W	10/11/2016	6/22/2017	corn	22	837	4159
McPherson	38°15'50.83" N 97°35'33.36" W	10/11/2016	6/20/2017	wheat	15	772	3724

There were no solar radiation data available for the fall period in Ellsworth, therefore cumulative evapotranspiration in this location represents values from January to June (harvesting).

Table 2. Number of varieties tested, total nitrogen (N) rate (lb/a), average grain yield (bu/a) and grain protein concentration at 12% moisture adjustment for standard management (SM) and intensive management (IM) at each location in the 2016–2017 growing season in Kansas

Location	Varieties #	N rate		Grain yield		Grain protein	
		IM	SM	IM	SM	IM	SM
		---------- lb/a ----------		---------- bu/a ----------		---------- % ----------	
Ellsworth	38	130	95	97 a	87 b	10.6 a	10.0 b
Conway Springs	48	130	90	71 a	64 b	10.4 a	9.9 b
McPherson	48	100	60	77 a	68 b	10.0 a	9.5 b

Within location, different letters mean statistical significant difference between intensive (IM) and standard (SM) management at $P < 0.05$ (LSD).

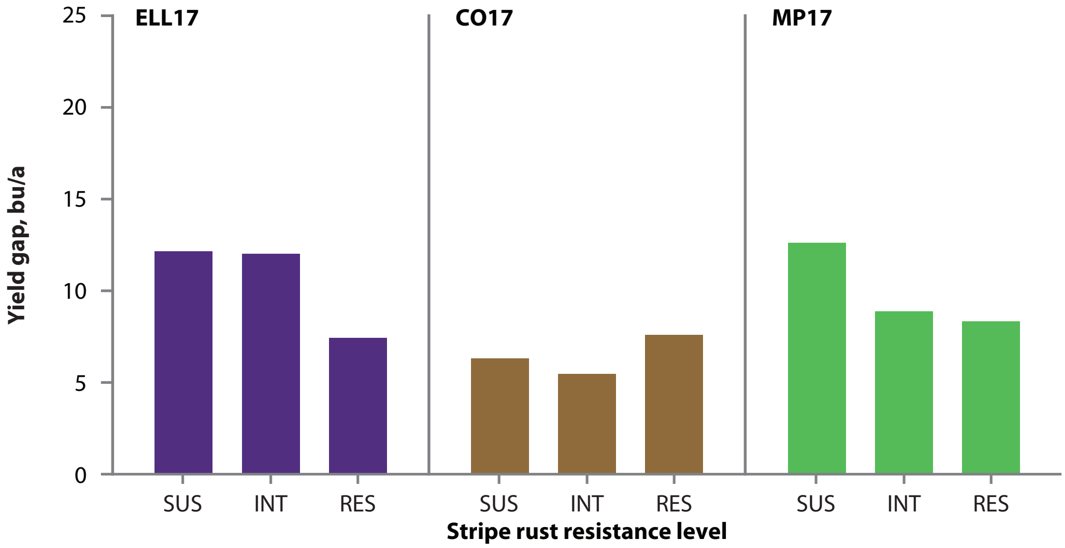

Figure 1. Yield gap between standard (SM) and intensive management (IM) for different variety resistance levels to stripe rust disease at the three locations of Ellsworth, Conway Springs, and McPherson, KS, 2017. SUS = susceptible, INT = intermediate, RES = resistant. Within location, yield gap means for each resistance level were not significantly different at *P* < 0.05 (LSD).

