KANSAS STATE UNIVERSITY Agronomy

KANSAS FIELD RESEARCH 2022

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Research and Extension

KANSAS STATE UNIVERSITY AGRICULTURAL EXPERIMENT STATION AND COOPERATIVE EXTENSION SERVICE

KANSAS FIELD RESEARCH 2022

Contents

3 2022 Field Book Contributors

Weather

5 East Central Kansas Experiment Field

7 Kansas River Valley Experiment Field

9 2022 Weather Report

Corn

19 Effect of Late Planting Dates on Corn Yield

26 Corn Tiller Yield Contributions are Dependent on Environment: A 17 Site-Year Kansas Study

32 How Relevant is High-Cadence Earth Observation for Maize Crop Phenology Classification?

Soybeans

38 Effect of Early Planting on Soybean Yield

41 Soybean Seed Yield Productivity and Biological Nitrogen Fixation in Kansas

48 Do Late Season Soybean Management Practices Impact Seed Yields in East Kansas?

Wheat

53 Wheat Yield Response to Nitrogen Rate Depends on Foliar Fungicide Application

58 Increasing Winter Wheat Grain Yield by Replicating the Management Adopted in High-Yielding Commercial Fields

65 Winter Wheat Response to Timing of Fungicide Application During the 2020–2021 Growing Season

71 Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2020–2021 Growing Season in Kansas

78 Wheat Variety-Specific Response to Seeding Rate Under Intensive Management Conditions in Western Kansas in 2020–2021

84 Winter Wheat Variety Response to Timing and Number of Fungicide Applications During the 2020–2021 Growing Season in Kansas

Weed Management

90 Fall-Planted Cover Crops for Weed Suppression in Western Kansas

96 Confirmation and Control of Imazamox-Resistant Shattercane

102 Response of Conventional Sorghum to IMIFLEX, Zest WDG, and FirstAct

106 Glyphosate-Resistant Palmer Amaranth Control in XtendFlex Soybean

Management Practices

111 Cover Crop Grazing Effects on Soil Compaction Indicators in Western and Central Kansas

118 Spring and Summer Cover Crop Effects on Dryland Wheat and Grain Sorghum Yields in Western Kansas

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

128 Yield Response to Nitrogen Management in a Corn-Soybean Sequence in North Central Kansas – 2021 Season

133 Historical Characterization of Sorghum Grain Filling Dynamics

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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.

2021 Weather Information

The 2021 weather was a year of extremes for precipitation and temperature. Precipitation during 2021 was 20% over the average, but only 5 months had rainfall over the average (Table 1). Overall, the 2021 growing season was about average, but hotter in June with 12 days over 90°F. The summer of 2021 had 35 days exceeding 90°F and one exceeding 100°F, which equals an average of 35 days exceeding 90°F, in the last 3 years. There were 14 days with low temperatures in the single digits, compared to an average of 9 days in the previous 3 years. The last freezing temperature in the spring was April 22 (average, April 18), and the first killing frost in the fall was November 3 (average, October 21). There were 195 frost-free days, greater than the long-term average of 185.

Rainfall and cooler temperatures from April through May made planting and field work challenging in the spring. Replanting was required for several corn and grain sorghum studies. There was adequate moisture to maintain corn and grain sorghum through a hot and dry June. The corn and grain sorghum hybrid trials averaged 159 and 148 bu/a, respectively. The early maturing soybean variety trial averaged 60.1 bu/a, and the later maturing variety trial averaged 62 bu/a, both well above the averages of the last year.

Table 1. Precipitation at the East Central Kansas Experiment Field, Ottawa

Month	2021	35-year avg.	Month	2021	35-year avg.
	---------------- in. ----------------			---------------- in. ----------------	
January	3.26	1.03	July	3.09	3.37
February	0.16	1.32	August	3.00	3.59
March	4.78	2.49	September	2.44	3.83
April	3.24	3.50	October	4.61	3.43
May	12.28	5.23	November	0.63	2.32
June	6.85	5.21	December	0.34	1.45
Annual total				44.68	36.78

Kansas River Valley Experiment Field

Introduction

The 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 occur. 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.

2021 Weather Information

The year was generally warmer than last year, with near average rainfall during most of the growing season. The frost-free season was 191 days at both Rossville and Paramore units (average = 173 days). The winter season included 14 and 15 days in the single digits or lower at Rossville and Paramore, respectively, which was fewer than the average of 18 single-digit days in the 2018 and 2019 (4 and 5 days, respectively in 2020). The last spring freeze was April 22 (average = April 21), and the first fall freeze was October 30 (average = October 11). There were 41and 49 days above 90°F at Paramore and Rossville, respectively, and 1 above 100°F at Paramore. Precipitation was below normal at both fields for the year (Table 1), with 7 months of below average precipitation. May rainfall was about twice of normal for the May 30-year average. Irrigation for corn started in June, much earlier than normal, with an average total of 7 inches for the corn. Soybeans were irrigated an average of 3.4 inches at the end of July and August. The corn performance trials averaged 242 bu/a for the irrigated and 224 for the dryland. The soybean performance trials averaged 77.1 bu/a for the irrigated and 84 bu/a for the dryland. The sudden death syndrome foliar symptoms in soybean were first seen in mid-August in most fields in 2021, causing significant yield loss in susceptible soybeans in the irrigated trial due to the disease.

Table 1. Precipitation at the Kansas River Valley Experiment Field

	Rossville Unit		Paramore Unit	
Month	**2021**	**30-year avg.**	**2021**	**30-year avg.**
	------------------- in. -------------------		------------------- in. -------------------	
January	2.06	3.18	1.86	3.08
February	0.06	4.88	0.06	4.45
March	4.39	5.46	3.79	5.54
April	2.68	3.67	2.68	3.59
May	7.52	3.44	6.58	3.89
June	2.42	4.64	3.45	3.81
July	2.95	2.97	2.22	3.06
August	2.55	1.90	3.37	1.93
September	2.46	1.24	2.50	1.43
October	3.47	0.95	4.22	0.95
November	1.19	0.89	1.14	1.04
December	0.31	2.42	0.25	2.46
Total	32.06	35.64	32.12	35.23

2022 Weather Report

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

	Alexander		Ashland Bottoms		Belleville	
	Actual	**Normal***	**Actual**	**Normal**	**Actual**	**Normal**
January	0.17	0.71	0.99	0.65	0.56	0.49
February	0.00	0.84	0.09	0.96	0.08	0.77
March	4.55	1.48	3.41	1.83	3.80	1.58
April	1.44	2.26	2.45	3.13	1.47	2.93
May	6.81	3.78	5.39	4.65	3.20	4.55
June	1.99	4.08	1.42	4.83	0.79	4.06
July	2.73	4.18	5.92	4.01	4.54	4.63
August	2.33	3.50	1.54	4.64	5.97	3.24
September	3.06	1.99	3.76	2.69	1.79	2.75
October	3.00	1.78	2.78	2.18	4.23	2.11
November	0.28	0.93	1.40	1.54	0.17	1.20
December	0.00	0.99	0.13	1.06	0.03	1.03
Annual	26.36	26.52	29.28	32.17	26.63	29.34
Last spring freeze	4/23/2021		4/23/2021		4/23/2021	
First fall freeze	10/17/2021		10/31/2021		10/22/2021	
Frost free days	177		191		182	
Number of days > 90°F	55		53		40	
Number of days > 100°F	11		6		3	
Number of days < 10°F	20		15		19	

*Normal = 30-year average, 1981–2010.

Table 2. Precipitation at Brownell, Buhler, and Colby

	Brownell		Buhler		Colby	
	Actual	**Normal***	**Actual**	**Normal**	**Actual**	**Normal**
January	0.37	0.56	2.48	0.80	0.33	0.41
February	0.09	0.74	0.02	1.25	0.17	0.56
March	4.39	1.40	4.23	2.38	3.73	0.92
April	0.67	1.93	1.04	2.92	0.64	1.97
May	4.39	2.99	7.25	4.89	5.59	2.92
June	2.63	2.83	4.02	5.01	1.26	2.62
July	3.65	3.83	1.61	4.20	2.17	3.81
August	0.56	3.07	4.96	3.89	1.21	3.04
September	1.19	1.84	1.94	2.98	1.66	1.44
October	2.70	1.76	5.89	2.64	0.52	1.56
November	0.38	0.76	0.22	1.65	0.07	0.63
December	0.00	0.88	0.05	1.16	0.06	0.51
Annual	21.02	22.59	33.71	33.77	17.41	20.39
Last spring freeze	4/23/2021		4/23/2021		4/23/2021	
First fall freeze	10/16/2021		10/31/2021		10/15/2021	
Frost free days	176		191		175	
Number of days > 90°F	73		55		55	
Number of days > 100°F	23		4		4	
Number of days < 10°F	22		16		20	

*Normal = 30-year average, 1981–2010.

Table 3. Precipitation at Garden City, Goodland, and Greensburg

	Garden City		Goodland		Greensburg	
	Actual	**Normal***	**Actual**	**Normal**	**Actual**	**Normal**
January	0.29	0.47	0.23	0.32	0.87	0.71
February	0.08	0.59	0.00	0.47	0.06	0.81
March	2.36	1.13	3.07	0.88	4.34	1.92
April	0.51	1.65	0.41	1.69	0.24	2.41
May	5.93	2.79	3.19	2.81	2.88	3.39
June	1.35	3.07	1.52	2.96	2.65	3.87
July	0.69	3.16	1.12	3.08	1.48	3.16
August	0.70	2.80	1.72	3.06	2.23	3.46
September	2.81	1.33	0.27	1.40	5.87	2.04
October	1.02	1.34	0.19	1.41	3.67	2.28
November	0.17	0.49	0.01	0.54	0.27	0.96
December	0.00	0.73	0.05	0.47	0.00	0.96
Annual	15.91	19.55	11.78	19.09	24.56	25.97
Last spring freeze	4/23/2021		5/13/2021		4/22/2021	
First fall freeze	10/16/2021		10/15/2021		11/13/2021	
Frost free days	176		155		205	
Number of days > 90°F	75		72		82	
Number of days > 100°F	18		14		22	
Number of days < 10°F	16		25		11	

*Normal = 30-year average, 1981–2010.

Table 4. Precipitation at Hays, Hutchinson, and Keats

	Hays		Hutchinson		Keats	
	Actual	**Normal***	**Actual**	**Normal**	**Actual**	**Normal**
January	0.47	0.56	1.69	0.58	0.90	0.64
February	0.00	0.81	0.01	1.12	0.10	1.14
March	4.45	1.32	4.54	1.96	3.61	2.17
April	1.07	2.13	0.72	2.34	2.06	3.38
May	7.62	3.6	3.06	4.75	4.68	5.23
June	0.80	3.03	2.90	4.20	2.03	5.47
July	2.39	3.95	3.52	3.33	7.41	4.62
August	3.30	3.47	2.25	3.42	2.52	4.40
September	2.08	2.13	2.08	2.01	2.83	3.41
October	1.58	1.68	3.62	2.32	3.60	2.50
November	0.20	0.90	0.32	1.12	1.14	1.62
December	0.00	0.86	0.00	1.16	0.32	1.19
Annual	23.96	24.44	24.71	28.31	31.20	35.77
Last spring freeze	4/23/2021		4/22/2021		4/23/2021	
First fall freeze	10/17/2021		11/13/2021		11/13/2021	
Frost free days	177		205		204	
Number of days > 90°F	77		62		55	
Number of days > 100°F	23		11		5	
Number of days < 10°F	18		15		13	

*Normal = 30-year average, 1981–2010.

Table 5. Precipitation at Kiro, Leoti, and Manhattan

	Kiro		Leoti		Manhattan	
	Actual	Normal*	Actual	Normal	Actual	Normal
January	1.86	0.89	0.04	0.38	0.90	0.64
February	0.06	1.31	0.01	0.51	0.10	1.14
March	3.79	2.25	0.51	1.27	3.61	2.17
April	2.68	3.81	0.53	1.95	2.06	3.38
May	5.93	5.17	7.83	2.31	4.68	5.23
June	3.26	4.92	0.22	2.58	2.03	5.47
July	2.99	3.99	1.79	2.87	7.41	4.62
August	3.06	4.55	1.30	3.11	2.52	4.40
September	2.73	3.52	2.90	1.40	2.83	3.41
October	4.37	2.85	1.34	1.66	3.60	2.50
November	1.14	1.78	0.10	0.64	1.14	1.62
December	0.25	1.49	0.01	0.60	0.32	1.19
Annual	32.12	36.53	16.58	19.28	31.20	35.77
Last spring freeze	4/23/2021		4/24/2021		4/23/2021	
First fall freeze	10/31/2021		10/17/2021		11/13/2021	
Frost free days	191		176		204	
Number of days > 90°F	48		58		55	
Number of days > 100°F	1		9		5	
Number of days < 10°F	15		18		13	

*Normal = 30-year average, 1981–2010.

Table 6. Precipitation at Marquette, Mitchell, and Norcatur

	Marquette		Mitchell		Norcatur	
	Actual	Normal*	Actual	Normal	Actual	Normal
January	2.03	0.90	0.69	0.68	0.07	0.44
February	0.04	1.22	0.09	0.82	0.40	0.52
March	3.72	2.35	3.98	1.45	4.94	1.20
April	0.96	2.98	1.78	2.60	0.67	2.71
May	8.42	5.42	3.54	4.39	5.78	4.26
June	2.15	4.75	1.09	3.77	1.89	3.19
July	1.54	4.19	1.59	4.84	0.96	4.23
August	4.05	3.51	2.11	3.58	0.79	3.63
September	3.79	2.97	1.70	2.72	2.22	2.10
October	2.18	2.44	2.98	1.98	1.69	2.27
November	0.03	1.56	0.03	1.21	0.04	0.91
December	0.11	1.29	0.00	1.04	0.04	0.76
Annual	29.02	33.58	19.58	29.08	19.49	26.22
Last spring freeze	4/23/2021		4/23/2021		5/13/2021	
First fall freeze	11/13/2021		11/5/2021		10/15/2021	
Frost free days	204		196		155	
Number of days > 90°F	58		62		70	
Number of days > 100°F	5		15		16	
Number of days < 10°F	13		17		21	

*Normal = 30-year average, 1981–2010.

Table 7. Precipitation at Ottawa, Rossville, and Scandia

	Ottawa, ECK		Rossville, KRV		Scandia	
	Actual	**Normal***	**Actual**	**Normal**	**Actual**	**Normal**
January	3.26	1.22	2.06	0.74	0.48	0.49
February	0.16	1.57	0.06	1.18	0.03	0.77
March	4.78	2.29	4.39	2.08	4.35	1.58
April	3.24	3.79	2.68	3.48	1.40	2.93
May	12.07	5.82	6.77	5.06	2.89	4.55
June	5.49	5.55	2.81	5.11	0.97	4.06
July	4.66	3.75	3.29	4.32	1.60	4.63
August	2.74	4.63	2.21	4.60	3.46	3.24
September	2.70	4.05	2.68	3.75	1.02	2.75
October	4.61	3.08	3.61	2.71	2.84	2.11
November	0.63	2.39	1.19	1.67	0.16	1.20
December	0.34	1.71	0.31	1.37	0.06	1.03
Annual	44.68	39.85	32.06	36.07	19.26	29.34
Last spring freeze	4/23/2021		4/23/2021		5/14/2021	
First fall freeze	11/4/2021		10/31/2021		10/15/2021	
Frost free days	195		191		154	
Number of days > 90°F	36		38		33	
Number of days > 100°F	1		0		0	
Number of days < 10°F	14		14		21	

*Normal = 30-year average, 1981–2010.

Table 8. Precipitation at Selkirk, Tipton, and Topeka

	Selkirk		Tipton		Topeka, KRV	
	Actual	**Normal***	**Actual**	**Normal**	**Actual**	**Normal**
January	0.24	0.28	0.69	0.68	1.86	0.89
February	0.03	0.48	0.09	0.82	0.06	1.31
March	2.98	0.83	3.98	1.45	3.79	2.25
April	0.59	1.56	1.78	2.60	2.68	3.81
May	6.35	2.36	3.54	4.39	5.93	5.17
June	0.74	2.78	1.09	3.77	3.26	4.92
July	1.58	3.04	1.59	4.84	2.99	3.99
August	0.76	2.78	2.11	3.58	3.06	4.55
September	1.14	1.20	1.70	2.72	2.73	3.52
October	1.66	1.44	2.98	1.98	4.37	2.85
November	0.09	0.38	0.03	1.21	1.14	1.78
December	0.00	0.48	0.00	1.04	0.25	1.49
Annual	16.16	17.61	19.58	29.08	32.12	36.53
Last spring freeze	5/13/2021		4/23/2021		4/23/2021	
First fall freeze	10/16/2021		11/5/2021		10/31/2021	
Frost free days	156		196		191	
Number of days > 90°F	53		62		48	
Number of days > 100°F	8		15		1	
Number of days < 10°F	24		17		15	

*Normal = 30-year average, 1981–2010.

Table 9. Precipitation at Wamego

	Wamego	
	Actual*	**Normal**
January	0.90	0.69
February	0.10	1.16
March	3.61	2.09
April	2.06	3.50
May	4.68	5.11
June	2.03	5.19
July	7.41	4.66
August	2.52	4.11
September	2.83	2.86
October	3.60	2.41
November	1.14	1.67
December	0.32	1.28
Annual	31.20	34.73
Last spring freeze	4/23/2021	
First fall freeze	11/13/2021	
Frost free days	204	
Number of days > 90°F	55	
Number of days > 100°F	5	
Number of days < 10°F	13	

*Normal = 30-year average, 1981–2010.

Table 10. Location references per field locations

Field location	Mesonet site	Normals site*
	(Actual precipitation, temperatures)	(Normal precipitation)
Alexander	La Crosse	Bison 3NW (BSNK1)
Ashland Bottoms	Ashland Bottoms	Manhattan ASOS (MHK)
Belleville	Belleville 2W	Scandia (SCDK1)
Brownell	Ness City	Ness City (NESK1)
Buhler	Flickner Innovation Farm	Newton (NWTK1)
Colby	Colby	Colby 1SW (CBKK1)
Garden City	Garden City	Garden City (GESK1)
Goodland	Sherman	Goodland Renner Field (GLD)
Greensburg	Lake City	Greensburg (GEEK1)
Hays	Hays	Hays 1 S (HASK1)
Hutchinson	Hutchinson 10SW	Hutchinson 10SW (HINK1)
Keats	Manhattan	Manhattan (MHTK1)
Kiro	Silver Lake 4E	Topeka ASOS (TOP)
Leoti	Leoti	Leoti (LEOK1)
Manhattan	Manhattan	Manhattan (MHTK1)
Marquette	McPherson 1S	McPherson (MCPK1)
Mitchell	Mitchell	Beloit (BELK1)
Norcatur	Norton 4SW	Norton Dam (NTDK1)
Ottawa, ECK	Ottawa 2SE	Ottawa (OTTK1)
Rossville, KRV	Rossville 2SE	Rossville (RVEK1)
Scandia	Scandia	Scandia (SCDK1)
Selkirk	Tribune 6NE	Tribune 13NNE (GRWK1)
Tipton	Mitchell	Beloit (BELK1)
Topeka, KRV	Silver Lake 4E	Topeka ASOS (TOP)
Wamego	Manhattan	Wamego 4W (WAMK1)

*Normal = 30-year average, 1981–2010.

Effect of Late Planting Dates on Corn Yield

E. Adee

Summary
Planting date studies have been conducted for corn over many years. Often the focus has been to determine optimum planting date for maximizing yield. In some areas, planting early-maturing corn hybrids as early as possible has been a successful strategy for avoiding hot, dry conditions at the critical pollination and early grain fill stages. Planting later can be an alternative strategy that attempts to avoid the most intense heat by moving the critical growth stages for corn centered around pollination to later in the growing season. This strategy has been adopted by some growers in areas that often encounter heat and moisture stress during the growing season. However, crop insurance cutoff dates for planting are earlier than some farmers may want to plant some of their corn acres. The purpose of these studies was to assess the yield potential for corn planted after the insurance planting cutoff date and to compare corn yields from a wide range of planting dates. Corn planted from the second week of June until even the 4th week can yield from 50 to 70% of the highest yield of the earlier planting dates.

Procedures
Corn planting date studies were conducted at Kansas River Valley (Topeka) and East Central Kansas (Ottawa) Experiment Fields in 2018, 2019, 2020, and 2021. The experiment at Topeka was irrigated with irrigations totaling 9.5 inches applied June 8 through August 13, 2018; 3.5 inches from June 30 through July 30, 2019; 4.1 inches from June 15 through August 17, 2020; 6.45 inches from June 14 to August 25, 2021. An overhead sprinkler irrigation system applied roughly 0.8 inch of water at each irrigation event. The experiment at Ottawa received no irrigation. A single hybrid was planted at each location at four or five planting dates in 2018 and 2019, while a shorter and longer season hybrid was planted at each date and location in 2020. Corn was planted every two to three weeks from April 10 to June 11 at Topeka and from April 13 to June 29 at Ottawa in 2018; April 19 to June 11 at Topeka and from April 13 to June 28 at Ottawa in 2019; April 10 to June 10 at Topeka and April 8 to June 8 at Ottawa in 2020; and April 6 to June 10 at Topeka and from April 5 to June 23 at Ottawa in 2021. The U.S. Department of Agriculture's final planting date for corn at both locations was May 25. At Topeka, Pioneer 1197AM (111 relative maturity (RM)) was planted at 32,900 seeds per acre, and at Ottawa Pioneer 1138AM (111 RM) was planted at 26,500 seeds/a in 2018 and 2019. In 2020, DK 51-91 (101 RM) and DK 64-25 (114 RM) hybrids were planted at Ottawa, and DK 51-20 (101 RM) and DK 65-95 (115 RM) were planted at Topeka at the same seeding rates as the previous years at both locations. In 2021, DK 51-91 (101 RM) and DK 65-95 (115 RM) were planted at Ottawa, and Integra 5081 (100 RM) and DK 65-95 (115 RM) were planted at Topeka at the same seeding rates as the previous years at both locations The experiment utilized a randomized complete block design with four replications. Individual plots were 30-ft (12 rows) wide and 30- to 40-ft long. Yields were determined from the middle two rows of each plot to avoid influence from neighboring plots. Usually, two harvest dates were required at each location to allow the later planted corn to mature and dry sufficiently for harvest. Yields

were corrected to 15.5% grain moisture. Nitrogen and weed control were managed to have no effect on yields.

Results

In 2018, the growing season started off cool, with seedlings from the first planting date taking more than 16 days to emerge, but the weather warmed up quickly. Seedlings from the second planting date emerged approximately 3 days after the first planting date emerged. The rest of the growing season continued to be warmer than average, with below-average rainfall during April through July. Although temperatures remained high in August, rainfall exceeded the 30-year average.

In 2019, there was a cool period in early May, then temperatures were closer to average for June and July, with August being cooler. Rainfall was above average for every month except July, with some months more than double the 30-year average. At Topeka, the corn emerged 10, 6, 4, and 5 days after planting for the respective planting dates.

In 2020, there were cool periods in April and May that slowed the emergence of corn planted earlier, however, June was warmer and drier than normal, requiring irrigation at Topeka. July was wetter than normal with 3 times the average rainfall. Corn emergence was 19, 12, 7, and 5 days for the earliest to latest planting dates, respectively.

In 2021, similar to 2020, there were cool/cold periods in April and May, with snow on April 20, that slowed corn emergence in the earlier planted corn. The days to emergence at Topeka were 20, 14, 7, and 4 days, respectively, for the earliest to the latest planting dates. At Ottawa, the day to emergence were 35, 14, 7, and 8 days for earliest to latest planting dates, respectively.

The 2018 and 2019 yield results from Ottawa were greatly influenced by the weather, specifically hot and dry periods in July when the corn planted in early to mid-May was trying to pollinate. As a result, the corn planted at the end of May or first week of June yielded as well or better than the earlier planting dates because rain events occurred when the corn was pollinating (Tables 1, 2). Corn planted in the last week of June had good pollination weather but yielded 60–70% of the highest yields each year, reflecting the lack of growing season that reduced yield potential.

The corn yield response to planting date in Ottawa in 2020 was very different than the previous two years, with the highest yield 40 to 80 bu/a higher than the two previous years. The above-average rainfall in July was favorable for pollination, resulting in the highest yields from corn planted at the end of April through mid-May for both the short and full season hybrids (Table 3). Corn planted in the first week of June yielded just greater than 70% of the highest yields. The full season hybrid yielded more than the short season at every planting date, indicating that switching to a shorter season hybrid due to delayed planting will not increase yield.

In 2021, the highest corn yield at Ottawa was with the early April planting of the full season hybrid, similar to 2020 (Table 4). The next highest yield was with the short season hybrid planted the first part of June, very different from the previous years. In contrast, the lowest yield was with the short season hybrid planted in early April. The

June 23 planting experienced hot/dry conditions shortly after planting, resulting in crusting issues with very few plants emerging (data not shown), therefore, the data from that planting date were not included in the results.

For all years at Topeka, the yield-limiting factor of moisture stress was greatly reduced by repeated irrigations, resulting in a more traditional yield response to planting date (Tables 5-8). The highest yield was when corn was planted in the last half of April in 2018 and 2019 (Tables 5, 6). In 2020, the highest yield was with the April 10 planting date for both the short and full season hybrids (Table 7). The full and shorter season hybrids' yields were almost equal when planted June 11. Similar to 2020, the highest yield in 2021 at Topeka, was with the full season hybrid planted in early April (Table 8). The short season hybrid planted early had the lowest yield, similar to results from Ottawa this year. Both hybrids planted in early June averaged 70% of high yield for the study.

Generally, grain test weights were lower with the last planting dates at both locations for all years, especially with the full season hybrid (Tables 1–8). This reduction in grain test weight was related to the shorter grain fill period for the later planting dates.

Overall, the planting date for the highest yield at Ottawa varies, depending on the environment experienced that year (Figure 1). With irrigation to help reduce some of the variability at Topeka, the highest yield tended to be with the earlier planting dates (Figure 2). Planting corn in June at Ottawa generally yielded 70% of the highest yield, and the June planting at Topeka generally averaged 60%.

Switching from a full to a shorter season hybrid due to delayed planting generally did not increase yield at either location. However, the shorter season hybrid may not take as long to mature and dry down at harvest (Tables 1–8).

The preliminary results from four years of experiments provide an example of how later planting date can be a viable option to avoid stressing the corn at critical stages when moisture is limiting, or when planting is delayed because of excess rainfall. The results from the irrigated experiment at Topeka illustrate that if moisture is not limiting, but planting is delayed, corn can still produce a substantial yield, though reduced from the potential of the optimum. These data also show the variable response to planting date in dryland production of corn in Kansas, which is often related to the conditions at pollination.

Table 1. Effect of planting date on dryland corn at the East Central Kansas Experiment Field, Ottawa, in 2018

Planting date	Grain moisture	Grain test weight	Grain yield	Percent high yield
	%	lb/bu	bu/a	%
13-Apr	15.3 d[†]	62.0 a	98 a	88 ab
30-Apr	15.6 d	62.9 a	93 ab	83 ab
18-May	18.8 b	60.7 b	60 bc	52 c
8-Jun	18.0 c	58.8 c	96 a	86 ab
29-Jun	23.7 a	52.5 d	66 bc	60 bc
Pr>F	<0.0001	<0.0001	0.05	0.046

[†]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

Table 2. Effect of planting date on dryland corn at the East Central Kansas Experiment Field, Ottawa, in 2019

Planting date	Grain moisture	Grain test weight	Grain yield	Percent high yield
	%	lb/bu	bu/a	%
16-Apr	15.6 c[†]	56.7 a	115 ab	92 ab
6-May	16.1 c	57.3 a	112 b	90 b
31-May	17.5 b	56.2 a	124 a	99 a
28-Jun	21.8 a	51.3 b	91 c	73 c
Pr>F	<0.0001	<0.0001	0.0005	0.0005

[†]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

Table 3. Effect of planting date on dryland corn at the East Central Kansas Experiment Field, Ottawa, in 2020

Planting date	Hybrid rel. mat.	Plant pop.	Grain moisture	Grain test weight	Grain yield	Percent high yield
	days	plants/a	%	lb/bu	bu/a	%
8-Apr	101	26572	15.0 f[†]	52.0 c	90 d	49 d
28-Apr	101	26935	16.1 e	55.5 ab	136 bc	74 bc
18-May	101	26862	17.5 d	55.2 a	146 b	79 b
8-Jun	101	26499	23.8 b	50.0 d	128 c	69 c
8-Apr	114	27007	17.5 d	56.3 a	153 b	83 b
28-Apr	114	27080	18.3 d	56.5 ab	180 a	98 a
18-May	114	27080	19.6 c	55.3 ab	179 a	97 a
8-Jun	114	27806	25.0 a	50.6 d	140 bc	76 bc
Pr>F		0.61	<0.0001	<0.0001	<0.0001	<0.0001

[†]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

Table 4. Effect of planting date on dryland corn at the East Central Kansas Experiment Field, Ottawa, in 2021

Planting date	Hybrid rel. mat.	Plant pop.	Grain moisture	Grain test weight	Grain yield	Percent high yield
	days	plants/a	%	lb/bu	bu/a	%
5-Apr	102	25615	15.4 cd[†]	57.0 a	117 c	63 c
26-Apr	102	25263	14.5 d	57.6 a	131 bc	70 bc
4-June	102	27085	17.9 bc	57.5 a	163 ab	88 ab
8-Apr	115	25840	16.6 bcd	58.4 a	186 a	100 a
28-Apr	115	21345	19.0 b	57.3 a	151 b	81 b
4-June	115	24975	25.1 a	53.9 b	135 bc	72 bc
Pr>F		0.14	<0.0001	0.007	0.004	0.003

[†]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

Table 5. Effect of planting date on corn under irrigation at Kansas River Valley Experiment Field, Topeka, in 2018

Planting date	Plant pop.	Grain moisture	Grain test weight	Grain yield	Percent high yield
	plants/a	%	lb/bu	bu/a	%
10-April	30750	17.1 b[†]	62.1 ab	215 a	84 a
23-April	30500	17.4 b	62.3 a	240 a	94 a
18-May	30375	17.0 b	61.3 b	219 a	85 a
11-June	27875	25.6 a	52.3 c	127 b	50 b
Pr>F	0.25	<0.0001	<0.0001	0.0050	0.003

[†]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

Table 6. Effect of planting date on corn under irrigation at the Kansas River Valley Experiment, Field, Topeka, in 2019

Planting date	Plant pop.	Grain moisture	Grain test weight	Grain yield	Percent high yield
	plants/a	%	lb/bu	bu/a	%
19-April	31878	17.8 c[†]	58.2 a	243 a	98 a
14-May	30625	21.1 bc	55.8 ab	213 ab	87 ab
1-June	30625	24.7 b	52.5 b	177 bc	71 bc
11-June	32375	32.3 a	47.5 c	131 c	53 c
Pr>F	0.32	0.0003	0.0021	0.0047	0.0042

[†]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

Table 7. Effect of planting date on irrigated corn at the Kansas River Valley Experiment Field, Topeka, in 2020

Planting date	Hybrid rel. mat.	Plant pop.	Grain moisture	Grain test weight	Grain yield	Percent high yield
	days	plants/a†	%	lb/bu	bu/a	%
8-Apr	101	29984 c	12.4 f	56.4 c	192 c	77 c
30-Apr	101	29984 c	13.3 e	56.8 ab	167 d	67 d
21-May	101	35452 b	13.8 d	57.4 ab	140 e	56 e
10-Jun	101	30564 c	20.2 b	54.2 d	152 de	60 de
8-Apr	115	33323 ab	17.1 a	60.2 a	254 a	100 a
30-Apr	115	30202 c	19.6 ab	56.4 ab	230 ab	91 b
21-May	115	34413 ab	16.9 ab	60.5 ab	222 b	88 b
10-Jun	115	33904 ab	24.2 d	56.8 d	153 de	61 de
Pr>F		<0.0001	<0.0001	0.001	<0.0001	<0.0001

†Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

Table 8. Effect of planting date on irrigated corn at the Kansas River Valley Experiment Field, Topeka, in 2021

Planting date	Hybrid rel. mat.	Plant pop.	Grain moisture	Grain test weight	Grain yield	Percent high yield
	days	plants/a†	%	lb/bu	bu/a	%
8-Apr	100	35149	11.7 d	52.7	119 c	49 c
30-Apr	100	35501	12.3 cd	55.6	166 b	67 b
21-May	100	35000	14.5 bcd	54.4	185 b	75 b
10-Jun	100	35625	19.2 b	55.6	166 b	66 b
8-Apr	115	34630	17.4 bc	56.6	247 a	100 a
30-Apr	115	35697	18.4 b	58.3	239 a	95 a
21-May	115	35125	17.6 bc	56.9	231 b	95 a
10-Jun	115	36875	25.9 a	56.1	180 b	75 b
Pr>F		0.25	0.0005	0.18	<0.0001	<0.0001

†Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$.

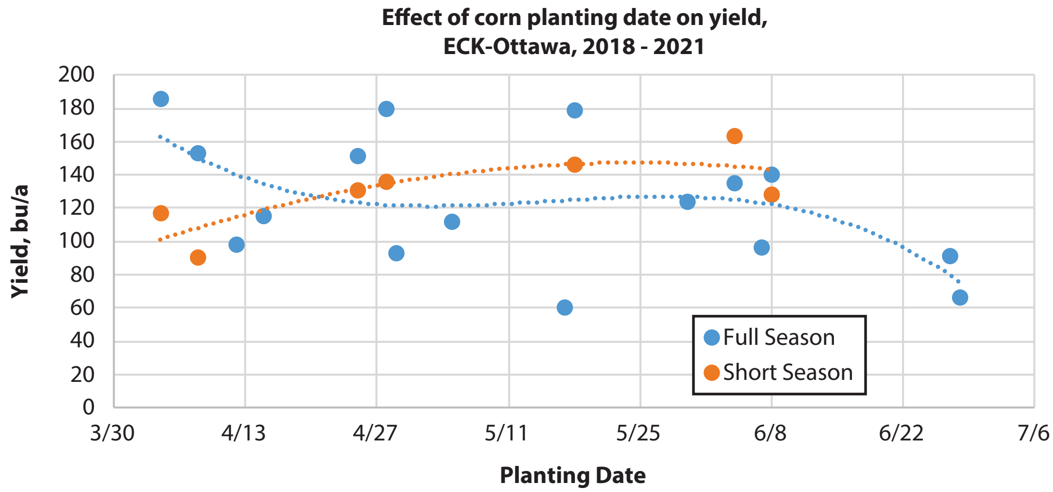

Figure 1. Effect of corn planting date on yield averages at East Central Kansas Experiment Field, Ottawa, 2018–2021.

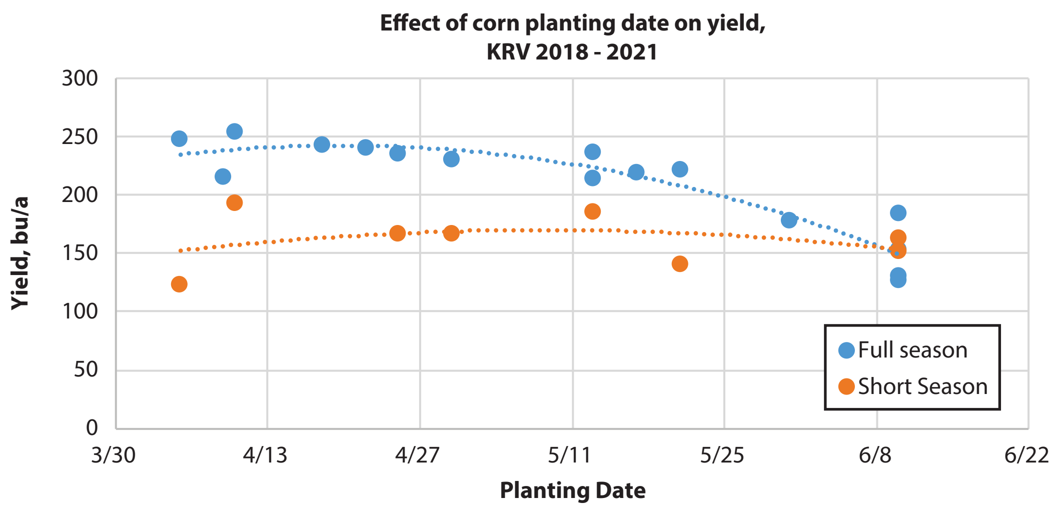

Figure 2. Effect of corn planting date on yield averages at Kansas River Valley Kansas Experiment Field, Topeka, 2018–2021.

Corn Tiller Yield Contributions are Dependent on Environment: A 17 Site-Year Kansas Study

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Summary
Historic breeding efforts in corn (*Zea mays* L.) have resulted in uniform, single-stalked phenotypes with limited potential for environmental plasticity. Therefore, plant density is a critical yield component for corn, as corn is unable to successfully compensate for a deficit of plants. Other grass crop species can overcome plant density deficits via vegetative branching (tillering), but this trait is historically undesirable in corn. Improving corn flexibility across plant densities has potential benefits, particularly considering diverse yield environments and seasonal weather uncertainties due to climate change. The present study evaluated tiller presence with two hybrids in a range of plant densities across the state of Kansas to identify yield impacts and potential usefulness of this plasticity trait in corn. Tiller presence was identified as neutral or additive to final yields, but fine-tuning plant density was confirmed as key to maximizing grain yields. Tillers have potential to stabilize yields across plant densities in productive environments. This capability may offer a source of production stability for growers when deficits develop in plant density after planting.

Introduction
Plant density is a management strategy to optimize the balance between crop needs and resource availability (Laitinen and Nikoloski, 2019). Specifically in corn (*Zea mays* L.), optimal plant density has historically increased as a key driver of modern yield gains (Duvick et al., 2004). Crop plasticity, the ability of a genotype to express alternative phenotypes and adapt to contrasting environmental scenarios, is marginal in corn compared to other cultivated crops. Due to this comparatively lower plasticity, corn yields are notably dependent on plant density. This attribute is less desirable in challenging or otherwise unpredictable growing conditions (Mylonas et al., 2020).

Corn adjusts its final grain production via yield components (namely ears per area, kernels per ear, and weight per kernel). The corn yield component most easily altered via management practices is ears per area, which is adapted with plant density and prolific (multi-eared) hybrid selection. Other Poacea species, such as wheat (*Triticum aestivum* L.) and grain sorghum (*Sorghum bicolor* L. Moench), increase the number of inflorescences per area by producing additional vegetative shoots (tillers). Although genetically different from its more grass-like ancestor (*Zea mays* ssp. *parviglumis*), corn remains

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capable of producing tillers. This trait is often suppressed in modern hybrids (Moulia et al., 1999). Corn tillers that do appear may remain vegetative, produce harvestable grain, or develop abnormal inflorescences without harvestable grain ("tassel ears"). Due to these unpredictable, undesirable outcomes, corn tillers have been historically associated with yield reductions. For this reason, corn tillers are commonly referred to as "suckers" (Jenkins, 1941).

Growers commonly voice concerns about tiller presence in corn fields, and conclusive evidence on tillering impacts (particularly in Kansas) is lacking. Therefore, this multi-season study sought to understand 1) the impact of tiller expression on yield in varying environments, and 2) the potential of tillers as a plasticity trait in Kansas environments.

Procedures

Data presented in this report were collected during a multi-year statewide study (2019-2021). Location characterizations are provided in Table 1.

Twelve site-years were established with a split-split-plot design, evaluating three factors: whole plot of planting density with three levels (10000, 17000, and 24000 plants/a), sub-plot of hybrid with two levels (P0805AM and P0657AM), and sub-sub-plot of tiller presence with two levels (removal at the V10 [tenth-leaf; Ritchie et al., 1997] development stage [TR], or intact throughout the season [TI]; Table 1). The remaining five site-years were established without the tiller presence factor (Table 1). In total, seventeen site-years were evaluated with at least three replications each.

Grain yields were harvested from the two central plot rows and adjusted to 15.5% standard grain moisture. Sites were clustered into three yield environments (low-, moderate-, and high-yielding; LYE, MYE, and HYE respectively) via a k-means algorithm. A linear mixed effects model was fit with grain yield as the response considering 1) fixed effects of treatment factors interacting with yield environment, and 2) random effects of site-year and design factors. The fitted model was subjected to a 3-way analysis of variance (ANOVA) and subsequent means comparison (Tukey method). A second linear mixed effects model was fit with grain yield as the response considering 1) fixed effects of observed plant density, observed tiller density, and interactions with yield environment; and 2) random effects of site-year and design factors. Predictions were generated with model coefficients based on the range of density observations across trials. All analyses and figures were generated with the R software (R Core Team, 2021).