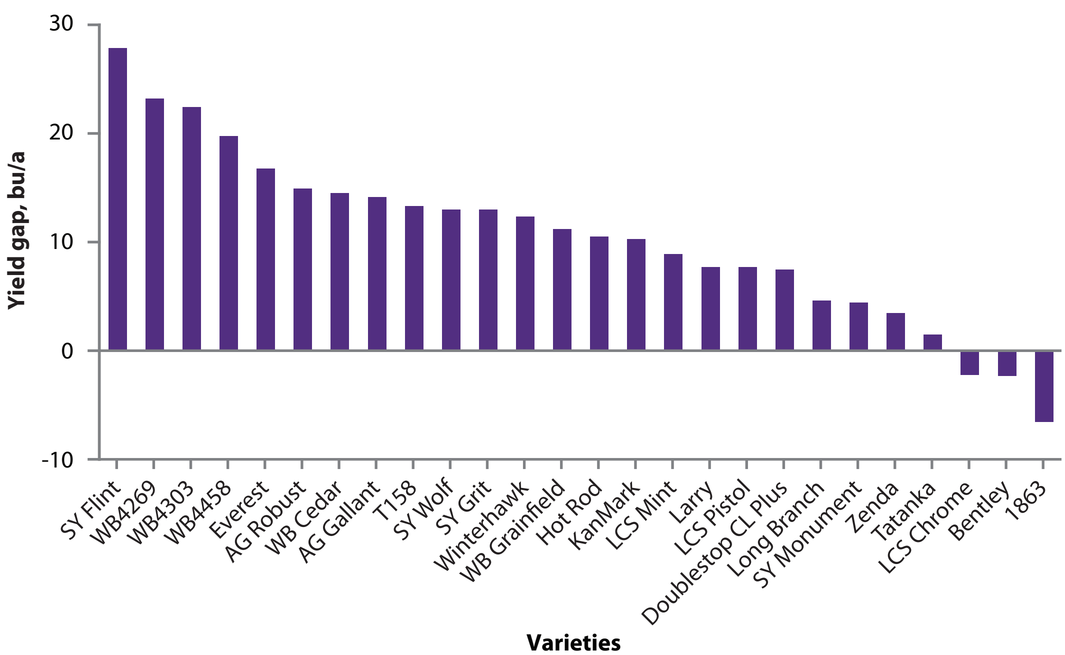

Figure 2. Yield gap between standard intensive management for varieties with different resistance levels to stripe rust disease for the location in Ellsworth, KS, 2017. Yield gap means were only statistically different between the varieties with the highest (28 bu/a) and lowest yield gap (-7 bu/a) *P* < 0.05 (LSD). The other varieties were not significantly different from each other.

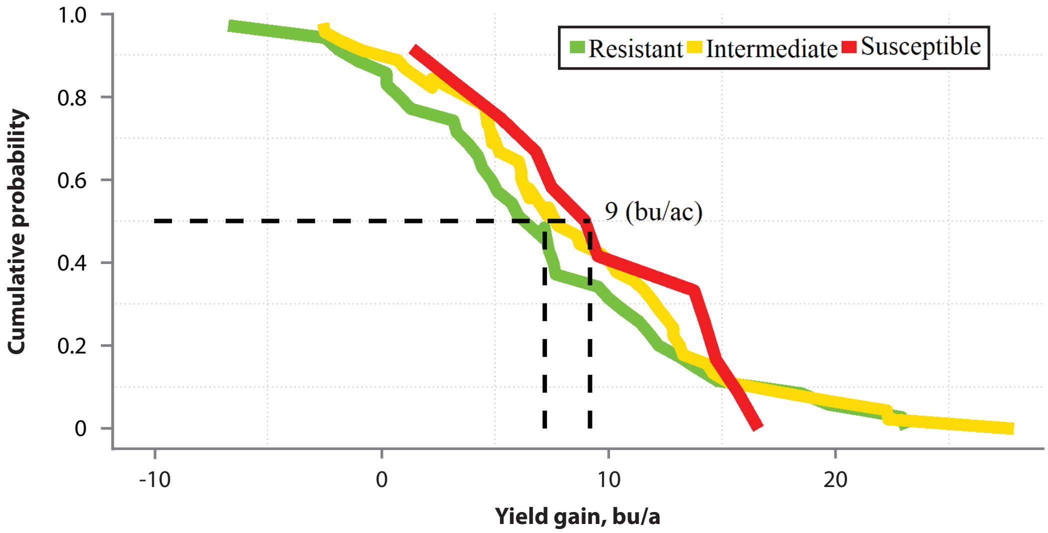

Figure 3. Cumulative probability of yield gain from standard (SM) to intensive management (IM) for different variety resistance levels to stripe rust disease at the three locations of Ellsworth, Conway Springs, and McPherson, KS, 2017.

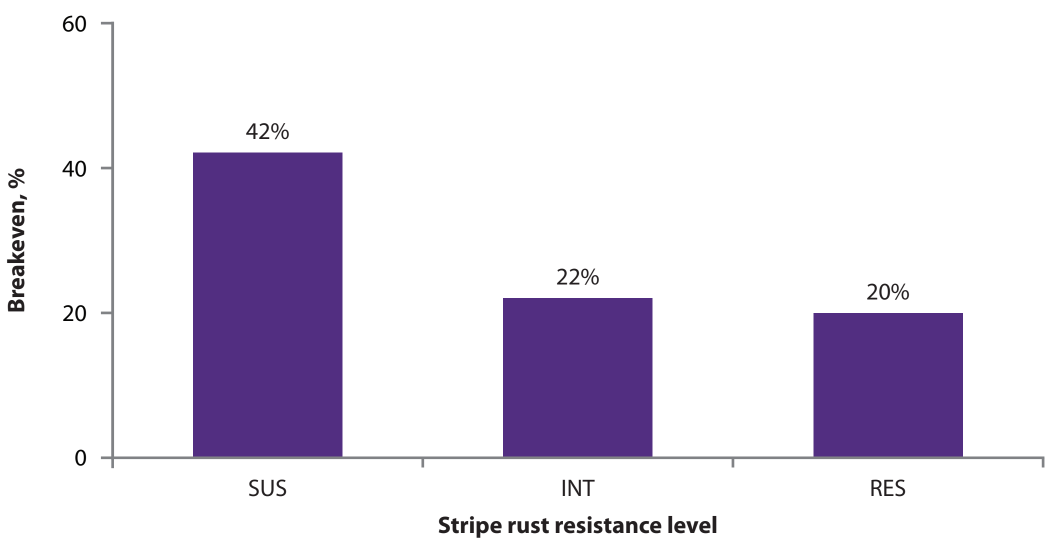

Figure 4. Probability of breakeven (%) for the additional N rate (40 lb/a) and two fungicide applications at Feekes GS 6 and 10.5. Means at the three locations of Ellsworth, Conway Springs, and McPherson, KS, 2017. SUS = susceptible, INT = intermediate, RES = resistant.

Tillage Study for Corn and Soybeans: Comparing Vertical, Deep, and No-Tillage

E.A. Adee

Summary
Trends from a tillage study conducted since 2011 are beginning to show that corn yields are greater when there is an occasional deep tillage. The yield of soybeans have not been affected significantly by tillage systems ranging from no-till to conventional tillage every year.

Introduction
The need for tillage in corn and soybean production in the Kansas River Valley continues to be debated. The soils of the Kansas River Valley are highly variable, with much of the soil sandy to silty loam in texture. These soils tend to be relatively low in organic matter (< 2%) and susceptible to wind erosion. Although typically well drained, these soils can develop compaction layers under certain conditions. A tillage study was initiated in the fall of 2011 at the Kansas State University Kansas River Valley Experiment Field near Topeka to compare deep vs. shallow vs. no-tillage vs. deep tillage in alternate years. Corn and soybean crops are be rotated annually. This is intended to be a long-term study to determine if soil characteristics and yields change in response to a history of each tillage system.

Procedures
A tillage study was laid out in the fall of 2011 in a field that had been planted with soybean. The tillage treatments were (1) no-tillage, (2) deep tillage in the fall and shallow tillage in the spring every year, (3) shallow tillage in the fall following both crops, and (4) deep tillage followed by a shallow tillage in the spring only after soybean, and shallow tillage in the fall after corn. In the fall of 2010, prior to the soybean crop, the entire field was subsoiled with a John Deere V-ripper. After soybean harvest, 30- × 100-ft individual plots were tilled with a Great Plains TurboMax vertical tillage tool at 3 in. deep or a John Deere V-ripper at 14 in. deep. Spring tillage was with a field cultivator. Starting in the fall of 2012 the treatments were with the TurboMax or a Great Plains Sub-soiler Inline Ripper SS0300. Spring tillage in 2013-2016 was with the TurboMax and a field cultivator in 2017 on the required treatments. Each tillage treatment had 4 replications.