Results

The ANOVA results for the treatment factor model are shown in Table 2. The interaction of yield environment with both plant density ($P \leq 0.001$) and tiller presence ($P \leq 0.01$) impacted final yields. Subsequent means comparisons are shown by yield environment in Figure 1. Plant density thresholds for grain yields within the evaluated ranges were 10,000 plants/a in the LYE, 17,000 plants/a in the MYE, and 24,000 plants/a in the HYE. Tiller presence did not reduce yields in any environment, instead tillers increased the overall yields in the HYE.

The ANOVA results for the observational analysis are shown in Table 2. The interaction of yield environment with both observed plant density and observed tiller density impacted yield predictions, in addition to the triple interaction of environment and observed densities (all significant at $P \leq 0.001$). Plotted predictions are shown by yield environment in Figure 2. Overall yields both with and without tillers were stable across observed plant densities in the LYE. Overall yields were more stable with greater tiller densities across observed plant densities in the MYE and HYE. Regardless of yield environment, greatest yields were realized when plant density was optimized, minimizing tiller expression.

The results of this study support the hypotheses that 1) tiller presence alone does not reduce corn yields across environments; and 2) tillers are an indication of plant density deficits but can be useful in stabilizing these deficits in productive environments. Additional information on this study can be found in Veenstra et al. (2021).

References

Duvick, D. N., Smith, J. S. C., & Cooper, M. (2004). Long-term selection in a commercial hybrid maize breeding program. In *Plant Breeding Reviews* (pp. 109–151). John Wiley & Sons, Inc. *https://doi.org/10.1002/9780470650288.ch4*.

Jenkins, M. T. (1941). Influence of climate and weather on growth of corn. In *Yearbook of Agriculture*. United States Department of Agriculture.

Laitinen, R. A. E., & Nikoloski, Z. (2019). Genetic basis of plasticity in plants. *Journal of Experimental Botany*, *70*(3), 739–745. *https://doi.org/10.1093/jxb/ery404*.

Moulia, B., Loup, C., Chartier, M., Allirand, J. M., & Edelin, C. (1999). Dynamics of architectural development of isolated plants of maize (*Zea mays* L.), in a non-limiting environment: The branching potential of modern maize. *Annals of Botany*, *84*(5), 645–656. *https://doi.org/10.1006/anbo.1999.0960*.

Mylonas, I., Sinapidou, E., Remountakis, E., Sistanis, I., Pankou, C., Ninou, E., Papadopoulos, I., Papathanasiou, F., Lithourgidis, A., Gekas, F., Dordas, C., Tzantarmas, C., Kargiotidou, A., Tokamani, M., Sandaltzopoulos, R., & Tokatlidis, I. S. (2020). Improved plant yield efficiency alleviates the erratic optimum density in maize. *Agronomy Journal*, *112*(3), 1690–1701. *https://doi.org/10.1002/agj2.20187*.

R Core Team. (2021). *R: a language and environment for statistical computing*. *https://www.r-project.org/*.

Ritchie, S. W., Hanway, J. J., & Benson, G. O. (1997). How a corn plant develops. *Iowa State University Coop. Ext. Serv.*, *48*.

Veenstra, R. L., Messina, C. D., Berning, D., Haag, L. A., Carter, P., Hefley, T. J., Prasad, P. V. V., & Ciampitti, I. A. (2021). Effect of tillers on corn yield: Exploring trait plasticity potential in unpredictable environments. *Crop Science*, *61*(5), 3660–3674. *https://doi.org/10.1002/csc2.20576*.

Table 1. Site-year characterizations

Site-year	Latitude	Longitude	Treatment structure	pH	OM	NO_3-N	NH_4-N	P	Soil texture
	°N	°W		H_20	% LOI	ppm	ppm	Mehlich, ppm	
Manhattan 19 $_L$	39.14	96.64	D × G × P	6.3	1.0	1.8	1.3	37.5	Sandy Loam
Garden City 19 $_M$	37.83	100.86	D† × G × P	6.6	1.0	2.0	0.0	42.0	Sandy Loam
Goodland 19 $_H$	39.25	101.78	D† × G × P	6.5	2.7	26.8	2.1	52.1	Silt Loam
Keats 20 $_H$	39.23	96.72	D × G × P	7.0	4.5	18.0	4.1	118.0	Silty Clay Loam
Buhler 20 $_M$	38.14	97.73	D × G	6.4	2.9	17.9	4.8	24.0	Silty Clay Loam
Greensburg 20 $_H$	37.58	99.37	D × G	5.4	2.6	37.1	13.6	84.9	Clay Loam
Garden City 20 $_H$	37.83	100.86	D × G × P	5.2	1.6	18.4	10.7	55.0	Sandy Loam
Goodland 20 $_H$	39.25	101.78	D × G × P	5.8	3.8	36.9	17.9	106.0	Silt Loam
Colby A 20 $_M$	39.39	101.06	D × G × P	5.4	3.3	19.9	4.3	70.0	Silt Loam
Colby B 20 $_L$	39.38	101.06	D × G × P	6.5	3.2	43.5	36.4	31.0	Silt Loam
Keats 21 $_H$	39.23	96.72	D × G × P	6.6	6.2	23.3	12.7	106.4	Silt Loam
Buhler 21 $_M$	38.14	97.73	D × G	6.3	2.6	11.7	7.8	13.3	Silt Loam
Greensburg 21 $_M$	37.58	99.37	D × G	5.6	2.3	33.4	7.4	68.8	Loam
Selkirk 21 $_H$	38.70	101.54	D × G	7.9	2.7	14.0	5.8	90.9	Loam
Garden City 21 $_M$	37.83	100.86	D × G × P	5.5	1.6	14.2	5.2	52.1	Sandy Loam
Goodland 21 $_H$	39.25	101.78	D × G × P	6.5	2.9	36.9	11.1	65.4	Loam
Colby A 21 $_L$	39.39	101.06	D × G × P	7.1	2.9	23.8	7.1	93.0	Clay Loam

Site-year identifiers with year (2019-2021) and yield environment (L-low, M-moderate, H-high); trial coordinates (°N and °W); treatment structure (D, plant density; G, genotype; P, tiller presence); and soil characterization [pH, organic matter (OM – loss on ignition (LOI)), nitrate concentration (NO_3-N), ammonium concentration (NH_4-N), phosphorus (P – Mehlich), and soil texture].
† Missing one level of designated treatment factor.

Table 2. Analysis of variance results for grain yield

Model	Source	df	Residual df	F value	*P*-value
Treatment factors	**Environment (E) × Plant density (D)**	**9**	**51.43**	**165.84**	***
	E × Genotype (G)	3	248.00	0.34	ns
	E × Tiller presence (P)	**3**	**186.00**	**4.92**	**
	E × D × G	6	248.00	1.35	ns
	E × D × P	6	186.00	1.96	ns
	E × G × P	3	186.00	1.68	ns
	E × D × G × P	6	186.00	0.71	ns
	Marginal R^2 = 0.80, Conditional R^2 = 0.88				
Field observations	**Environment (E) × Observed plant density (M)**	**3**	**56.32**	**132.09**	***
	E × Observed tiller density (T)	**3**	**351.09**	**22.35**	***
	E × M × T	**3**	**392.12**	**14.34**	***
	Marginal R^2 = 0.77, Conditional R^2 = 0.86				

Tested source of variation (Source), degrees of freedom (df), degrees of freedom of residuals (Residual df), F value, and the associated *p* value significance are presented. All sources with *P*-values ≤ 0.05 are shown in boldface font. Coefficient of determination values are provided.
*** Significant at P ≤ 0.001. ** Significant at P ≤ 0.01, ns not significant.

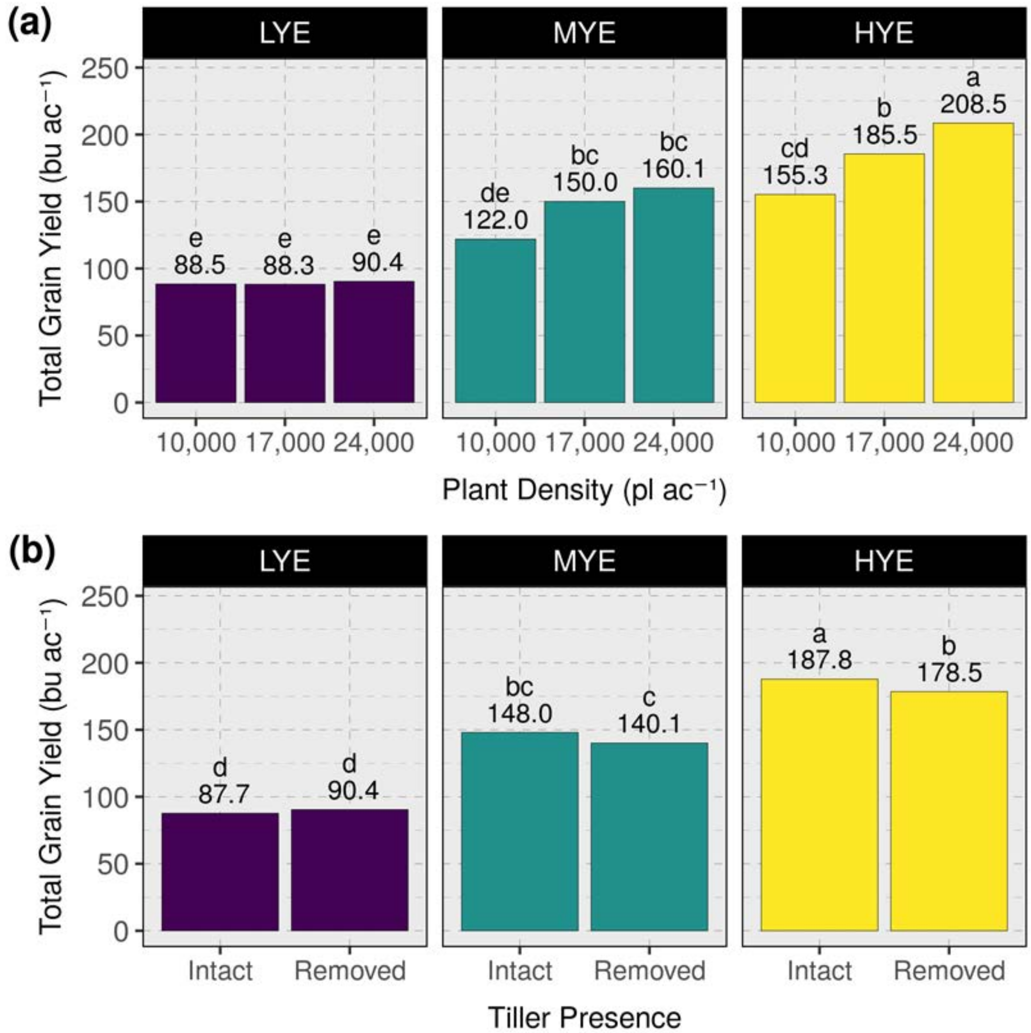

Figure 1. Mean yields and pairwise comparisons of treatment factors deemed significant in Table 2 (a, plant density; b, tiller presence) by yield environment (LYE, low-yielding environment; MYE, moderate-yielding environment; HYE, high-yielding environment). Means within a panel not sharing a common letter are significant at the 0.05 probability level.

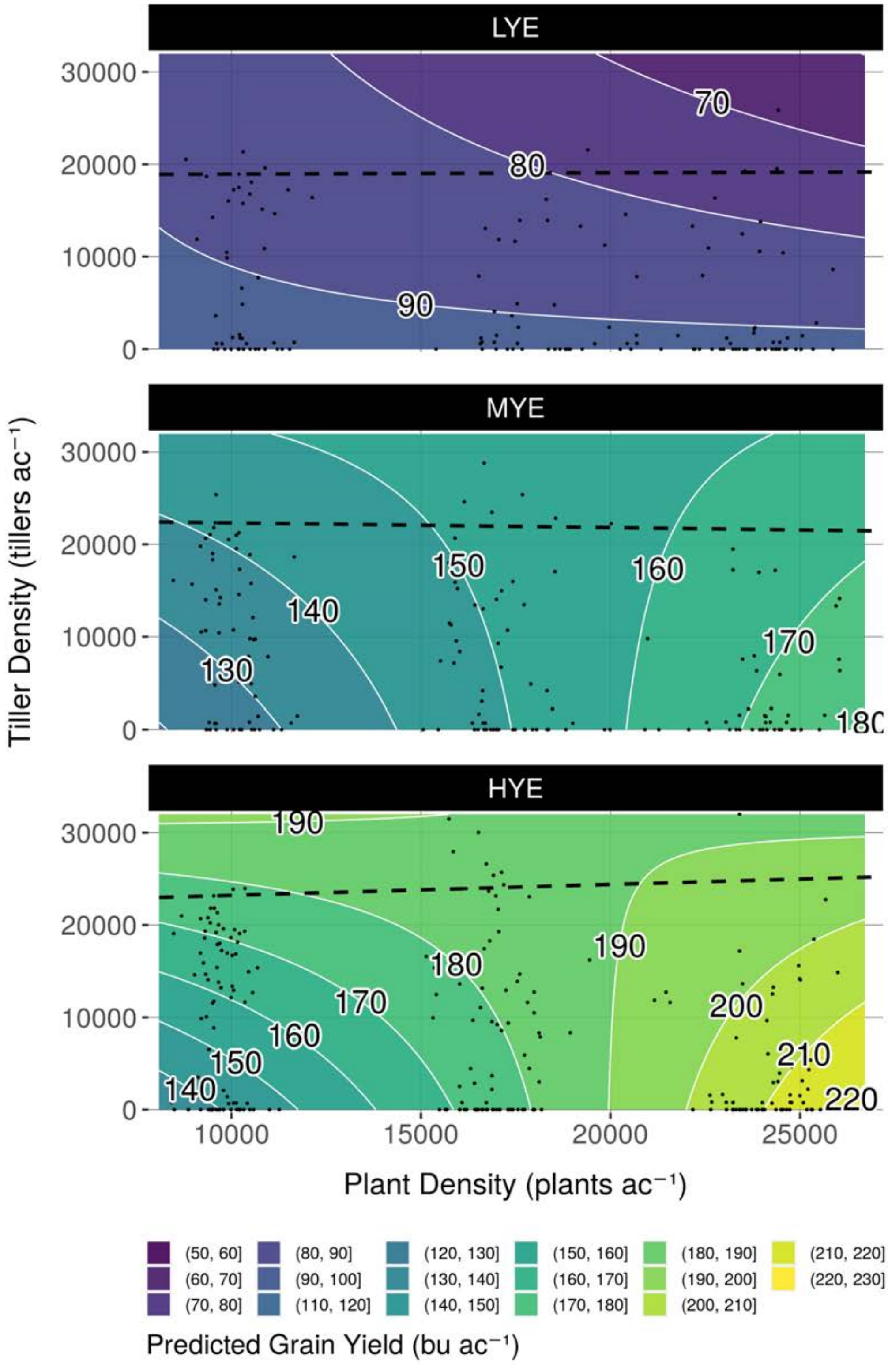

Figure 2. Observed density-based yield predictions by yield environment (LYE, Low-yielding environment; MYE, Moderate-yielding environment; HYE, High-yielding environment). Contours are shaded, delineated by white lines, and labeled according to 10 bu/a yield intervals. Observed plant densities and tiller densities are indicated with black points, and dashed regression lines consider the upper 95% of observed tiller densities by yield environment. Extrapolations beyond black points and dashed black lines are shown only for the purpose of comparing environments on the same density scales.

How Relevant is High-Cadence Earth Observation for Maize Crop Phenology Classification?

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Summary
Crop phenology can be defined as the study of biological processes such as emergence, flowering, and senescence that are associated with and affected by environmental growing conditions. The ability to reliably detect crop phenology and its spatial-temporal variability is critical for farmers, policymakers, and government agencies, since it has implications for the entire food chain. Currently, two methods are the most used to report crop phenology. Land surface phenology provides insight into the overall trend, whereas USDA-NASS weekly reports provide insight into the development of specific crops at the regional level. High-cadence earth observations may be able to improve the accuracy of these estimations and bring more precise crop phenology classifications closer to what farmers need. The use of robust classifiers (e.g., random forest, RF) to manage large data sets is required to successfully achieve this goal. This study compared the output of an RF classifier model using weather, two different satellite sources (Planet Fusion; PF and Sentinel-2; S-2), and ground truth data to improve maize (*Zea mays* L.) crop phenology classification during the 2017 growing season in Kansas. Our findings indicate that high-cadence (PF) data can enhance crop classification metrics (f1-score = 0.94) as compared to S-2 (f1-score = 0.86). This study emphasizes the significance of very high temporal resolution (daily) earth observation data for agricultural crop monitoring and decision-making tools.

Introduction
Crop phenology examines how the biological processes of emergence, flowering, and senescence respond to environmental factors (Liang et al., 2011). Several studies have attempted to address crop phenology using earth observations (remote sensing) (Rulm and Vulic, 2005; Henebry and de Beurs, 2013) or mathematical models supported by weather data (Rezaei et al., 2018). Crop phenology depicts the more agronomically important stages, which are linked to critical phases when management measures can and should be applied.

A weekly survey of regional extension agricultural agents provides official phenology crop progress estimates in the United States (Gao and Zhang, 2021). Crop development is summarized by agricultural district (as determined by the U.S. Department of Agriculture), and some developmental stages are combined into broader categories. As a result, the data may not accurately represent a county, district, or even a single farm (Gao et al., 2017). This study investigates whether high-cadence satellite data affects

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crop phenology classification for agronomic purposes. This study compares the output of an RF classifier model using two independent satellite data sources with different temporal and spatial resolutions, along with weather data.

Procedures

The current study was performed in the state of Kansas (US), specifically in the Southwest (SW) area, over the counties of Morton, Stanton, Grant, and Stevens, and the Central (CK) region, which encompasses the counties of Stafford and Pratt (Figure 1).

Crop Quest Inc. provided us with valuable ground-truth data compiled during a five-year period, from 2013 to 2017, by making repeated visits to each farmer field to monitor changes in maize crop phenology throughout the growing season. Each field was visited an average of five times over the season, though frequency varies across the large database of field observations. The final dataset included crop phenology measurements per field, and geolocated fields for both regions.

This analysis used the following remote sensing products:

1. Planet Fusion images on daily basis (3-meter resolution, R, G, B, NIR bands),
2. Sentinel-2 images (only images with less than 20% clouds, 10-meter resolution, same bands), and
3. Weather data.

Different vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Green Chlorophyll Vegetation Index (GCVI), Chlorophyll Vegetation Index (CVI), and Normalized Green Index (NGI) were calculated based on the spectral bands from both products (PF and S-2). From PRIMS layers (https://prism.oregonstate.edu/) we extracted precipitation, mean, maximum and minimum temperature, and vapor pressure deficit.

The Random Forest (RF) classifier was implemented with the Scikit-Learn library (Pedregosa et al., 2011), in a Python 3.8 environment. Further details related to the analysis and model evaluation are described in Nieto et al., 2022.

To test the performance of the model, the metrics used were overall accuracy, precision, recall, and f1-score, since these are the most suitable for classification purposes.

Results

Best Combination of Variables

The NIR band, EVI, minimum temperature, maximum temperature, vapor pressure deficit, and day of the year were related with the highest scores in the southwest region dataset. The best f1-scores were 0.94 for the southwest region and 0.93 for the central region when the factors were included. Also, to test additional model options, numerous combinations were attempted (only spectral data; only weather parameters; EVI and weather; NIR and weather, etc.). As an example of this, the model's f1-scores were 0.79 for SW and 0.76 for central regions when only weather variables were included in the evaluation.

Model Performance Using PF Data in Both Regions

The model comprising NIR, EVI, minimum temperature, maximum temperature, vapor pressure deficit, and day of the year resulted in f1 values of 0.94 for SW and 0.93 for central region (Figure 2 a, b). A confusion matrix depicts the classification results for each crop phenological stage, with the correct components along the main diagonal and the results for precision and recall along the X and Y axes. In the southwest area, most stages had recall and precision scores between 1.0 and 0.75, but R1, R3, and V15 had weak metrics ranging from 0 to 0.66. In the central region, most stages had recall values between 1.0 and 0.87, although some (R2, V10, V11, V12, and V13) had recall values below 0.67. Precision ranged from 0.76 to 1.0 for all stages.

Model Performance Using Sentinel-2 Data

The same model used for S-2 data yielded results inferior to those reported before. Due to the season duration, the first dataset only comprised three crop phenological stages. Overall, the classification produced a high f1-score (0.86) but uneven metrics for each stage. For the VT stage, recall and precision were both zero (Figure 3, a). A second analysis included an enlarged dataset with data from 3 days before and after the field data collection. The overall f1-score was lowered to 0.74, although the dataset included more phenological stages. Finally, the search was extended from 3 to 10 days before and after the field data collection. Overall performance was consistently weaker when the S-2 dataset was used instead of the PF output (Figure 3).

Final Considerations

Combining satellite-based (NIR band surface reflectance, EVI), weather data (maximum and lowest temperatures, VPD), and day of the year data, a random forest model could accurately classify maize crops in two distinct production zones for maize crops in Kansas. The study emphasizes the necessity of high-quality ground truth data and high-cadence earth observation.

Currently available agricultural phenology solutions rely on broad measurements and large geographic regions. While these are useful tools for policymakers and governments, there is still room for improvement in terms of farmer solutions. Confusion and wrong inferences may come from the mismatch between reported and field events. Enhancing crop phenology classification and reporting has a significant impact on every step of the food production chain, enabling precise, proactive, rather than reactive, regional, and field-level policies.

References

Gao, F., & Zhang, X. (2021). Mapping crop phenology in near real-time using satellite remote sensing: Challenges and opportunities. J. Remote Sens. 2021.

Gao, F., Anderson, M. C., Zhang, X., Yang, Z., Alfieri, J. G., Kustas, W. P., ... & Prueger, J. H. (2017). Toward mapping crop progress at field scales through fusion of Landsat and MODIS imagery. Remote Sens. Environ. 188, 9-25.

Henebry, G. M., & de Beurs, K. M. (2013). Remote sensing of land surface phenology: A prospectus. In Phenology: An Integrative Environmental Science (pp. 385-411). Springer, Dordrecht

Liang, L., Schwartz, M. D., & Fei, S. (2011). Validating satellite phenology through intensive ground observation and landscape scaling in a mixed seasonal forest. Remote Sens. Environ. 115(1), 143-157.

Nieto, L., Houborg, R., Zajdband, A., Jumpasut, A., Prasad, P. V., Olson, B. J., & Ciampitti, I. A. (2022). Impact of High-Cadence Earth Observation in Maize Crop Phenology Classification. Remote Sensing, 14(3), 469

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., ... & Duchesnay, E. (2011). Scikit-learn: Machine learning in Python. J. Machine Learning Res. 12, 2825-2830.

Rezaei, E. E., Siebert, S., Hüging, H., & Ewert, F. (2018). Climate change effect on wheat phenology depends on cultivar change. Scientific reports, 8(1), 1-10.

Ruml, M., & Vulić, T. (2005). Importance of phenological observations and predictions in agriculture. J. Agric. Sci. (Belgrade), 50(2), 217-225.

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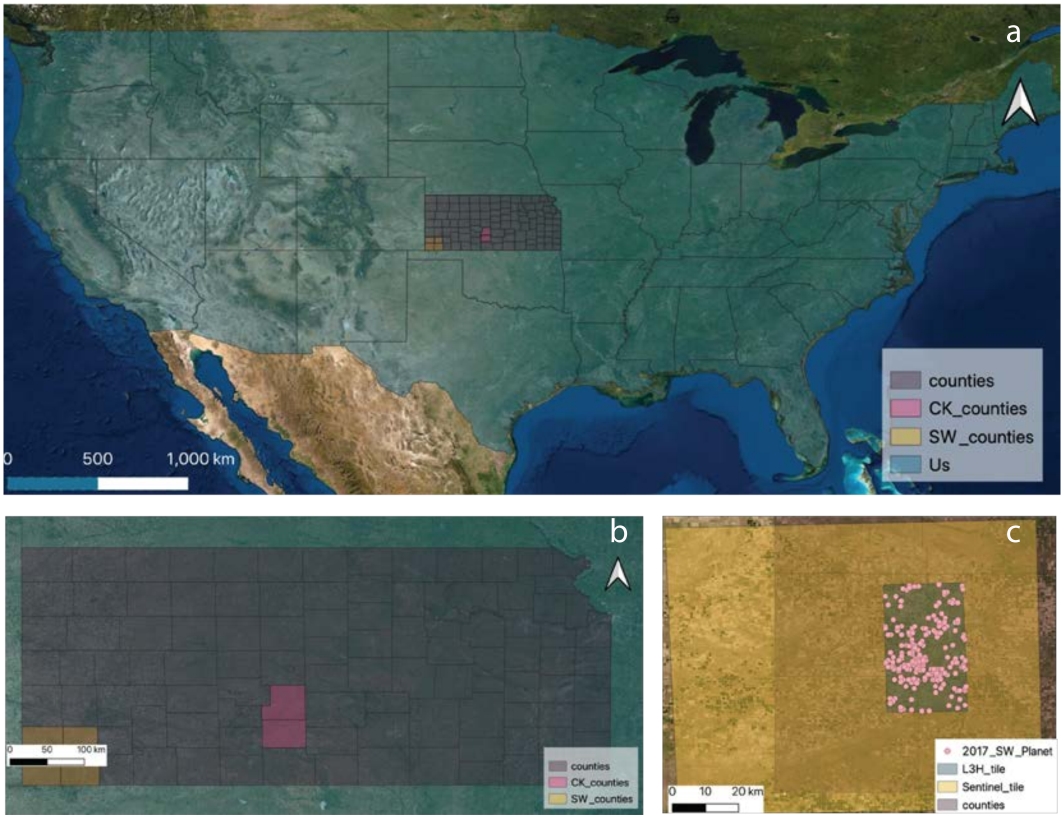

Figure 1. Area of study a) state of Kansas (US); b) Southwest (SW) region and Central (CK); c) large orange rectangle represents the Sentinel-2 tile covering the area. The green rectangle corresponds to the Planet fusion (PF) tiles over the area; and pink dots represent ground truth field data collection sites.

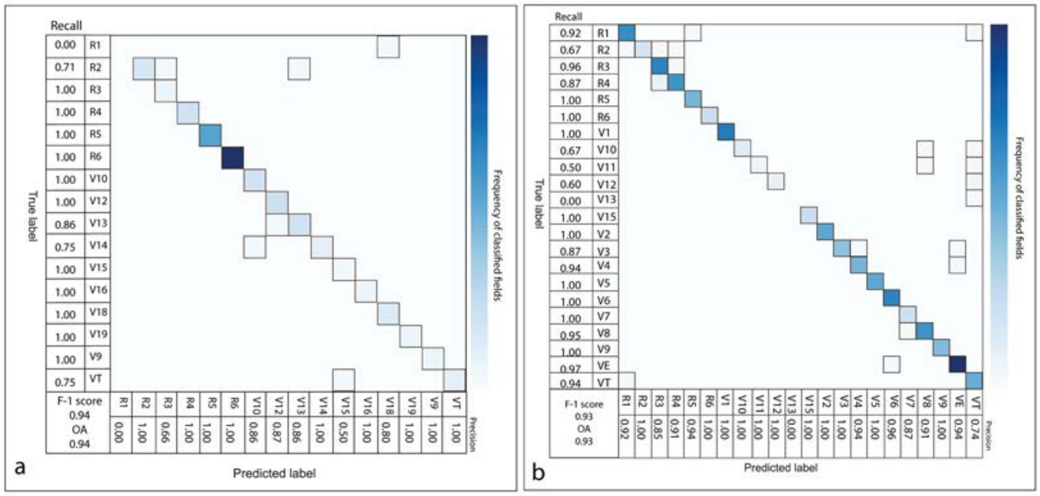

Figure 2 (a) Confusion matrices with PF-based classification results for the Southwest region (SW) and for (b) Central KS region (CK), including recall and precision for each crop phenology stage, and f1-score and overall accuracy (OA).

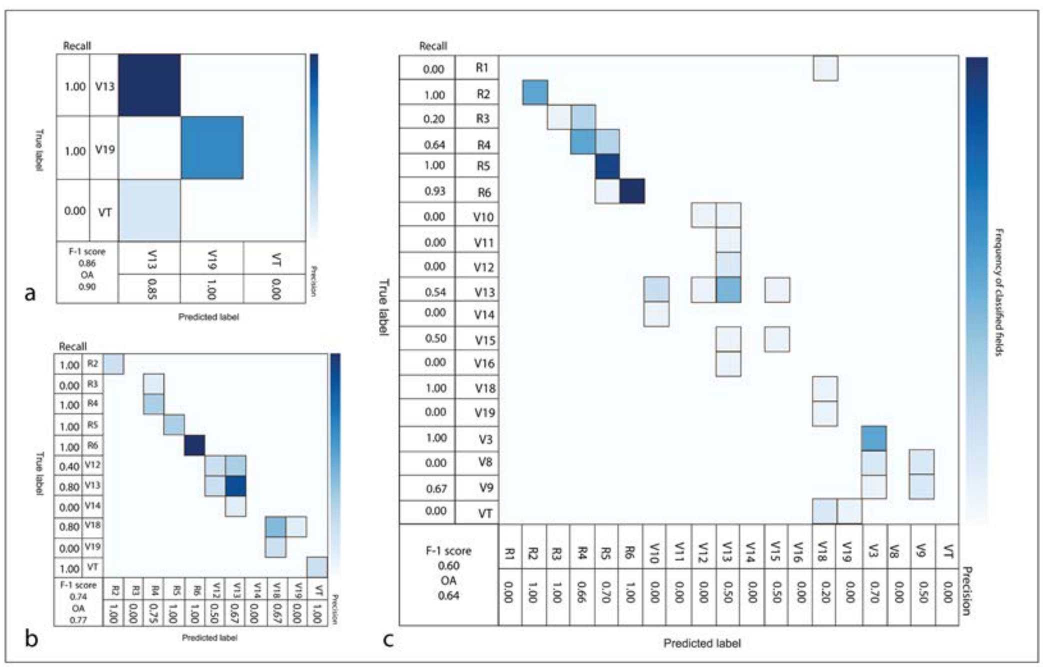

Figure 3. Confusion matrices with S-2-based classification results for the Southwest (SW) region, (a) including imagery on the date of data collection, (b) including data within 3 days before and after, (c) including data within 10 days before and after. All matrices include recall and precision for each crop phenology stage, and f1-score and overall accuracy (OA).

Effect of Early Planting on Soybean Yield

E. Adee and S. Dooley

Summary

In an effort to increase soybean yield potential, early planting dates have been promoted as a management practice that can increase soybean yields. Early planting of soybeans can be a relative term, meaning late April/early May for some soybean producers in Kansas. For the purpose of this study, the definition of early planted soybeans is late March/early April. Theoretically, the earlier planting date could allow for more vegetative growth and absorption of more light before blooming, increasing the yield potential. With the improvement of soybean seed treatments to protect seed when emergence is slowed due to cool and wet conditions, the early planting may be a viable option. The planting dates were late March, mid-late April, and May. One of the variety/population treatments planted early yielded 6 bu/a better than the next highest yield at the mid-April planting date at Topeka. None of the other variety/population combinations yielded higher than the mid-late April planting dates at either location.

Procedures

In 2021, early soybean planting studies were conducted at two Kansas State University Experiment fields, the Kansas River Valley (Topeka) and North Central (Scandia). The experiment at Topeka was irrigated, receiving 3.2 inches of water from August 2 to September 8. The experiment at Scandia was dryland. Two varieties were planted at two seeding rates (100,000 and 150,000 seeds/a) at each of three planting dates in both studies. The varieties at Topeka were Asgrow AG37XF1 (Maturity Group 3.7) and AG40XF0 (MG 4.0) treated with Acceleron + ILeVO, and at Scandia were Golden Harvest GH3442XF (MG 3.4) and GH4452XF (MG 4.4) treated with Cruisermaxx + Vibrance + Saltro. The planting dates at Topeka were March 30, April 15, and May 4. The Scandia planting dates were March 31, April 27, and May 24. Soybeans were planted in four 30-inch row plots (10 ft wide) × 30 to 40 feet long. The experiment at Topeka utilized a randomized complete block design with four replications, and at Scandia, the variety and seeding rate treatments were randomized within each planting date block. Yields were determined from the middle two rows of each plot to avoid influence from neighboring plots. Yields were corrected to 13% grain moisture. Weed control was managed to have no effect on yields.

Results

The soil conditions were good for planting in Topeka during late March, but 3 inches of snow fell on April 20 as the first planting date was starting to crack through. Seedlings of the first planting date at Topeka emerged by April 27. In spite of taking nearly a month to emerge there were no large gaps in the stand. At Scandia, there was no snow recorded on April 20, but the temperatures dropped to 25°F. Seedlings of the first planting date started to emerge April 19, with full emergence by May 7.

The highest yield of 80 bu/a was with the shorter season variety planted March 30 at 150,000 seeds/a at Topeka, and the lowest yield was with the shorter season variety planted May 4 at 100,000 seeds/a (Figure 1). Yields of any of the variety/seeding rate/

planting date combinations showed no significant difference between the high and low yielding treatments.

At Scandia, there was little yield response to planting date (Figure 2). There was no yield advantage for planting any of the variety/seeding rate treatments in late March (Figure 2). Generally, the highest yields were with the April 27 planting date, although the high population, shorter MG variety yielded higher at the May 24 planting date.

While caution should be used in making conclusions from this limited data set, it was shown that there can be a very positive yield response to planting soybeans in late March/early April for certain variety/seeding rate combinations. For most variety/seeding rate treatments, there was no major yield loss due to early planting. Further research is needed to determine if these trends for yield response are consistent. An additional study could be to identify the varieties that respond with increased yield due to the early planting date more consistently than other varieties.

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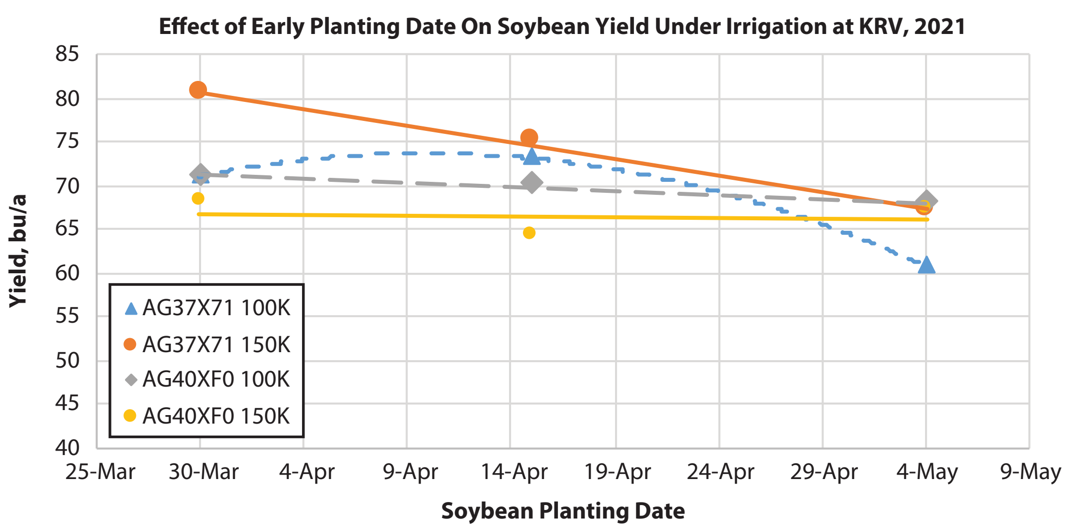

Figure 1. Effect of soybean planting date with soybean varieties of different maturity groups, planted at two seeding rates, on yield at Kansas River Valley Experiment Field, Topeka, 2021.

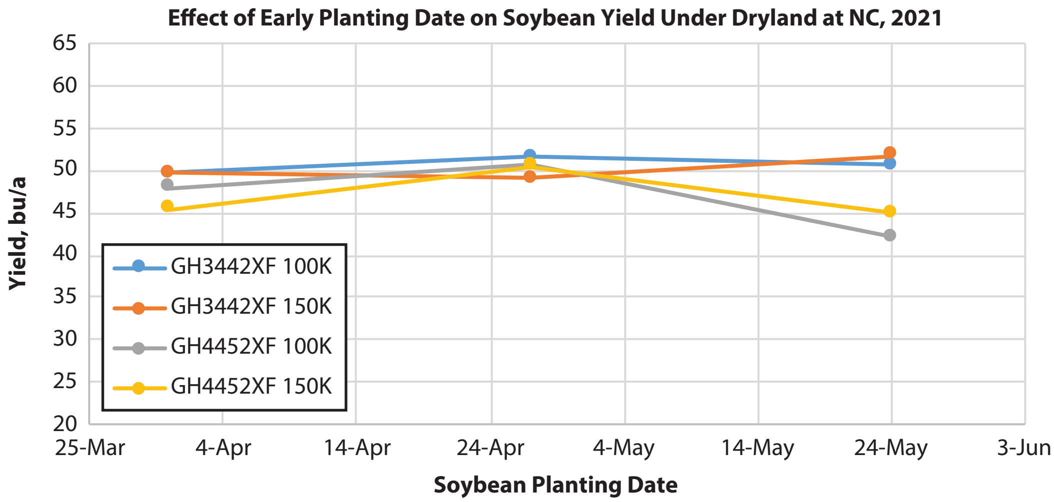

Figure 2. Effect of soybean planting date with soybean varieties of different maturity groups, planted at two seeding rates, on yield at North Central Experiment Field, Scandia, 2021.

Soybean Seed Yield Productivity and Biological Nitrogen Fixation in Kansas

L.F.A. Almeida, A.A. Correndo, E. Adee, S. Dooley, and I.A. Ciampitti

Summary
Soybean [*Glycine max* (*L.*) Merr.] productivity (seed yield) and biological nitrogen fixation (BNF) were evaluated in response to different fertilization strategies. The study comprised four different locations in Kansas during the 2021 growing season, two irrigated (Topeka and Scandia) and two dryland (Kiro and Ashland Bottoms) sites. Greater seed yields were recorded in Topeka and Kiro (80 bu/a) relative to Scandia (55 bu/a) and Ashland Bottoms (51 bu/a), without observing fertilizer effects on yields. Overall, the relative abundance of ureides (% RAU), an indicator of the level of BNF, increased as the crop matured and showed a negative association with the soil N level. The main objective of this study was to identify how different levels of nitrogen (N) and sulfur (S) fertilization affect the seed yield and the biological nitrogen fixation (BNF) in soybean.

Procedures
In the 2021 season, four soybean trials were established at Topeka (39°04'38.1" N, 95°46'05.4" W), Kiro (39°05'31.2" N, 95°47'50.4" W), Scandia (39°49'51.2" N, 97°50'22.8" W), and Ashland Bottoms (39°08'40.1" N, 96°37'42.6" W). The experiments were arranged under a randomized complete block design with five replications. Plot length was set to 50 feet in all the trials, width to 15 feet in both Kiro and Topeka, and 20 feet in both Scandia and Ashland Bottoms locations. Row spacing was 30 inches at all locations. The soil was tilled at Topeka, Kiro, and Ashland Bottoms. Planting dates ranged from mid to late May, and two genotypes were used (AG40X70 in Topeka and Kiro, and P39A45X in Scandia and Ashland Bottoms) (Table 1).

Weather
Topeka and Kiro accumulated approximately 23 inches of rain each during the growing season, while Ashland Bottoms had only 14.5, and Scandia had 12 inches. Both Topeka and Kiro locations had 6.2 inches after the first month, Scandia had 3.8 inches, and Ashland Bottoms only had 2.5 inches. Maximum temperatures higher than 95°F were reported during 19 days at Ashland Bottoms and 7 at Scandia. Between June and September, both Kiro and Topeka recorded 6 days with temperatures above 95°F (Figure 2).

Soil Fertility
Topeka and Kiro soils had considerably more clay and greater NO_3 and SO_4^{-2} than the other two sites in both sampled depths. Soil organic matter (SOM) was also found in greater levels at Topeka and Kiro, respectively, 2 and 3% (Table 2).

Treatments
A total of five treatments were tested (Table 3): (1) a Check (0 N, 0 S); (2) an omission plot for S (N); (3) an omission plot for N (S), a low N rate combined with S (NS);

and (4) a high rate of N combined with S (Full). Fertilizer sources, nutrient rates, and timing are described in Table 3.