Dry fertilizer (11-52-60 nitrogen (N), phosphorus (P), and potassium (K)) was applied to the entire field prior to fall tillage in 2012 and to the soybean stubble in 2013 and 2014. In fall of 2015 and 2016, 14-52-40-10 (N, P, K, and sulfur (S)) was applied to the soybean stubble prior to fall tillage. Nitrogen (150 lb in 2012 and 2013; and 180 lb in 2014, 2015, 2016, and 2017) was applied in March prior to corn planting. Corn hybrid Pioneer 1395 was planted at 30,600 seeds/a on April 12, 2012; P1498HR at 32,000 seeds/a on April 30, 2013; P1105 at 32,000 seeds/a on April 21, 2014, and April 14, 2015; P1257 at 32,000 seeds/a on April 12, 2016; and Midland 534 at 32,000 seed/a on April 24, 2017. Soybean variety Pioneer 93Y92 was planted at 155,000 seeds/a on May 14, 2012; P94Y01 3833 at 140,000 seeds/a on May 15, 2013; Asgrow 3833 at 140,000 seeds/a on May 21, 2014; Midland 3884NR2 with ILeVO seed treatment at 144,000 seeds/a on June 1, 2015; Stine 42RE02 with ILeVO seed treatment at 140,000 seeds/a on May 31, 2016; all in 30 inch rows. On May 26, 2017, Pioneer 39T67 with ILeVO seed treatment was planted at 140,000 seeds/a in 15 inch rows with a Kinze 3000 planter. Soybeans were planted after soybeans in the setup year.

Irrigation to meet evapotranspiration (ET) rates was started May 26 and concluded August 1 for corn and started July 5 and concluded August 23 for soybean in 2012. Irrigation for corn started June 24, 2013 and concluded August 1. Irrigation for soybeans in 2013 started June 30 and concluded September 8. Irrigation in 2014 started July 1 and ended August 16 for corn and started July 22 and ended August 22 for soybeans. In 2015, the first irrigation for both crops was June 23, and the last on August 24. The first irrigation on corn in 2016 was on June 20, and the last on August 4, while only the irrigation for soybean was on August 18. In 2017, the first and last irrigations on corn were June 13 and August 8, respectively, and July 16 and August 8, respectively, for soybeans. Two yields were taken from each plot from the middle 2 rows of planter passes. Corn was harvested on August 31, 2012; September 25, 2013; September 11, 2014; September 10, 2015; September 16, 2016; and September, 20, 2017. Soybeans were harvested on October 5, 2012; October 10, 2013; October 9, 2014; October 3, 2015; and October 17, 2016. Four 15-inch rows of soybeans were harvested for yield on October 17, 2017.

A preliminary comparison of the different tillage systems across both crops of the rotation was made by calculating gross income per acre. The gross income per acre was calculated by multiplying the average yield for each crop by the closing market price on January 3, 2016, $3.51 and $9.11/bu for corn and soybean, respectively, then dividing by 2 to get the average gross income per acre. Differences between cost of tillage operations and herbicide weed control were not factored in this preliminary comparison.

Results

Yields of corn or soybeans did not differ due to tillage in the setup year of the study (Table 1). The yields were respectable considering the extreme heat and drought experienced this growing season. The growing conditions were better in 2013, resulting in higher yields in both corn and soybeans, but no significant differences between tillage treatments (Table 2 and 3). In 2014, the corn yields were very good and Sudden Death Syndrome lowered soybean yields, but there were no differences between tillage treatments (Tables 2 and 3). The cool and rainy start to the season in 2015 slowed corn growth and lowered yields, while the soybeans had very good yields (Tables 2 and 3). In 2016 and 2017, corn and soybean had very good yields, the deep tillage treatments yielded higher than the shallow tillage in the corn, but not in the soybeans. In the corn, there had been a trend with the yield data that was becoming closer to being significantly different as the years progressed, as indicated by the Pr>F value that was decreasing. Combining data from 2013–2017 for analysis showed corn yields are favored by deep tillage, but soybean yields are not affected by tillage system (Tables 2 and 3). Averages of stand counts taken at the V5 stage in the corn for 2014–2017 did not show any differences (Table 2). We anticipate that it will take several years for any characteristics of a given tillage system to build up to the point of influencing yields.

Comparing the average gross income per acre across both crops showed that different systems had the higher income within a given year. This varying response is probably due to the environmental conditions experienced prior to or during each growing season. However, when averaged across the five years, there was up to $20/a advantage for the systems that included deep tillage vs. the no-tillage or shallow tillage only systems.

Conclusions

While the influence of tillage system on corn yield appears to be increasing with time, soybean yields appear to perform equally well with any of the systems. Numerous other factors need to be considered when comparing tillage systems, such as soil erosion, water conservation, weed control options (becoming more challenging with herbicide-resistant weeds), labor, equipment costs, and time available to conduct field work. Identifying the yield-limiting conditions may vary between fields based on soil type and environmental conditions during a season and over the long term.