Soil and Plant Sampling
A compound (6 cores) sampling at 0–6 inches depth was performed to describe initial fertility, and also 0–8 and 8–24 inches sampling was done to describe NO_3-N, NH_4-N, and SO_4^{-2}-S prior planting. During the cropping season, additional soil samplings were collected at phenological stages of R2 (full-bloom), R4 (full-pod), and R6 (full-seed) (Fehr et al., 1971) at depths of 0–8 inches and 8–24 inches for all soil N and S determinations (Table 3).

Soybean tissue samples were collected as whole plants at the phenological stages of R2, R4, and R6 to measure biomass. Main stem samples were taken for the determination of relative abundance of ureide-N (RAU) (Moro et al., 2021). In early to mid-October, all the trials had the mid-rows cut by a combine, which provided seed yield adjusted to 13% in bushels per acre.

Data Analysis
Seed yield and relative abundance of ureides (RAU) were tested with an analysis of variance (ANOVA) under mixed effect models. For seed yield, treatment and site were considered as a fixed factor, and block as random. In the case of RAU, treatment, site, and stage are considered fixed, and blocks as random. When significant effects were found ($P \leq 0.05$), comparisons were performed using Tukey's test. Analysis was accomplished with R software (R Core Team, 2020) and packages lme4 and emmeans.

Results
Seed Yield
Soybean seed yield did not show an interaction nor fertilization effects ($P > 0.05$) but differed between sites. Topeka and Kiro yields reached 80 bu/a while Scandia and Ashland Bottoms yielded on average 55 and 51 bu/a, respectively (Figure 1). The abundance of water in the initial development of the soybean and greater soil fertility must have been the main drivers for the higher yields in Topeka and Kiro.

Relative Abundance of Ureides
The RAU did not show an interaction nor treatment effect ($P > 0.05$), but site and stage differed statistically. The treatment with the highest N input (300 lb/a), combined N fertilization with AMS and urea, was applied at planting and R3 stages, and even though not significant, it decreased RAU. The decay in this BNF activity occurred in R4 and R6 phenological stages, and compared to the other treatments, the decrease in ureide content in the xylem sap reflected in an RAU until 40% lower (Figure 3), emphasizing the effect of the mineral N in the N_2 fixation dynamics. From biomass, samplings were calculated as dry biomass per acre, and it has a positive correlation with crop growth during the season (data not shown).

Soil Nitrate and Sulfate
We observed a negative relationship between RAU and total N (nitrate-N + ammonium-N) in the soil, more evident for treatments where fertilizer was provided at a

higher rate (Figure 4). According to soil results, sulfate levels were also related to greater RAU levels, but the main driver was N (with more soil N inversely related to N fixation).

References

Fehr, W. R., Caviness, C. E., Burmood, D. T., and Pennington, J. S. (1971). Stage of Development Descriptions for Soybeans, *Glycine Max* (L.) Merrill 1. *Crop Sci.* 11, 929–931. doi:10.2135/cropsci1971.0011183X001100060051x.

Moro, L. H., Tamagno, S., Anelise, L., Torres, A. R., Schwalbert, R. A., and Ciampitti, I. A. (2021). Relative abundance of ureides differs among plant fractions in soybean. *Eur. J. Agron.* 122, 126175. doi:10.1016/j.eja.2020.126175.

R Core Team (2020). R: A Language and Environment for Statistical Computing. Available at: https://www.r-project.org/.

Table 1. Site descriptors and crop management for the 2021 season

Site	Soil type	Tillage	Soybean variety	Seeding rate	Irrigation
				seeds/a	inches
Topeka	Eudora silt loam	Yes	AG40X70	140000	1.7
Kiro	Muir silt loam	Yes	AG40X70	140000	---
Scandia	Crete silt loam	No	P39A45X	140000	7.5
Ashland Bottoms	Eudora silt loam	Yes	P39A45X	130000	---

Table 2. Soil fertility at the planting time of soybean in the four locations across Kansas during the 2021 growing season

Site	Depth	pH	SOM	Sand	Silt	Clay	P	K	Depth	NO_3	NH_4	SO_4^{-2}
	inches	------------------------ % ------------------------					------ ppm ------		inches	----------- ppm -----------		
Topeka	0–6	6.77	2	32	56	12	16.7	227.9	0–8	6.1	4.9	3.6
									8–24	5	4.5	3.2
Kiro	0–6	5.49	3	16	62	22	27.3	419.7	0–8	8.9	6.8	5.3
									8–24	9.9	6.4	4.2
Scandia	0–6	7.5	1.2	46	42	12	46	186.4	0–8	3.1	3.1	2
									8–24	3.2	2.7	2.1
Ashland Bottoms	0–6	6	1.4	56	36	8	36.1	152.7	0–8	3.1	2.2	2.4
									8–24	2.1	1.87	1.8

SOM = Soil organic matter.

Table 3. Treatments description at planting time and R3 growth stage in Kansas during the 2021 season

	Planting			R3 growth stage			Total nutrients applied	
Treatment	**N**	**S**	**Source**	**N**	**S**	**Source**	**N**	**S**
	-- lb/a --							
Check	---	---	---	---	---	---	0	0
N	26.3	---	Urea (58)	---	---	---	26.3	0
S	---	30	Gypsum (130)	---	---	---	0	30
NS	26.3	30	AMS (125)	---	---	---	26.3	30
Full	150	15	Urea (297)	150	15	Urea (297)	300	30
			AMS (64)			AMS (64)		

Check = no treatment applied.
N = an omission plot for S.
S = an omission plot for N.
NS = a low N rate combined with S.
Full = a high rate of N combined with S.

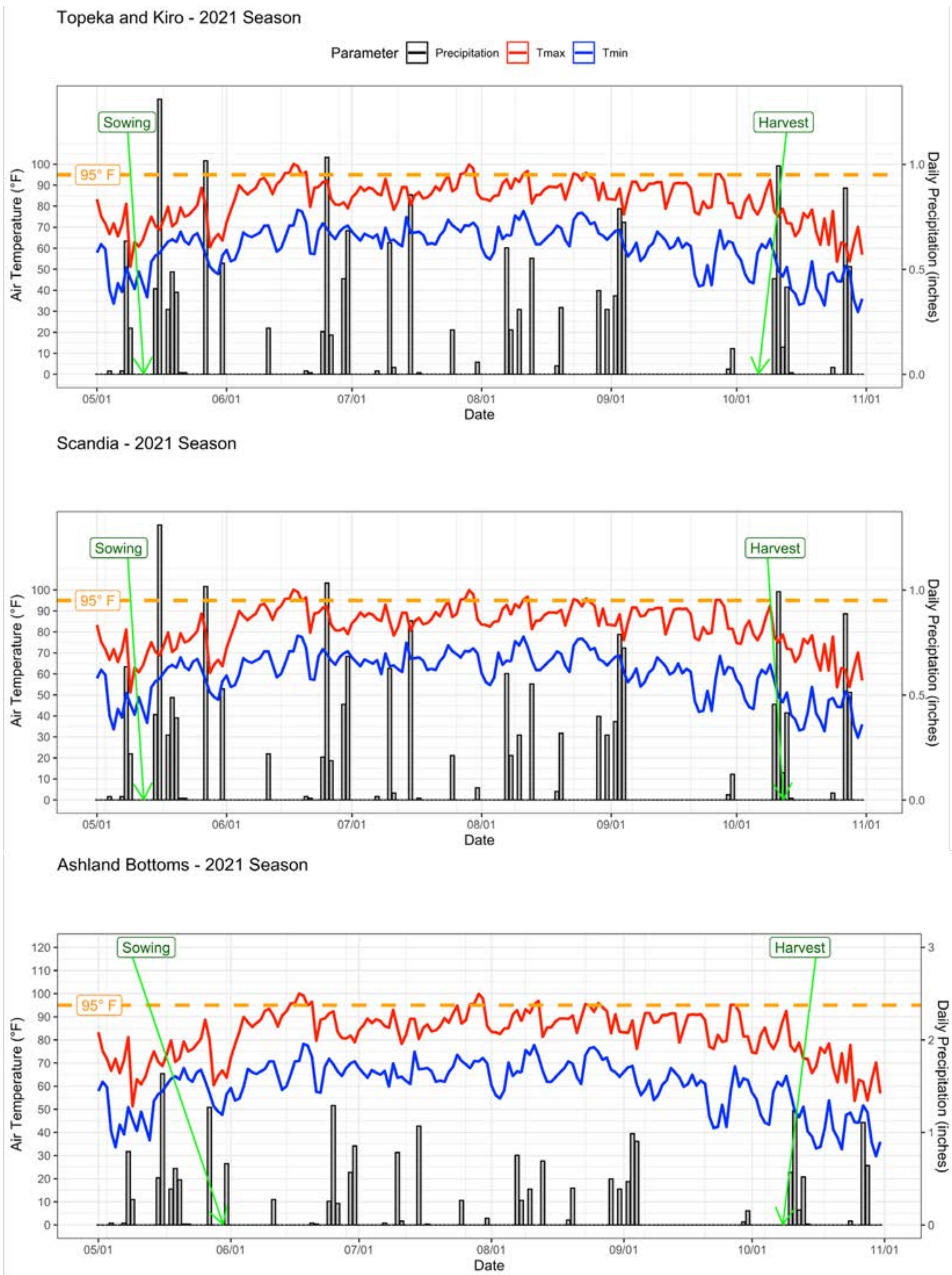

Figure 1. Daily precipitation in inches, and maximum and minimum temperatures (°F) for the 2021 growing season in Kansas, at three Mesonet weather stations.

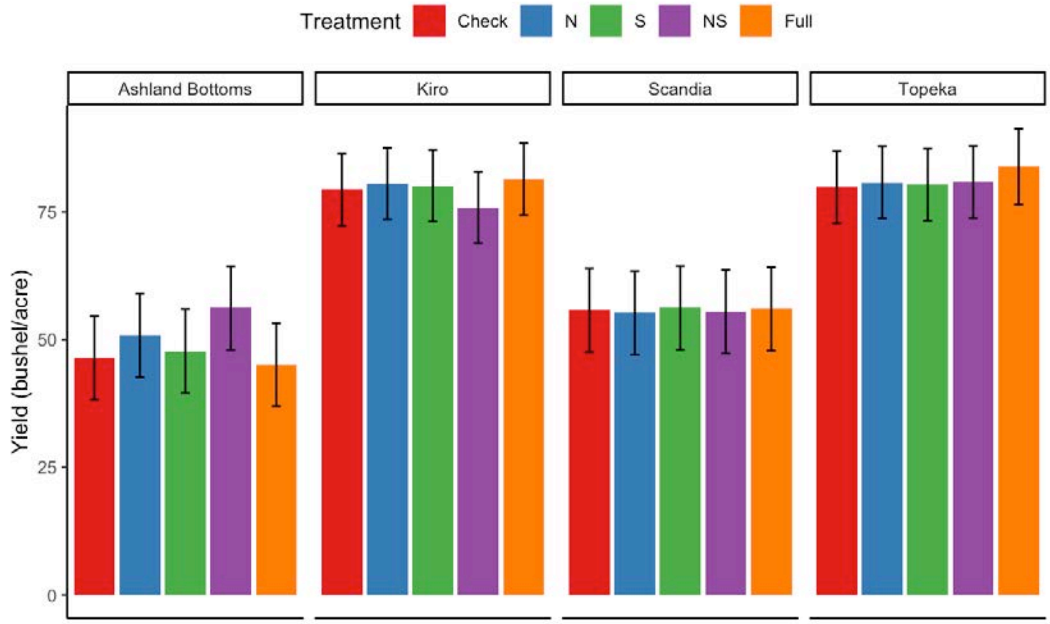

Figure 2. Soybean seed yield in bushel per acre across the 4 sites under study in Kansas during the 2021 season. Overlapping error bars indicate no statistical difference between treatments.

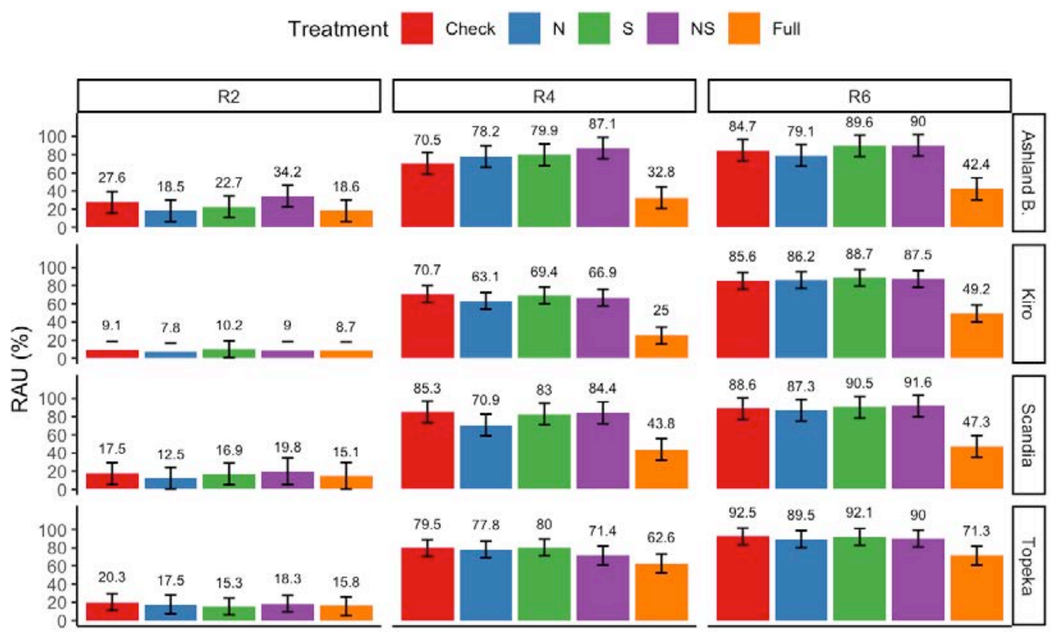

Figure 3. Relative abundance of ureides (% RAU) means being shown between treatments in 3 phenological stages at four sites in Kansas during the 2021 cropping season.

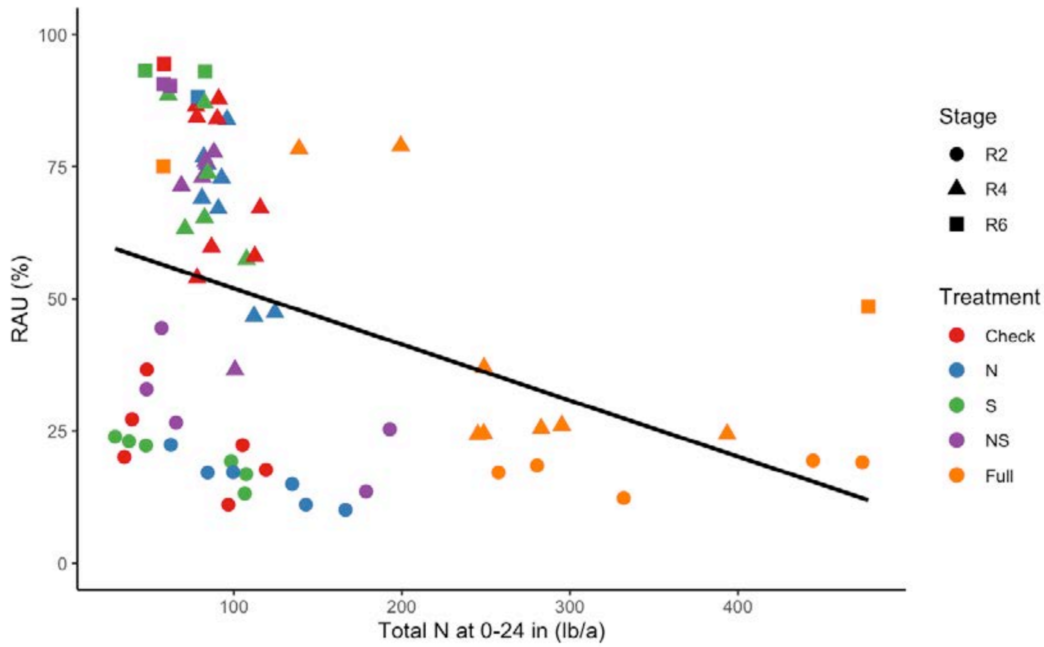

Figure 4. Total N (nitrate-N + ammonium-N, lb N/a) in the soil at 0–24 inches depth sampling for the 2021 season. RAU = Relative abundance of ureides.

Do Late Season Soybean Management Practices Impact Seed Yields in East Kansas?

A.A. Correndo, L.F.A. Almeida, E. Adee, and I.A. Ciampitti

Introduction

In soybean (*Glycine max* [L.] Merr.), maintaining favorable growth conditions (e.g., water, solar radiation, and nutrients) during the seed filling period is crucial to avoid limitations that could reduce seed weight and ultimately constrain seed yield. The objective of this study was to explore potential effects and identify if "late-season" management practices can contribute to increasing seed weight and seed yield in soybeans.

Procedures

In the 2021 season, two soybean studies were conducted in Topeka (39.08° N, 95.77° W), and Kiro (39.09° N, 95.79° W). Soils were Eudora silt loam (Topeka) and Muir silt loam (Kiro), with 2 and 3% of soil organic matter (SOM, 0–6 in.), respectively. Right before planting, composite soil samples (6 cores) were taken from 0–6 in. depth to describe general soil fertility (Table 1).

Both Topeka and Kiro (adjacent locations) accumulated approximately 23 inches of rain each during the growing season (Figure 1). Between June and September, both locations recorded 6 days with temperatures above 95°F.

Plots were arranged in a randomized complete blocks design (RCBD) with four repetitions. Plots were 35 feet long at Topeka and 25 feet long at Kiro, and had four rows spaced at 30 in. in both locations. When needed, treatments were sprayed with a hand-held backpack sprayer. Treatments were applied at full pod formation (R4 stage) and consisted of different management practices:

- Fungicide protection late-season application
- Insecticide protection late-season application
- Full-foliar protection (fungicides+insecticides late-season application)
- N fixation longevity (inoculant late-season application)
- Plant nutrition -standard- (sulfur (S) late-season application)
- Plant nutrition -complete- (micronutrients plus S late-season application)
- Nutrition -complete- + N fixation (combination of both for improving nutrition)
- Intensified inputs (all practices combined)
- Control condition (standard practices)

At physiological maturity (R7 stage) plant samples were collected from 12.5 sq ft (5 ft × 30 inch) to determine aboveground biomass at the control treatment.

At harvest maturity (R8), an area of 18.75 sq ft in the two central rows of each plot was manually harvested to determine final seed yield.

Data Analysis

The data analysis was executed by performing an analysis of variance (ANOVA) split by variable (seed yield, seed weight, and biomass) and location. For each ANOVA, a mixed model structure was considered, with treatment as the fixed factor and block as the random factor. Treatment effects were considered significant if *P*-value ≤ 0.05. Analyses were carried out using the lme4 and emmeans packages of R software (R Core Team, 2020).

Results

Seed Yield

Seed yield ranged between 54 and 85 bu/a at Topeka and between 63 to 88 bu/a at Kiro (Figure 2). No significant seed yield differences between treatments were observed at either of the locations (*P*-value > 0.05), averaging 66 bu/a for Topeka and 75 bu/a for Kiro.

Seed Weight

Seed weight ranged between 0.28 and 0.33 lb/1000 seeds at Topeka and between 0.27 to 0.37 lb/1000 seeds at Kiro (Figure 3). No significant seed weight differences between treatments were observed at either of the locations (*P*-value > 0.05), averaging 0.30 lb/1000 seeds for Topeka and 0.31 lb/1000 seeds for Kiro.

Plant Dry Biomass

Final dry biomass ranged between 6,346 and 12,354 lb/a at Topeka and between 5,764 to 14,997 lb/a at Kiro (Figure 4). No significant final biomass differences between treatments were observed at either of the locations (*P*-value > 0.05), averaging 9,102 lb/a for Topeka and 10,373 lb/a for Kiro.

Conclusions

The tested late-season treatments did not impact seed yield, seed weight, or crop biomass production. Specific soil and weather conditions may be needed to observe differences between the tested treatments. Future research could consider exploring more environments across Kansas to identify specific production conditions that are responsive to late-season management practices.

References

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Table 1. Soil fertility at the planting time of soybean at Topeka and Kiro, KS, locations during the 2021 growing season

Site	pH	SOM	Sand	Silt	Clay	P	K
	------------------ % ------------------					---------- ppm ----------	
Topeka	6.8	2.0	32	56	12	17	228
Kiro	5.5	3.0	23	62	16	27	420

Table 2. General soybean crop management at Topeka and Kiro, KS, locations during the 2021 growing season

Site	Tillage	Irrigation	Planting date	Row spacing	Soybean variety	Seeding rate (seeds/a)	Harvest
Topeka	Vertical	Yes	05/12/2021	30 in.	AG40X70	141,000	10/04/2021
Kiro	Vertical	Rainfed	05/12/2021	30 in.	AG40X70	141,000	10/08/2021

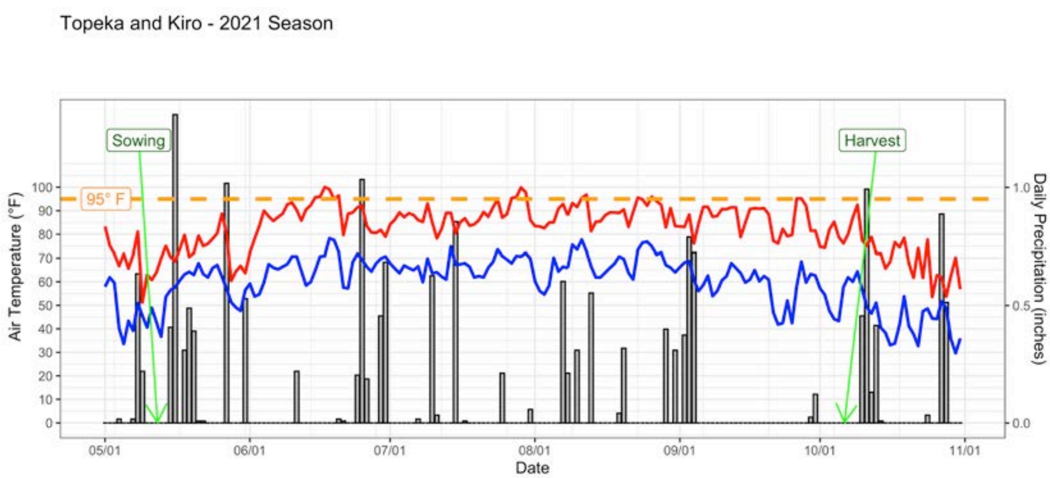

Figure 1. Daily precipitation in inches, and maximum and minimum temperatures (°F) at Topeka and Kiro, KS, locations for the 2021 growing season. Source: Kansas Mesonet (*https://mesonet.k-state.edu/*).

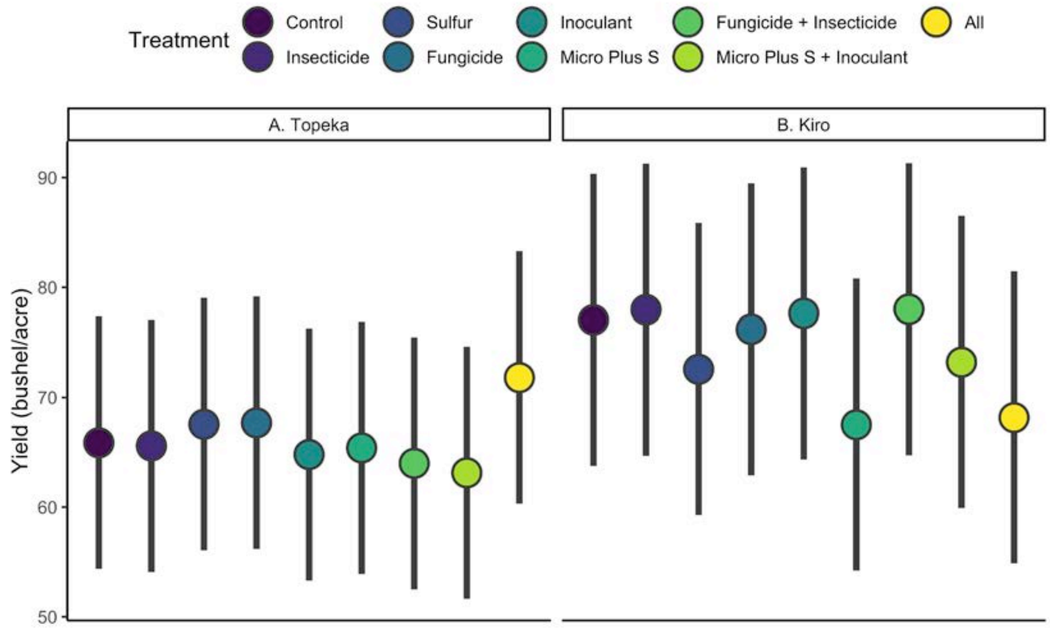

Figure 2. Seed yield (bu/a) for each treatment at Topeka and Kiro, KS, locations for the 2021 growing season. Vertical bars are the standard deviations.

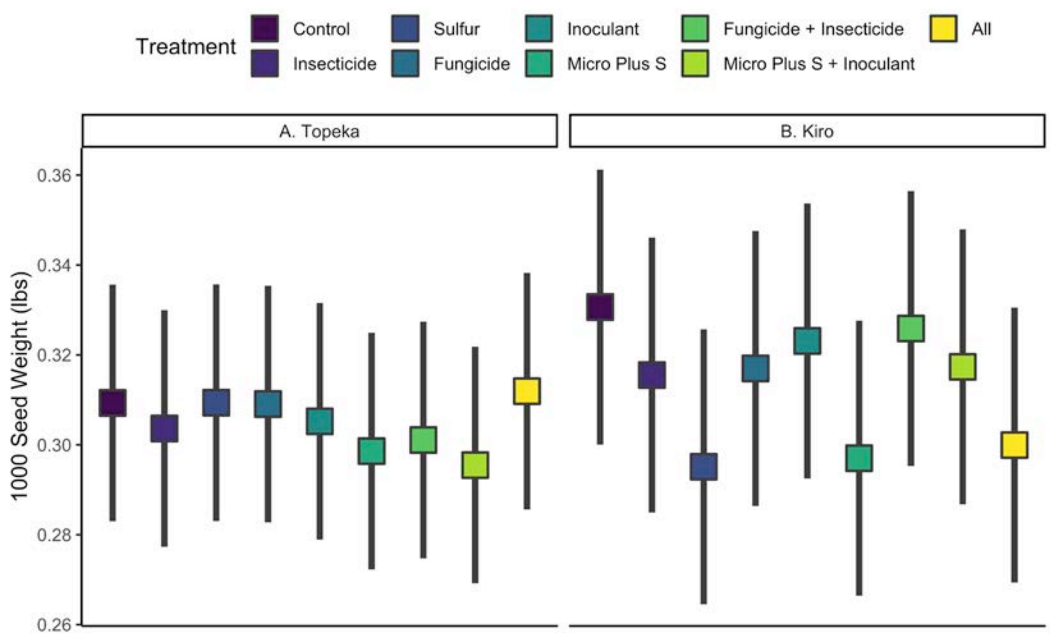

Figure 3. Final seed weight rate for each treatment at Topeka and Kiro, KS, locations for the 2021 growing season. Vertical bars are the standard deviations.

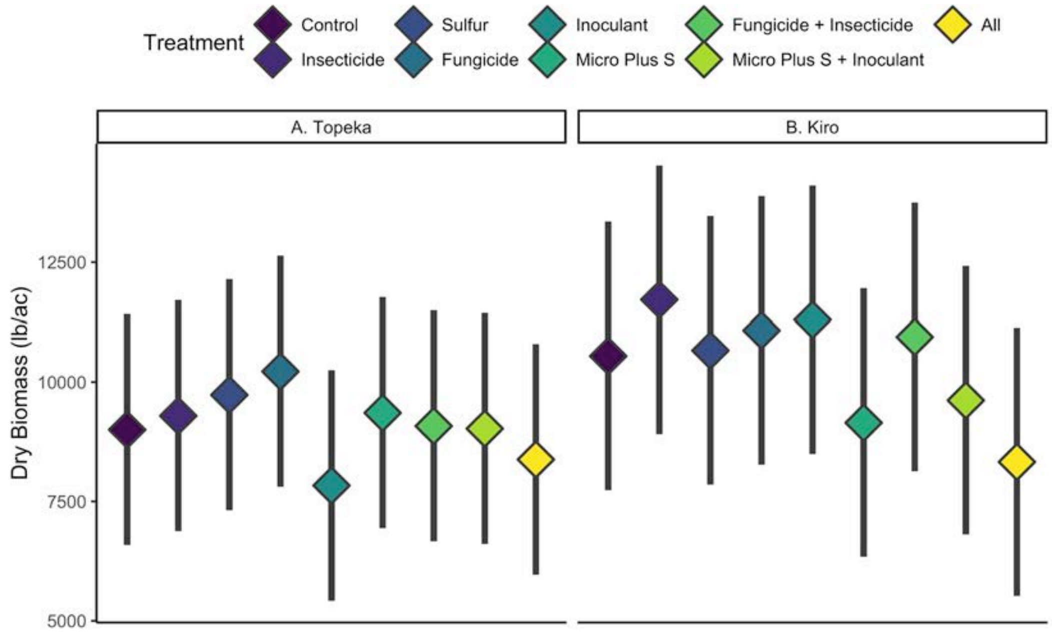

Figure 4. Final dry biomass at physiological maturity (R7) for each treatment at Topeka and Kiro, KS, locations for the 2021 growing season. Vertical bars are the standard deviations.

Wheat Yield Response to Nitrogen Rate Depends on Foliar Fungicide Application

R.P. Lollato, L.O. Pradella, N. Giordano, L. Ryan, L.M. Simão, and J.R. Soler

Summary

Nitrogen (N) and fungicide are among the most important factors impacting wheat yields in Kansas. However, there is limited information on whether foliar fungicides interact with N rates in wheat yield determination. Thus, our objectives were to evaluate wheat yield as impacted by different N rates with or without the use of foliar fungicide. One field experiment was established using a factorial structure of five N rates (0, 30, 60, 90, and 120 pounds of N per acre) by two fungicide management practices (either absent or 13 fluid ounces per acre of Nexicor) in a split-plot design near Hutchinson, KS, during the 2020–2021 wheat growing season. The variety Larry was planted at 90 pounds of seed per acre, N was the whole plot and fungicide was the subplot. There was a significant interaction between N and fungicide on winter wheat grain yield, where the benefit of fungicide was greater with higher N rates. In the absence of fungicide, wheat yields ranged from 51.1 bushels per acre in the zero N rate, to 68.5 bu/a in the highest N rate. Meanwhile, grain yield ranged from 57.3 bu/a when no N was applied, to 83.8 bu/a in the highest N rate. Despite higher yields when fungicides were applied, grain yield within fungicide treatment plateaued at the 90 pounds of N per acre rate. This experiment provided initial empirical evidence for the interaction between N management and fungicide. More field experiments are expected to validate this in future years.

Introduction

A recent survey of management practices adopted in ~700 commercial fields in Kansas suggested that nitrogen (N) management and foliar fungicide applications were among the largest drivers of wheat yield (Jaenisch et al., 2021). This information was well aligned with a previous survey of practices adopted by wheat growers who entered their crop into the Kansas Wheat Yield Contest (Lollato et al., 2019a), reinforcing the importance of both variables for wheat yields in the state. Considering the large yield gap of winter wheat in this region (Lollato et al., 2017), further research is warranted on agronomic practices to increase yields.

Crop N requirement is linked to yield potential (de Oliveira Silva et al., 2020a, b); thus, higher yielding environments require greater N rates to optimize yield (Lollato et al., 2019b, 2021). Meanwhile, foliar fungicides protect the crop canopy, increasing solar radiation interception and grain yield (Jaenisch et al., 2019, 2022). Data-rich experiments suggested that, depending on environmental conditions during the growing season and on cultivar susceptibility, winter wheat yield gain from fungicides in the US central Great Plains can range from -27 to +97% (Cruppe et al., 2017, 2021).

Reasons justifying potential interactions between N and fungicide include (1) that higher N rates can create a lusher canopy that decreases wind flow and creates a more favorable environment for disease development, and (2) that the crop receiving foliar fungicide may have a greater yield potential, thus increasing N requirements (Salgado et al., 2017). Therefore, our objectives were to explore the potential interaction between these two important yield-determining management factors for wheat in Kansas.

Procedures

A two-way factorial experiment was conducted in a split-plot design near Hutchinson, KS, during the 2020–2021 winter wheat growing season. Whole plot treatments included five N rates (0, 30, 60, 90, and 120 pounds of N per acre) and sub-plots were either the presence or absence of a foliar fungicide application at heading. The foliar fungicide product used was Nexicor applied at 13 fluid ounces per acre.

The winter wheat variety Larry was sown at 90 pounds of seed per acre on October 8, 2020, in combination with 50 pounds of diammonium phosphate as starter fertilizer. The previous crop was soybeans and the field was established under no-tillage practices. The field was maintained weed-free using commercially available herbicides. No insect pressure was observed during the experiment. Nitrogen fertilizer treatments were established on March 10, 2021, at the spring tillering stage, and fungicide was applied on April 30, 2021, at the heading stage. Plots were harvested on June 22, 2021, using a Massey Ferguson 8 XP small plot combine.

One composite soil sample, consisting of 15 individual soil cores, was retrieved from each of the 0–6 and 6–24 inch depths at sowing. For each depth, the sample was analyzed for soil fertility and texture. Grain yield and grain moisture were measured at harvest maturity and yield was corrected to 13% moisture for statistical analysis. Data were analyzed using a two-way analysis of variance considering N rate, fungicide, and their interactions as fixed effects, and replication and N rate nested within replication as random effects.

Results

Soil and Weather Conditions

Although winter wheat in Kansas is often subjected to drought and heat stresses during important yield-determining portions of the season (Couedel et al., 2021; Lollato et al., 2020; Sciarresi et al., 2019), the 2020–2021 growing season in Hutchinson was favorable for good yielding conditions. Overall, 3.7 inches of fall precipitation ensured good crop establishment and average fall temperatures of 45.1°F promoted crop tillering (Table 1). A total of 12.2 inches of precipitation in the winter and spring helped with N incorporation into the soil profile and reduced potential impacts of drought stress. Mild temperatures (51.3 to 74.5°F) during the spring and early summer decreased the incidence of heat stress. Total NO_3-N in the soil profile at sowing was 57 pounds of N per acre (Table 2). We also note that the soil pH in the 0- to 6-inch depth was 4.7 in the study site (Table 2), which could have limited wheat yields in the study even for a tolerant variety (Lollato et al., 2019c).

Grain Yield

Grain yield ranged from 51.1 to 83.8 bushels per acre across the different N rates and foliar fungicide treatments (Figure 1). Statistical analysis suggested a significant interaction between N rate and foliar fungicide (Table 3). Here, the benefit of fungicide was greater with higher N rates. In the absence of fungicide, wheat yields increased from

51.1 bu/a in the zero N rate to 65.9–68.5 bu/a in the 90 and 120 pounds of N per acre rates, respectively, with no statistical differences between the two highest rates. When fungicide was applied, grain yield increased from 57.3 bu/a when no N was applied, to 81.7–83.8 bu/a in the two highest N rates, which again did not differ statistically from each other. Interestingly, though not biologically meaningful, wheat grain yield with 30 pounds of N per acre and foliar fungicide (69.3 bu/a) was statistically the same as that receiving 90 or 120 pounds of N per acre in the absence of foliar fungicide.

Conclusions

This experiment only reports on one site-year of data, so conclusions are preliminary. Nonetheless, we collected empirical evidence to support the hypothesis that nitrogen rates interact with foliar fungicide management. Further research will be performed to quantify the probability of these responses in a large number of Kansas environments.

References

Couëdel, A., Edreira, J.I.R., Lollato, R.P., Archontoulis, S., Sadras, V. and Grassini, P., 2021. Assessing environment types for maize, soybean, and wheat in the United States as determined by spatio-temporal variation in drought and heat stress. Agricultural and Forest Meteorology, 307, p.108513.

Cruppe, G., Edwards, J.T. and Lollato, R.P., 2017. In-season canopy reflectance can aid fungicide and late-season nitrogen decisions on winter wheat. Agronomy Journal, 109(5), pp.2072-2086.

Cruppe, G., DeWolf, E., Jaenisch, B.R., Onofre, K.A., Valent, B., Fritz, A.K. and Lollato, R.P., 2021. Experimental and producer-reported data quantify the value of foliar fungicide to winter wheat and its dependency on genotype and environment in the US central Great Plains. Field Crops Research, 273, p.108300.

de Oliveira Silva, A., Ciampitti, I.A., Slafer, G.A. and Lollato, R.P., 2020a. Nitrogen utilization efficiency in wheat: A global perspective. European Journal of Agronomy, 114, p.126008.

de Oliveira Silva, A., Slafer, G.A., Fritz, A.K. and Lollato, R.P., 2020b. Physiological basis of genotypic response to management in dryland wheat. Frontiers in plant science, 10, p.1644.

Jaenisch, B.R., de Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant Population and Fungicide Economically Reduced Winter Wheat Yield Gap in Kansas. Agronomy Journal, 111(2), pp.1-16.

Jaenisch, B.R., Munaro, L.B., Bastos, L.M., Moraes, M., Lin, X. and Lollato, R.P., 2021. On-farm data-rich analysis explains yield and quantifies yield gaps of winter wheat in the US central Great Plains. Field Crops Research, 272. Article no. 108287.

Jaenisch, B.R., L.B. Munaro, K.S. Jagadish, and R.P. Lollato. 2022. Modulation of wheat yield components in response to management intensification to reduce yield gaps. Frontiers in Plant Science. 13: 772232. *https://doi.org/10.3389/fpls.2022.772232.*

Lollato, R.P., Edwards, J.T. and Ochsner, T.E., 2017. Meteorological limits to winter wheat productivity in the US southern Great Plains. Field Crops Research, 203, pp.212-226.

Lollato, R.P., Ruiz Diaz, D.A., DeWolf, E., Knapp, M., Peterson, D.E. and Fritz, A.K., 2019a. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Science, 59(1), pp.333-350.

Lollato, R.P., Figueiredo, B.M., Dhillon, J.S., Arnall, D.B. and Raun, W.R., 2019b. Wheat grain yield and grain-nitrogen relationships as affected by N, P, and K fertilization: a synthesis of long-term experiments. Field Crops Research, 236, pp.42-57.

Lollato, R.P., Ochsner, T.E., Arnall, D.B., Griffin, T.W. and Edwards, J.T., 2019c. From field experiments to regional forecasts: Upscaling wheat grain and forage yield response to acidic soils. Agronomy Journal, 111(1), pp.287-302.

Lollato, R.P., Bavia, G.P., Perin, V., Knapp, M., Santos, E.A., Patrignani, A. and DeWolf, E.D., 2020. Climate-risk assessment for winter wheat using long-term weather data. Agronomy Journal, 112(3), pp.2132-2151.

Lollato, R.P., Jaenisch, B.R. and Silva, S.R., 2021. Genotype-specific nitrogen uptake dynamics and fertilizer management explain contrasting wheat protein concentration. Crop Science, 61(3), pp.2048-2066.

Salgado, J.D., Lindsey, L.E. and Paul, P.A., 2017. Effects of row spacing and nitrogen rate on wheat grain yield and profitability as influenced by diseases. Plant disease, 101(12), pp.1998-2011.

Sciarresi, C., Patrignani, A., Soltani, A., Sinclair, T. and Lollato, R.P., 2019. Plant traits to increase winter wheat yield in semiarid and subhumid environments. Agronomy Journal, 111(4), pp.1728-1740.

Table 1. Weather data for the 2020–2021 winter wheat growing season at Hutchinson, KS

Season	Tmax (°F)	Tmin (°F)	Precip. (in.)	ETo (in.)
Fall*	57.5	32.7	3.7	7.6
Winter	48.2	25.2	6.2	7.3
Spring	74.5	51.3	5.9	15.2

*Fall: Sowing to December 31. Winter: January 1 - March 31. Spring: April 1 to harvest date.

Table 2. Soil pH, nitrate nitrogen (NO_3-N), Mehlich phosphorus (P), potassium (K), sulfur (S), organic matter (OM), and texture (percent sand, silt, and clay) for two different depths at the experimental site near Hutchinson, KS, during the 2020–2021 winter wheat growing season

Depth (in.)	pH	NO_3-N ppm	P-M ppm	K ppm	S ppm	OM %	Sand %	Silt %	Clay %
0–6	4.7	8.9	71.2	212.6	11.3	2.1	36.00	42.00	22.00
6–24	5.7	4.4	21.2	189.3	11.0	2.0	34.00	40.00	26.00

Table 3. Analysis of variance for winter wheat grain yield as affected by nitrogen rate, foliar fungicide management, and their interaction for a field experiment conducted during the 2020–2021 growing season near Hutchinson, KS

Effect	Num. DF	Den. DF	F Value	Pr > F
N rate	4	24	118.26	<.0001
Fungicide	1	3	49.39	0.0059
N rate × Fungicide	4	24	8.98	0.0001

DF = degrees of freedom. Num. = numerator. Den. = denominator.