Table 1. Effects of tillage treatments on corn and soybean yields in 2012 at Kansas River Valley experiment fields

Tillage treatment	Corn yield	Soybean yield
	bu/a	bu/a
No-tillage	196	59.9
Fall subsoil/spring field cultivate	202	55.5
Fall vertical tillage	198	57.9
Pr>F*	0.64	0.14

*The lower the Pr>F value, the greater probability that there is a significant difference between yields.

Table 2. Effects of tillage treatments on corn yields and plant stands in 2013–2017 at Kansas River Valley experiment fields

	Corn yield					Average	Average stand
Tillage treatment	2013	2014	2015	2016	2017	corn yield	2013–2017
	----------	----------	----------	bu/a	----------	----------	plants/a
No-tillage	221	243	205	183 b*	226	216 bc	32,406
Fall subsoil/spring field cultivate	217	259	213	202 a	233	225 a	31,844
Fall vertical tillage	196	259	207	189 b	226	215 c	31,797
Fall subsoil after soybean/vertical tillage after corn	219	256	214	195 a	234	224 ab	31,406
Pr>F#	0.48	0.27	0.10	0.005	0.59	0.03	0.11

*Values followed by the same letter are not significantly different at Pr = 0.05.
#The lower the Pr>F value, the greater probability that there is a significant difference between yields.

Table 3. Effects of tillage treatments on soybean yields in 2013–2017 at Kansas River Valley experiment fields

Tillage treatment	Soybean yield 2013	2014	2015	2016	2017	Average soybean yield
	---------- bu/a ----------					
No-tillage	62.4	52.8	69.7	80.2	67.4	66.5
Fall subsoil/spring field cultivate	64.3	54.6	73.1	76.1	72.8	68.9
Fall vertical tillage	64.4	55.5	72.8	78.6	68.1	67.9
Fall subsoil after soybean/vertical tillage after corn	66.3	53.4	70.9	75.7	70.1	67.3
Pr>F#	0.52	0.59	0.23	0.11	0.098	0.34

#The lower the Pr>F value, the greater probability that there is a significant difference between yields.

Table 4. Income return comparison of tillage systems for corn/soybean rotation at Kansas River Valley experiment fields

Tillage treatment	Average gross income from corn and soybean crops* 2013	2014	2015	2016	2017	Average gross income
	---------- $/a ----------					
No-tillage	672	667	677	686	704	682
Fall subsoil/spring field cultivate	674	703	707	701	741	709
Fall vertical tillage	637	709	695	690	707	687
Fall subsoil after soybean/vertical tillage after corn	686	693	699	687	730	700

*Gross income = ((average corn yield × $3.51 + average soybean yield × $9.11)/2) (Closing grain price January 3, 2016, Cargill, Topeka, KS).

Evaluating Teff Grass as a Summer Forage

J.M. Davidson, D. Min, R.M. Aiken, and G.J. Kluitenberg

Summary
The objectives of this study were to determine the forage yield, nutritive value, and water use efficiency of teff grass (*Eragrostis tef*) under field conditions as compared to sorghum sudangrass and forage pearl millet. Water use efficiency was determined by regressing above-ground biomass on crop water use between sampling periods. Yield was determined by quadrat area clippings of above-ground biomass. Nutritive value was determined using wet chemical analysis. Cultivars showed significant differences in biomass production at all sampling dates in both years. Teff grass demonstrated potential to provide producers with a fast-growing and competitive forage crop by reaching optimum yields at an earlier date than other commonly grown forages.

Introduction
This study was conducted in 2016 and 2017 to determine if teff grass could be established as a summer forage in Kansas. Native to Ethiopia, teff grass is a fine-stemmed, warm-season annual that uses the C_4 photosynthetic pathway. Providing producers with alternative forages offers greater flexibility in diversifying their rotations. Our objectives were to determine the forage yield, nutritive value, and water use efficiency of teff grass under field conditions as compared to sorghum sudangrass and forage pearl millet.

Procedures
Field sites were established at the Kansas State University Northwest Research-Extension Center in Colby, KS, on a Keith silt loam in 2016 and on a Richfield silt loam in 2017. Four commonly available teff varieties, along with sorghum sudangrass and forage pearl millet, were planted on June 8, 2016, and May 31, 2017, in 30- × 20-ft plots at rates of 10 lb/a for teff and 20 lb/a for sorghum sudangrass and pearl millet. Teff grass was sown to a depth of 0.25 in., whereas sorghum sudangrass and forage pearl millet were sown to a depth of one in. Plots were arranged in a randomized complete block design with four replicates. Fertilizer applications included 61 lb/a nitrogen (N) and 30 lb/a phosphorus in both years. Weed management in 2016 included one application of dicamba (Sterling Blue 6 oz/a) and 2,4-D-LV6 (6 oz/a) and another application of 2,4-D-LV6 (16 oz/a). In 2017, one application of 2,4-D-LV6 (10 oz/a) was made. In both years hand hoeing was required to maintain clean plots. Plots were irrigated (2 in. in 2016, 1.2 in. in 2017) after planting to aid emergence in both years. Apart from that, no irrigation was applied during the 2016 and 2017 growing seasons.

Above-ground biomass was measured by harvesting plants within a 30- × 30-in. quadrat. In 2016, harvest began on all plots once the majority of teff grass plots had reached late boot stage. All plots were harvested on the same day every 4–5 days from 40–58 days after planting (DAP). In 2017, each plot was harvested once it reached late boot stage. Teff grass varieties were harvested from 41–63 DAP, whereas sorghum sudangrass and forage pearl millet were harvested from 63–82 DAP. In order to compare cultivars, 2017 data will be examined by days after boot stage (DAB), with the initial harvest being zero DAB. Dry matter yield was determined after samples were dried to a constant weight at 120°F. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined via wet chemical analysis of ground samples. Crude protein (CP) was calculated by multiplying total N (%) by 6.25. Stored soil water was measured using neutron thermalization. Soil water depletion was determined by the difference in stored soil water between two sampling periods. Crop water use (CWU) was determined by the summation of soil water depletion plus precipitation. No corrections were made for drainage, runoff, or evaporative losses. Water use efficiency (WUE) was determined by regressing above-ground biomass on CWU between sampling periods. Precipitation data were obtained from the Kansas Mesonet. Leaf area index (LAI) was measured using a LI-COR LAI-2000 instrument.

Results

Environmental Conditions

The growing seasons extended from planting to 58 and 82 DAP in 2016 and 2017, respectively. Total precipitation for each growing season was 4.3 in. in 2016, and 7.4 in. in 2017. Average maximum/minimum air temperatures for each growing season were 87.7/60.2°F in 2016 and 91.5/63.6°F in 2017.

Crop Development

Emergence was recorded at 6 DAP in 2016 and 9 DAP in 2017. In 2017, one pearl millet plot was removed from the study due to poor stand development. In 2016, all teff varieties reached the late boot stage within 41–48 DAP (Table 1). Sorghum sudangrass and pearl millet reached the late boot stage at 72 and 58 DAP, respectively. In 2017, all teff varieties reached the late boot stage within 41–43 DAP (Table 2). Sorghum sudangrass and pearl millet reached the late boot stage at 63 DAP.

Biomass and Crop Water Use

Cultivars showed significant differences in biomass production at all sampling dates in both years. In 2016, there were only two sampling dates (44 and 58 DAP) at which all teff varieties were similar. The highest-producing teff variety, Excalibur, was similar to sorghum sudangrass in biomass production at every sampling date except for 40 DAP and 58 DAP (Figure 1A). Excalibur was only similar to pearl millet in biomass production at one sampling date: 40 DAP (Figure 1A). Crop water use only differed at two dates (54 and 58 DAP). Excalibur showed WUE similar to that of sorghum sudangrass at 54 DAP (Table 1).

In 2017, teff varieties produced similar biomass at every sampling date except 15 DAB. Teff variety Excalibur was similar to pearl millet in biomass production at every sampling date except for zero DAB (i.e., the date of the initial harvest) and 20 DAB (Figure 1B). Sorghum sudangrass produced significantly more biomass than all other cultivars at every sampling date (Figure 1B). Crop water use has yet to be determined for the 2017 growing season.