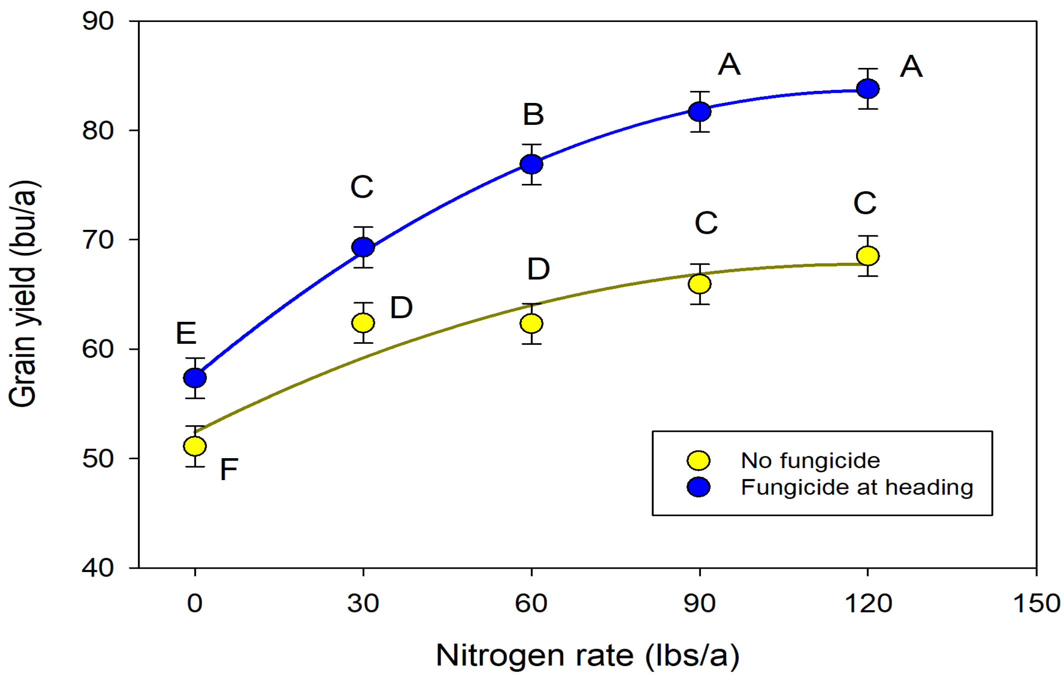

Figure 1. Winter wheat grain yield as function of nitrogen rate and foliar fungicide application during the 2020–2021 growing season near Hutchinson, KS. Means followed by the same letter are not statistically different at *P* < 0.05.

Increasing Winter Wheat Grain Yield by Replicating the Management Adopted in High-Yielding Commercial Fields

L. Ryan, L.A. Haag, J.D. Holman, and R.P. Lollato

Summary

Large winter wheat yield gaps between farmer yields and yield potential in the southern Great Plains indicate the need to improve recommendations of best management strategies to profitably bridge this gap. Many studies have been completed on individual management factors pre-determined by the individual researcher, but we are not aware of studies comparing combination of practices that producers are currently using, which would be more relevant for real-world scenarios. Our objective was to determine the yield gains resulting from management intensification using combination of practices currently adopted in commercial wheat fields. Four management intensities (i.e., Low, Average, High, and Top) were derived from a survey of 656 commercial fields, and replicated in trials conducted in four and six locations in western and central Kansas. Management intensities were tested factorially on two adapted varieties. Grain yield in central Kansas ranged from 45.5 bu/a in the Low management intensity to 69.3 bu/a in the High and Top intensities, with the Average management increasing yields by 30% as compared to the Low intensity, and the High management increasing yields 18% from the Average. The variety WB4269 outyielded Zenda (63.2 and 58.7 bu/a) across central environments. In western Kansas, there was a significant variety by management interaction, where wheat yield increased from the Low and Average intensities to the High and Top intensities (72.8–78.9 to 90.7–96.0 bu/a). The WB-Grainfield and KS Dallas varieties produced similar yields in the western environments. Using similar management practices as the producers with high-yield results in central and western Kansas narrowed the yield gap, and further increases in management intensification were not warranted. Variety selection played an important role either by increasing attained yields or by interacting with management practices.

Introduction

The adoption of conservative farming practices has led to large (approximately 55% or more) hard red winter wheat (*Triticum aestivum L.*) yield gaps between actual and potential yields in Kansas and most of the US central Great Plains (Jaenisch et al., 2021; Lollato et al., 2017; Patrignani et al., 2014). While part of this conservative management is justified due to harsh weather (Couedel et al., 2021; Lollato et al., 2020; Sciarresi et al., 2019), evidence suggests that the highest yielding growers (i.e., those that competed in state and national yield contests) were able to narrow this yield gap to less than 15% (Lollato et al., 2019c). Thus, efforts to improve management practices to narrow this yield gap profitably and effectively are warranted to sustainably increase food production.

Among the most important management practices that can potentially narrow the wheat yield gap in this region are fertilization practices (Lollato et al., 2019a, 2021) and foliar fungicides (Cruppe et al., 2021; Jaenisch et al., 2019), as quantified by de

Oliveira Silva et al. (2020). We note, though, that other practices such as crop rotation and sowing date (Munaro et al., 2020), seeding rate (Bastos et al., 2020), fungicide and insecticide seed treatments (Pinto et al., 2019), in-furrow fertilizer (Maeoka et al., 2020), and liming (Lollato et al., 2013; 2019b) have also benefited wheat yields in this region.

Many studies evaluating strategies to narrow the yield gap have treatments originally designed by the researcher him/herself (e.g., de Oliveira Silva et al., 2020; Jaenisch et al., 2019, 2022). While these studies can provide valuable information, they usually do not quantitatively reflect practices currently adopted by growers. To our knowledge, the practices (or combination of practices) tested in other studies not been quantitatively determined by the practices that producers are already using in commercial fields. Still, we argue that using field experiments to replicate the different management intensities adopted in commercial wheat fields can help identify avenues to increase yields while maintaining treatment parsimony and connection to current practices. Thus, our objective was to quantify the yield gain for wheat resulting from adopting the same management practices as those adopted by top commercial wheat growers, as compared to the average- and low-yielding fields, using Kansas as a case study.

Procedures

Two experiments were conducted in several locations in Kansas, one representing growers in the central region and one in the western region of the state. Central Kansas locations included two at Ashland Bottoms [Belvue silt loam (1) and Bismarckgrove-Kimo complex (2)]; Belleville (Crete silt loam); Hutchinson (Ost Loam): Manhattan (Kahola silt loam); and Tipton (Harney silt loam). Western Kansas locations included Colby (Keith silt loam); Garden City (Ulysses silt loam); Leoti (Richfield silt loam); and Norcatur (Holdrege silt loam). The study was set up in a two-way factorial experiment in a split-plot design with management intensity as the whole plot, and wheat variety as the sub-plot. Management intensities were based on a survey of management practices adopted in 656 wheat fields (Jaenisch et al., 2021). Fields were categorized by grain yield into Low (bottom 30% yielding fields), Average, High (top 30% yielding fields), and Top (top 5% yielding fields) categories. The frequency of adoption of different management practices was quantified for each group and replicated as treatments. A listing of management practices used in each treatment is provided in Table 1. Two hard red winter wheat varieties were planted at each location, including Zenda and WB4269 in the central locations, and KS Dallas and WB-Grainfield in the western locations. Central locations were sown following harvest of a preceding soybean crop while western locations followed a period of fallow, as was regionally common according to the survey of adopted practices.

Treatments were established according to Table 1, either by hand-spreading fertilizers or by using a CO_2-pressurized backpack sprayer for application of foliar fungicides. Plots were harvested with a Massey Ferguson 8XP small plot, self-propelled combine. Grain weight, test weight, and moisture content were measured at harvest with an on-board HarvestMaster GrainGage system. Grain yield was calculated with an adjustment to 13% moisture content. Statistical analysis was completed using RStudio v. 2021.09.0. Two-way analysis of variance with environments as the random effect detected the effects of variety, management, and their interaction. Means were separated at the alpha = 0.05 level.

Results

Central Kansas

The main effects of management and variety both influenced grain yield in the Central Kansas experiment, however, with no significant interaction. The 'Low' management yielded on average 45.5 bu/a across environments and varieties. Increasing inputs to average management increased yield by 29.5% to 58.9 bu/a. High management resulted in a grain yield of 69.3 bu/a, an increase of 17.7% compared to the average level. Further increases in inputs did not significantly increase yield as compared to high management. Across all levels of management intensity, WB4269 produced 7.7% greater grain yield than Zenda (63.2 vs. 58.7 bu/a).

The WB4269 variety yielded higher than Zenda in all locations except for Manhattan, where the two varieties had similar yield (Table 2). In all central Kansas locations, increases in management intensity generally increased grain yield. The Ashland Bottoms trials and the Hutchinson trial had similar effects of treatments, where the increase from Low to Average and from Average to High input levels produced increases in grain yield. Manhattan and Tipton trials did not have a significant increase in yield when increasing inputs from Low to Average management. In Manhattan, the High management intensity increased yield by 25.0% compared to the Average treatment. A 26.8% increase in grain yield was observed with the High treatment in Tipton compared to the Low input level. All locations in central Kansas showed no significant differences in grain yield between the High and Top management intensities except for Belleville, where there was a 4.7% increase with the Top treatment.

Of the management practices included in the treatments, seeding rate may have been among the most impactful for increasing grain yield due the previous crop of soybeans. Higher seeding rates are needed in lower yielding environments (Bastos et al., 2020), which often occur when winter wheat is planted following summer crop harvest, to compensate for later planting dates (Lollato et al., 2019c; Staggenborg et al., 2003). Consistent with findings from Lollato et al. (2019a) that optimum nitrogen rates to maximize grain yield are about 100 lb N/a, our study in central Kansas maximized yield when increasing nitrogen from 80 to 120 lb N/a. Fungicide applied at the jointing stage did not increase yield in the Top management, a practice that has been found to be dependent on the cultivar and environment (Watson et al., 2020).

Western Kansas

In the western Kansas experiment, there was a significant management by variety interaction on grain yield. General yield trends showed no significant increases in grain yield between the Low and the Average management intensities, which ranged from 72.8–78.9 bu/a. As inputs were increased to the High and Top levels of management, grain yield significantly increased to 90.7–96.0 bu/a. Increasing management intensity from the High to the Top level did not further increase grain yield. The significant management by variety interaction was brought about by numerical (though not statistical) differences between varieties as function of management, where KS Dallas had lower numerical yields than WB-Grainfield at the Low and Average treatments, and greater numerical yields at the High and Top treatments.

Both varieties in the western region yielded similarly in all locations except Leoti, where WB-Grainfield yielded 5.1% more than KS Dallas (Table 2). The Garden City and Norcatur trials responded similarly to increases in management intensity, where the only significant increase in yield occurred when increasing intensity from the Average level to High. In Leoti, a 9.6% increase in yield occurred when management increased from Low to Average, and an 8.5% increase when increasing from Average to High management. The Colby location did not have any significant differences in grain yield among treatments. None of the western locations experienced increases in yield between the High and the Top management intensities.

Although seeding rate increased between Low and Average management, there was no observed increase in yield, in part due to being planted at optimal timing following fallow. This was also observed by Lollato et al. (2019c) where yield was unaffected by increasing seeding rate when planted at the optimal timing. It also aligns with the findings of Bastos et al. (2020) where wheat yield was less responsive to seeding rates at high yielding environments. The increase of management intensity from Average to High input levels is where we see the largest overall increase of input levels with the addition of several factors, which resulted in an increase in grain yield. The most beneficial of these factors was the addition of sulfur fertilizer, which is documented to increase the plant's ability to respond to nitrogen applications (Salvagiotti and Miralles, 2008). The addition of fungicide also likely played a role in increasing grain yields, which has been observed with the presence of disease pressure (Cruppe et al., 2021; Jaenisch et al., 2019; Lollato et al, 2019c).

Conclusions

In both central and western Kansas, using similar management practices as the top 30% of producers increased grain yield and decreased the yield gap. A further increase in management intensity was not necessary to increase yield in the conditions experienced in 2021. Variety impacted both regions, affecting yield either by increasing yield or by interacting with the management intensity.

References

Bastos, L. M., Carciochi, W., Lollato, R. P., Jaenisch, B. R., Rezende, C. R., Schwalbert, R., Vara Prasad, P. V., Zhang, G., Fritz, A. K., Foster, C., Wright, Y., Young, S., Bradley, P., & Ciampitti, I. A. (2020). Winter Wheat Yield Response to Plant Density as a Function of Yield Environment and Tillering Potential: A Review and Field Studies. *Frontiers in Plant Science*, *11,* 54.

Couëdel, A., Edreira, J. I. R., Pisa Lollato, R., Archontoulis, S., Sadras, V., & Grassini, P. (2021). Assessing environment types for maize, soybean, and wheat in the United States as determined by spatio-temporal variation in drought and heat stress. *Agricultural and Forest Meteorology*, *307*, 108513.

Cruppe, G., DeWolf, E., Jaenisch, B. R., Andersen Onofre, K., Valent, B., Fritz, A. K., & Lollato, R. P. (2021). Experimental and producer-reported data quantify the value of foliar fungicide to winter wheat and its dependency on genotype and environment in the U.S. central Great Plains. *Field Crops Research*, *273*,108300.

de Oliveira Silva, A., Slafer, G. A., Fritz, A. K., & Lollato, R. P. (2020). Physiological Basis of Genotypic Response to Management in Dryland Wheat. *Frontiers in Plant Science*, *10,* 1644.

Jaenisch, B. R., Munaro, L. B., Bastos, L. M., Moraes, M., Lin, X., & Lollato, R. P. (2021). On-farm data-rich analysis explains yield and quantifies yield gaps of winter wheat in the U.S. central Great Plains. *Field Crops Research*, *272*, 108287.

Jaenisch, B.R., L.B. Munaro, S.V. Krishna Jagadish, and R.P. Lollato. 2022. Modulation of Wheat Yield Components in Response to Management Intensification to Reduce Yield Gaps. Frontiers Plant Science 13:772232. https://doi.org/10.3389/fpls.2022.772232.

Jaenisch, B. R., Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D. A., & Lollato, R. P. (2019). Plant Population and Fungicide Economically Reduced Winter Wheat Yield Gap in Kansas. *Agronomy Journal*, *111*(2), 650–665.

Lollato, R. P., Bavia, G. P., Perin, V., Knapp, M., Santos, E. A., Patrignani, A., & DeWolf, E. D. (2020). Climate-risk assessment for winter wheat using long-term weather data. *Agronomy Journal*, *112*(3), 2132–2151.

Lollato, R. P., Edwards, J. T., & Ochsner, T. E. (2017). Meteorological limits to winter wheat productivity in the U.S. southern Great Plains. *Field Crops Research*, *203*, 212–226.

Lollato, R. P., Edwards, J. T., & Zhang, H. (2013). Effect of Alternative Soil Acidity Amelioration Strategies on Soil pH Distribution and Wheat Agronomic Response. *Soil Science Society of America Journal*, *77*(5), 1831–1841.

Lollato, R. P., Figueiredo, B. M., Dhillon, J. S., Arnall, D. B., & Raun, W. R. (2019a). Wheat grain yield and grain-nitrogen relationships as affected by N, P, & K fertilization: A synthesis of long-term experiments. *Field Crops Research*, *236*, 42–57.

Lollato, R. P., Jaenisch, B. R., & Silva, S. R. (2021). Genotype-specific nitrogen uptake dynamics and fertilizer management explain contrasting wheat protein concentration. *Crop Science*, *61*(3), 2048–2066.

Lollato, R. P., Ochsner, T. E., Arnall, D. B., Griffin, T. W., & Edwards, J. T. (2019b). From Field Experiments to Regional Forecasts: Upscaling Wheat Grain and Forage Yield Response to Acidic Soils. *Agronomy Journal*, *111*(1), 287–302.

Lollato, R. P., Ruiz Diaz, D. A., DeWolf, E., Knapp, M., Peterson, D. E., & Fritz, A. K. (2019c). Agronomic Practices for Reducing Wheat Yield Gaps: A Quantitative Appraisal of Progressive Producers. *Crop Science*, *59*(1), 333–350.

Maeoka, R. E., Sadras, V. O., Ciampitti, I. A., Diaz, D. R., Fritz, A. K., & Lollato, R. P. (2020). Changes in the Phenotype of Winter Wheat Varieties Released Between 1920 and 2016 in Response to In-Furrow Fertilizer: Biomass Allocation, Yield, and Grain Protein Concentration. *Frontiers in Plant Science*, *10,* 1786.

Munaro, L. B., Hefley, T. J., DeWolf, E., Haley, S., Fritz, A. K., Zhang, G., Haag, L. A., Schlegel, A. J., Edwards, J. T., Marburger, D., Alderman, P., Jones-Diamond, S. M., Johnson, J., Lingenfelser, J. E., Unêda-Trevisoli, S. H., & Lollato, R. P. (2020). Exploring long-term variety performance trials to improve environment-specific genotype × management recommendations: A case-study for winter wheat. *Field Crops Research*, *255*, 107848.

Patrignani, A., Lollato, R. P., Ochsner, T. E., Godsey, C. B., & Edwards, Jeff. T. (2014). Yield Gap and Production Gap of Rainfed Winter Wheat in the Southern Great Plains. *Agronomy Journal*, *106*(4), 1329–1339.

Pinto, J. G. C. P., Munaro, L. B., Jaenisch, B. R., Nagaoka, A. K., & Lollato, R. P. (2019). Wheat Variety Response to Seed Cleaning and Treatment after Fusarium Head Blight Infection. *Agrosystems, Geosciences & Environment*, *2*(1), 1-8.

Salvagiotti, F., & Miralles, D. J. (2008). Radiation interception, biomass production and grain yield as affected by the interaction of nitrogen and sulfur fertilization in wheat. *European Journal of Agronomy*, *28*(3), 282–290.

Sciarresi, C., Patrignani, A., Soltani, A., Sinclair, T. and Lollato, R.P., 2019. Plant traits to increase winter wheat yield in semiarid and subhumid environments. Agronomy Journal, 111(4), pp.1728-1740.

Staggenborg, S. A., Whitney, D. A., Fjell, D. L., & Shroyer, J. P. (2003). Seeding and Nitrogen Rates Required to Optimize Winter Wheat Yields following Grain Sorghum and Soybean. *Agronomy Journal*, *95*(2), 253–259. Watson, B. H., Hunger, R. M., & Marburger, D. A. (2020). Economic returns of one versus two fungicide applications in Oklahoma winter wheat. *Crop Science*, *60*(1), 441-453.

Table 1. Combinations of management practices adopted in 656 commercial winter wheat fields based on different yield levels in the central and western environments

	Central Kansas				Western Kansas			
Management practice	**Low**	**Average**	**High**	**Top**	**Low**	**Average**	**High**	**Top**
Yield goal (bu/a)	35	55	75	95	35	55	80	95
Seeding rate (seeds/a)	1,000,000	1,200,000	1,450,000	1,450,000	750,000	900,000	1,050,000	1,050,000
Seed treatment	No	Yes	Yes	Yes	No	No	Yes	Yes
Split N application	No	No	Yes	Yes	No	No	Yes	Yes
Nitrogen (lb N/a)	40	80	120	160	40	80	120	180
Phosphorus (lb P/a)	0	20	30	35	0	0	30	30
Sulfur (lb S/a)	0	10	10	20	0	0	10	20
Chloride (lb KCl/a)	0	15	15	15	0	0	0	0
Micronutrients	No	No	No	Yes	No	No	No	Yes
Jointing fungicide	No	No	No	Yes	No	No	No	Yes
Flag leaf fungicide	No	No	Yes	Yes	No	No	Yes	Yes

Table 2. Grain yield by management intensity, variety, and location for the central and western Kansas experiments

Central Kansas grain yield (bu/a)							
Management intensity	**Ashland Bottoms 1**	**Ashland Bottoms 2**	**Belleville**	**Hutchinson**	**Manhattan**	**Tipton**	**Sites combined**
Low	51.7 c*	46.0 c	41.2 d	40.3 c	35.7 b	48.8 b	45.5 c
Average	64.1 b	61.6 b	59.9 c	53.5 b	45.2 b	57.3 ab	58.9 b
High	79.1 a	73.3 a	67.5 b	64.5 a	56.7 a	61.9 a	69.3 a
Top	77.0 a	74.8 a	70.7 a	67.9 a	57.0 a	61.6 a	70.2 a
Variety							
WB4269	70.7 a	65.2 a	63.3 a	58.4 a	49.1 a	60.4 a	61.9 a
Zenda	65.2 b	62.6 b	56.3 b	54.7 b	48.2 a	54.2 b	58.7 b

Western Kansas grain yield (bu/a)					
Management intensity	**Colby**	**Garden City**	**Leoti**	**Norcatur**	**Sites combined**
Low	84.2 a	79.4 b	82.2 c	49.6 b	73.9 b
Average	83.5 a	82.3 b	90.1 b	48.1 b	76.0 b
High	87.7 a	101.6 a	97.8 a	90.1 a	94.3 a
Top	83.0 a	101.9 a	96.8 a	83.6 a	91.3 a
Variety					
WB-Grainfield	66.2 a	92.1 a	94.0 a	66.2 a	84.3 a
KS Dallas	69.5 a	90.5 a	89.4 b	69.5 a	83.4 a

*Letters denote significance at the 0.05 probability level.

Winter Wheat Response to Timing of Fungicide Application During the 2020–2021 Growing Season

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Summary

Foliar fungicides applied at the flag leaf stage can improve wheat grain yield in Kansas, but there is limited information on the impact of earlier or combined applications of fungicide on wheat grain yield. We conducted a field study in six Kansas locations during the 2020–2021 growing season to evaluate the yield and test weight of the winter wheat variety WB-Grainfield in response to different fungicide application timings. The trial was conducted in a randomized complete block design with four replications to evaluate (1) a non-treated control; Topguard applied at 5 ounces per acre at (2) jointing, (3) heading; and (4) jointing plus heading. The study was conducted in two locations with contrasting soil textures near Ashland Bottoms, in two locations with different previous crops resulting in optimum- and late-sowing dates near Belleville, in one location near Hutchinson, and another near Manhattan. Statistical analysis indicated that for both grain yield and grain test weight, there were significant fungicide timing by location interactions, suggesting that the response to fungicide was location-specific. Grain yield ranged from 28 bushels per acre in the no fungicide treatment in Manhattan to 109.9 bu/a with dual-fungicide in the Belleville field sown at the optimum time. Depending on environment, the increase in yield due to the fungicide application as compared to the untreated control ranged from 0.7 to 8.0 bu/a in the jointing application, from -1.8 to 19.3 bu/a in the heading application, and from -1.4 to 17.7 bu/a in the dual application. Grain test weights ranged from 54.1 pounds per bushel without fungicide in one of the trials near Ashland Bottoms, to 62.8 lb/bu near Hutchinson with the dual fungicide application. Test weight benefits due to fungicide depended on location and ranged from -0.1 to 1.7 lb/bu in the jointing application, from -0.9 to 2.6 lb/bu in the heading application, and from -0.3 to 3.9 lb/bu in the dual application. This research is an initial step in determining the benefits of foliar fungicide timing to winter wheat yield and test weight. The results from this study suggest that benefits are substantial, however, the magnitude depended on the environmental conditions experienced during the growing season.

Introduction

The application of foliar fungicides has been associated with increased wheat yields in Kansas (Cruppe et al., 2021; de Oliveira Silva et al., 2020, 2021; Jaenisch et al., 2019, 2021, 2022; Munaro et al., 2020; Lollato et al., 2019; Sassenrath et al., 2019). However, most of the existing research has focused on a single fungicide application at flag leaf emergence (e.g., Cruppe et al., 2017, 2021), even though some intensive production systems maximizing wheat yield have used a dual-fungicide system (Lollato and Edwards, 2015). Understanding the potential benefits of dual fungicide application, as

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well as of application timings, can potentially help narrow the large yield gaps for wheat in this region (Lollato et al., 2017).

The most prevalent diseases causing yield losses to Kansas wheat are leaf and stripe rust (Hollandbeck et al., 2019), perhaps justifying the majority of the research focused on late-season fungicide applications. However, Hollandbeck et al. (2019) also suggested that early-season diseases such as tan spot and septoria might cause significant yield losses if the conditions are favorable for development of such diseases. There is a need to better understand the effects of different timings of fungicide application on winter wheat grain yield in the state. Likewise, different products might offer different levels of protection (DeWolf et al., 2019). Therefore, testing the interaction between fungicide timing and product on wheat yield is warranted.

The objective of this study was to evaluate the response of winter wheat in terms of grain yield and test weight to different fungicide timings in Kansas.

Procedures

A field experiment was conducted in six Kansas locations during the 2020–2021 winter wheat growing season, including two fields with contrasting soil texture characteristics near Ashland Bottoms, two fields with different previous crops resulting in optimum- and late-sowing dates near Belleville, one field near Hutchinson and one field near Manhattan. The experiments were established in a randomized complete block design with four treatments and four replications. Treatments included (1) a non-treated control; Topguard foliar fungicide applied at 5 ounces per acre at (2) jointing, (3) heading, and (4) jointing plus heading. All treatments were applied with non-ionic surfactant and a spray volume of 15 gallons per acre using a backpack sprayer. The winter wheat variety evaluated at all locations was WB-Grainfield. Harvest occurred using a Massey Ferguson XP8 small-plot, self-propelled combine. Plot ends were trimmed at harvest time to avoid border effect. Measurements included grain yield (corrected for 13% moisture content) and grain test weight. Statistical analysis was performed using a two-way ANOVA in PROC GLIMMIX procedure in SAS v. 9.4 where treatment, location, and their interactions were considered fixed effects, and replication nested within location was treated as a random effect.

Results

Weather Conditions

The study locations had anywhere from 10.9 to 18.6 inches of precipitation during the growing season, with corresponding crop reference evapotranspiration of 30.4 to 32.7 inches (Table 1). These precipitation and atmospheric water demand values resulted in water supply:water demand ratios of 0.14 to 0.85 depending on location and portion of the season considered, suggesting that water deficit was possibly limiting wheat yields differently according to location. However, water deficit and temperature stresses are common themes of wheat production in Kansas (Couedel et al., 2021; Lollato et al., 2020; Sciarresi et al., 2019) and therefore represent conditions experienced at growers' fields.

Grain Yield
Grain yield was affected by the interaction of fungicide and location ($P < 0.01$), suggesting that fungicide management ranked differently at each location evaluated. Manhattan was the lowest yielding environment; grain yields ranged between 26.1 and 31.5 bu/a with no effect of fungicide (Table 2). At four locations (the two fields in Ashland Bottoms, Belleville optimum, and Hutchinson), grain yield was greatest in the treatments receiving fungicide at heading as well as in the dual fungicide treatment (Table 2). In Belleville sown late, the treatment receiving a fungicide application at heading resulted in the highest yield (Table 2). Depending on environment, the increase in yield due to the fungicide application as compared to the untreated control ranged from 0.7 to 8.0 bu/a in the jointing application, from -1.8 to 19.3 bu/a in the heading application, and from -1.4 to 17.7 bu/a in the dual application. Grain test weight ranged from 54.1 lb/bu without fungicide in one of the trials near Ashland Bottoms, to 62.8 lb/bu near Hutchinson with the dual fungicide application.

Grain Test Weight
Similar to grain yield, the response of grain test weight to foliar fungicide management also depended on location, as evidenced by the significant interaction between fungicide treatment and location ($P < 0.01$). In Manhattan and Belleville sown late, there was no effect of fungicide treatment on wheat test weight (Table 2). In one field in Ashland Bottoms and in Belleville sown at the optimum time, the greatest test weights occurred in the heading or dual fungicide application treatments (Table 2). In the other Ashland Bottoms field, test weight in the control treatment was lower than that of any treatment receiving fungicides. In Hutchinson, the highest test weight occurred for the dual fungicide treatment. Differences from the untreated control ranged from -0.1 to 1.7 lb/bu in the jointing application, from -0.9 to 2.6 lb/bu in the heading application, and from -0.3 to 3.9 lb/bu in the dual fungicide application, depending on environment.

Preliminary Conclusions
Results suggest that the optimum fungicide management strategy depended on location. In locations with lower yield potential, the application of foliar fungicides did not improve grain yield or grain test weight. In higher yielding locations, application of a foliar fungicide at heading usually produced yields similar to that of a dual fungicide application at jointing plus at heading.

References
Couëdel, A., Edreira, J.I.R., Lollato, R.P., Archontoulis, S., Sadras, V. and Grassini, P., 2021. Assessing environment types for maize, soybean, and wheat in the United States as determined by spatio-temporal variation in drought and heat stress. Agricultural and Forest Meteorology, 307, p.108513.

Cruppe, G., DeWolf, E., Jaenisch, B.R., Onofre, K.A., Valent, B., Fritz, A.K. and Lollato, R.P., 2021. Experimental and producer-reported data quantify the value of foliar fungicide to winter wheat and its dependency on genotype and environment in the US central Great Plains. Field Crops Research, 273. Article no. 108300.

Cruppe, G., Edwards, J.T. and Lollato, R.P., 2017. In-season canopy reflectance can aid fungicide and late-season nitrogen decisions on winter wheat. Agronomy Journal, 109(5), pp.2072-2086.

de Oliveira Silva, A., Slafer, G.A., Fritz, A.K. and Lollato, R.P., 2020. Physiological basis of genotypic response to management in dryland wheat. Frontiers in Plant Science, 10, p.1644.

de Oliveira Silva, A., Jaenisch, B.R., Ciampitti, I.A. and Lollato, R.P., 2021. Wheat nitrogen, phosphorus, potassium, and sulfur uptake dynamics under different management practices. Agronomy Journal, 113(3), pp.2752-2769.

DeWolf, E. 2019. Foliar fungicide efficacy ratings for wheat disease management 2019. Kansas St. Univ. Agric. Exp. Stat. Coop. Ext. Ser. EP130.

Hollandbeck, G.F., E. DeWolf, and T. Todd. 2019. Kansas cooperative plant disease survey report. Preliminary 2019 Kansas wheat disease loss estimates. Kansas Department of Agriculture. https://agriculture.ks.gov/docs/default-source/pp-disease-reports-2012/2017-kswheat-disease-loss-estimates.pdf?sfvrsn=ce1382c1_0.

Jaenisch, B.R., de Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant population and fungicide economically reduced winter wheat yield gap in Kansas. Agronomy Journal, 111(2), pp.650-665.

Jaenisch, B.R., Munaro, L.B., Bastos, L.M., Moraes, M., Lin, X. and Lollato, R.P., 2021. On-farm data-rich analysis explains yield and quantifies yield gaps of winter wheat in the US central Great Plains. Field Crops Research, 272. Article no. 108287.

Jaenisch, B.R., L.B. Munaro, K.S. Jagadish, and R.P. Lollato. 2022. Modulation of wheat yield components in response to management intensification to reduce yield gaps. Frontiers in Plant Science. 13:772232. https://doi.org/10.3389/fpls.2022.772232.

Lollato, R.P. and Edwards, J.T., 2015. Maximum attainable wheat yield and resource-use efficiency in the southern Great Plains. Crop Science, 55(6), pp.2863-2876.

Lollato, R.P., Edwards, J.T. and Ochsner, T.E., 2017. Meteorological limits to winter wheat productivity in the US southern Great Plains. Field Crops Research, 203, pp.212-226.

Lollato, R.P., Ruiz Diaz, D.A., DeWolf, E., Knapp, M., Peterson, D.E. and Fritz, A.K., 2019. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Science, 59(1), pp.333-350.

Lollato, R.P., Bavia, G.P., Perin, V., Knapp, M., Santos, E.A., Patrignani, A. and DeWolf, E.D., 2020. Climate-risk assessment for winter wheat using long-term weather data. Agronomy Journal, 112(3), pp.2132-2151.

Munaro, L.B., Hefley, T.J., DeWolf, E., Haley, S., Fritz, A.K., Zhang, G., Haag, L.A., Schlegel, A.J., Edwards, J.T., Marburger, D. and Alderman, P., 2020. Exploring long-term variety performance trials to improve environment-specific genotype × management recommendations: A case-study for winter wheat. Field Crops Research, 255. Aricle no. 107848.

Sassenrath, G.F., Farney, J. and Lollato, R., 2019. Impact of Fungicide and Insecticide Use on Wheat Production in a High-Rainfall Environment. Crop, Forage & Turfgrass Management, 5(1), pp.1-10.

Sciarresi, C., Patrignani, A., Soltani, A., Sinclair, T. and Lollato, R.P., 2019. Plant traits to increase winter wheat yield in semiarid and subhumid environments. Agronomy Journal, 111(4), pp.1728-1740.

Table 1. Average maximum (Tmax) and minimum (Tmin) temperatures, cumulative precipitation, grass reference evapotranspiration (ETo), and the ratio of water supply (WS) to water demand (WD) during the growing season at the six study locations during 2020–2021

Location	Season*	Tmax	Tmin	Precipitation	ETo	WS:WD
		(°F)	(°F)	(inch)	(inch)	
Ashland Bottoms*	Fall**	57.7	32.6	4.0	7.8	0.51
	Winter	47.1	25.0	4.5	6.9	0.65
	Spring	75.2	53.4	9.4	16.0	0.59
Belleville*	Fall	56.1	30.0	1.1	8.0	0.14
	Winter	43.7	21.6	4.3	6.5	0.67
	Spring	74.9	50.4	5.5	17.2	0.32
Hutchinson	Fall	59.1	33.3	3.7	8.7	0.43
	Winter	48.2	25.2	6.2	7.3	0.85
	Spring	75.9	52.8	8.1	16.7	0.49
Manhattan	Fall	56.9	32.4	4.0	7.5	0.53
	Winter	47.4	25.5	4.6	7.3	0.63
	Spring	75.7	54.3	10.0	15.6	0.64

*Fall: October 1 - December 31. Winter: January 1 - March 31. Spring: April 1 - June 30.
**There were two fields located near Ashland Bottoms and two fields located near Belleville.

Table 2. Winter wheat grain yield and grain test weight as affected by the interaction of fungicide management and location at the six study sites conducted during the 2020–2021 growing season

	Fungicide treatment			
Location	**No**	**Jointing**	**Heading**	**Jointing + Heading**
	-------------------------------- Grain yield (bu/a) --------------------------------			
Ashland Bottoms 1	65.8	73.1	**80.8***	**83.5**
Ashland Bottoms 2	64.9	72.9	**84.1**	**81.4**
Belleville (late)	56.6	57.4	**67.0**	55.2
Belleville (optimum)	92.4	96.0	**103.7**	**109.9**
Hutchinson	60.1	65.0	**76.9**	**71.9**
Manhattan	28.0	31.5	26.1	29.7
	---------------------------- Grain test weight (lb/bu) ----------------------------			
Ashland Bottoms 1	54.2	**55.6**	**56.8**	**56.5**
Ashland Bottoms 2	54.1	55.8	**56.5**	**57.5**
Belleville (late)	61.5	61.5	60.7	61.3
Belleville (optimum)	56.3	57.4	**58.6**	**59.3**
Hutchinson	58.9	59.6	61.5	**62.8**
Manhattan	55.5	55.4	55.6	56.0

Timing of fungicide application is referred to as growth stage in the Feekes scale of cereal development (FK6 = jointing; FK10 = heading).
*Numbers in bold represent those in the highest yielding group based on post-hoc analysis of mean comparison using Tukey's test.

Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2020–2021 Growing Season in Kansas

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Summary
The objective of this project was to evaluate the winter wheat stand count and grain yield responses to seeding rate and its interaction with seed cleaning and seed treatment in Kansas during the 2020–2021 growing season. Experiments evaluating the response of the wheat variety SY Monument to three seeding rates (600,000, 900,000, and 1,200,000 seeds per acre), three seed cleaning intensities (none, air screen, and gravity table), and two seed treatments (none and insecticide + fungicide) were established in a split-split plot design conducted in a complete factorial experiment in ten Kansas locations. In-season measurements included stand count and grain yield. Despite a few location-specific results, the general trends were uniform to be generalized across locations as there were significant main effects of population and seed treatment for both stand and yield, but no significant seed cleaning effect or interactions among factors. Across locations, plant population increased with increases in seeding rate from 391,616 to 556,771 plants per acre from the lowest to the highest seeding rate, as expected. Seed treatment increased plant population from 467,778 to 492,211 plants/a. Grain yield increased from 68.8 to 72.5 bushels per acre as function of seeding rate, with higher yields associated with higher seeding rates. Grain yield increased from 69.8 bu/a in the untreated control to 71.8 bu/a when the seed was treated. This research is an initial step in evaluating the value of the seed certification process and does not compare certified seed versus bin-run seed. The seed used in this study was derived from a commercial seed production field (i.e., high quality seed) and not from commercial grain production fields.

Introduction
Yield potential is defined as the yield of an adapted cultivar when only limited by weather conditions (i.e., temperature regime, solar radiation, and, in the case of rainfed crops, water availability) and in the absence of stresses caused by manageable factors. Using data from well-managed field experiments where the crop achieved levels close to its potential (i.e., Lollato and Edwards, 2015), Lollato et al. (2017) estimated that current wheat yields of commercial fields in Kansas are about 50% of their long-term water-limited potential, suggesting that appropriate management could economically improve wheat yields at the state level. This yield gap was further confirmed in several replicated field studies (de Oliveira Silva et al., 2020, 2021; Jaenisch et al., 2019, 2022) and surveys of commercial fields (Jaenisch et al., 2021; Lollato et al., 2019). To ensure potential conditions can be attained, the first step after variety selection and sowing date (Munaro et al., 2020) is to ensure a good population establishment through high quality seed, appropriate seeding rate, and seed treatment. A recent review of winter

wheat response to seeding rate suggested that the optimum seeding rate depended on yield environment (Bastos et al., 2020). Grain yield was independent of population in high-yielding environments such as high fertility fields sown at the appropriate time, when tillering is abundant. Higher seeding rates were required in lower-yielding environments where the crop does not have as much time to tiller. Similar results were reported by Fischer et al. (2019) and Lollato et al. (2019) suggesting an insensitivity of wheat to seeding rate in high-yielding environments; and by Jaenisch et al. (2019) suggesting that higher seeding rates were required in lower-yielding environments. More recently, Jaenisch et al. (2022) showed that reduced seeding rates could reduce light interception during grain filling and consequently grain yield.

Not all planted seeds become an emerged plant. In fact, Bastos et al. (2020) suggested that the ratio of achieved over target plant density ranged from 60 to 100% in nine Kansas experiments. Factors that might impact this ratio include seed quality and seed treatment (Pinto et al., 2019). While seed cleaning (e.g., air screening followed by gravity table) can affect seed size; and seed treatment can reduce the risk of disease transmission–thus both improving seed quality–the effects of seed cleaning and treatment on wheat grain yield have been inconsistent (Edwards and Krenzer, 2006). Thus, the objectives of this project were to assess winter wheat establishment and grain yield as affected by different combinations of seeding rate, seed cleaning, and seed treatment in several Kansas locations. This is the report of the third year of a three-year project. Data from the first two years was reported by Lollato et al., 2020a, 2021.

Procedures

Field experiments were conducted in ten locations during the 2020–2021 winter wheat growing season, including two fields with different soil textures near Ashland Bottoms, two fields with different previous crops (and consequent sowing dates) near Belleville, one field near Colby, two fields with early- or optimum-sowing dates near Hutchinson, and one field each near Manhattan, Mitchel, and Leoti. In Colby and Mitchell, plots were comprised of eight 10-in. spaced rows wide and 40-ft long, while at the remaining locations plots were seven 7.5-in. spaced rows wide by 30-ft long. A total of eighteen treatments resulting from the factorial combination of three seeding rates (600,000, 900,000, and 1,200,000 seeds/a), three seed cleaning intensities (none, air screen, and gravity table + color sorting), and two seed treatments (none and insecticide + fungicide) were established in a split-split plot design. The different seed treatments were established by collecting seed at three different intervals during the seed cleaning process: immediately after harvest, after air screening, and on the top of the gravity table. More details about the air screening and gravity table used were provided by Lollato et al. (2020). Seed treatment consisted of 5 oz/a of Cruiser Maxx and 0.75 oz/a Cruiser 5FS. The same wheat variety ('SY Monument') was evaluated at all locations. Harvest occurred using a Massey Ferguson XP8 small-plot, self-propelled combine.