Nutritive Value

Cultivars differed in CP and NDF at nearly every sampling date in both years. In 2016, teff variety Corvallis and pearl millet had the greatest CP content at 54 DAP (Table 1). In 2017, teff variety Moxie and pearl millet had the highest above-ground biomass CP content for clippings by quadrat area at 15 DAB (Table 2). The ADF varied the least among cultivars in both years (Figure 1E and F). Pearl millet had lower NDF values than Haymore and Excalibur teff varieties in 2016 at 54 DAP (Table 1).

Canopy Formation

Cultivars differed in LAI at all dates in both years with the exception of 10 DAB in 2017 (Figure 1C and D). Teff varieties differed at every sampling date in 2016 except 54 and 58 DAP. Sorghum sudangrass showed significantly less LAI than pearl millet and teff at all dates in 2016 (Figure 1C). All cultivars were more similar in 2017.

Conclusion

Teff grass can be a competitive forage crop in Kansas. In 2016, teff grass variety Excalibur had dry matter yield and water use efficiency similar to sorghum sudangrass. In 2017, variety Excalibur had dry matter yield similar to pearl millet. Teff grass showed nutritive values similar to sorghum sudangrass and pearl millet in both 2016 and 2017. Since significant variation occurred amongst teff varieties, further research evaluating available varieties of teff grass would greatly help producers in choosing which variety to grow.

Table 1. Forage performance indicators at 54 days after planting in 2016[1]

Cultivars	Biomass	Crop water use	Water use efficiency	Leaf area index	Crude protein	Acid detergent fiber	Neutral detergent fiber	Days to boot stage
	t/a	in.	lb biomass A^{-1} in^{-1} water	ft^2 ft^{-2}	------------------- % -------------------			
Corvallis	1.9 d	6.69 ab	570 c	4.99 b	16.8 a	30.3	58.8 bc	43
Haymore	1.7 cd	6.69 ab	510 c	4.87 b	14.7 b	32.2	60.3 a	41
Moxie	1.8 bcd	7.24 ab	500 bc	5.36 b	16.3 a	31.0	59.2 abc	48
Excalibur	2.1 bc	6.92 ab	610 ab	5.17 b	13.8 b	32.6	60.1 ab	43
SS	2.4 ab	6.49 b	740 a	3.61 c	13.8 b	31.7	58.7 bc	72
PM	2.7 a	7.44 a	730 a	7.30 a	17.4 a	30.1	57.5 c	58

[1]Results are presented for four varieties of teff grass as well as sorghum sudangrass (SS) and forage pearl millet (PM).
Note: Means with different letters within a column are significantly different according to a least significant difference test (a = 0.05).

Table 2. Forage performance indicators at 15 days after boot stage in 2017

Cultivars	Biomass	Crop water use	Water use efficiency	Leaf area index	Crude protein	Acid detergent fiber	Neutral detergent fiber	Days to boot stage
	t/a	in.	lb biomass A^{-1} in^{-1} water	ft^2 ft^{-2}	------------------- % -------------------			
Corvallis	1.8 d	†	†	4.3	10.7 b	33.6 b	62.2 b	41-43
Haymore	2.5 bcd	†	†	4.6	9.5 b	36.1 a	65.1 a	41
Moxie	1.9 cd	†	†	4.7	11.7 ab	33.8 b	61.1 b	41-43
Excalibur	2.7 bc	†	†	5.0	8.8 b	35.4 a	62.5 b	41-43
SS	4.2 a	†	†	4.3	10.9 ab	35.8 a	61.9 b	63
PM	2.8 b	†	†	4.5	13.0 a	35.3 a	62.7 b	63

[1]Results are presented for four varieties of teff grass as well as sorghum sudangrass (SS) and forage pearl millet (PM).
Note: Means with different letters within a column are significantly different according to a least significant difference test (a = 0.05).
† Means not yet calculated. Data are still being analyzed.

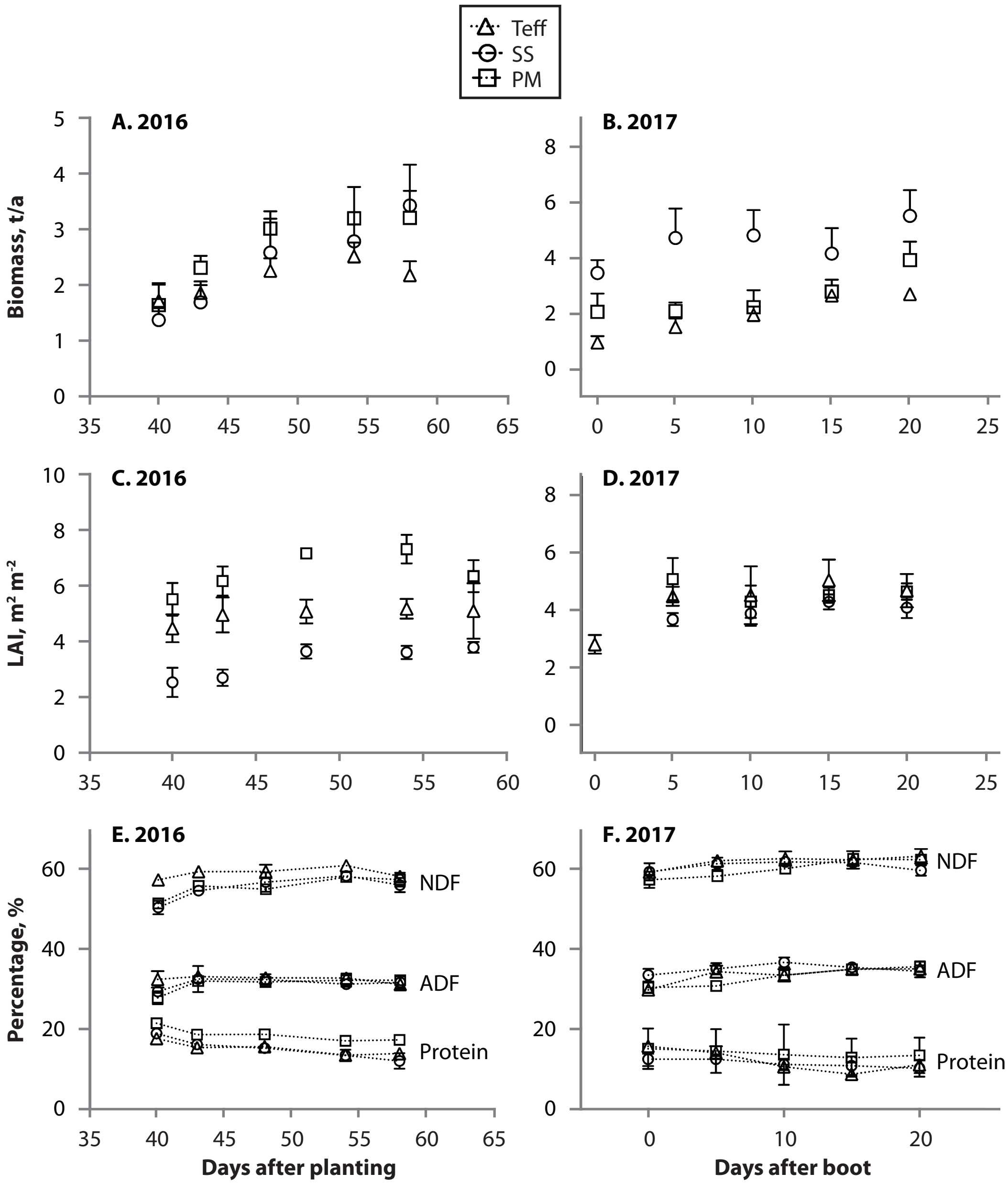

Figure 1. Above-ground biomass, leaf area index (LAI), and nutritive values for teff grass, sorghum sudangrass (SS), and forage pearl millet (PM) in 2016 and 2017. In both years, teff grass is represented by the variety Excalibur.

Kansas Field Research 2018

Chemical Disclaimer
Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Experiments with pesticides on nonlabeled crops or target species do not imply endorsement or recommendation of nonlabeled use of pesticides by Kansas State University. All pesticides must be used consistent with current label directions. Current information on weed control in Kansas is available in *2018 Chemical Weed Control for Field Crops, Pastures, Rangeland, and Noncropland*, Report of Progress 1139, available from the KSRE Bookstore, 24 Umberger Hall, Kansas State University, or at: ***www.bookstore.ksre.ksu.edu/*** (type Chemical Weed Control in search box).

These and other articles are available at the Kansas Agricultural Experiment Station Research Reports site at: ***http://newprairiepress.org/kaesrr***

Publications from Kansas State University are available at: ***www.ksre.ksu.edu***

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

K-State Research and Extension is an equal opportunity provider and employer.

July 2018