Measurements and Statistical Analyses

In-season measurements included stand count measured about 20–30 days after sowing and grain yield at harvest maturity, corrected for 13% moisture content. Statistical analysis of the data collected in this experiment was performed using a three-way ANOVA in PROC GLIMMIX procedure in SAS v. 9.4. Because of the large number of locations included in the study, we treated location as a random factor, as well as replication nested within location. Random effects also included the ones to account for the statistical design of the experiment, including the seeding rate nested within replication, and the seeding rate by seed treatment nested within replication.

Results

Weather Conditions

The ten locations evaluated during the 2020–2021 winter wheat growing season provided contrasting environments for the evaluation of the different treatments (Table 1). Growing season precipitation ranged from 10.9 inches in Belleville to 18.6 inches in Manhattan, with corresponding grass reference evapotranspiration (ETo) ranging from 27.8 inches in Leoti to 35.9 inches in Colby. The corresponding water supply (WS) to water demand (WD) ratios ranged from 0.34 to 0.62. These relatively dry conditions are typical of the weather usually experienced by winter wheat in this region (Couedel et al., 2021; Lollato et al, 2020b; Sciarresi et al., 2019).

Stand Count

There were significant main effects of seeding rate and seed treatment for stand count, with no significant seed cleaning effect or interactions among any of the factors studied. Across locations, plant population increased with increases in seeding rate from 391,616 at the 600,000 seeds/a treatment, to 491,596 plants/a in the 900,000 seeds/a treatment, to 556,771 plants/a in the 1,200,000 seeds/a treatment. Seed treatment increased plant population from 467,778 plants/a in the untreated control to 492,211 plants/a when fungicide and insecticide seed treatment were provided.

Grain Yield

Similar to the results for stand count, there were main effects of seeding rate and seed treatment on grain yield, with no significant seed cleaning effect or interactions among any of the factors studied. Grain yield increased from 68.8 bu/a in the lowest population, to 70.9 bu/a at the 900,000 seeds/a treatment, to 72.5 bu/a in the highest seeding rate evaluated. Grain yield increased from 69.8 bu/a in the untreated control to 71.8 bu/a when the seed was treated with fungicide and insecticide seed treatment.

Preliminary Conclusions

Despite some location-specific responses due to different yield levels, our results showed a clear benefit from increases in seeding rate and from the presence of a fungicide plus insecticide seed treatment, in improving both stand establishment and grain yield of winter wheat. It is important to highlight that this research evaluates the value of the seed certification process; and does not compare certified seed versus bin-run seed. The most important difference here is that the seed used in this study was derived from commercial seed production fields (i.e., high quality seed) instead of commercial grain production fields. This was the third year of this research, and the results from the first and second years were published in Lollato et al. (2020, 2021). A comprehensive study including all three years of this research will soon be conducted.

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References

Bastos, L.M., Carciochi, W., Lollato, R.P., Jaenisch, B.R., Rezende, C.R., Schwalbert, R., Vara Prasad, P.V., Zhang, G., Fritz, A.K., Foster, C. and Wright, Y., 2020. Winter wheat yield response to plant density as a function of yield environment and tillering potential: A review and field studies. Frontiers in Plant Science, 11, p.54.

Couëdel, A., Edreira, J.I.R., Lollato, R.P., Archontoulis, S., Sadras, V. and Grassini, P., 2021. Assessing environment types for maize, soybean, and wheat in the United States as determined by spatio-temporal variation in drought and heat stress. Agricultural and Forest Meteorology, 307, p.108513.

de Oliveira Silva, A., Slafer, G.A., Fritz, A.K. and Lollato, R.P., 2020. Physiological basis of genotypic response to management in dryland wheat. Frontiers in plant science, 10, p.1644.

de Oliveira Silva, A., Jaenisch, B.R., Ciampitti, I.A. and Lollato, R.P., 2021. Wheat nitrogen, phosphorus, potassium, and sulfur uptake dynamics under different management practices. Agronomy Journal, 113(3), pp.2752-2769.

Edwards, J.T. and Krenzer, E.G., 2006. Quality of farmer-saved wheat seed is variable in the southern Great Plains. Crop Management, 5(1).

Jaenisch, B.R., de Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant population and fungicide economically reduced winter wheat yield gap in Kansas. Agronomy Journal, 111(2), pp.650-665.

Jaenisch, B.R., Munaro, L.B., Bastos, L.M., Moraes, M., Lin, X. and Lollato, R.P., 2021. On-farm data-rich analysis explains yield and quantifies yield gaps of winter wheat in the US central Great Plains. Field Crops Research, 272. Article No. 108287.

Jaenisch, B.R., L.B. Munaro, K.S. Jagadish, and R.P. Lollato. 2022. Modulation of wheat yield components in response to management intensification to reduce yield gaps. Frontiers in Plant Science. 13:772232. https://doi.org/10.3389/fpls.2022.772232.

Lollato, R.P. and Edwards, J.T., 2015. Maximum attainable wheat yield and resource-use efficiency in the southern Great Plains. Crop Science, 55(6), pp.2863-2876.

Lollato, R.P., Edwards, J.T. and Ochsner, T.E., 2017. Meteorological limits to winter wheat productivity in the US southern Great Plains. Field Crops Research, 203, pp.212-226.

Lollato, R.P., Ruiz Diaz, D.A., DeWolf, E., Knapp, M., Peterson, D.E. and Fritz, A.K., 2019. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Science, 59(1), pp.333-350.

Lollato, R.P., Mark, K., Jaenisch, B.R. and Haag, L., 2020a. Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2018–2019 Growing Season in Kansas. Kansas Agricultural Experiment Station Research Reports, 6(5), p.24.

Lollato, R.P., Bavia, G.P., Perin, V., Knapp, M., Santos, E.A., Patrignani, A. and DeWolf, E.D., 2020b. Climate-risk assessment for winter wheat using long-term weather data. Agronomy Journal, 112(3), pp.2132-2151.

Lollato, R.P., Jaenisch, B.R. and Haag, L., 2021. Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2019–2020 Growing Season in Kansas. Kansas Agricultural Experiment Station Research Reports, 7(5), p.26.

Munaro, L.B., Hefley, T.J., DeWolf, E., Haley, S., Fritz, A.K., Zhang, G., Haag, L.A., Schlegel, A.J., Edwards, J.T., Marburger, D. and Alderman, P., 2020. Exploring long-term variety performance trials to improve environment-specific genotype × management recommendations: A case-study for winter wheat. Field Crops Research, 255, p.107848.

Pinto, J.G., Pereira, C., Munaro, L.B., Jaenisch, B.R., Nagaoka, A.K. and Lollato, R.P., 2019. Wheat Variety Response to Seed Cleaning and Treatment after Fusarium Head Blight Infection. Agrosystems, Geosciences & Environment, 2(1).

Sciarresi, C., Patrignani, A., Soltani, A., Sinclair, T. and Lollato, R.P., 2019. Plant traits to increase winter wheat yield in semiarid and subhumid environments. Agronomy Journal, 111(4), pp.1728-1740.

Table 1. Average maximum (Tmax) and minimum (Tmin) temperatures, and cumulative precipitation, grass reference evapotranspiration (ETo) and the ratio of water supply (WS) to water demand (WD) during three portions of the growing season at the ten study locations during 2020–2021

Location*	Season	Tmax	Tmin	Precipitation	ETo	WS:WD
		°F	°F	inch	inch	
Ashland Bottoms	Fall	57.7	32.6	4.0	7.8	0.51
	Winter	47.1	25.0	4.5	6.9	0.65
	Spring	75.2	53.4	9.4	16.0	0.59
Belleville	Fall	56.1	30.0	1.1	8.0	0.14
	Winter	43.7	21.6	4.3	6.5	0.67
	Spring	74.9	50.4	5.5	17.2	0.32
Colby	Fall	56.8	27.2	0.9	9.9	0.09
	Winter	44.6	20.1	4.2	7.6	0.56
	Spring	73.0	46.9	7.5	18.4	0.41
Hutchinson	Fall	59.1	33.3	3.7	8.7	0.43
	Winter	48.2	25.2	6.2	7.3	0.85
	Spring	75.9	52.8	8.1	16.7	0.49
Manhattan	Fall	57.6	33.0	4.0	7.8	0.51
	Winter	46.5	25.0	4.6	6.8	0.68
	Spring	75.1	53.4	10.0	15.6	0.64
Mitchell	Fall	57.7	31.0	2.6	8.8	0.30
	Winter	44.6	20.1	4.7	7.2	0.65
	Spring	73.0	46.9	6.4	17.1	0.38
Leoti	Fall	61.2	29.4	0.1	10.8	0.01
	Winter	47.0	20.9	2.3	7.4	0.31
	Spring	74.8	47.5	8.7	9.6	0.90

*There were two fields near each of Ashland Bottoms, Belleville, and Colby.

Table 2. Effects of seeding rate, seed cleaning method and seed treatment on plant population and grain yield across 10 Kansas locations during the 2020–2021 winter wheat growing season

Factor	Description	Plant population	Grain yield
		(plants/a)	(bu/a)
Population	600,000 seeds/a	391,616 a	68.8 b
	900,000 seeds/a	491,596 b	70.9 ab
	1,200,000 seeds/a	556,771 c	72.5 a
Seed cleaning	None	480,467	69.9366
	Air	469,745	70.7739
	Table	489,772	71.6372
Seed treatment	None	467,778 b	69.8 b
	Treated	492,211 a	71.8 a
Test of fixed effects		Pr > |t|	Pr > |t|
	Seeding rate (R)	<.0001	0.0183
	Seed cleaning (C)	0.0873	0.108
	Seed treatment (T)	0.0004	0.0013
	R × C	0.3077	0.9665
	R × T	0.6755	0.6091
	C × T	0.5364	0.1896
	R × C × T	0.759	0.7919

Wheat Variety-Specific Response to Seeding Rate Under Intensive Management Conditions in Western Kansas in 2020–2021

R.P. Lollato, N. Giordano, L. Ryan, L.M. Simão, J.R. Soler, and L.O. Pradella

Summary
Wheat response to seeding rate is variable and depends on resource availability during the growing season (e.g., fertility, moisture, and temperature). Our objective was to evaluate winter wheat population and grain yield responses to seeding rate and its interaction with variety in a highly-managed production system where manageable stresses were limited. This study was established to evaluate the response of the wheat varieties Joe, WB-Grainfield, Langin, and LCS Revere to five seeding rates ranging from 200,000 to 1,000,000 seeds per acre. The site was managed by growers that consistently win state and national wheat yield contests near Leoti, KS. The trial was established on September 25, 2020, after a long summer fallow in sorghum residue, approximately 10 days after a 0.3-in. rainfall event, ensuring good stand establishment. The fall was dry, but spring conditions were favorable for high yields with cool temperatures and about 11 inches of precipitation. There were significant effects of seeding rate and variety on stand count, but the interaction was weak ($P = 0.12$). Main effects suggested that the stand count increased with increases in the seeding rate (from 252,265 to 521,347 plants per acre), with the 800,000 and 1,000,000 seeds/a rates attaining the highest stands. However, we note that final populations were closer to the target population at lower seeding rates as compared to higher seeding rates. Grain yield also depended primarily on variety and on seeding rate, with no interaction between both effects. Grain yield ranged between 97 and 101.3 bushels per acre for the seeding rates ranging between 600,000 and 1,000,000, and from 89.9 to 93.3 bu/a for lower seeding rates. Langin was the highest yielding variety (102 bu/a), followed by LCS Revere and WB-Grainfield (94.7–97.5 bu/a), and lastly by Joe (90.3 bu/a). These results suggest that wheat grain yield responses to seeding rate were not dependent on variety, with optimum seeding rates as low as 600,000 seeds/a. We note that increasing seeding rates beyond 600,000 seeds/a led to numerical but not statistical increases in yield.

Introduction
Wheat responses to seeding rate are inconsistent, ranging from quadratic to positive linear, quadratic-plateau, plateau-negative linear, and even inexistent (Jaenisch et al., 2019, 2022; Fischer et al., 2019; Lollato et al., 2019). The quadratic response suggests that there is an optimum population to optimize yields. In this case, populations below the optimum may limit crop yields due to sub-optimum stands, and populations above the optimum may limit crop yields due to increased disease pressure, insects, lodging, or insufficient resources such as fertility. Recently, some Kansas evidence suggested that wheat responses to seeding rate were dependent on the level of resource availability of the environment (Bastos et al., 2020). In high-yielding environments (greater than 90 bu/a) where the crop is not limited by resources (including fertility levels, and optimal temperatures and moisture for tillering), crop yield was unresponsive to plant

population. Similar results were derived from the Kansas Wheat Yield Contest (Lollato et al., 2019) and from studies with intensively managed wheat in Kansas (Jaenisch et al., 2019) and in Mexico (Fischer et al., 2019). Meanwhile, in average (65 bu/a average) and low (45 bu/a average) yielding environments, wheat responded to increases in plant population up until about 25 to 31 plants per square feet (approximately 1.1 to 1.35 million plants/a), leveling out at greater populations (Bastos et al., 2020). The optimum plant population might also depend on the variety's tillering potential (Bastos et al., 2020), as varieties with greater tillering potential might require less population to maximize yields when compared to varieties with lower tillering potential (Jaenisch et al., 2022).

The majority of the studies evaluating wheat yield response to seeding rate were performed under standard management conditions, not excessively high fertility levels, or other management factors (e.g., Whaley et al., 2000; Lloveras et al, 2004; Bastos et al., 2020). Thus, in this study we aimed to understand wheat response to seeding rate in a scenario with highly available resources. This is relevant in a context in which the increases in food production are needed to feed an increasing global population, especially in regions characterized by actual yields well below the potential yields, such as in Kansas and neighboring states (Jaenisch et al., 2021; Lollato and Edwards, 2015; Lollato et al., 2017; 2019; Patrignani et al., 2014). Since resource availability and variety-specific tillering capacity seem to govern wheat yield response to plant population, our objective was to evaluate the grain yield response of different winter wheat varieties to seeding rate, including extremely low seeding rates, in a highly-managed commercial field in western Kansas.

Procedures

A field experiment was conducted during the 2020–2021 winter wheat growing season in a commercial wheat field near Leoti, KS. The research plots comprised of seven 7.5-in. spaced rows wide and were 30-ft long. A two-way factorial treatment structure was established in a completely randomized block design and included four commercial wheat varieties (i.e., Joe, Langin, WB-Grainfield, and LCS Revere) and five seeding rates (200,000, 400,000, 600,000, 800,000, and 1,000,000 seeds/a). All seeds were treated with insecticide and fungicide seed treatment to avoid potential stand losses due to pests (Pinto et al., 2020). The experiments were planted on September 25, 2020, after a long summer fallow in sorghum residue; wheat was the second crop after manure application (5 tons per acre, providing about 150 pounds of N and P). In-furrow diammonium phosphate was applied with the seed at 50 pounds of product per acre. Management of the field consisted of 40 pounds of N per acre, with 3.5 ounces per acre Rave herbicide in February, 180 pounds of N per acre as urea on March 10, and 13 ounces per acre of Nexicor fungicide at heading. Combined with the soil fertility available at sowing, all the manageable stresses were likely reduced. Harvest occurred using a Massey Ferguson XP8 small-plot, self-propelled combine.

A total of 15 individual soil cores (0- to 24-in. depth) were collected from each location and divided into 0- to 6-in. and 6- to 24-in. increments for initial fertility analysis. The individual cores were mixed to form one composite sample, which was later analyzed for base fertility levels (Table 1). In-season measurements included stand count (measured about 20–30 days after sowing) and grain yield at harvest maturity (corrected for 13%

moisture content). Statistical analysis of the data collected in this experiment was performed using a two-way ANOVA in PROC GLIMMIX procedure in SAS v. 9.4. Non-linear regression analyses was used to test the grain yield response to plant population, and the residuals from this relationship were subjected to ANOVA to test the effect of wheat variety.

Results

Weather Conditions

The 2020–2021 growing season was dry in the fall (0.4 inch precipitation) and winter (2.3 inch precipitation), with water supply only representing 1 and 31% of crop water demand. The spring, however, had 8.7 inches of precipitation that represented 90% of crop water demand (Table 1). This, together with mild temperatures, ensured high yielding conditions in the experiment location. These mild spring conditions are not typical of the study region, which is usually characterized by high likelihood of water and temperature stresses (Couedel et al., 2021; Lollato et al., 2020; Sciarresi et al., 2019).

Seeding Rate and Variety Effects on Stand Establishment and Grain Yield

There was a significant seeding rate effect on final stand establishment (Table 3). Overall, increases in seeding rate resulted in greater stand count, as expected. However, we note that final populations were closer to the target population at lower seeding rates as compared to higher seeding rates. For instance, the target population of 200,000 plants/a resulted in 252,265 plants/a; while the target of 1,000,000 plants/a resulted in 521,347 plants/a. This is usually observed in seeding rate studies (Bastos et al., 2020). There was also a variety effect on final stand establishment, where Joe resulted in more plants per acre than Langin or WB-Grainfield, and LCS Revere had statistically the same population as all other varieties (Table 3).

Grain yield was affected by seeding rate and by variety independently, with no variety × seeding rate interaction, suggesting that varieties responded similarly to seeding rate (Table 3). Overall, there was a linear-plateau grain yield response to seeding rate, increasing from 89.9 bu/a in the 200,000 seeds/a rate, to anywhere from 97 to 101.3 bu/a in the seeding rates ranging from 600,000 to 1,000,000 seeds/a, with no significant statistical differences among the higher seeding rates. The variety Langin had the highest grain yield (102.1 bu/a), followed by LCS Revere and WB-Grainfield (94.7 to 97.5 bu/a), and finally Joe had the lowest grain yield (90.3 bu/a).

The overall relationship between plant population and grain yield is shown in Figure 1a. Grain yield showed a quadratic relationship as a function of plant population, with the highest yields visually observed between the populations of 300,000 and 550,000 plants/a. Analysis of the residuals of this relationship as affected by wheat variety indicated a significant variety effect (Figure 1b). This analysis evaluates the effect of variety on grain yield when the effect of plant population is accounted for. LCS Revere out-yielded the expected yield for a given population by 8.3 bu/a, while WB-Grainfield and Langin were 0.7 to 3.7 bu/a from the expected yield for a given population. Joe yielded 4.3 bu/a less at a given population than the yield that would be expected for that population level.

Preliminary Conclusions

This trial provided information on wheat response to seeding rate within a highly managed scenario, during a dry growing season. At yield levels ranging between 90 and 102 bu/a, wheat response to seeding rate was independent of variety, and yield maximized at 600,000 seeds/a. Yield increases reported for seeding rates beyond 600,000 seeds/a were not statistically significant.

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References

Bastos, L.M., Carciochi, W., Lollato, R.P., Jaenisch, B.R., Rezende, C.R., Schwalbert, R., Vara Prasad, P.V., Zhang, G., Fritz, A.K., Foster, C. and Wright, Y., 2020. Winter wheat yield response to plant density as a function of yield environment and tillering potential: A review and field studies. Frontiers in Plant Science, 11, p.54.

Couëdel, A., Edreira, J.I.R., Lollato, R.P., Archontoulis, S., Sadras, V. and Grassini, P., 2021. Assessing environment types for maize, soybean, and wheat in the United States as determined by spatio-temporal variation in drought and heat stress. Agricultural and Forest Meteorology, 307, p.108513.

Fischer, R.A., Ramos, O.M., Monasterio, I.O. and Sayre, K.D., 2019. Yield response to plant density, row spacing and raised beds in low latitude spring wheat with ample soil resources: an update. Field crops research, 232, pp.95-105.

Jaenisch, B.R., de Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant population and fungicide economically reduced winter wheat yield gap in Kansas. Agronomy Journal, 111(2), pp.650-665.

Jaenisch, B.R., Munaro, L.B., Bastos, L.M., Moraes, M., Lin, X. and Lollato, R.P., 2021. On-farm data-rich analysis explains yield and quantifies yield gaps of winter wheat in the US central Great Plains. Field Crops Research, 272. Article No. 108287.

Jaenisch, B.R., L.B. Munaro, K.S. Jagadish, and R.P. Lollato. 2022. Modulation of wheat yield components in response to management intensification to reduce yield gaps. Frontiers in Plant Science. 13:772232. https://doi.org/10.3389/fpls.2022.772232.

Lollato, R.P. and Edwards, J.T., 2015. Maximum attainable wheat yield and resource-use efficiency in the southern Great Plains. Crop Science, 55(6), pp.2863-2876.

Lollato, R.P., Edwards, J.T. and Ochsner, T.E., 2017. Meteorological limits to winter wheat productivity in the US southern Great Plains. Field Crops Research, 203, pp.212-226.

Lollato, R.P., Ruiz Diaz, D.A., DeWolf, E., Knapp, M., Peterson, D.E. and Fritz, A.K., 2019. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Science, 59(1), pp.333-350.

Lollato, R.P., Bavia, G.P., Perin, V., Knapp, M., Santos, E.A., Patrignani, A. and DeWolf, E.D., 2020. Climate-risk assessment for winter wheat using long-term weather data. Agronomy Journal, 112(3), pp.2132-2151.

Patrignani, A., Lollato, R.P., Ochsner, T.E., Godsey, C.B. and Edwards, J.T., 2014. Yield gap and production gap of rainfed winter wheat in the southern Great Plains. Agronomy Journal, 106(4), pp.1329-1339.

Pinto, J.G.C.P., Munaro, L.B., Jaenisch, B.R., Nagaoka, A.K. and Lollato, R.P., 2019. Wheat Variety Response to Seed Cleaning and Treatment after Fusarium Head Blight Infection. Agrosystems, Geosciences & Environment, 2(1), pp.1-8.

Sciarresi, C., Patrignani, A., Soltani, A., Sinclair, T. and Lollato, R.P., 2019. Plant traits to increase winter wheat yield in semiarid and subhumid environments. Agronomy Journal, 111(4), pp.1728-1740.

Table 1. Initial soil fertility measured at wheat sowing during the 2020-2021 growing season for the trial conducted near Leoti, KS

Depth	pH	NO_3-N	P-M	K	Ca	Mg	S	OM %	CECS meq/ 100 g	Sand %	Silt %	Clay %
inch		----------------------------	----------------------------	----------------------------	ppm	----------------------------	----------------------------					
0–6	6.8	16.2	118.6	793.2	2,497.2	324.5	7.1	2.1	20.88	18.00	54.00	28.00
6–24	7.0	12.5	40.2	716.8	2,858.4	497.9	6.3	1.9	22.81	16.00	48.00	36.00

Variables include, respectively, soil pH, nitrate-N, Mehlich phosphorus, potassium, calcium, magnesium, sulfur, organic matter, cation exchange capacity, and soil texture (sand, silt, and clay percent).

Table 2. Weather conditions including average maximum (Tmax) and minimum (Tmin) air temperatures, and cumulative precipitation and reference evapotranspiration (ETo) near Leoti, KS, during the 2020–2021 growing season

Season*	Tmax	Tmin	Precipitation	ETo	WS:WD**
	°F	°F	inch	inch	
Fall	61.2	29.4	0.1	10.8	0.01
Winter	47.0	20.9	2.3	7.4	0.31
Spring	74.8	47.5	8.7	9.6	0.90

*Fall: October 1 - December 31. Winter: January 1 - March 31. Spring: April 1 - June 30.
**Water supply (WS) to water deficit (WD) ratio.

Table 3. Stand count and grain yield of four winter wheat varieties (WB-Grainfield, Joe, LCS Revere, and Langin) as affected by seeding rate ranging from 200,000 to 1,000,000 seeds/a

Factor	Description	Plant population		Grain yield	
		(plants/a)		(bu/a)	
Seeding rate	200,000	252265	d*	89.9	c
(seeds/a)	400,000	358482	c	93.3	bc
	600,000	411590	b	99.3	a
	800,000	488597	a	101.3	a
	1,000,000	521347	a	97	ab
Variety	WB-Grainfield	400791	b	94.7	b
	Joe	439738	a	90.3	c
	LCS Revere	405748	ab	97.5	b
	Langin	379548	b	102.1	a
Test of fixed effects	SRATE	<.0001		0.0002	
	VAR	0.0267		<.0001	
	SRATE × VAR	0.1287		0.8956	

SRATE = seeding rate. VAR = variety.
*Significance of fixed effects resulting from the ANOVA as well as post-hoc mean grouping. Means followed by the same letter are not significantly different at $P = 0.05$.

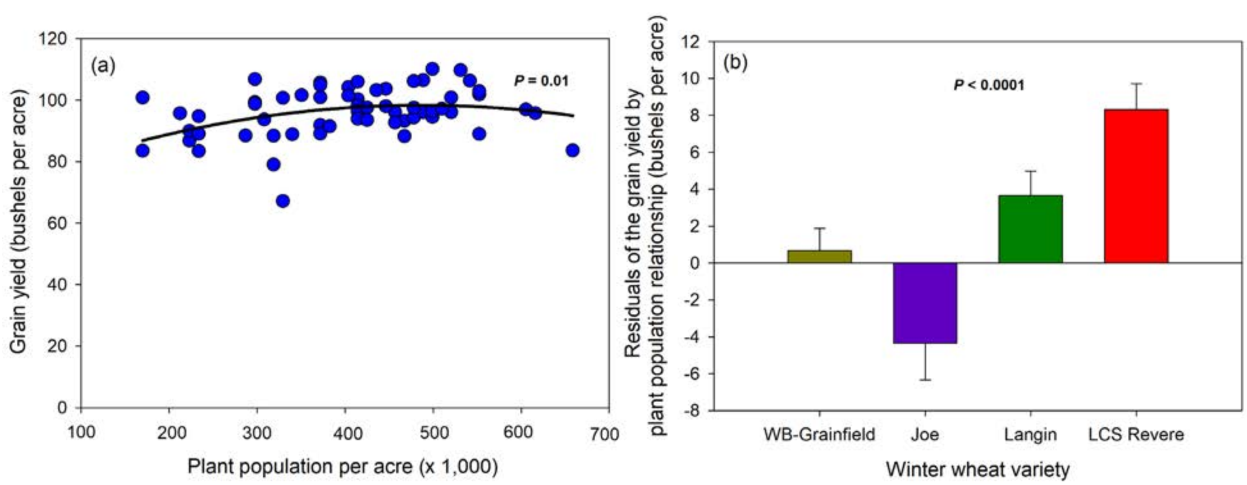

Figure 1. (A) Winter wheat grain yield as function of plant population across all varieties and seeding rates evaluated, and (B) analysis of variance of the residuals of the relationship of grain yield by plant population as affected by winter wheat variety. Data represents one location near Leoti, KS, during the 2020–2021 growing season.

Winter Wheat Variety Response to Timing and Number of Fungicide Applications During the 2020–2021 Growing Season in Kansas

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Summary

The objective of this project was to evaluate the yield response of different winter wheat varieties to different fungicide management treatments during the 2020–2021 growing season in Kansas. Fourteen varieties were evaluated under four fungicide treatments (no fungicide, application either at jointing, heading, or at both stages) in four locations across Kansas in a split-plot design. Disease incidence was assessed approximately 20 d after each fungicide application. Septoria blotch and tan spot were the most prevalent early-season diseases at the studied fields, while stripe rust, leaf rust, and tan spot prevailed later in the season. While varieties responded differently to fungicide management and there was a range in yield response across locations, there was an overall yield increase of 4.2 bushels per acre resulting from the jointing fungicide application; 10.3 bu/a from the heading fungicide; and 9.9 bu/a from the combination of both applications. Although there were some similarities, the ranking of the highest yielding varieties was not uniform across locations. While different reactions occurred regarding the response of the varieties to fungicide management, overall susceptible varieties had a greater response to fungicide management compared to varieties with intermediate or high levels of genetic resistance. Our preliminary data suggest that the application of fungicide to winter wheat in Kansas might be advantageous, but the degree of this benefit will depend upon the environment, variety, and level of disease incidence.

Introduction

Average wheat yields in Kansas have been relatively low (~45–50 bu/a) and well below the long-term dryland yield potential of ~70–75 bu/a in the region (Lollato et al., 2017, 2019). Recent studies indicated that nitrogen and fungicide management are the two main factors contributing to the difference between the current and potential dryland winter wheat yields in this region (Jaenisch et al., 2019, 2021, 2022; de Oliveira Silva et al., 2020; Munaro et al., 2020), although the response to fungicides depends on environmental conditions (Cruppe et al., 2017, 2021). Fungal diseases have been among the leading causes of yield losses in Kansas; still, only about 22% of the wheat grown in the region is protected by foliar fungicides (USDA-NASS, 2020). Foliar fungicide often provides control of the most common leaf fungal diseases (especially with susceptible genotypes or under high yielding environments). But the economic return and yield gain of foliar fungicides are inconsistent, depending on environmental conditions. The environment for winter wheat in Kansas is often characterized by re-occurring heat and drought stresses (Couedel et al., 2021; Lollato et al., 2020; Sciarresi et al., 2019), which partially explains the conservative behavior of Kansas wheat producers. Given

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the importance of fungicides in protecting the yield potential of the crop, our objectives were to evaluate the yield response of different winter wheat varieties to fungicide timing and the number of applications in a range of environmental conditions.

Procedures

Four rainfed field experiments were established during the 2020–2021 winter wheat growing season in different locations in Kansas: Two experiments were established in Ashland Bottoms sown under different soil conditions (Ashland Bottoms A = Belvue silt loam and Ashland Bottoms B = Bismarckgrove silt loam), one experiment was established near Belleville, and another near Hutchinson. All experiments were sown using no-tillage practices and following a previous soybean crop. Experiments were sown using a commercial no-till drill (Great Plains 606-NT drill) at a seeding rate of 2.5 million seeds per acre. Initial soil fertilizer was applied according to soil fertility analyses, and spring nitrogen management was adjusted according to a yield goal of 75 bu/a at all locations. Weeds and insects were controlled as needed.

Treatments, Experimental Design, and Disease Evaluation

Fourteen commercially available varieties were evaluated under four different fungicide management strategies. Fungicide treatments consisted of (1) a no fungicide control, or 5 ounces per acre of Topguard [1-(2-fluorophenyl)-1-(4-fluorophenyl)-2-(1H-1,2,4-triazol-1-yl) ethanol] applied at (2) jointing (Feekes GS6), (3) heading (Feekes GS10), and (4) both GS6 and GS10. Varieties were selected based on their different levels of genetic resistance to the most common fungal diseases in Kansas. Treatments were arranged in a split-plot design with fungicide treatment assigned to the main plots and varieties to the subplots. Main plots were arranged in a randomized complete block design with three to four replications. Disease incidence and severity of the major diseases that occurred naturally were individually assessed approximately 20 d after each fungicide application based on a 1 to 9 scale, where 1 is highly resistant and 9 is highly susceptible (Bockus et al., 2007). Grain weight and moisture content were measured at harvest maturity using a Massey Ferguson 8XP self-propelled small-plot combine and yields were corrected to 13% moisture.

Statistical Analyses

Disease and yield data were analyzed through a three-way analysis of variance (ANOVA) using the GLIMMIX procedure on SAS v. 9.4 (SAS Institute Inc., Cary, NC) and the PDIFF statement for comparisons between least square means. The effects of environment, variety, fungicide management, and their interaction were treated as fixed effects, and block nested within environment and its interaction with fungicide management were treated as random effects.

Results

Weather Conditions and Prevalent Diseases in the Studied Fields

The 2020–2021 wheat growing season was characterized by adequate precipitation amounts and distribution which, combined with colder temperatures during spring, contributed to satisfactory wheat yields in most locations. The average maximum and minimum temperatures were similar for Ashland Bottoms (average Tmax = 59.4°F and Tmin = 37.4°F) and Hutchinson (average Tmax = 59.9°F and Tmin = 37.8°F), but were lower in Belleville (average Tmax = 57.3°F and Tmin = 33.5°F) (Table 1). The same pattern occurred for precipitation, where Ashland Bottoms and Hutchinson had 17.9 and 17.5 inches of rain, respectively, and Belleville had the lowest precipitation amount (10.9 inches) (Table 1).

Disease incidence was grouped into early (i.e. disease assessment conducted 20 d after the jointing fungicide application) and late season diseases (i.e. disease assessment conducted 20 d after the heading fungicide application). Belleville and Ashland A (Belvue silt loam) had the lowest averages for early season disease incidence, while Ashland B (Bismarckgrove silt loam) and Hutchinson had intermediate levels of disease incidence. In the first assessment, septoria tritici blotch (STB) was the most prevalent disease in all four locations, followed by stripe rust in three and tan spot in one location. Hutchinson, Belleville, and Ashland A had similar levels of late season disease incidence, while levels were significant lower in Ashland B, with stripe rust being the most prevalent disease in three out four locations, and leaf rust in one location (Ashland B).

Variety × Fungicide × Environment Interactions

There was a significant interaction between variety, fungicide management, and environment, indicating that variety response to fungicide management depended on environment. In Ashland Bottoms A (Table 2) and in Hutchinson (Table 3), there was an increase in yield benefit when comparing the dual and the single application (either at heading or jointing) to the control, with greater differences with applications later in the season. Specifically, there was a yield difference of 12.1 bu/a from the dual application, 9.1 bu/a from the heading application, and 6.9 bu/a from the jointing application when compared to the control in Ashland Bottoms A. These differences were 14.4 bu/a, 13.2 bu/a, and 3.2 bu/a when doing the same comparisons in Hutchinson. In Ashland A and in Hutchinson, the majority of the grain yields falling into the highest yielding group were varieties that received either fungicide at heading or the dual fungicide treatment. In Belleville (Table 2), the greatest response was when the foliar fungicide was applied at jointing (4.5 bu/a difference), followed by the dual application (2.6 bu/a). In Ashland Bottoms B (Table 2), the greatest yield benefit was derived from the heading application (17.4 bu/a), followed by the dual application (10.5 bu/a). Bob Dole was the highest yielding variety in all locations. Larry, WB4303, and WB-Grainfield were in the highest yielding group in Belleville at different fungicide management strategies. Tatanka, WB4269, WB4303, and WB-Grainfield were in the highest yielding group in Ashland B. In Hutchinson, virtually all varieties were in the highest yielding group when a fungicide was applied at heading or as dual fungicide.

Different reactions were observed regarding the response of the varieties to fungicide management. The ranking of varieties with the greatest response to the dual and to the heading application was similar in both experiments in Ashland Bottoms (WB-Grainfield, WB4458, WB4303, and SY Monument) (Table 2). The same pattern was observed for the varieties with the lowest response to fungicide management in these experiments (Bob Dole, Zenda, LCS Chrome, Green Hammer, and Double Stop). No patterns were observed for Belleville or Hutchinson (Table 3). With a few exceptions, varieties with low levels of resistance to the most prevalent diseases had the greatest yield benefit from either one or the dual fungicide application.

Preliminary Conclusions

The effect of foliar fungicide was neither uniform across environments nor across varieties. However, our data suggest that wheat with the application of fungicide usually out-yielded the non-fungicide control, but the degree of this benefit was dependent upon the environment, on the varieties evaluated (resistant vs. susceptible varieties), and the level of disease incidence in the field.

References

Bockus, W. W., Su, Z., Garrett, K. A., Gill, B. S., Stack, J. P., Fritz, A. K., Roozeboom, K. L. & Martin, T. J. (2007). Number of experiments needed to determine wheat disease phenotypes for four wheat diseases. Plant disease, 91(1), 103-108.

Couëdel, A., Edreira, J.I.R., Lollato, R.P., Archontoulis, S., Sadras, V. and Grassini, P., 2021. Assessing environment types for maize, soybean, and wheat in the United States as determined by spatio-temporal variation in drought and heat stress. Agricultural and Forest Meteorology, 307, p.108513.

Cruppe, G., Edwards, J.T. and Lollato, R.P., 2017. In-season canopy reflectance can aid fungicide and late-season nitrogen decisions on winter wheat. Agronomy Journal, 109(5), pp. 2072-2086.

Cruppe, G., DeWolf, E., Jaenisch, B.R., Onofre, K.A., Valent, B., Fritz, A.K. and Lollato, R.P., 2021. Experimental and producer-reported data quantify the value of foliar fungicide to winter wheat and its dependency on genotype and environment in the US central Great Plains. Field Crops Research, 273, p.108300.

de Oliveira Silva, A., Slafer, G.A., Fritz, A.K. and Lollato, R.P., 2020. Physiological basis of genotypic response to management in dryland wheat. Frontiers in plant science, 10, p. 1644.

Jaenisch, B.R., de Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant population and fungicide economically reduced winter wheat yield gap in Kansas. Agronomy Journal, 111(2), pp. 650-665.

Jaenisch, B.R., Munaro, L.B., Bastos, L.M., Moraes, M., Lin, X. and Lollato, R.P., 2021. On-farm data-rich analysis explains yield and quantifies yield gaps of winter wheat in the US central Great Plains. Field Crops Research, 272, p.108287.

Jaenisch, B.R., L.B. Munaro, S.V. Krishna Jagadish, and R.P. Lollato. 2022. Modulation of wheat yield components to management intensification to reduce yield gaps. Frontiers in Plant Science 13:772232. https://doi.org/10.3389/fpls.2022.772232.

Lollato, R. P., Edwards, J. T., Ochsner, T. E. (2017). Meteorological limits to winter wheat productivity in the U.S. southern Great Plains. Field Crops Res. 203, 212–226. doi: 10.1016/j.fcr.2016.12.014.

Lollato, R. P., Ruiz Diaz, D. A., DeWolf, E., Knapp, M., Peterson, D. E., Fritz, A. K. (2019b). Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Sci. 59, 333–350. doi: 10.2135/cropsci2018.04.0249.

Lollato, R.P., Bavia, G.P., Perin, V., Knapp, M., Santos, E.A., Patrignani, A. and DeWolf, E.D., 2020. Climate-risk assessment for winter wheat using long-term weather data. Agronomy Journal, 112(3), pp.2132-2151.

Munaro, L.B., Hefley, T.J., DeWolf, E., Haley, S., Fritz, A.K., Zhang, G., Haag, L.A., Schlegel, A.J., Edwards, J.T., Marburger, D. and Alderman, P., and R.P. Lollato. 2020. Exploring long-term variety performance trials to improve environment-specific genotype × management recommendations: A case-study for winter wheat. Field Crops Research, 255, p. 107848.

Sciarresi, C., Patrignani, A., Soltani, A., Sinclair, T. and Lollato, R.P., 2019. Plant traits to increase winter wheat yield in semiarid and subhumid environments. Agronomy Journal, 111(4), pp.1728-1740.

USDA-NASS. (2020). 2019 Agricultural chemical use survey wheat. 2018-5, 1–2. Available at: *https://bit.ly/3r309oC*.

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Table 1. Average maximum (Tmax) and minimum (Tmin) temperatures and precipitation during the 2020–2021 wheat growing season for the four studied sites in Kansas

Location	Tmax	Tmin	Precipitation
	--------------------------- °F	---------------------------	in.
Ashland Bottoms*	59.4	37.4	17.9
Belleville	57.3	33.5	10.9
Hutchinson	59.9	37.8	17.5
Average	58.9	36.3	15.4
Max	59.9	37.8	17.9
Min	57.3	33.5	10.9

*There were two field experiments conducted near Ashland Bottoms.

Table 2. Wheat grain yield as affected by fungicide management and variety in the two experiments conducted in Ashland Bottoms (A = Belvue silt loam and B = Bismarckgrove silt loam) in Kansas during the winter wheat season of 2020–2021

	Ashland Bottoms A				Ashland Bottoms B			
Variety	Control	Jointing	Heading	Dual	Control	Jointing	Heading	Dual
	---------- Grain yield (bu/a) ----------							
Bentley	53.6	60.1	73.0	**79.1***	49.2	49.9	68.3	60.0
Bob Dole	73.3	**80.2**	**79.0**	**78.8**	62.0	60.9	**77.2**	65.1
DoubleStop	70.7	70.6	66.1	67.4	58.8	58.9	67.2	61.4
Everest	51.8	62.2	61.2	70.4	50.9	53.1	65.5	58.5
Green Hammer	72.0	**74.6**	71.6	72.5	55.5	57.7	55.7	58.4
Larry	71.9	**77.8**	79.2	**80.8**	56.0	57.3	67.0	65.8
LCS Chrome	63.4	67.4	67.4	68.2	59.0	60.4	**69.8**	62.7
SY Monument	48.7	58.3	70.1	69.5	46.7	48.8	68.9	64.3
Tatanka	69.0	**78.1**	**79.9**	**78.7**	59.4	63.3	**77.2**	**69.3**
WB4269	62.6	70.8	71.9	**74.7**	52.4	57.1	**75.8**	65.9
WB4303	55.7	67.1	70.5	**75.4**	48.2	54.9	**73.9**	**69.5**
WB4458	55.5	62.7	67.8	**75.5**	43.6	45.3	61.3	63.0
WB-Grainfield	57.2	66.2	68.8	**78.2**	52.1	56.1	**74.2**	**69.6**
Zenda	63.5	69.1	69.3	68.9	54.6	54.7	69.1	61.9

*Values in bold belong to the highest yielding group.

Table 3. Wheat grain yield as affected by fungicide management and variety in Belleville and Hutchinson in Kansas during the winter wheat season of 2020–2021

	Belleville				Hutchinson			
Variety	Control	Jointing	Heading	Dual	Control	Jointing	Heading	Dual
	---------- Grain yield (bu/a) ----------							
Bentley	69.4	71.6	70.5	72	56.3	61	**76.4**	**74.7**
Bob Dole	71.8	**73.7**	71.7	68.7	70.2	70.2	**81.5**	**82.4**
DoubleStop	61.3	65.3	58.3	61.6	70	68.4	70.3	**76.6**
Everest	61	69.4	62.7	65.1	58.2	61.6	**73.9**	**77.2**
Green Hammer	66.7	69.4	62.6	67.1	65.5	63.8	**72.3**	**72**
Larry	69.7	**73.7**	**72.4**	**74.1**	60.6	67.6	**71.3**	**77.7**
LCS Chrome	65.6	67.5	63.6	65.6	58.4	63.2	70.2	**71.4**
SY Monument	64.5	71.3	70.4	67.8	57.7	63.9	**72.1**	66.3
Tatanka	69.2	68	71.7	71.4	63.9	**71.4**	**75.4**	**80.6**
WB4269	64.3	71	68.1	64.2	61	66.6	**74.8**	**76**
WB4303	65.6	**74**	71.1	**79.1**	61.8	65.7	**80.1**	**82**
WB4458	59.6	64.5	63.4	63.8	57.1	56.1	77	**75.9**
WB-Grainfield	65.9	**74.2**	**74.1**	72.1	54.4	59.9	**76**	74.7
Zenda	58.3	62.2	55.8	56.9	63.4	64	**71.7**	**72.6**

*Values in bold belong to the highest yielding group.

Fall-Planted Cover Crops for Weed Suppression in Western Kansas

S. Dhanda, V. Kumar, A.K. Obour, A. Dille, and J.D. Holman

Summary

The widespread evolution of herbicide-resistant (HR) kochia and Palmer amaranth warrants the use of alternative ecological-based strategies for weed management in no-tillage (NT) dryland cropping systems in western Kansas. A field study was established in the fall of 2020 at Kansas State University Agricultural Research Center near Hays, KS, to determine the impact of fall-planted cover crop (CC) mixture on 1) kochia and Palmer amaranth suppression (density and biomass reduction), and 2) Palmer amaranth emergence dynamics in subsequent grain sorghum. A CC mixture of winter triticale, winter pea, radish, and rapeseed was planted in wheat stubble in the fall of 2020. The CC mixture was terminated at triticale heading stage on May 26, 2021 by using 1) Roundup PowerMax (glyphosate) at 32 fl oz/a, and 2) Roundup PowerMax at 32 fl oz/a + Degree Xtra (premix of acetochlor + atrazine) at 2.2 quart/a. A chemical fallow treatment (without CC) was included for comparison. The study site was planted with grain sorghum hybrid 'DKS 38-16' on June 10, 2021. The CC mixture produced an average of 1360 lb/a aboveground biomass at the time of termination. The CC terminated with Roundup PowerMax + Degree Xtra had 98 and 95% less total weed density at 0 and 30 days after termination (DAT), respectively, compared to chemical fallow. No difference in weed density was observed at later evaluations. At grain sorghum harvest, CC terminated with Roundup PowerMax and Roundup PowerMax + Degree Xtra reduced total weed biomass by 61% and 73%, respectively, compared to chemical fallow. The time taken to reach 10, 50, and 90% cumulative emergence of Palmer amaranth was delayed by 9, 15, and 21 days, respectively, in CC terminated with Roundup PowerMax and 11, 39, and 128 days, respectively, in CC terminated with Roundup PowerMax + Degree Xtra when compared with chemical fallow. Grain sorghum yield did not differ between CC and chemical fallow treatments. These results suggest that a fall-planted CC mixture can play an important role for kochia and Palmer amaranth suppression in NT dryland crop production in western Kansas.

Introduction

Weed management is crucial during fallow periods in NT dryland wheat-sorghum-fallow (WSF) rotations in western Kansas. Fallow periods in this 3-year crop rotation stretch from wheat harvest to sorghum planting and from sorghum harvest to wheat planting. Evolution of HR weed species such as kochia [*Bassia scoparia* (L.) A. J. Scot] and Palmer amaranth (*Amaranthus palmeri* S. Watson) further poses a serious challenge for weed management (Heap 2022). This shows the need for developing alternative, ecological-based weed management strategies. Cover crop use is being widely promoted primarily because of several benefits, including weed suppression, improved soil health, and enhanced precipitation use efficiency (Kumar et al., 2020). However, in the semiarid environments such as western Kansas, soil moisture is the most limiting factor and growing CC under such conditions is questionable (Holman et al., 2018, 2021). To explore alternative uses of CC for weed suppression in dryland conditions, a CC study was established in the fall of 2020 at Kansas State University Agricultural Research Center near Hays, KS. The main objectives of this study were to determine the impact of fall-planted CC mixture replacing fallow period after wheat harvest in WSF rotation terminated with Roundup PowerMax (glyphosate) or Roundup PowerMax + Degree Xtra (commercial premix of acetochlor + atrazine) on (1) weed density and biomass suppression, and (2) Palmer amaranth emergence dynamics in grain sorghum.

Procedures

The study site was under WSF rotation for >10 years and had a natural seedbank of Palmer amaranth and glyphosate-and dicamba-resistant kochia. A CC mixture (60 lb/a) of winter triticale (60%) + winter peas (30%) + radish (5%) + rapeseed (5%) was planted in wheat stubble on September 20, 2020. The study was set up in a randomized complete block design with three treatments and four replications. The plots were 145-ft by 43-ft in size. The treatments consisted of chemical fallow (without CC and weeds were controlled with herbicides), CC terminated with Roundup PowerMax (32 fl oz/a), and CC terminated with Roundup PowerMax (32 fl oz/a) + Degree Xtra (2.2 quart/a). The CC was terminated at triticale heading stage on May 26, 2021, using Roundup PowerMax alone and Roundup PowerMax + Degree Xtra. Chemical fallow plot was cleaned with Gramoxone (32 fl oz/a) + Degree Xtra (2.2 quart/a) at the time of sorghum planting. Sorghum hybrid 'DKS 38-16' was planted on June 10, 2021, at 43,500 plants/a. Urea ammonium nitrate (UAN) was applied at planting at 20 gal/a. Total weed density and biomass were recorded at 0, 30, 60, 80, and 140 days after CC termination (DAT) using two quadrats (10 ft^2 each) randomly placed in the center of each plot. Palmer amaranth emergence was monitored at weekly intervals by counting and removing emerged seedlings using two permanent quadrats (10 ft^2 each) from each plot. Sorghum was harvested on November 4, 2021 and grain yield was recorded. Data were subjected to ANOVA using PROC mixed in SAS v. 9.3 software (SAS Inst. Inc., Cary, NC). Means were separated using Fisher's protected LSD test at $P < 0.05$. Cumulative emergence of Palmer amaranth was fitted using the drc package in R software using the following equation (Knezevic et al., 2007):

$$Y = \{100/1 + \exp\,[b(\log X + \log T_{50})]\}$$

where, Y refers to the percent cumulative emergence, X is the number of days, T_{50} is the days required to reach 50% cumulative emergence, and b is the slope of each curve.

Results

The CC at termination had an average biomass of 1360 lb/a. Results suggested that CC treatments significantly reduced total weed density compared to chemical fallow at 0 and 30 DAT; however, no differences were observed at later sampling times (Figure 1). The CC terminated with Roundup PowerMax and Roundup PowerMax + Degree Xtra had 50 and 65% lesser weed biomass at 80 DAT, respectively, compared to chemical fallow (Figure 2 and 3). At sorghum harvest, weed biomass was 61 and 73% less in CC treatments terminated with Roundup PowerMax and Roundup PowerMax + Degree Xtra, respectively, compared to chemical fallow. The time taken to reach 10, 50, and 90% cumulative emergence of Palmer amaranth was delayed by 9, 15, and 21 days, respectively, in CC terminated with Roundup PowerMax and 11, 39, and 128 days, respectively, in CC terminated with Roundup PowerMax + Degree Xtra as compared to chemical fallow (Figure 4). Sorghum grain yield did not differ among treatments with an average yield of 27 bu/a, most likely due to limited growing season precipitation.

Conclusions

Results indicate that replacing fallow period with fall-planted CC mixture and terminated with combination of Roundup PowerMax and residual herbicides can provide effective weed suppression (density, biomass) in subsequent NT dryland grain sorghum.

References

Heap I (2022) The International Herbicide-Resistant Weed Database. *http://www.weedscience.org.* Accessed: February 14, 2022.

Holman J, Arnet K, Dille A, Maxwell S, Obour A, Roberts T, Roozeboom K, Schlegel A (2018) Can cover (or forage) crops replace fallow in the semiarid Central Great Plains? Crop Sci 58:932-944.

Holman J, Obour A, Assefa Y (2021) Fallow replacement cover crops in a semi-arid High Plains cropping system. Crop Sci 61:3799-3814.

Knezevic SZ, Streibig JC, Ritz C (2007) Utilizing R software package for dose-response studies: the concept and data analysis. Weed Technol 21:840-848.

Kumar V, Obour A, Jha P, Liu R, Manuchehri MR, Dille JA, Holman J, Stahlman PW (2020) Integrating cover crops for weed management in the semiarid US Great Plains: opportunities and challenges. Weed Sci 68:311-323.

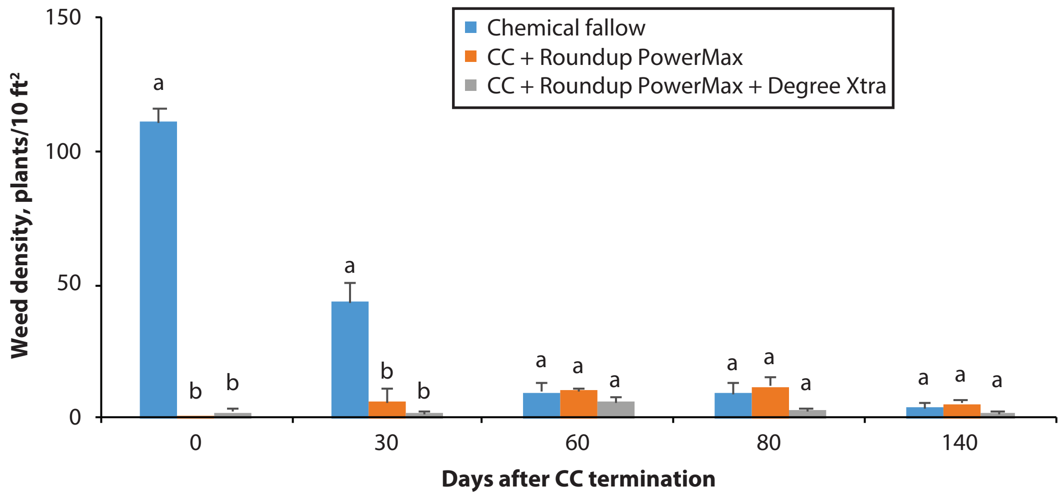


Figure 1. Total weed density among treatments. Means with the same letter are not significantly different (P < 0.05) among treatments within days after cover crop (CC) termination.

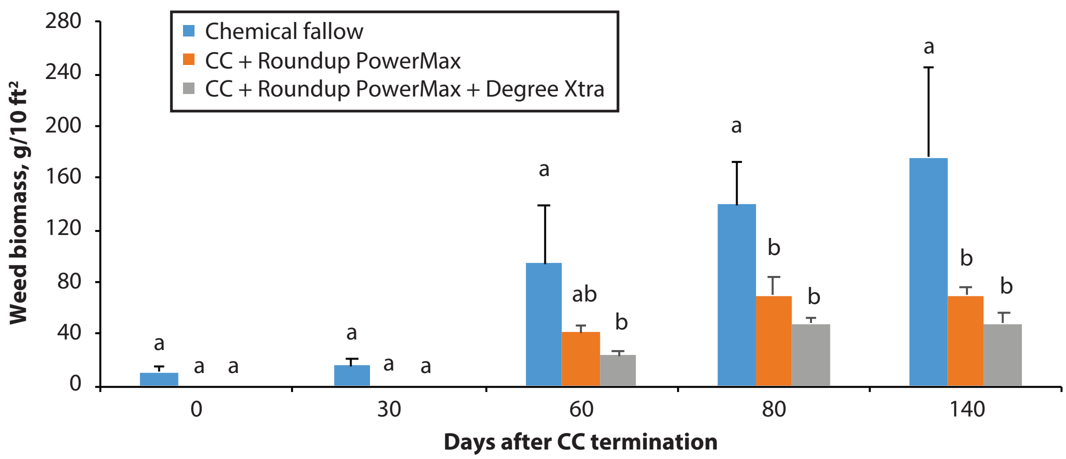


Figure 2. Total weed biomass among treatments. Means with the same letter are not significantly different (P < 0.05) among treatments within days after cover crop (CC) termination.

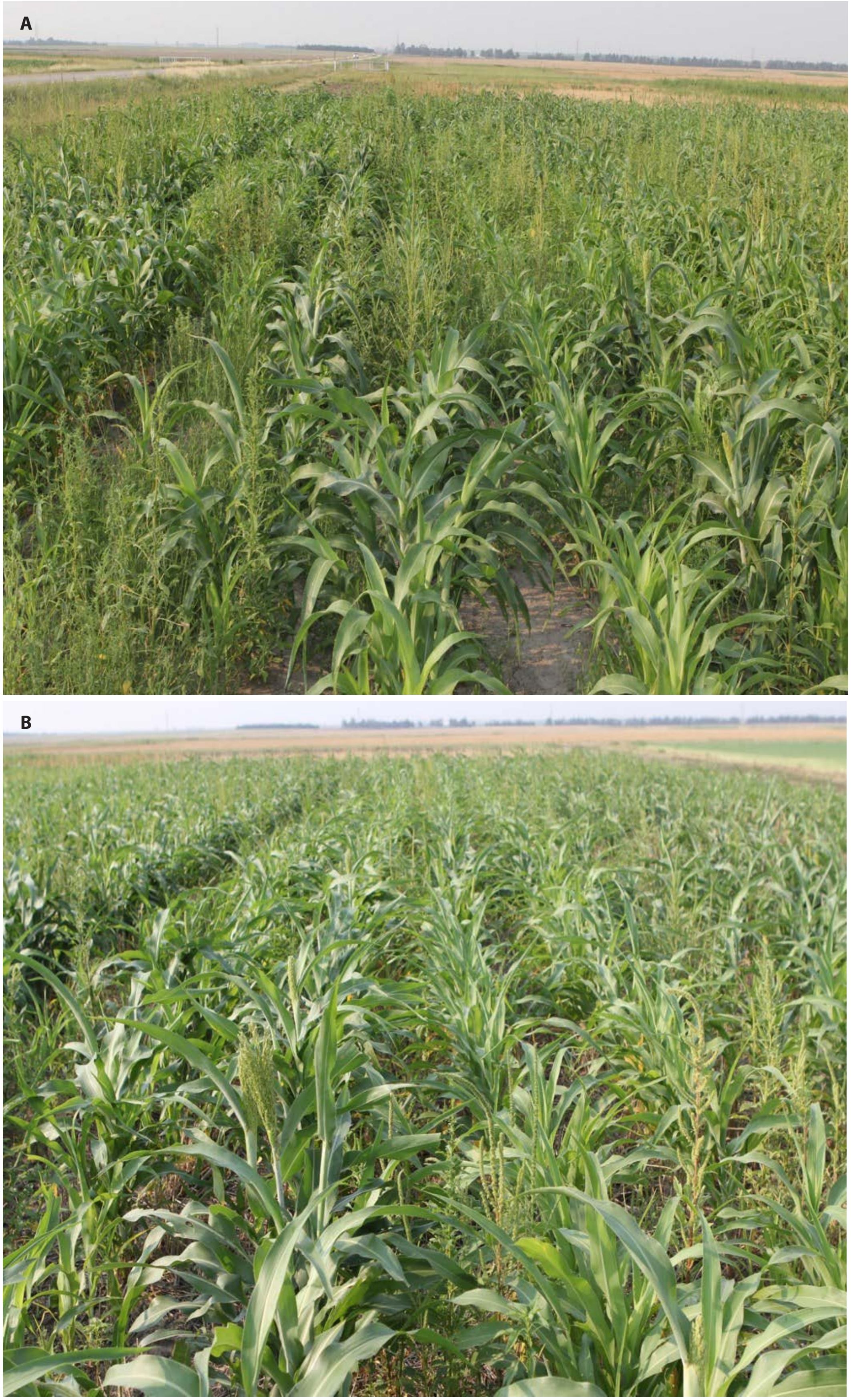


Figure 3. Weed suppression in sorghum at 80 days after cover crop (CC) termination in (A) chemical fallow, and (B) CC terminated with Roundup PowerMax + Degree Xtra.

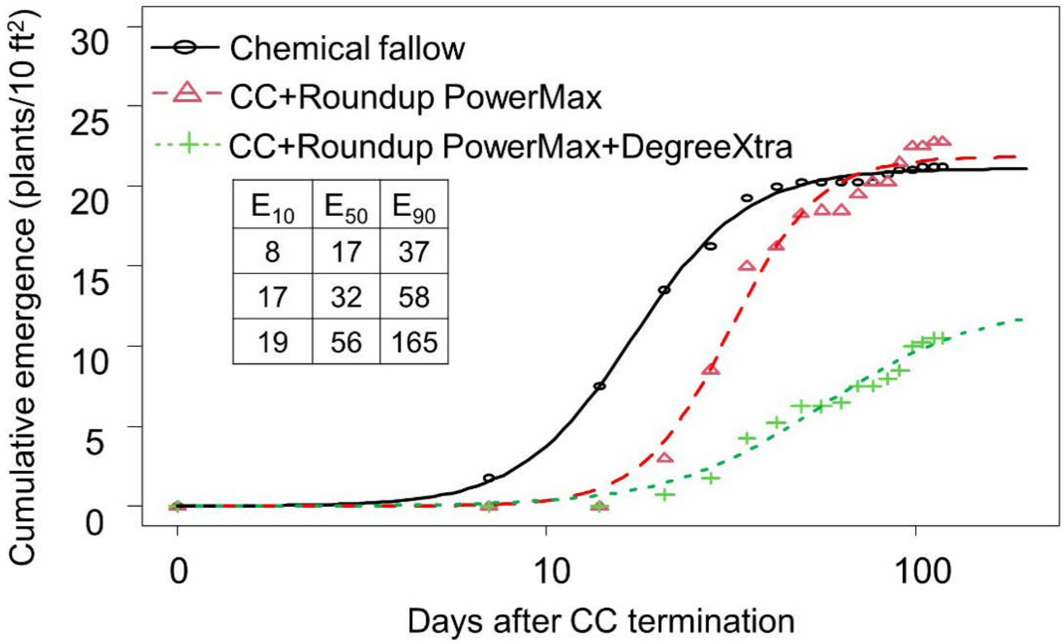


Figure 4. Cumulative emergence of Palmer amaranth among treatments. E_{10}, E_{50}, and E_{90} indicate the days required for 10, 50, and 90% cumulative emergence of Palmer amaranth, respectively.

Confirmation and Control of Imazamox-Resistant Shattercane

V. Kumar, R. Liu, T.L. Lambert, R. Perumal, and B. Bean[1]

Summary

Shattercane is a summer annual grass weed species commonly found in grain sorghum producing regions, including Kansas. Recent development and commercialization of grain sorghum hybrids with tolerance to acetolactate synthase (ALS) and acetyl-CoA-carboxylase (ACCase) inhibiting herbicides will allow producers to use these herbicides for in-season control of shattercane. In a recent field survey, three shattercane populations (DC8, GH4, and PL8) collected from sorghum fields in northwestern Kansas survived the field-use rate (6 fl oz/a) of postemergence (POST) applied IMIFLEX (imazamox). The main objectives of this research were to (1) confirm and characterize the level of resistance to imazamox in those suspected imazamox-resistant (IMI-R) shattercane populations, and (2) determine the effectiveness of alternative POST herbicides for controlling IMI-R shattercane populations. Imazamox dose-response experiments were conducted in greenhouse conditions at the Kansas State University Agricultural Research Center near Hays, KS. A susceptible shattercane population (SUS) collected from sorghum field in Rooks County, KS, was included for comparison. Dose-response analysis revealed that all three populations exhibited a 3.5- to 5.3-fold resistance to imazamox as compared to SUS population. In a field study, POST treatments of nicosulfuron (Zest), quizalofop (Aggressor), clethodim (Select Max), glyphosate (Roundup PowerMax), and glufosinate (Liberty) provided an excellent control (92 to 100%) of IMI-R population at 21 days after treatment (DAT). These results report the first case of imazamox-resistant shattercane in Kansas. Growers should adopt effective alternative POST herbicides tested in this research for managing IMI-R shattercane.

Introduction

Shattercane (*Sorghum bicolor* L.) is one of the most problematic summer annual grass weed species in the sorghum producing region in the Central Great Plains (CGP), including Kansas. Shattercane is closely related to grain sorghum and can exchange genes through crossing and hybridization. If left uncontrolled, season-long infestation of shattercane can cause >95% yield reductions in grain sorghum. Herbicide options for shattercane control in grain sorghum are relatively limited.

Sorghum hybrids (igrowth and Inzen) with tolerance to ALS inhibitors such as imazamox (IMIFLEX herbicide) and nicosulfuron (Zest WDG herbicide) have recently been developed. Both Inzen and igrowth sorghum will allow producers to use POST applications of ALS inhibitors (Zest WDG on Inzen and IMIFLEX on igrowth sorghum) for grass weed control. In addition, Double Team sorghum with tolerance to quizalofop-p-ethyl (FirstAct; an ACCase inhibiting herbicide) will also be available for grass weed control. Among these three technologies, the igrowth sorghum has been commercially available, while the other two technologies are in the pipeline. Nonetheless, all three newly developed herbicide-tolerant (HT) sorghum technologies (igrowth, Inzen, and Double Team) will potentially improve the grass weed control options in

[1] United Sorghum Checkoff Program, Agronomy Director, Lubbock, TX.

grain sorghum. Three new HT grain sorghum technologies may be widely adopted soon. A field survey was initiated in the fall of 2019 to determine the response of shattercane populations from the CGP region to ALS and ACCase-inhibiting herbicides. Out of several collections, three shattercane populations (DC8, GH4, and PL8) from northwestern Kansas survived the field-use rate of IMIFLEX (6 fl oz/a) in a preliminary discriminate-dose assay. The main objectives of this research were to (1) confirm and characterize the level of resistance to imazamox in those three putative imazamox-resistant (IMI-R) shattercane populations, and (2) determine the effectiveness of alternative POST herbicides for controlling IMI-R shattercane populations.

Procedures

Field Survey and Greenhouse Screening

A field survey for collection of matured seeds of shattercane was initiated in the fall of 2019 from grain sorghum fields in western Kansas. A total of 30 to 40 populations (40 to 50 seed heads per population) were collected from each field site and were combined to create a composite sample. In preliminary discriminate-dose experiments at the Kansas State University Agricultural Research Center near Hays, KS (KSU-ARCH), three shattercane populations from Decatur (DC8), Graham (GH4), and Phillips (PL8) counties in northwestern Kansas survived (≤ 65 % control at 21 days after treatment) the field-use rate of IMIFLEX (6 fl oz/a). All surviving plants from each population were allowed to grow for seed production in greenhouse conditions and were used in dose-response experiments. In addition to these three putative imazamox-resistant (IMI-R) populations, a shattercane population with known susceptibility to imazamox (IMI-S) was also identified from Rooks County, KS. Plants from all three IMI-R and SUS populations were grown in 4-inch squared plastic pots containing commercial potting mixture. Young seedlings (3- to 4-leaf stage) from each population were separately treated with various doses of IMIFLEX: 0, 1/8X, 1/4X, 1/2X, 1X, 2X, 4X, and 8X, where 1X = field-use rate of IMIFLEX (6 fl oz/a). Data on percent visual injury and shoot dry weights were collected at 21 days after treatment (DAT). Shoot dry weights (% of nontreated) from each population were fitted using 3-parameter log-logistic model in *drc* package in *R* software using following equation (Knezevic et al., 2007):

$$Y = \{100/1 + \exp [b (\log X + \log GR_{50})]\}$$

where, Y refers to the shoot dry weights (% of nontreated), X is the herbicide dose, GR_{50} is the IMIFLEX dose needed to reduce shoot dry weights of each population by 50%, and b is the slope of each curve.

Field Study

A field study was conducted at KSU-ARCH during summer 2021 to evaluate the efficacy of alternative POST herbicides for managing IMI-R shattercane populations. Seeds of PL8 shattercane population were planted using a 4-row planter in a fallow field. Experiments were conducted in a randomized complete block design with 4 replications. Eight different POST herbicide programs, including FirstAct (10 fl oz/a), Select Max (16 fl oz/a), Zest WDG (1.33 oz/a), Roundup PowerMax (32 fl oz/a), Liberty (32 fl oz/a), Gramoxone + AAtrex (48 + 32 fl oz/a), Callisto + AAtrex (6 + 32 fl oz/a), and a nontreated weedy check were tested. Data on percent visual control (on a scale of 0 to 100%, where 0 = no control and 100% = complete control) were recorded at 14 and 28 days after treatment (DAT). Data were subjected to ANOVA using PROC Mixed in SAS 9.3 and means were separated using Fisher's protected LSD test at $P \leq 0.05$.

Results

Dose-Response Study

Based on a fitted model, the estimated GR_{50} values (IMIFLEX doses needed for 50% shoot dry weight reduction at 21 DAT) for three putative IMI-R shattercane populations (DC8, GH4, and PL8) ranged from 3.2 to 4.8 fl oz/a while it was only 0.9 fl oz/a for SUS population (Figures 1 and 2). Based on GR_{50} values, all three IMI-R populations exhibited a 3.5- to 5.3-fold resistance to IMIFLEX as compared to SUS population (Figure 1).

Field Study

Results indicated that POST herbicides, including Zest, FirstAct, Select Max, Roundup PowerMax, and Liberty provided an excellent control (92 to 100%) of PL8 shattercane population at 21 DAT (Table 1 and Figure 3). In contrast, a moderate control (85%) of PL8 shattercane population was observed with Gramoxone + AAtrex, while the least control (38%) was observed with Callisto + AAtrex (Table 1).

Conclusions

Results from this greenhouse study indicated that three putative IMI-R shattercane populations from northwestern Kansas had evolved low-level resistance to imazamox. The field study showed an excellent control of PL8 shattercane population with alternative POST herbicides, including FirstAct and Zest WDG. Altogether, these results suggest that Inzen and Double Team sorghum technologies can provide an alternative option for effective shattercane control.

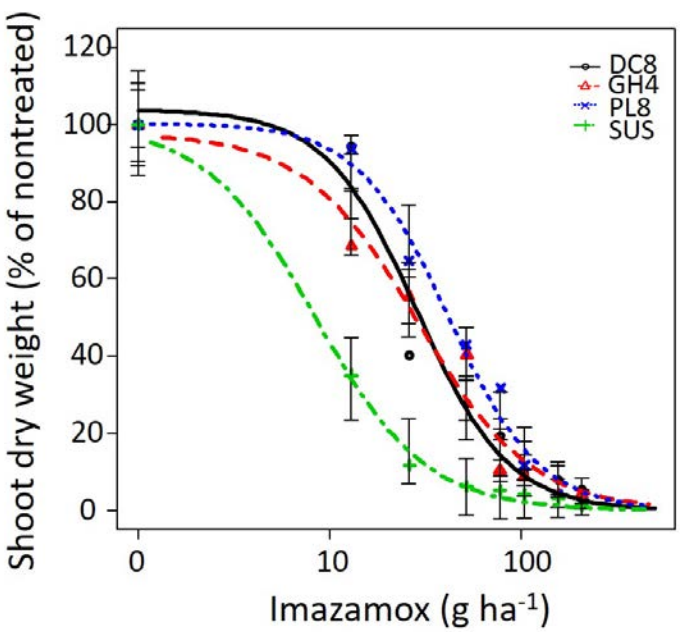
References

Knezevic SZ, Streibig JC, Ritz C (2007) Utilizing R software package for dose-response studies: the concept and data analysis. Weed Technol 21:840-848.

Table 1. Effectiveness of POST herbicides on PL8 shattercane population at 21 days after treatment (DAT)

Herbicide	Rate (oz/a)	14 DAT	21 DAT
FirstAct[1]	10	96 a	98 a
Select Max[2]	16	93 a	98 a
Zest WDG[1]	1.33	84 b	92 a
Roundup PowerMax[3]	32	100 a	100 a
Liberty[3]	32	100 a	100 a
Gramoxone + AAtrex[2]	48 + 32	81 b	85 b
Callisto + AAtrex[1]	3 + 32	61 c	38 c
Nontreated	---	---	

[1]Crop oil concentrate (COC) at 0.5% v/v was included.
[2]Nonionic surfactant (NIS) at 0.25% v/v was included.
[3]Ammonium sulfate (AMS) at 2% v/v was included.



Population	GR50	RF
DC8	3.2	3.5
GH4	3.3	3.6
PL8	4.8	5.3
SUS	0.9	--

Figure 1. Shoot dry weight (% of nontreated) response of imazamox-resistant and susceptible shattercane population (SUS) to various doses of IMIFLEX herbicide at 21 days after treatment. Populations were collected from three counties in northwestern Kansas: Decatur (DC8), Graham (GH4), and Phillips (PL8).

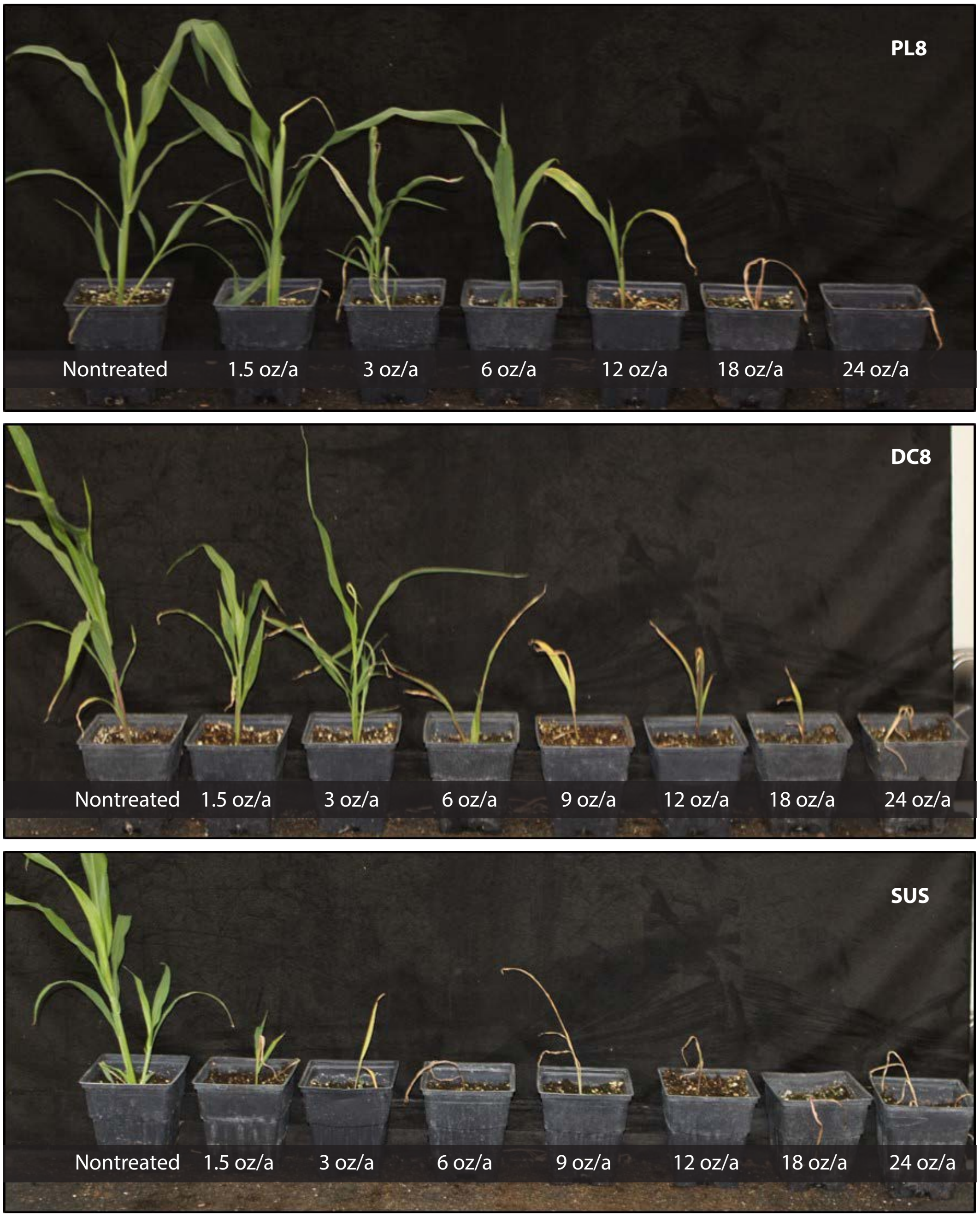


Figure 2. Visual response of imazamox-resistant and susceptible shattercane population (SUS) to various doses of IMIFLEX herbicide at 21 days after treatment. Populations were collected from three counties in northwestern Kansas: Decatur (DC8), Graham (GH4), and Phillips (PL8).

Figure 3. Visual response of the Phillips County, KS, (PL8) shattercane population: nontreated (A) and glyphosate (B) at 21 days after treatment.

Response of Conventional Sorghum to IMIFLEX, Zest WDG, and FirstAct

R. Liu, V. Kumar, M. Marrs, and T.L. Lambert

Summary

Grass weed control in sorghum has been a serious challenge for sorghum growers. The newly developed herbicide-tolerant (HT) sorghum technologies such as igrowth, Inzen, and Double Team sorghum will allow growers to use IMIFLEX, Zest WDG, and FirstAct respectively, for in-season weed control. However, the adoption of these HT sorghum technologies may increase the use of these labeled herbicides and increase the likelihood of herbicide drift or tank contamination to conventional sorghum. Three separate field studies were conducted at Kansas State University Agricultural Research Center (KSU-ARCH) near Hays, KS, to understand the response of conventional sorghum to various rates of IMIFLEX, Zest WDG, and FirstAct applied at two different growth stages. Results indicated that field-use rates (1X) of IMIFLEX, Zest WDG, and FirstAct resulted in 90 to 100% injury and complete or near-complete grain yield loss of conventional sorghum. In addition, low rates of Zest WDG (as low as 1/50X) and FirstAct (as low as 1/10X) also caused significant injury and grain yield loss of conventional sorghum. In conclusion, these results suggested that either drift or tank-contamination of these herbicides (even at low rates) can cause significant injury or grain yield loss of conventional sorghum. Proper adherence to the stewardship guidelines are necessary to avoid the drift or tank-contamination from these herbicides to conventional sorghum.

Introduction

Sorghum ranks after wheat, corn, and soybean as the fourth most planted crop in Kansas. It is a C_4 plant with high tolerance to heat and drought conditions. Weed control, especially for grass species, has been a serious challenge to growers.

Three HT sorghum technologies, including igrowth, Inzen, and Double Team have recently been developed. The newly developed HT sorghum technologies offer producers postemergence (POST) herbicide options for in-season weed control. Advanta Seeds developed igrowth sorghum. It has tolerance to IMIFLEX herbicide (imazamox, an active ingredient). Inzen sorghum is developed by Pioneer and provides tolerance to Zest WDG herbicide (nicosulfuron, an active ingredient). Both herbicides belong to acetolactate synthase (ALS) inhibitors (Group 2). Double Team sorghum is developed by S&W Seed Co. and carries tolerance to FirstAct herbicide (quizalofop-p-ethyl, an active ingredient). FirstAct is an acetyl-CoA-carboxylase (ACCase) inhibitor (Group 1).

Adoption of these HT sorghum technologies will increase the use of these labeled herbicides and may potentially increase the physical drift and/or tank contamination to nearby conventional sorghum. The objective of this study was to understand the response of conventional sorghum to various rates of IMIFLEX, Zest WDG, and FirstAct at two different sorghum growth stages.

Procedures

Three separate field studies were conducted in the 2021 growing season at the KSU-ARCH near Hays, KS. Conventional sorghum hybrid 'DKS 38-16' was planted at 46,500 seeds/a on June 8, 2021. Randomized complete block design was used in each experiment. Six rates of IMIFLEX, Zest WDG, and FirstAct, including 1/200X, 1/100X, 1/50X, 1/25X, 1/2X, and 1X (field-use rates of IMIFLEX = 6 fl oz/a; Zest WDG = 1.33 oz/a, and FirstAct = 10 fl oz/a) were separately tested at early (3- to 5-leaf, EPOST) and late (flag leaf, LPOST) growth stage of sorghum. A nontreated check was also included in each experiment. All herbicide applications were carried out using a CO_2-operated backpack sprayer equipped with Turbo Teejet AIXR 110015 nozzles and calibrated to deliver 15 gallons of spray solution per acre. Appropriate adjuvants were used for each herbicide as dictated by the herbicide label. Experimental areas were maintained weed free throughout the season to ensure no weed competition. Data on sorghum visual injury (%) were collected at biweekly intervals and grain yields were recorded at harvest. All data were subjected to ANOVA using Proc GLM in SAS program. Means were separated using Fisher's LSD test ($\alpha = 0.05$).

Results

Response to IMIFLEX Herbicide

Results indicated that 3 to 6 fl oz/a rate of IMIFLEX applied across both growth stages resulted in 70 to 90% sorghum injury at the time of crop maturity. Consistent with percent visual injury, 64 to 98% grain yield loss of conventional sorghum was observed when exposed to 3 to 6 fl oz/a rates of IMIFLEX herbicide (Table 1). No significant crop injury was observed with low tested rates (1/200 to 1/25X) of IMIFLEX (Table 1).

Response to Zest WDG Herbicide

Results showed that conventional sorghum injury (%) ranged from 79 to 100% when exposed to Zest WDG at 1/50 X up to 1X rate (1X = 1.33 oz/a) regardless of application timing (Table 2). Zest WDG applied at field-use rate (1X) resulted in complete or near-complete grain yield loss regardless of application timing (Table 2).

Response to FirstAct Herbicide

Results showed that exposure of FirstAct herbicide applied at 1/10X to 1X field use rate (10 fl oz/a), resulted in 63 to 100% crop injury and 38 to 100% grain yield loss regardless of application timing (Table 3).

Conclusions

These results suggested that drift and/or tank-contamination of IMIFLEX, Zest WDG, and FirstAct even at low rates can cause significant injury and grain yield loss of conventional sorghum. Growers adopting the new sorghum technologies should be proactive and follow the stewardship guidelines to avoid drift and/or tank-contamination from these herbicides to conventional sorghum.

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Table 1. Crop injury (%) at maturity and grain yield response of conventional sorghum to different rates of IMIFLEX applied at two timings

Dose (fl oz/a)[a]	Application timing[b]	Injury (%)[c]	Yield (bu/a)[d]
Nontreated	---	0 d	93 a
0.03	EPOST	1 d	79 a
0.06	EPOST	2 d	90 a
0.12	EPOST	4 d	91 a
0.24	EPOST	2 d	86 a
3.00	EPOST	70 c	33 b
6.00	EPOST	90 a	8 c
0.03	LPOST	1 d	90 a
0.06	LPOST	1 d	97 a
0.12	LPOST	3 d	87 a
0.24	LPOST	3 d	88 a
3.00	LPOST	80 b	16 bc
6.00	LPOST	85 ab	1 c

[a] Herbicide treatments were applied with appropriate adjuvants as dictated by IMIFLEX label using a backpack sprayer equipped with AIXR 110015 nozzles.
[b]EPOST = early (3- to 5-leaf). LPOST = late (flag leaf).
[c, d] Means within each column having same letters were not significantly different according to Fisher's protected LSD test ($P < 0.05$).

Table 2. Crop injury (%) at maturity and grain yield response of conventional sorghum to different rates of Zest WDG applied at two timings

Dose (oz/a)[a]	Application timing[b]	Injury (%)[c]	Yield (bu/a)[d]
Nontreated	---	0 e	78 a
0.007	EPOST	1 e	77 a
0.013	EPOST	3 e	74 a
0.027	EPOST	85 cd	16 b
0.133	EPOST	100 a	2 c
0.665	EPOST	91 bc	1 c
1.330	EPOST	98 ab	1 c
0.007	LPOST	2 e	77 a
0.013	LPOST	2 e	74 a
0.027	LPOST	82 d	2 c
0.133	LPOST	89 cd	0 c
0.665	LPOST	88 cd	0 c
1.330	LPOST	90 c	0 c

[a] Herbicide treatments were applied with appropriate adjuvants as dictated by Zest WDG label using a backpack sprayer equipped with AIXR 110015 nozzles.
[b]EPOST = early (3- to 5-leaf). LPOST = late (flag leaf).
[c, d] Means within each column having same letters were not significantly different according to Fisher's protected LSD test ($P < 0.05$).

Table 3. Crop injury at maturity and grain yield response of conventional sorghum to different rates of FirstAct applied at two timings

Dose (fl oz/a)[a]	Application timing[b]	Injury (%)[c]	Yield (bu/a)[d]
Nontreated	---	0 d	86 a
0.05	EPOST	3 d	78 ab
0.1	EPOST	3 d	76 ab
0.2	EPOST	5 d	63 bc
1	EPOST	83 b	26 d
5	EPOST	100 a	1 e
10	EPOST	100 a	0 e
0.05	LPOST	3 d	82 a
0.1	LPOST	3 d	83 a
0.2	LPOST	4 d	79 ab
1	LPOST	63 c	53 c
5	LPOST	96 a	2 e
10	LPOST	100 a	0 e

[a] Herbicide treatments were applied with appropriate adjuvants as dictated by FirstAct label using a backpack sprayer equipped with AIXR 110015 nozzles.
[b]EPOST = early (3- to 5-leaf). LPOST = late (flag leaf).
[c, d] Means within each column having same letters were not significantly different according to Fisher's protected LSD test ($P < 0.05$).

Glyphosate-Resistant Palmer Amaranth Control in XtendFlex Soybean

R. Liu, V. Kumar, and T.L. Lambert

Summary

XtendFlex soybean is a triple-stacked trait technology that allows growers to use dicamba (XtendiMax) and glufosinate (Liberty) for in-season control of glyphosate-resistant (GR) weed species, including Palmer amaranth. A field study was conducted at the Kansas State University Agricultural Research Center (KSU-ARCH) near Hays, KS, to determine the effectiveness of POST applied XtendiMax and Liberty alone or in sequential applications for GR Palmer amaranth control in XtendFlex soybean. The study site had a natural infestation of GR Palmer amaranth. Results showed that early post-emergence (EPOST) applications of XtendiMax or Liberty followed by (*fb*) a late post-emergence (LPOST) application of Liberty provided an excellent control (98%) of GR Palmer amaranth compared to XtendiMax or Liberty alone at 30 days after treatment (DAT). All treatments provided >80% control throughout the season, except for Roundup PowerMax alone (59 to 78%). Consistent with percent visual control, all tested treatments significantly reduced GR Palmer amaranth biomass (0 to 96 g/10 ft^2) compared to non-treated check (178 g/10 ft^2). Soybean yield for majority of the tested treatments were significantly higher (ranging from 28 to 33 bu/a), compared to nontreated check (23 bu/a). In conclusion, these results suggest that sequential treatments of EPOST XtendiMax *fb* LPOST XtendiMax or Liberty and EPOST Liberty *fb* LPOST Liberty can provide effective control of GR Palmer amaranth in XtendFlex soybeans.

Introduction

XtendFlex soybean is a triple-stacked trait technology (tolerates glyphosate, dicamba, and glufosinate herbicides) that has recently been commercialized. This technology allows growers to use Roundup PowerMax, XtendiMax and Liberty for in-season weed control. GR Palmer amaranth is common in Kansas cropping systems (Kumar et al., 2020). The proper use of XtendiMax and Liberty can be helpful in managing GR Palmer amaranth in XtendFlex soybean. The objective of this study was to determine the effectiveness of POST applied XtendiMax and Liberty alone or in sequential applications for GR Palmer amaranth control in XtendFlex soybean.

Procedures

A field study was conducted at KSU-ARCH near Hays, KS, to determine the effectiveness of POST applied XtendiMax and Liberty alone or in sequential applications for the control of GR Palmer amaranth in XtendFlex soybean. XtendFlex soybean variety AG37XF1 was planted at 156,900 seeds/a on June 5, 2021. Study site had a natural infestation of GR Palmer amaranth. A randomized complete block design with four replications was used. A total of 8 herbicide treatments were tested, including a nontreated check, stand-alone applications of Roundup PowerMax at 32 fl oz/a, XtendiMax at 22 fl oz/a, Liberty at 32 fl oz/a, or in sequential applications at early post-emergence (EPOST) at V3-4 soybeans (3- to 5-inch Palmer amaranth) on July 7, 2021, followed by (*fb*) a late post-emergence (LPOST) applied 10 days after EPOST to 6- to 8-inch Palmer amaranth on July 17, 2021. All treatments were applied with appropriate adjuvants as dictated by each label using a CO_2-operated backpack sprayer calibrated to deliver 15 gallons of spray solution per acre. Turbo Teejet Induction 110015 nozzles were used for treatments containing XtendiMax, and AIXR 110015 nozzles were used for Roundup PowerMax or Liberty treatments. Data on soybean injury (%) and GR Palmer amaranth control (%) at 7, 10, 30, and 80 days after LPOST treatment (DAT) were recorded. At soybean maturity, GR Palmer amaranth biomass was collected using an 10-ft^2 quadrat placed at the center of each plot. Soybean yield (bu/a) was also recorded. All data were subjected to ANOVA using PROC MIXED in SAS program. Means were separated using Fisher's protected LSD test ($\alpha = 0.05$).

Results

Palmer Amaranth Control

Results showed that EPOST applications of XtendiMax or Liberty *fb* a LPOST application of Liberty provided excellent control (98%) of GR Palmer amaranth compared to EPOST XtendiMax or Liberty alone at 30 DAT (Figure 1A, Figure 3C). Overall, all treatments provided >80% control of GR Palmer amaranth throughout the season, except for Roundup PowerMax (59 to 78%) (Figure 1A; Figure 3B).

GR Palmer Amaranth Biomass Reduction

Consistent with percent control, all tested treatments reduced GR Palmer amaranth biomass significantly (0 to 96 g/10 ft^2) compared to nontreated check (178 g/10 ft^2) (Figure 1B; Figure 3).

Soybean Yield

Soybean grain yields for the majority of the tested treatments did not differ but were significantly higher (ranging from 28 to 33 bu/a) compared to nontreated check (23 bu/a) (Figure 2; Figure 3).

Conclusions

Results suggested that sequential treatments comprising EPOST XtendiMax *fb* LPOST XtendiMax or Liberty and EPOST Liberty *fb* LPOST Liberty provided season-long control of GR Palmer amaranth compared with EPOST Liberty or XtendiMax alone treatments.

References

Kumar V, Liu R, Stahlman PW (2020) Differential sensitivity of Kansas Palmer amaranth populations to multiple herbicides. Agron J, *https://doi.org/10.1002/agj2.20178*.

Table 1. List of POST treatments tested in XtendFlex soybean

No.	Herbicide program*	Rate (fl oz/a)	Timing
1	Nontreated	---	---
2	Roundup PowerMax	32	EPOST
3	Liberty	32	EPOST
4	XtendiMax	22	EPOST
5	XtendiMax *followed by (fb)* XtendiMax	22 *fb* 22	EPOST *fb* LPOST
6	XtendiMax *fb* Liberty	22 *fb* 32	EPOST *fb* LPOST
7	Liberty *fb* XtendiMax	32 *fb* 22	EPOST *fb* LPOST
8	Liberty *fb* Liberty	32 *fb* 32	EPOST *fb* LPOST

*All treatments were applied with appropriate adjuvants as dictated by each label using a backpack sprayer equipped with Turbo Teejet Induction 110015 nozzles (for treatments containing XtendiMax) or AIXR 110015 nozzles (for Roundup PowerMax or Liberty).

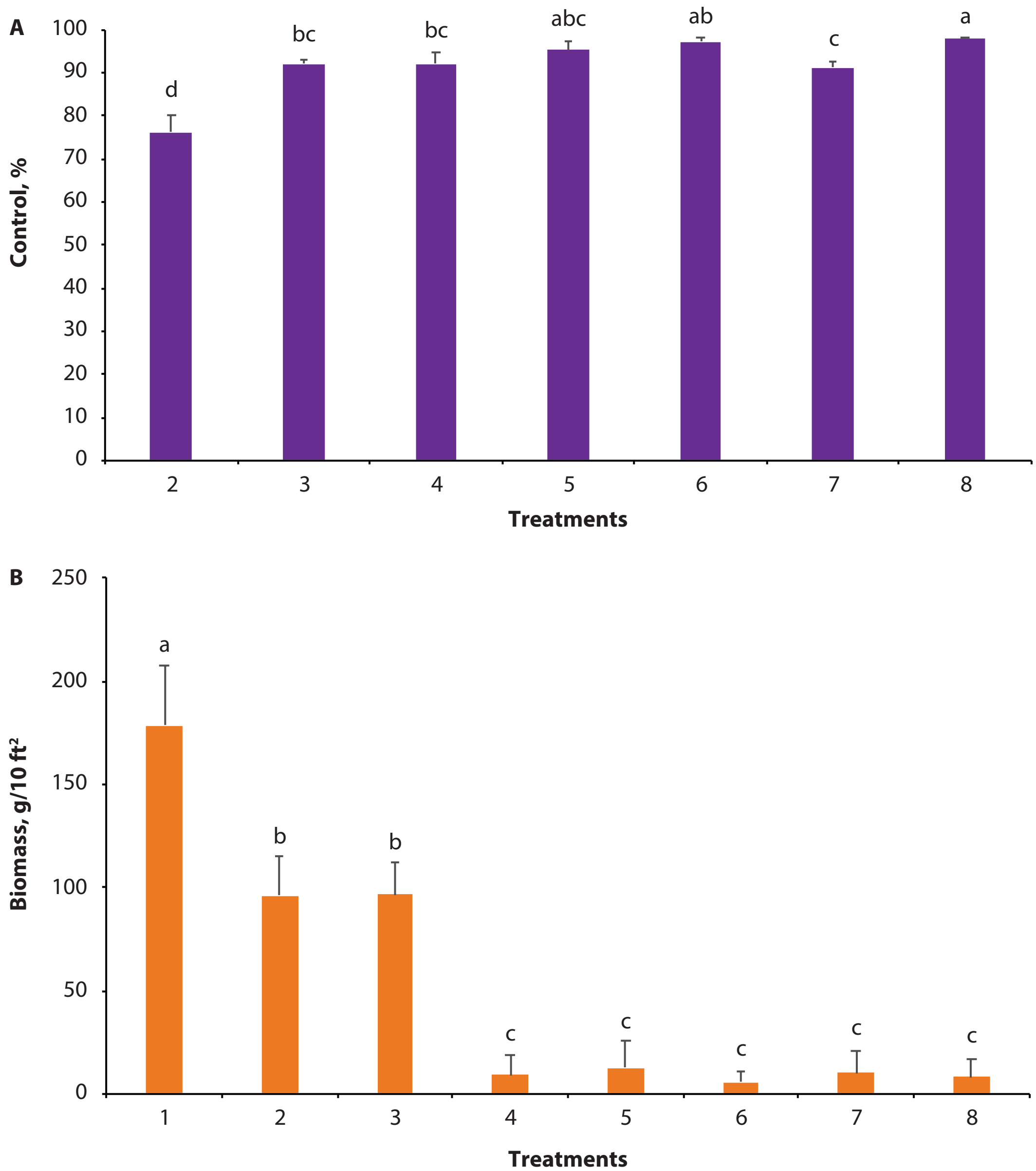

Figure 1. Glyphosate-resistant Palmer amaranth control at 30 days after treatment (A) and aboveground biomass at soybean maturity (B) with all tested POST treatments in Xtend-Flex soybean. Bars with same letters are not significantly different according to Fisher's protected LSD test (P < 0.05). See Table 1 for treatment details.

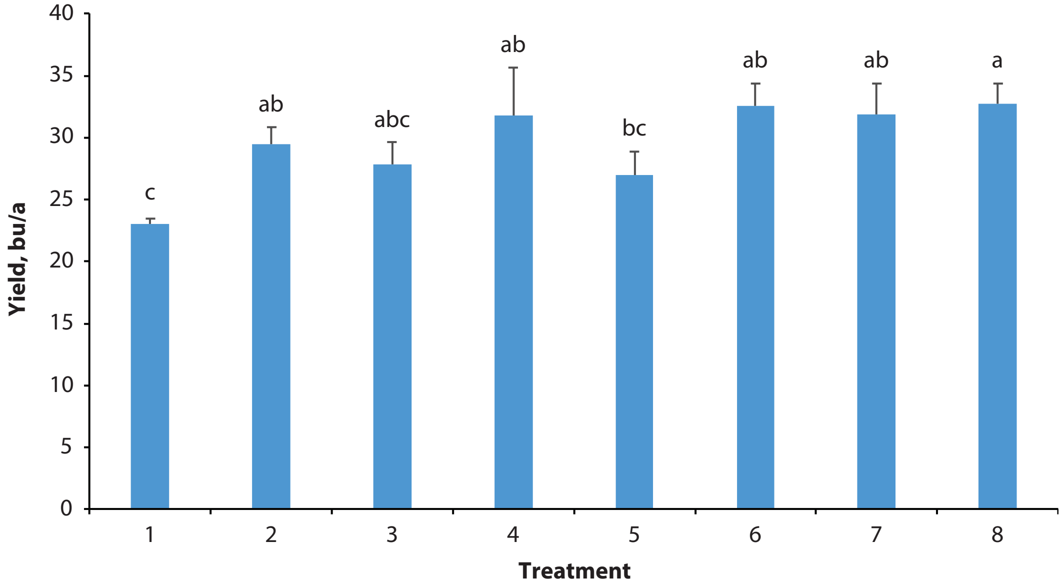

Figure 2. Effect of POST treatments on XtendFlex soybean grain yield at KSU-ARCH near Hays, KS. Bars with same letters are not significantly different according to Fisher's protected LSD test ($P < 0.05$). See Table 1 for treatment details.

Figure 3. Photos of each plot taken at 30 days after treatment: non-treated check (A); Roundup PowerMax EPOST at 32 fl oz/a (B); XtendiMax EPOST at 22 fl oz/a (C); and XtendiMax EPOST at 22 fl oz/a *fb* Liberty LPOST at 32 fl oz/a (D). EPOST = early postemergence. LPOST = late postemergence. *fb* = followed by.

Cover Crop Grazing Effects on Soil Compaction Indicators in Western and Central Kansas

L.M. Simon, A.K. Obour, J.D. Holman, S.K. Johnson, and K.L. Roozeboom

Summary

Grazing cover crops (CCs) on no-till (NT) croplands in western and central Kansas could increase the profitability of crop production in these water-limited environments. However, little information exists about potential soil compaction associated with grazing CCs in these cropping systems. From 2019 to 2021, two studies investigated the effects of grazing CCs on soil bulk density and penetration resistance in NT cropping systems. At the Kansas State University HB Ranch near Brownell, KS, CCs grazed with yearling heifers were compared to ungrazed CCs and fallow under NT or occasional tillage (OT). In another study, CCs grazed with yearlings or cow-calf pairs were compared to ungrazed CCs across seven site-years on producer fields in western Kansas (Alexander and Hays) and central Kansas (Marquette 1 and 2). Soil bulk density and penetration resistance measurements were made at the time of subsequent grain crop planting following CCs. At Brownell, CC management, tillage, and their interaction had no significant effect ($P > 0.05$) on soil bulk density. Across years, bulk densities with fallow, ungrazed CCs, and grazed CCs were 1.11, 1.15, and 1.15 g/cm^3 at the 0- to 2-inch soil depth, respectively. Soil bulk densities with NT and OT were 1.14 and 1.14 g/cm^3 at the 0- to 2-inch soil depth, respectively. Similarly, CC grazing had no significant effect on soil bulk density and penetration resistance across the seven on-farm sites-years. At the western Kansas locations, soil bulk density averaged 1.23 g/cm^3 at the 0- to 2-inch soil depth with grazed or ungrazed CCs. At the central Kansas locations, soil bulk density averaged 1.31 and 1.36 g/cm^3 at the 0- to 2-inch soil depth for grazed and ungrazed CCs, respectively. Bulk density measured at 2- to 6-inch depth was not different between grazed and ungrazed CC in either study. At Alexander, penetration resistance was 0.52 and 0.52 MPa with grazed and ungrazed CCs, respectively. Penetration resistance was 0.36 and 0.34 MPa with grazed and ungrazed CCs, respectively, at Marquette 1. Results showed that grazing CCs never increased soil bulk density or penetration resistance compared to ungrazed CCs. Based on these findings, grazing CCs on NT fields can be a strategy for producers to balance profitability and soil health.

Introduction

No-tillage (NT) and cover crops (CCs) have been recommended to regenerate soil health degraded after years of conventionally-tilled, low-intensity crop production. Soil health benefits of adopting CCs in the NT cropping systems include increased soil organic carbon, enhanced nutrient cycling, reduced compaction, increased water infiltration, and reduced wind and water erosion. However, establishment costs and the risk of CCs reducing subsequent grain yields present a major barrier to adoption of CCs in water-limited western and central Kansas. Some producers have sought to overcome these factors by integrating livestock (usually cattle or sheep) to graze CCs. Most CC species can provide high-quality forage, which can extend the grazing season for livestock and delay grazing of native perennial grasslands. Based on these benefits, there is motivation for Natural Resources Conservation Service (NRCS) cost-share programs to allow grazing on enrolled CCs to increase producer adoption of CCs.

Despite the potential economic benefits of integrating livestock, there is concern that grazing CCs on NT fields could cause the development of yield-limiting soil compaction that would require tillage to remediate. Little information exists about the effects of grazing CCs on soil compaction in NT cropping systems in Kansas and the central Great Plains region. Experience with crop residue grazing suggests that grazing time, duration, and stocking rates are key considerations to prevent soil degradation. Therefore, the objective of this research was to quantify CC grazing impacts on indicators of soil compaction in NT cropping systems in western and central Kansas.

Procedures

Two studies were conducted from 2019 to 2021 to investigate the effects of grazing CCs on two indicators of soil compaction (soil bulk density and penetration resistance). The first study was initiated in 2015 at the Kansas State University HB Ranch near Brownell, KS. The study compared grazed and ungrazed CCs to fallow under NT or occasional tillage (OT) in a winter wheat-grain sorghum-fallow crop rotation. The study site had a silt loam soil type and averages 22 inches of precipitation annually. The experimental design was a split-split-plot randomized complete block with four replications. Main plots were the three crop phases of the wheat-sorghum-fallow crop rotation; split-plots were grazed CCs, ungrazed CCs, and fallow; and split-split-plots (300 ft^2) were NT and OT. In this study, spring CCs (oats and triticale) were planted into sorghum residues. Every year, CCs were stocked between late May and early June with yearling heifers (1000 lb each) at a stocking rate of 775 lb/a. Heifers were moved daily for four days across the four replications. In this study, OT was implemented with a single tillage pass of a QuinStar Fallow Master sweep plow (QuinStar Equipment Company, Quinter, KS) to a depth of 3 inches in July between CC termination and winter wheat planting, but was otherwise managed the same as NT.

A second study was initiated in 2018 on producer fields near Alexander, Hays, and Marquette, KS, to further test the effects of grazing CCs on soil properties. At these locations, grazed CCs were compared to ungrazed CCs. Whole fields at Alexander and Hays were 80 and 50 acres, respectively, and were considered western locations (22 to 24 inches average annual precipitation). Whole fields at Marquette were 93 (Marquette 1) and 80 acres (Marquette 2), respectively, and were considered central locations (28 to 30 inches average annual precipitation). All locations had silt loam soils. At on-farm sites, four areas of 0.75 to 2.5 acres in size were assigned within each field as fenced zones to exclude grazing (ungrazed plots). Cattle were allowed full access to the adjacent unfenced areas with a single watering area at one end of the field. Grazed areas directly adjacent to the four ungrazed plots and away from the watering area were assigned as grazed plots for a total of eight plots at each location.

At Alexander, the field was managed under a NT winter wheat-corn-fallow rotation. In 2019, spring CCs (oats, triticale, barley, pea, rapeseed, and sunflower) were planted into corn residues and grazed with yearlings (600 lb each) from May 14 to June 14 at a stocking rate of 350 lb/a. In 2020, summer CCs (sorghum-sudangrass, German millet, sunn hemp, sunflower, and radish) were planted immediately after wheat harvest and grazed with yearlings (750 lb each) from August 7 to September 18 at a stocking rate of 575 lb/a. At Hays, the field was managed under a NT winter wheat-grain sorghum-fallow rotation, and CC mixtures were the same as described for Alexander at similar points in the rotation. In 2019, summer CCs were planted immediately after wheat harvest and grazed with cow-calf pairs (1388 lb/a combined) from August 24 to October 10 at a stocking rate of 350 lb/a. In 2021, spring CCs were planted into grain sorghum residues and grazed with yearlings (575 lb each) from June 30 to July 20 at a stocking rate of 550 lb/a. At Marquette 1, the field was managed under a NT winter wheat-soybean rotation, and fall CCs (triticale, rapeseed, radish) were planted into wheat residues. In 2018–2019, yearlings (600 lb each) grazed from December 17 to February 10 at a stocking rate of 550 lb/a. In 2020–2021, yearlings (575 lb each) grazed from January 1 to February 14 at a stocking rate of 550 lb/a. At Marquette 2, the field was managed under a NT winter wheat-grain sorghum-soybean rotation, and CCs were the same as described for Marquette 1. In 2019–2020, fall CCs were planted into wheat residues and grazed with yearlings (575 lb each) from January 9 to February 17 at a stocking rate of 550 lb/a.

Soil samples were collected at each site to determine bulk density at the time of grain crop planting following CCs. Two intact soil cores of 6 inches in depth and 2 inches in diameter were collected from each plot. In the grazed plots, care was taken to avoid trails of heaviest cattle traffic. Samples were split into 0- to 2- and 2- to 6-inch increments and dried at 221°F for a minimum of 48 hours. Soil bulk density was computed as mass of oven-dried soil divided by volume of the core. In 2021 at Alexander and Marquette 1, penetration resistance was measured at 10 random points within each plot to a depth of 0–6 inches using a hand cone penetrometer (Eijkelkamp Co., Giesbeek, the Netherlands), and readings were divided by the area of the cone (2 cm^2). Values of penetration resistance were adjusted to a field capacity gravimetric water content of 0.35 (g/g). Statistical analyses were completed using PROC GLIMMIX of SAS v. 9.3 (SAS Institute, Cary, NC) with year, treatment, tillage, and their interactions considered fixed when appropriate for each study, and replication was always considered random. Treatment differences were considered significant at $P \leq 0.05$.

Results

At Brownell, the effects of treatment, tillage, and their interaction on soil bulk density were not significant ($P > 0.05$) at the 0- to 2- or 2- to 6-inch soil depths in any year of the study (Table 1). These results indicate that grazing CCs did not cause soil compaction compared to ungrazed CCs or fallow measured at subsequent winter wheat planting. Averaged across years, fallow, ungrazed CCs, and grazed CCs had soil bulk densities of 1.11, 1.15, and 1.15 g/cm^3 at the 0- to 2-inch soil depth and 1.39, 1.40, and 1.37 g/cm^3 at the 2- to 6-inch soil depth, respectively. Additionally, soil bulk density under NT was not different ($P > 0.05$) compared to OT plots (Table 1). Averaged across years, NT and OT had soil bulk densities of 1.14 and 1.14 g/cm^3 at the 0- to 2-inch soil depth and 1.40 and 1.36 g/cm^3 at the 2- to 6-inch soil depth, respectively. Soil bulk densities across CC management strategies, tillage operations, and soil depths were below the threshold of 1.6 g/cm^3 at which root-limiting compaction begins.

Across the seven on-farm site-years (Table 2), soil bulk density was different between CC treatments only at Marquette 1 in 2019 when bulk density in the 0- to 2-inch soil depth with ungrazed CCs (1.43 g/cm^3) was greater ($P < 0.05$) than grazed CCs (1.23 g/cm^3). At the western Kansas locations, average soil bulk densities with grazed and ungrazed CCs were 1.23 and 1.23 g/cm^3 at the 0- to 2-inch soil depth and 1.35 and 1.34 g/cm^3 at the 2- to 6-inch soil depth, respectively. At the central Kansas locations, soil bulk densities with grazed and ungrazed CCs were 1.31 and 1.36 g/cm^3 at the 0- to 2-inch soil depth and 1.51 and 1.50 g/cm^3 at the 2- to 6-inch soil depth, respectively. Soil bulk densities across all locations, CC management strategies, and soil depths were below the threshold of 1.6 g/cm^3 at which root-limiting compaction begins. Penetration resistance at the 0- to 6-inch soil depth with grazed CCs was not different from ungrazed CCs at both Alexander and Marquette 1 in 2021 (Figure 1). At Alexander, penetration resistance was 0.52 and 0.52 MPa with grazed and ungrazed CCs, respectively. At Marquette 1, penetration resistance was 0.36 and 0.34 MPa with grazed and ungrazed CCs, respectively. The measured penetration resistances across locations and CC management strategies were below the threshold of 2 MPa at which root-limiting compaction begins.

Our results showed that grazing CCs had no negative effects on soil bulk density compared to ungrazed CCs or fallow under NT or OT. Similarly, across seven on-farm site years, neither soil bulk density nor penetration resistance was ever increased with grazing CCs compared to ungrazed CCs. Based on these findings, grazing CCs on NT fields can be a strategy for producers to balance goals of environmental and economic sustainability in water-limited crop production. Allowing grazing of CCs enrolled in the NRCS cost-share programs could increase producer adoption of CCs in western and central Kansas to enhance regional soil health and increase system profitability.

Table 1. Effects of cover crop (CC) management and no-tillage (NT) or occasional tillage (OT) on soil bulk density at the Kansas State University HB Ranch near Brownell, KS

		Bulk density (g/cm^3)		
Treatment	**Tillage**	**2019**	**2020**	**2021**
		0- to 2-inch		
Fallow	NT	1.05a†	1.16a	1.17a
	OT	1.02a	1.17a	1.09a
Ungrazed CC	NT	1.07a	1.16a	1.14a
	OT	1.16a	1.18a	1.22a
Grazed CC	NT	1.06a	1.22a	1.20a
	OT	1.14a	1.20a	1.13a
		2- to 6-inch		
Fallow	NT	1.34a	1.39a	1.46a
	OT	1.24a	1.34a	1.41a
Ungrazed CC	NT	1.38a	1.40a	1.43a
	OT	1.32a	1.40a	1.36a
Grazed CC	NT	1.30a	1.38a	1.39a
	OT	1.28a	1.36a	1.35a

†Means with the same letter within columns are not different ($\alpha = 0.05$) across treatments and tillage.

Table 2. Cover crop (CC) grazing effect on soil bulk density at subsequent grain crop planting across seven site-years in western and central Kansas

			Bulk density (g/cm³)		
Region	**Location**	**Treatment**	**2019**	**2020**	**2021**
			0- to 2-inch		
Western	Alexander	Ungrazed CC	1.28a†	-	1.36a
		Grazed CC	1.14a	-	1.36a
	Hays	Ungrazed CC	-	1.25a	1.04a
		Grazed CC	-	1.32a	1.09a
Central	Marquette 1	Ungrazed CC	1.43a	-	1.36a
		Grazed CC	1.23b	-	1.38a
	Marquette 2	Ungrazed CC	-	1.28a	-
		Grazed CC	-	1.32a	-
			2- to 6-inch		
Western	Alexander	Ungrazed CC	1.38a	-	1.44a
		Grazed CC	1.44a	-	1.41a
	Hays	Ungrazed CC	-	1.38a	1.16a
		Grazed CC	-	1.41a	1.13a
Central	Marquette 1	Ungrazed CC	1.54a	-	1.49a
		Grazed CC	1.49a	-	1.53a
	Marquette 2	Ungrazed CC	-	1.48a	-
		Grazed CC	-	1.51a	-

†Means with the same letter within columns are not different ($\alpha = 0.05$) across treatments.

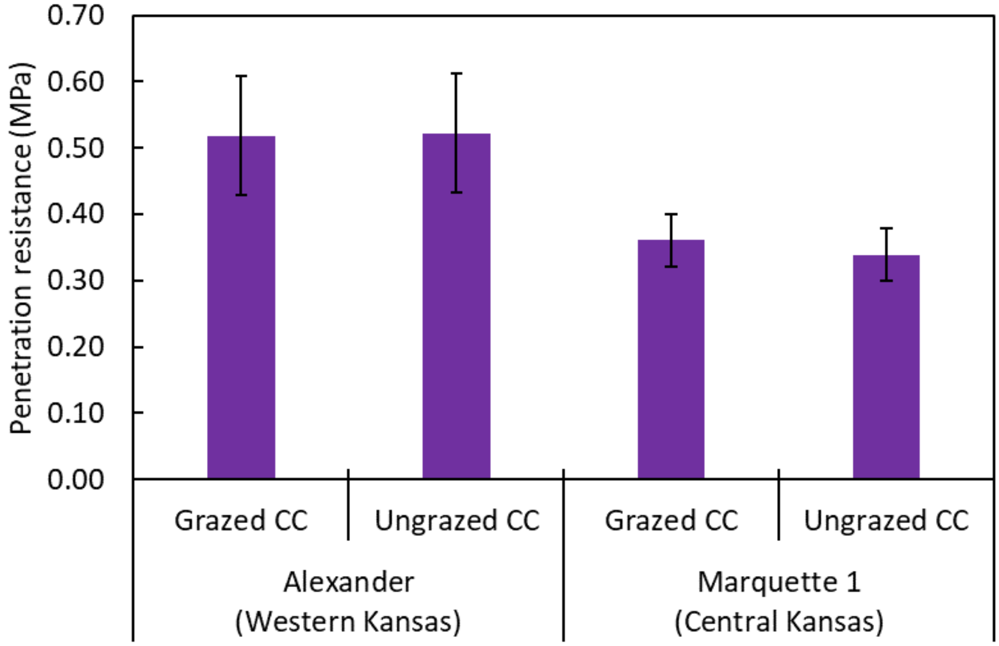

Figure 1. Effect of cover crop grazing on penetration resistance at the 0- to 6-inch soil depth at subsequent grain crop planting at two on-farm sites in 2021. Error bars indicate standard error (α = 0.05) and bars with the same letter are not significantly different (α = 0.05).

Spring and Summer Cover Crop Effects on Dryland Wheat and Grain Sorghum Yields in Western Kansas

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Summary

Incorporating cover crops (CC) to replace fallow in traditional dryland cropping systems in the semi-arid conditions of western Kansas has the potential to enhance soil health, suppress weeds, and increase precipitation use efficiency. The returns from haying or grazing can help cover costs of CC establishment and any reduction in yield from the subsequent grain crop. Two studies were initiated in 2015 and 2016 near Brownell, KS, to investigate dual-purpose spring and summer CC management effects on subsequent grain yields in a three-year no-till (NT) dryland winter wheat-grain sorghum-fallow cropping system. Cover crops were planted in early spring between grain sorghum and winter wheat or in mid-summer soon after wheat harvest. Cover crops were grazed with yearling heifers, hayed at a six-inch stubble height, or left standing (no forage removal). All CC treatments were compared to NT fallow with no CC. Results showed spring CCs reduced wheat yields between 25 and 31% compared to fallow (59 bu/a) in two of three years, with no difference in the other year. Wheat yields were not different among CC management strategies. Summer CCs reduced grain sorghum yields at rates up to 39% compared to fallow (67 bu/a) in one of three years only when CCs were grazed or left standing but not when CCs were hayed. Sorghum yields were not different in the other two years. Yields of wheat or grain sorghum grown more than one year following CCs in the crop rotation were unaffected by CC treatments. These results showed CCs reduced subsequent crop yields compared to fallow. However, grazed or hayed CCs had no negative effects on dryland wheat and grain sorghum yields compared to standing CCs. Allowing grazing or haying of CCs on land enrolled in Natural Resources Conservation Service cost-share programs could increase producer adoption of CCs in semi-arid western Kansas to enhance regional soil health and increase dryland cropping system profitability.

Introduction

Cover crops (CCs) have the potential to replace portions of the fallow periods in dryland cropping systems in semi-arid western Kansas to enhance soil health, suppress weeds, and increase precipitation use efficiency. In the dryland winter wheat-summer crop (usually grain sorghum or corn)-fallow crop rotation, two periods exist for growing CCs: 1) fallow ahead of wheat planting and 2) fallow following wheat harvest. Haying or grazing CCs could help to cover the costs of CC establishment and potential reductions in subsequent grain yields. Dual-purpose CCs can provide high-quality forage for livestock, which can offset losses in subsequent grain crop yield and potentially increase system profitability. Adjusting Natural Resources Conservation Service (NRCS) cost-share programs to allow grazing or haying of enrolled CCs could be an effective strategy to increase producer adoption of CCs in semi-arid areas like western Kansas.

Grazing CCs can extend the grazing season, delay grazing of native perennial grasslands, and is the most efficient means of utilizing CCs in years when biomass production is relatively low. Additionally, in years when biomass production is high, CCs can be harvested for hay for future feeding. Hay from CCs can be especially valuable during drought when hay supplies become scarce. More information is needed to understand the effects of such dual-purpose CCs on subsequent grain crop yields in the dryland cropping systems of western Kansas, which necessitates the current research. The objective of this study was to determine the effects of dual-purpose spring and summer CCs on wheat and grain sorghum yields in a three-year no-till (NT) dryland winter wheat-grain sorghum-fallow (WSF) cropping system.

Procedures

In 2015 and 2016, two studies were initiated at the Kansas State University HB Ranch near Brownell, KS, to investigate CC management options for dryland cropping systems in western Kansas. The climate at the study site is semi-arid and characterized by erratic rainfall amounts and distribution (Figure 1). The 30-year average annual precipitation is 22 inches. In both studies, the experimental design was a split-plot randomized complete block with four replications. Main plots were the three crop phases of the WSF crop rotation and split-plots (600 ft^2) were grazed, hayed, and standing (no forage removal) CCs. All CC treatments were compared to NT fallow with no CC. The first study was implemented from 2015 to 2019 and compared spring planted CCs to fallow before subsequent winter wheat (Figure 2a). In this study, CCs were a mixture of oats and triticale at a seeding rate of 32 and 38 lb/a, respectively. Spring CCs were planted with a Great Plains no-till drill (Great Plains Manufacturing Inc., Salina, KS) near the third week of March each year as field conditions would allow and terminated with herbicides [Aim EC (carfentrazone-ethyl) and Gramoxone (paraquat)] near the first week of June. The second study was implemented from 2016 to 2021 and compared summer planted CCs to fallow after wheat harvest before subsequent grain sorghum (Figure 2b). In this study, CCs were a mixture of forage sorghum, pearl millet, sunn hemp, and cowpea at seeding rates of 7.5, 2.5, 5, and 20 lb/a, respectively. Summer CCs were planted with the same drill as used for spring CCs shortly after wheat harvest near the third week of July as field conditions would allow and were terminated by killing frost near the third week of October. No fertilizer was applied to spring or summer CCs in this study.

In both studies, CC grazing and haying coincided with heading of the grass components of the cover crop. Grazed CCs were stocked with yearling heifers (weighing about 1000 lb each) at about three head/acre/day to remove approximately 30 to 40% of the available forage. Hayed CCs were harvested to a six-inch cutting height using a Carter small-plot forage harvester (Carter Manufacturing Company, Brookston, IN) to remove approximately 60 to 70% of the available forage. Some regrowth of CCs following grazing or haying and before termination occurred occasionally but was usually minimal with no significant impact in these studies. Following fallow or spring CCs, winter wheat was planted with the same drill as used for CCs near the first week of October at a seeding rate of 60 lb/a with 7.5-inch row spacing and harvested near the last week of June using a Massey-Ferguson 8XP plot combine (Kincaid Equipment Manufacturing, Haven, KS). Eleven months after wheat harvest and following fallow or summer CCs, grain sorghum was planted near the first week of June at a rate of

35,000 seeds/a with 15-inch row spacings with the same planting equipment as used for wheat. Grain sorghum was harvested near the third week of October using the same harvesting equipment as used for wheat. For both grain crops, 18 lb/a P_2O_5 and 5 lb/a N was applied as monoammonium phosphate (11-52-0) with the seed. Additionally, 75 lb/a N was applied as broadcasted urea (46-0-0) for a total of 80 lb/a N for both grain crops. This report summarizes dual-purpose spring and summer CC effects on yields of subsequent winter wheat and grain sorghum as they appeared in the cropping sequence since 2015 and 2016, respectively. Statistical analyses were completed using PROC GLIMMIX of SAS v. 9.3 (SAS Institute, Cary, NC) with year and treatment considered fixed and replication considered random. Treatment differences were considered significant at $P \leq 0.05$.

Results

Wheat yields in the three-year NT winter wheat-grain sorghum-CC system (Figure 2a) were reduced following CCs compared to fallow in two of three years. In 2016, wheat yields following spring CCs were similar to yields following fallow (59 bu/a) (Table 1). However, wheat yields were 31 and 25% less following CCs compared to fallow in 2017 (49 bu/a) and 2018 (42 bu/a), respectively. In all years, wheat yields were not different among CC management strategies (grazed, hayed, or standing). Grain sorghum yields were not different across treatments in all years of this study and averaged 55, 84, and 83 bu/a in 2017, 2018, and 2019, respectively.

Sorghum yields in the three-year NT winter wheat/CC-grain sorghum-fallow system (Figure 2b) were reduced following grazed or standing CCs in one of three years. In 2017, grain sorghum yields following summer CCs were 39% less compared to fallow (67 bu/a) when CCs were grazed or standing (Table 2). However, yields following hayed CCs (59 bu/a) were not significantly different from fallow. Grain sorghum in 2018 followed a failed CC in 2017. As expected, grain sorghum yields were not different across treatments in 2018 and averaged 87 bu/a. In 2019, grain sorghum yields were not different across treatments following a successful CC in 2018 and averaged 75 bu/a. Although grain sorghum yield after hayed CCs was greater compared to standing or grazed CCs in 2017, yields in 2018 and 2019 were not different among CC management strategies. Wheat yields were not different across treatments in any year of this study and averaged 45, 42, and 50 bu/a in 2019, 2020, and 2021, respectively.

In this study, spring CCs reduced subsequent winter wheat yields compared to fallow in two of three years with no differences among CC management strategies (grazed, hayed, or standing).

Summer CCs reduced subsequent grain sorghum yields compared to fallow in one of three years only when CCs were grazed or standing but not when CCs were hayed.

Yields of wheat or grain sorghum grown more than one year following CCs in the crop rotation were not different across treatments. These results show CCs can reduce subsequent dryland grain yields, though crops following grazed or hayed CCs yield similarly to when CCs are left standing (no forage removal). Grazing and haying of CCs could be effective practices in semi-arid western Kansas to generate income to offset losses when grain yields are reduced, which could increase producer adoption of CCs, enhance regional soil health, and increase dryland cropping system profitability.

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Table 1. Cover crop (CC) management effects on winter wheat and grain sorghum yields in a three-year no-till winter wheat-grain sorghum-CC system near Brownell, KS

Treatment	2016	2017	2018	2019
	---------- bu/a ----------			
	---------- Winter wheat yield ----------			
Fallow	59a[†]	49a	42a	---
Standing CCs	57a	35b	36b	---
Hayed CCs	53a	34b	35b	---
Grazed CCs	58a	32b	34b	---
Average	57A	38B	37B	---
	---------- Grain sorghum yield ----------			
Fallow	---	55a	89a	81a
Standing CCs	---	55a	80a	87a
Hayed CCs	---	55a	78a	78a
Grazed CCs	---	56a	89a	86a
Average	---	55B	84A	83A

[†]Means followed by the same lower-case letter are not different ($\alpha = 0.05$) across treatments within the same column and means followed by the same upper-case letter are not different ($\alpha = 0.05$) across years within the same row.

Table 2. Cover crop (CC) management effects on grain sorghum and wheat yields in a three-year no-till winter wheat/CC-grain sorghum-fallow system near Brownell, KS

Treatment	2017	2018	2019	2020	2021
	---------- bu/a ----------				
	---------- Grain sorghum yield ----------				
Fallow	67a†	85a	75a	---	---
Standing CCs	38b	87a	78a	---	---
Hayed CCs	59a	89a	72a	---	---
Grazed CCs	44b	85a	76a	---	---
Average	52C	87A	75B	---	---
	---------- Winter wheat yield ----------				
Fallow	---	---	48a	41a	49a
Standing CCs	---	---	48a	41a	50a
Hayed CCs	---	---	43a	40a	49a
Grazed CCs	---	---	46a	44a	51a
Average	---	---	45B	42B	50A

†Means followed by the same lower-case letter are not different ($\alpha = 0.05$) across treatments within the same column and means followed by the same upper-case letter are not different ($\alpha = 0.05$) across years within the same row.

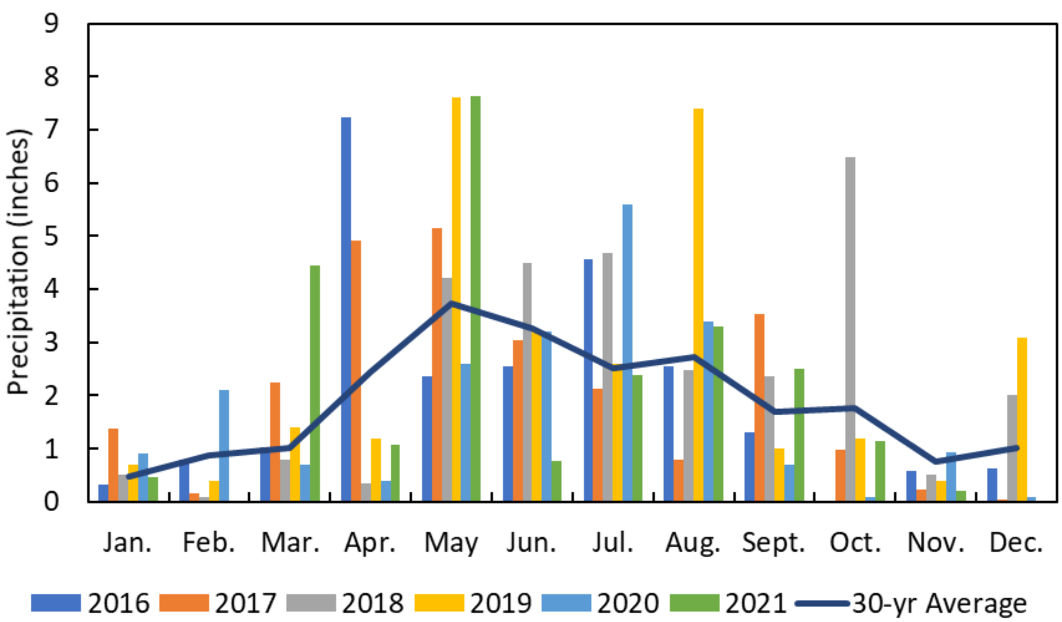

Figure 1. Monthly precipitation from 2016 to 2021 near Brownell, KS.

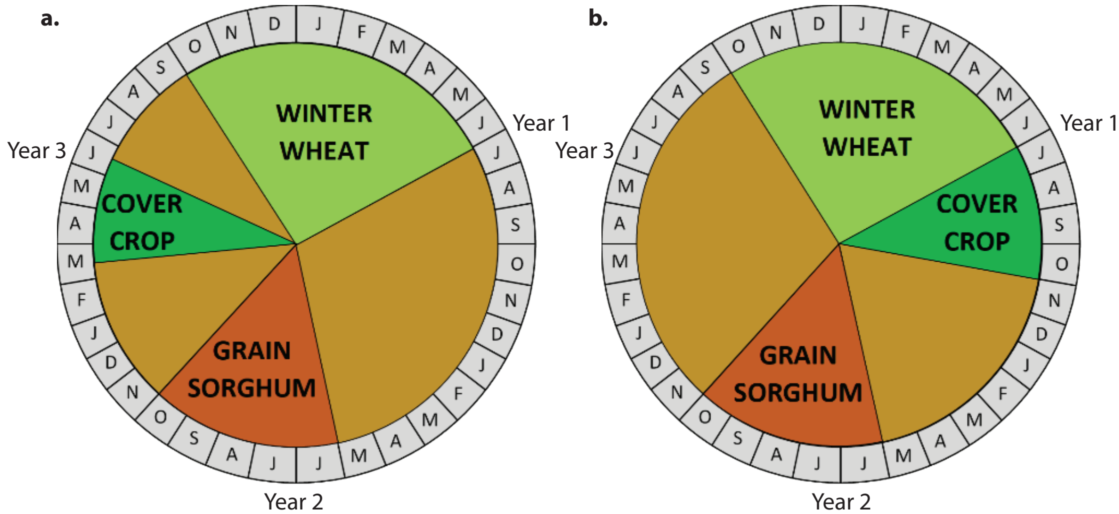

Figure 2. Cropping sequence of the (a.) winter wheat-grain sorghum-cover crop rotation and (b.) winter wheat/cover crop-grain sorghum fallow rotation. Brown areas indicate periods of no-till fallow between crops.

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

E. Adee

Summary
Trends from a tillage study conducted since 2011 have shown no clear differences between tillage systems for either corn or soybeans in lighter soils under irrigation. One year out of eight years has shown a yield advantage for either corn or soybeans for any tillage system, which appears to be related to environmental conditions experienced during the season. Averaged across all years of the study, the treatments with deep tillage either every or every-other year had about 4.5% higher corn yields, and soybeans had up to a 3.2% yield increase with some form of tillage.

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 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 conducted with a field cultivator. Starting in the fall of 2012 through fall of 2017, the treatments were conducted with the TurboMax or a Great Plains Sub-soiler Inline Ripper SS0300. Spring tillage in 2013–2016 was conducted with the TurboMax and a field cultivator in 2017 on the required treatments. Starting in the fall of 2017, the vertical tillage treatments were made using a Kuhn Krause Excelerator 8005. 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, 2016, and 2017 14-52-40-10 (N, P, K, and sulfur (S)) fertilizer was applied to the soybean stubble prior to fall tillage. In the fall of 2019, 16-75-75-10 (S) was applied, and 20-94-94-12.5 (S) was applied in the fall of 2020. Nitrogen (150 lb in 2012 and 2013; 180 lb in 2014, 2015, 2016, 2017, 2018, 2020, and 2021; 160 lb in 2019) was applied in March prior to corn planting. Soybeans were planted after soybeans in the setup year. Planting, harvest, and irrigation information for the study is included in Table 1. Irrigation was calibrated to meet evapotranspiration (ET) rates. All corn was planted in 30-inch rows, as well as soybeans through 2016. Soybeans were planted in 15-inch rows in 2017 through 2020. Soybeans were planted in 30-in. rows in 2021.

Results

Yields of corn or soybeans did not differ due to tillage in the setup year (2012) of the study (Table 2). 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 with no significant differences between tillage treatments (Tables 3 and 4). In 2014, the corn yields were very good and Sudden Death Syndrome lowered soybean yields, but there were no differences between tillage treatments (Tables 3 and 4). The cool and rainy start to the season in 2015 slowed corn growth and lowered yields, while the soybeans had very good yields (Tables 3 and 4). In 2016, which had extremes in soil moisture from dry to saturated, the deep tillage treatments produced higher yields than the shallow tillage in corn, but soybean yields were similar for both tillage treatments. There were soil moisture extremes again in 2017, but a cooler August was very favorable for yields of both crops, with no differences between yields with the different tillage systems. The 2018 growing season started off very cool, but quickly had above normal temperatures. The corn yields were very good, with no difference between tillage systems. The soybean yields were very good, the highest with the more conventional annual tillage and the vertical tillage systems. The 2019 season started off cool for most of May, then had near average temperatures for June and July, followed by a cooler August. The growing season was very wet except for July. The corn yields in 2019 were very good and the soybean yield was the highest observed in the study to date. The season in 2020 started off cool, but turned very hot and dry in June, requiring irrigation. July 2020 was very wet, with August near normal, resulting in average corn yields and very good soybean yields (no SDS symptoms). The 2021 season started off very similar to 2020 through June, with July and August being drier with near normal temperatures, with corn yields down some and soybean yields were very good. Combining data from 2013–2021 for analysis showed corn yields are favored by deep tillage, and soybean yields are likely to improve with any kind of tillage at Pr=0.07 (Tables 3 and 4). Averages of stand counts taken at the V5 stage in the corn for 2014–2021 did not show any differences (Table 3). We anticipated that it would take several years for any characteristics of a given tillage system to build up to the point of influencing yields. Deep soil samples were collected during the fall of 2020 to compare soil properties and soil health between tillage systems. Results of those data will be reported when analysis is completed.

Conclusions

The influence of tillage system on corn or soybean yield appears to be dependent on the year. A given set of environmental conditions may favor a system, but in Kansas the conditions can vary considerably each year. 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. The yield-limiting conditions may vary between fields based on soil type and environmental conditions during a season and over the long term.

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Table 1. Cropping details for tillage study at Kansas River Valley Experiment Field

	2013	2014	2015	2016	2017	2018	2019	2020	2021
					Corn				
Planting date	30-Apr	21-Apr	14-Apr	11-Apr	24-Apr	23-Apr	22-Apr	22-Apr	26-Apr
Hybrid/variety	Pioneer P1498 HR AQ	Pioneer P1105AM	Pioneer P1105AM	AgriGold 6538	Midland 534	Golden Harvest 11B63	Pioneer 1197	Pioneer 1197	NK 13-54
Seeding rate	30K	32K	31.7K	31.7K	32K	32K	32.4K	32.4K	33K
Row spacing (inches)	30	30	30	30	30	30	30	30	30
Harvest date	27-Sep	11-Sep	10-Sep	19-Sep	20-Sep	31-Aug	17-Sept	15-Sept	13-Sept
Irrigation (inches)									
May	0	0	0	0	0	0	0	0	0
June	1.58	0	1.58	2.24	2.88	4.71	1.03	4.8	1.7
July	3.51	4.74	2.29	4.40	3.63	6.55	2.36	0.8	2.55
August	0.77	2.19	2.87	0.70	1.81	0.84	0	.8	2.55
September	0	0	0	0	0	0	0	0	0
					Soybean				
Planting date	15-May	21-May	1-Jun	31-May	26-May	7-May	6-June	19-May	13-May
Hybrid/variety	Pioneer P94Y01	Asgrow 3833	Midland 3884NR2 + ILeVO	Stine 42RE02	Pioneer P39T67 + ILeVO	Midland 4373 RR2	Asgrow 36x6 + ILeVO	Pioneer P37A27+ ILeVO	AG40X70 + ILeVO
Seeding rate	144K	140K	144K	140K	140K	140K	140K	140K	140K
Row spacing (inches)	30	30	30	30	15	15	15	15	30
Harvest date	8-Oct	9-Oct	13-Oct	17-Oct	17-Oct	17-Oct	17-Oct	9-Oct	7-Oct
Irrigation (inches)									
May	0	0	0	0	0	0	0	0	0
June	1.58	0	0.74	0.74	0	0	0	0	0
July	3.51	1.55	0.74	4.40	1.82	3.90	1.51	0	.85
August	2.27	2.19	2.87	1.54	1.81	0.84	0	1.6	2.55
September	2.18	0	0	0	0	0	0	0	.85

Table 2. 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	
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 3. Effects of tillage treatments on corn yields and plant stands in 2013–2021 at Kansas River Valley experiment fields

	Corn yield, bu/a									Average corn yield	Average stand, plants/a
Tillage treatment	2013	2014	2015	2016	2017	2018	2019	2020	2021	2013–2021	2014–2021
No-tillage	221	243	205 b	183 b*	226	206	218	207	187 b	211 b	32,111
Fall subsoil/spring field cultivate	223	259	215 a	202 a	236	214	228	212	202 a	221 a	31,952
Fall vertical tillage	196	259	207 b	189 b	226	210	219	211	191 b	211 b	31,950
Fall subsoil after sb/vertical tillage after corn	214	256	211 ab	195 a	231	209	227	216	198 a	218 a	31,733
Pr>F#	0.14	0.27	0.05	0.005	0.46	0.7	0.22	0.36	0.006	0.001	0.69

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

Table 4. Effects of tillage treatments on soybean yields in 2013–2021 at Kansas River Valley experiment fields

	Soybean yield, bu/a									Average soybean yield
Tillage treatment	2013	2014	2015	2016	2017	2018	2019	2020	2021	2013–2021
No-tillage	62.4	52.8	69.7	80.2	67.4	69.3	78.1	73.1	80.3	69.2 b
Fall subsoil/spring field cultivate	64.3	55.2	73.1	76.0	72.8	71.2	79.2	72.5	85.8	71.5 a
Fall vertical tillage	64.4	55.5	72.8	78.6	68.1	75.0	80.5	76.0	84.4	71.4 a
Fall subsoil after sb/vertical tillage after corn	66.3	52.8	70.9	75.8	70.1	70.2	80.1	74.0	82.9	70.3 ab
Pr>F#	0.52	0.40	0.23	0.12	0.098	0.51	0.87	0.54	0.32	0.03

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

Yield Response to Nitrogen Management in a Corn-Soybean Sequence in North Central Kansas – 2021 Season

A.A. Correndo, O. Lanza Lopez, L.F.A. Almeida, and I.A. Ciampitti

Summary

The aim of this study was to evaluate the response of corn (*Zea mays* L.) grain yield to nitrogen (N) fertilizer application and its residual effect on soybean [*Glycine max* (*L.*) Merr.] seed yield. During the 2021 growing season, a corn-soybean rotation study was continued at Scandia, KS (USA), evaluating the effect of five N fertilizer rates (0, 53, 107, 161, and 214 lb N/a) applied in corn under both dryland and irrigated conditions. Average corn grain yields ranged from 124 to 147 bu/a for dryland, and from 159 to 203 bu/a for irrigated conditions. However, no significant grain yield response to fertilizer N rate was observed in either dryland or irrigated plots. Average soybean seed yields varied from 46 to 59 bu/a for dryland and from 76 to 86 bu/a for irrigated conditions. A significant effect of previous corn fertilizer N rate was observed under dryland conditions. Also observed was a significant positive soybean seed yield effect with corn maximum N rate (214 lb N/a) with respect to rates of 53 and 107 lb N/a. No residual effects of previous corn N rate were observed on soybean yields under irrigation.

Introduction

The aim of this study was to continue with the assessment, under both rainfed and irrigated conditions, of the response of corn grain yield to N fertilizer and the residual effects of the N fertilization practice on corn on the following soybean crop in north central Kansas.

Procedures

A third year of a long-term study under a corn-soybean rotation (started in 2019) was continued in the 2021 cropping season at the North Central Kansas Research Station (Scandia, KS; 39°49'41.60"N, 97°50'22.07"W) in a Crete silt loam soil (fine, montmorillonitic, mesic Typic Argiduolls/Pachic Argiustolls). Before planting, six cores per soil sample were collected per plot at 0–6 inches soil depth in both corn and soybean plots under rainfed and irrigated areas. General soil fertility was evaluated on those samples by testing for pH, soil organic matter (SOM, %), soil texture (%), extractable (M-3) phosphorus (P, mg/kg), potassium (K, mg/kg), and N as nitrate (NO_3-N) and as ammonia (NH_4-N) (Table 1). Additionally, 3 cores per plot were collected at 0-24 inches to evaluate initial soil N availability (NO_3-N + NH_4-N). Seasonal weather data were gathered from Kansas Mesonet (Kansas State University (https://mesonet.k-state.edu/)) (Figure 1) from the North Central Kansas Research Station (Scandia, KS). The corn experiment consisted of a total of five fertilizer N rates (Table 2) under a randomized complete block design with five replications in plots 20 ft width by 50 ft length. Soybean was the previous crop for corn plots. Under the same design, the N rate management on the previous corn crop (2020) was used as treatment for the 2021 soybean crop. Corn plots were planted on May 4, and soybean plots on May 12. Corn plots were mechanically harvested using a combine on October 17, 2021, from the two central rows, then corrected to 15.5% moisture content and scaled to bu/a. Soybean plots were mechanically harvested using a combine on October 5 (dryland) and October 12 (irrigated) from the two central rows then corrected to 13% of moisture and scaled to bu/a.

Data Analysis

The yield data analysis was executed by performing an analysis of variance (ANOVA) split by irrigation condition. For each condition, a mixed model was considered, with treatment (N rate) as the fixed and block as the random factor. When a significant treatment effect was observed ($P \leq 0.05$), mean comparisons were performed using the Tukey's adjustment procedure. Analyses were carried out using the nlme and emmeans packages of R software (R Core Team, 2020). Nitrogen response curves were evaluated with regression analysis using a quadratic function using nls function from *'stats'* package.

Results

Soil Fertility

The topsoil fertility showed similar levels between dryland and irrigated areas, with slightly acidic soil pH, adequate SOM level (approximately 3%), medium soil P, and high K. Initial soil N availability for corn at 0–24 inches (NO_3-N plus NH_4-N) averaged 106 lb N/a for the dryland and 122 lb N/a for irrigated areas, respectively. In both cases, between 59% to 89% of N was with the NO_3-N form.

Weather

The total precipitation during the planting-maturity period (May-September) was low, approximately 12 inches. The precipitation distribution pattern denoted low precipitation at the beginning of the season (< 5 in. during the first month) and a dry month of June. More regular and abundant precipitation events were registered during late July and August. Only 4 days with heat stress risks (T_{max}>95°F) were registered from June to August.

Corn Grain Yield

Although a positive yield trend was observed, corn grain yield did not significantly respond to N fertilization ($P > 0.05$) either under dryland or irrigated conditions (Figure 2), presumably due to the high initial soil N availability (>100 lb N/a). As expected for a dry season, greater yields were observed for irrigated (159 to 203 bu/a) as compared to dryland (124 to 147 bu/a), where yield was limited due to water stress. When initial soil N availability was added to the N rate (not shown), a regression model did not show any improvements detecting response to soil N availability (which was presumably a not limiting factor).

Soybean Seed Yield

Average soybean yields varied from 46 to 59 bu/a for dryland and from 76 to 86 bu/a under irrigation (Figure 3). Negligible effects of the corn N management from the previous season were significant ($P > 0.05$) under irrigated conditions for soybean seed yield. However, under dryland management, yields were significantly higher ($P < 0.01$) on plots where the previous corn received the maximum N rate (214 lb N/a) compared to rates of 53 and 107 lb N/a. Nonetheless, dryland soybean yields for previous N rates of 0 and 163 lb N/a were not statistically different from any other previous N rate.

References

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Table 1. Soil fertility (0–6 inches) at planting of corn and soybean crops at irrigated and dryland areas in Scandia, KS, for the 2021 cropping season

Crop	0- to 6-in. depth	pH	SOM	Clay	Silt	Sand	P	K	$N\text{-}NO_3$	$N\text{-}NH_4$
		-	%				ppm			
Corn	Dryland	5.9	3.1	23	60	17	13	501	8.9	6.9
	Irrigated	6.0	2.9	22	59	19	17	498	14	5.8
Soybean	Dryland	5.7	3.0	24	60	16	15	520	4.3	6.1
	Irrigated	6.2	2.9	25	57	18	18	495	8.1	4.7

Table 2. Crop management practices for corn and soybean crops at Scandia, KS, for the 2021 cropping season

Practices	Corn		Soybean	
Irrigation	Dryland	Irrigated	Dryland	Irrigated
Tillage	No-till			
Planting date	05/04/2021		05/12/2021	
Genotype	P1366AML		P39A45X (RR2-Xtend)	
Seeding rate	28,500 seeds/a	30,000 seeds/a	110,000 seeds/a	140,000 seeds/a
Row spacing	30 inches			
P fertilization	23 lb P/a			
N fertilization	0, 53, 107, 161, 214 lb N/a		zero N fertilization	

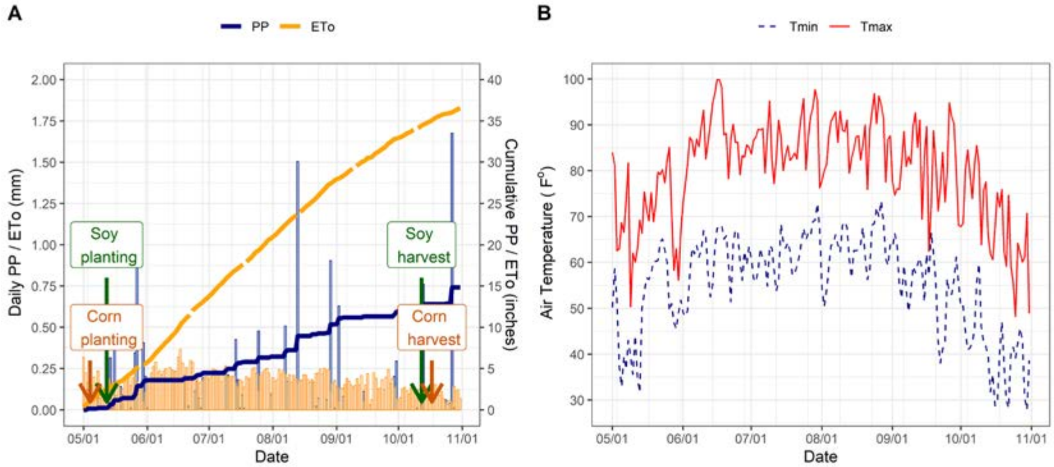

Figure 1. A) Daily and cumulative precipitation (PP) and reference evapotranspiration (ETo); and B) daily minimum and maximum air temperature for the 2021 cropping season at Scandia, KS.

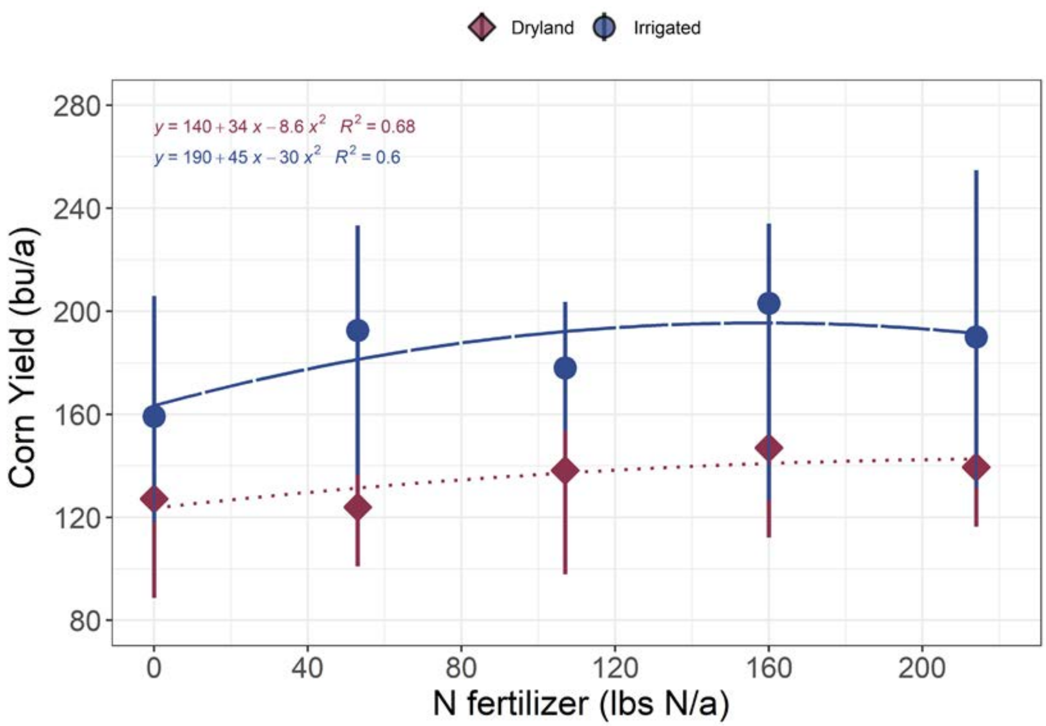

Figure 2. Corn grain yield (bu/a) versus N fertilizer rate treatments (applied as urea at V5 stage).

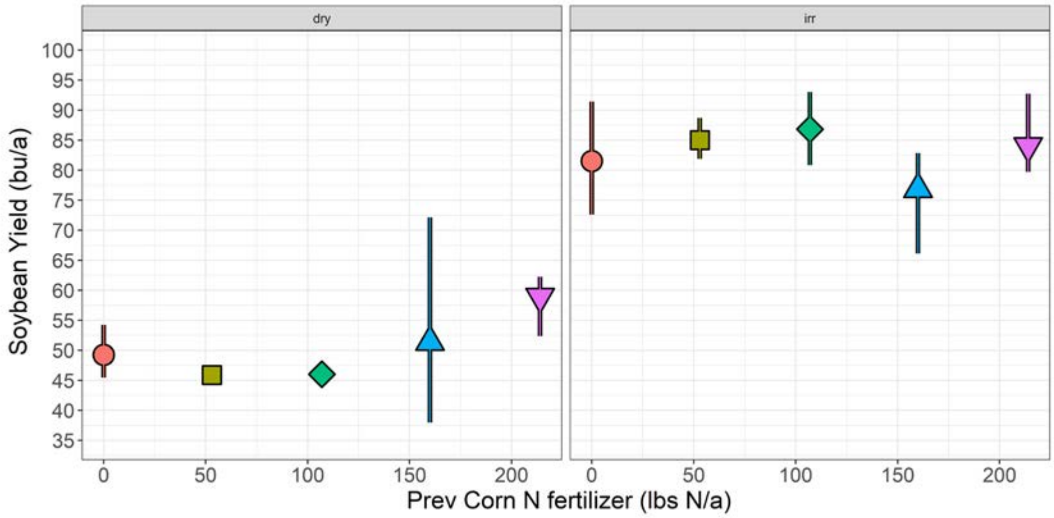

Figure 3. Soybean seed yield (bu/a) versus previous corn N fertilizer rate treatments (lb N/a). Overlapping error bars indicate the absence of statistical differences (Tukey LSD 5%).

Historical Characterization of Sorghum Grain Filling Dynamics

J. Grünberg, A.J.P. Carcedo, P.A. Demarco, L. Mayor, and I.A. Ciampitti

Summary

Understanding crop response to manipulations in source (number of leaves) and sink (panicle) during the growing season provides useful information to develop crop breeding strategies. In the present study, we assessed how source-sink manipulation can affect sorghum (*Sorghum bicolor* L.) yield and its components—grain number and grain weight (including grain filling dynamics)—for hybrids released in the past 60 years. The field experiment was conducted during the 2021 growing season in Wamego, KS (US), testing six commercially available grain sorghum hybrids released between 1963 and 2020. Grain weight significantly decreased from 28 to 21 mg in defoliation treatments among hybrids over time; and reached a maximum value of 34 mg when panicles were halved ($P < 0.05$). For the control scenario, yield consistently increased over time ($P < 0.01$). When source-sink treatments were applied, there was a reduction of 33 bu/a for the defoliation and 39 bu/a for the panicle halving ($P < 0.001$). Regarding grain number per unit area, the trend was similar across hybrids over time ($P < 0.1$) but decreased with the panicle halving to 1600 grains on average ($P < 0.001$) relative to both control and defoliation scenarios. Over time and across source-sink treatments, there was no significant change in grain filling rate. However, a significant reduction for the duration of the grain filling was documented for defoliated plants, with a greater decrease over time.

Introduction

Grain sorghum *(Sorghum bicolor* L.) is the fifth-largest cereal crop in the world (Ciampitti and Prasad, 2019), standing out for competitive advantages including high biomass production, grain quality, and yield stability under stress conditions such as drought and high temperatures (Gizzi and Gambin, 2016). Although sorghum possesses these desirable plant traits, the genetic gain in the past decades has been low compared to other crops. For example, whereas for maize the yield genetic gain increased 54-88 kg/ha (0.87-1.27 bu/a) per year (Fernandéz et al., 2022), for sorghum it was only 19-35 kg/ha (0.30-0.55 bu/a) per year (Demarco et al., 2021). Therefore, a better understanding of the source-sink balance for sorghum would help to develop breeding strategies to improve marketability in current production systems.

Previous studies on source-sink relationships provided evidence that crops could be yield-limited by source, sink, or both (Borras et al., 2004). In this context, source refers to photosynthesis capacity of green leaves, and sink refers to the growing capacity of organs (e.g., grain number and grain size) to accumulate assimilates (critical for yield formation). The rates and amounts of dry matter accumulation and the growth of harvestable organs of a crop are determined by the assimilate supply of green leaves (source strength) and the capacity of organs to store assimilates (sink strength) (Asseng et al., 2016).

This study was conducted to characterize yield and its components in response to manipulations on the source-sink ratio for sorghum hybrids with different years of release to identify plant traits associated with yield improvement.

Procedures

The study was conducted at the Corteva Agriscience research station in Wamego, KS (US), during the 2021 growing season. Six sorghum hybrids from Corteva Agriscience were selected to represent six decades of genetic selection (from 1960 until 2020).

Sorghum was planted on June 7, 2021, in eight-row plots. Each row length was 16 ft with 30-in. row spacing.

Standard agronomic practices were followed to maintain the field free of weeds, pests, and diseases during the season. The experimental design was a split-plot with factorial subplot structure. Hybrids were assigned to whole plots, and source-sink treatment factor was assigned to each sub-plot ten days after flowering. Three levels of source-sink ratio were included: 1) control; 2) increase of the source-sink ratio by halving the panicle along the rachis; and 3) reduction of the source-sink ratio by partially removing leaves.

To increase the source-sink ratio (treatment 2), all the branches from one side of the panicle were manually removed; with the expectation to remove 50% of the grains with a uniform distribution across the four panicle positions. To decrease the source-sink ratio (treatment 3), defoliation was accomplished by removing 80% of the leaves of each plant treated (Heiniger et al., 1993).

During the grain filling period, one panicle per plot and sub-plot was collected to characterize the seasonal dynamics of grain dry weight. In each of these plants, phenology was tracked daily before flowering and during the reproductive period. At the laboratory, 40 grains per panicle were separated by collecting 10 grains from each of four visually determined sections of the head. Fresh weight of the grains was first obtained, and then dry weight after drying those grains in an air-forced oven at 150°F until constant weight (Demarco et al., 2021). Grain weight, expressed as individual grain (mg), was calculated as the total grain dry weight divided to the total number of grains.

Grain filling rate and grain filling duration were estimated by fitting a bi-linear model [equations (1) and (2)] in each hybrid and source-sink treatment combination, with grain dry weight modeled on a day-time basis from flowering to harvest maturity:

$$\text{Grain weight (mg grain}^{-1}) = a + b \times x \qquad \text{for } x < c \qquad [1]$$

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

where x are the days after flowering, a is the y-intercept (mg grain^{-1}), b is the grain growth rate (mg grain/day), and c is the total duration of grain filling period (in days). Mixed-effects models were fitted with the nlme (Pinheiro et al., 2018) package in RStudio (RStudio team, 2016) for each of the treatments done. The effect on all variables under study was determined through analyses of variance (ANOVA). Relationships among variables were described through linear regression analysis.

Results

Final weight was significantly affected by modifications of the source-sink ratio during grain filling ($P \leq 0.001$, Table 1). The average weight per kernel increased by 34 mg when treatment 2 was applied. In contrast, grain weight was drastically reduced to 21 mg when treatment 3 was applied. Grain weight remained relatively stable across different years of release, with no significant changes. The impact of source-sink treatments remained the same across different years of release (Figure 1A).

On the other hand, a significant increase in both yield and grain number has been observed with the year of release ($P \leq 0.1$ and $P \leq 0.01$, respectively; Figure 1B and 1C). In addition, both variables (yield and grain number) were negatively affected when source-sink manipulation treatments were applied. Grain number across all hybrids was reduced significantly up to 1526 grains per ft^2 when panicles were halved. Regarding yield, a decrease was recorded from 137 bu/a in the control to 104 bu/a when reducing the source, and 98 bu/a when reducing the sink ($P \leq 0.001$). These reductions in yield and grain number didn't show differences across different hybrids tested.

Furthermore, when analyzing grain filling dynamics, a bi-linear relationship within these two variables showed that variations in grain filling duration were responsible for the major changes in grain. The results showed that the grain filling rate ranged from 0.59 to 1.35 mg of grain/day and it was neither affected by the year of release nor source-sink manipulation. However, grain filling duration was significantly reduced, from an average of 31 days in the control treatment to 26 days in treatment 3 ($P \leq 0.05$, Figure 1D). Furthermore, this reduction was more noticeable in newer released hybrids achieving the shortest grain filling duration when the source was manipulated (19 days shorter in the newest hybrid) ($P \leq 0.05$).

In conclusion, there was no decrease in grain number when the defoliation was applied relative to the control across all hybrids. This result emphasizes that the application of defoliation (10 days after flowering) did not impact grain number set or increase abortion rates. In contrast, both yield and grain weight component were affected by defoliation. These results indicated that sorghum is mostly limited by source, in agreement with the outcomes presented by Gambin and Borras (2007). An increase in yield due to genetic progress was also notable, with no differences in grain weight. Regarding grain filling period and dynamics, the defoliation effect was different throughout the years of release, where modern hybrids presented shorter duration of this stage. This reduction in the duration of the grain filling could be explained by a severe limitation on assimilates by defoliation, yet further analysis should be done to corroborate this hypothesis.

References

Asseng S., Kassie B.T., Labra M.H., Amador C., Calderini D.F., 2016. Simulating the impact of source-sink manipulations in wheat. Field Crops Research, 202 47-56.

Borrás L, Slafer GA, Otegui ME. 2004. Seed dry weight response to source–sink manipulations in wheat, maize and soybean: a quantitative reappraisal. Field Crops Res. 86: 131–146.

Ciampitti IA, Prasad PVV (2019) Sorghum: state of the art and future perspectives. Agronomy Monograph 58. American Society of Agronomy, Madison, WI, USA.

Demarco, P. A.; Mayor, L.; Prasad, P. V.; Messina, C. D.; and Ciampitti, I. A. (2021) "Sorghum Grain Filling and Dry Down Dynamics for Hybrids Released Over the Past Six Decades in the US," Kansas Agricultural Experiment Station Research Reports: Vol. 7: Iss. 5.

Fernández Javier A, Messina Carlos D, Salinas Andrea, Vara Prasad P V, Nippert Jesse B, Ciampitti Ignacio A. Kernel weight contribution to yield genetic gain of maize: A global review and US case studies, Journal of Experimental Botany, 2022; DOI:*10.1093/jxb/erac103*.

Gambin B.L. & Borras L., 2007. Plasticity of sorghum kernel weight to increased assimilate availability. Field Crops Research, 100 272-284.

Gizzi, G., & Gambin, B. L. (2016) Eco-physiological changes in sorghum hybrids released in Argentina over the last 30 years. Field crops research, 188, 41-49.

Heiniger R.W., Vanderlip R.L., Kofoid K.D., 1993. Influence of pollination pattern on intrapanicle caryopsis weight in sorghum. Crop Science, 33 549-555.

Pinheiro, J., Bates, D., DebRoy, S., & Sarkar, D. (2018). R.C.T. 2018. nlme: linear and nonlinear mixed effects models. R. package version 3. R.F.S.C.R. 2018.

RStudio Team. (2016). RStudio: Integrated Development for R. RStudio, Inc. Boston, MA. *https://www.rstudio.com/*.

Table 1. Analysis of variance and means for grain weight, grain number, yield, grain filling rate and duration for different years of release (YR) and three source-sink treatments (SS) in the 2021 field experiment

Year of release	Source-sink	Days to FL	Grain weight	Grain number	Yield	Grain filling rate	Grain filling duration
			mg/grain	ft^2	bu/a	mg grain/day	days
1960	Control	59	26.48	2909	132.1	1.03	31
1982	Control	61	25.63	2794	122.8	0.80	35
1997	Control	60	28.38	2629	128.0	1.15	30
2006	Control	59	28.23	2941	142.4	1.24	28
2010	Control	61	27.95	3350	160.6	1.22	29
2020	Control	60	30.29	2571	133.5	0.86	37
1960	Defoliation	58	21.47	2732	100.6	0.59	37
1982	Defoliation	61	20.55	2637	92.9	1.10	39
1997	Defoliation	61	19.91	3228	110.2	0.65	31
2006	Defoliation	59	19.69	3280	110.7	0.94	28
2010	Defoliation	61	22.31	2768	105.9	0.87	29
2020	Defoliation	61	20.32	3014	105.0	1.13	18
1960	Panicle halving	59	30.29	1585	82.3	1.22	30
1982	Panicle halving	61	36.47	1472	92.0	1.27	28
1997	Panicle halving	61	34.53	1885	111.6	1.18	30
2006	Panicle halving	58	35.42	1544	93.8	1.16	32
2010	Panicle halving	60	37.26	1448	92.5	1.10	31
2020	Panicle halving	58	32.19	2091	115.4	1.35	27
Source of variation							
Year of release (YR)			Ns	+	**	Ns	Ns
Source-sink (SS)			***	***	***	Ns	*
YR × SS			Ns	Ns	Ns	Ns	*

+ 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.

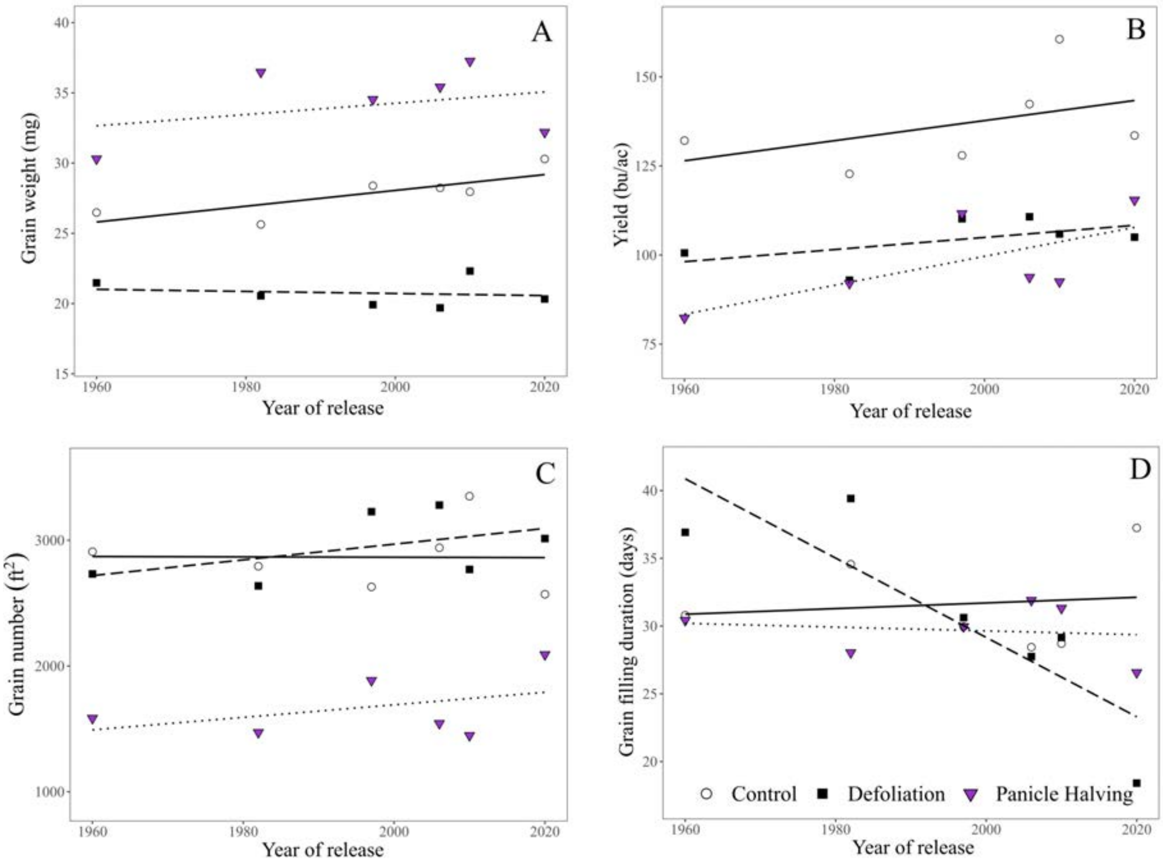

Figure 1. Grain weight (A), yield (B), grain number (C), and grain filling duration (D) across year of release (from 1960 to 2020). Source sink treatments: control = solid line and circles; defoliation = dashed line and squares; panicle having = dotted line and triangles.

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