KANSAS STATE UNIVERSITY
Agronomy

KANSAS FIELD RESEARCH 2021

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Research and Extension

KANSAS STATE UNIVERSITY AGRICULTURAL EXPERIMENT STATION AND COOPERATIVE EXTENSION SERVICE

KANSAS FIELD RESEARCH 2021

Contents

3 2021 Field Book Contributors

Weather

5 Field Station Weather Reports

Corn

15 Effect of Late Planting Dates on Corn Yield

23 Comparison of Static and Active Downforce on Corn at the Kansas River Valley Experiment Field in 2020

25 Corn Grain Weight: Dependence upon Nitrogen Supply and Source-Sink Relations

33 Corn Tiller Yield Contributions and Ear Development in Low Plant Densities

Cropping and Tillage

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

Grain Sorghum

43 Sorghum Grain Filling and Dry Down Dynamics for Hybrids Released Over the Past Six Decades in the US

Management Practices

50 Macronutrient Fertility on an Irrigated Corn/Soybean in Rotation

56 Does Grazing Cover Crops Impact Soil Properties?

61 Using a Sprayable Biodegradable Polymer to Reduce Soil Evaporation in Greenhouse Conditions

66 Laboratory Calibration of the Spectrum Field Scout TDR 300

70 Evaluating Traditional and Modern Laboratory Techniques for Determining Permanent Wilting Point

76 Preliminary Classification of Soil, Plant, and Residue Cover Using Convolutional Neural Networks

79 On-Farm Assessment of AquaSpy Soil Moisture Sensors for Irrigation Scheduling

85 Yield Response to Nitrogen Management in a Corn-Soybean Sequence in North Central Kansas

90 Forage Accumulation of Spring and Summer Cover Crops in Western Kansas

96 Dual-Purpose Cover Crop Effects on Soil Health in Western Kansas No-Till Dryland Cropping

102 Kansas Soil Health Partnership

Soybean

110 Co-Inoculation and Sulfur Fertilization in Soybeans

Weeds

117 Foxtail Management in Smooth Brome Hay Meadows

121 Efficacy of Imiflex, Zest, and Assure II on Green Foxtail Control

128 Auxinic Herbicide Mixtures for Controlling Multiple Herbicide-Resistant Kochia in Fallow

134 Interaction of 2,4-D with Glyphosate or Graminicides on Grass Weed Control in Enlist E3 Soybeans

141 Effect of Tank-Mixing Glyphosate, Dicamba, and Graminicides on Grass Weed Control in Roundup Ready 2 Xtend Soybeans

146 Control of Volunteer Enlist Corn in Enlist E3 Soybean

Wheat

150 Winter Wheat Response to Different Fungicide Management (Products and Timing of Application) During the 2019–2020 Growing Season

156 Winter Wheat Variety Response to Flag Leaf Foliar Fungicide Application in 2019–2020

161 Wheat Variety-Specific Response to Seeding Rate Under Intensive Management Conditions in Western Kansas in 2019–2020

167 Wheat Variety Response to Seeding Rate Across a Range of Kansas Environments in 2019–2020

173 Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2019–2020 Growing Season in Kansas

181 Testing Efficacy of Plant Growth Regulator Products for Enhanced Winter Wheat Grain Yield and Quality

184 Winter Wheat Variety Response to Timing and Number of Fungicide Applications During the 2019–2020 Growing Season in Kansas

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Field Station Weather Reports

East Central Kansas Experiment Field

Introduction

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

Soil Description

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

2020 Weather Information

Precipitation during 2020 was almost 30% lower than average, with nine months below average (Table 1). Overall, the 2020 growing season was warmer than average, especially starting in June. The summer of 2020 had 46 days exceeding 90°F but none exceeding 100°F, which compares to an average of 30 days exceeding 90°F, in the last 3 years. There were 5 days with low temperatures in the single digits, compared to an average of 11 days in the previous 3 years. The last freezing temperature in the spring was April 18 (average, April 18), and the first killing frost in the fall was October 15 (average, October 21). There were 180 frost-free days, less than the long-term average of 185.

Rainfall from the last week of April through May made planting and field work challenging in the spring. There was adequate moisture to get corn and grain sorghum through a hot and dry June. The corn and grain sorghum hybrid trials averaged 174 and 138 bu/a, respectively. However, the lack of moisture in August lowered soybean production. The early maturing soybean variety trial averaged 48 bu/a and the later maturing trial 48.6, both well below the averages of the last several years.

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.

2020 Weather Information

The year was generally warmer than last year, with below average rainfall during most of the growing season. The frost-free season was 183 days at both Rossville and Paramore units (average = 173 days), with 4 and 5 days in the single digits or lower at Rossville and Paramore, respectively, which was much fewer than the average of 18 single digit days in the previous 2 years. The last spring freeze was April 15 (average = April 21), and the first fall freeze was October 15 (average = October 11). There were 38 and 41 days above 90°F at Paramore and Rossville, respectively, and none above 100°F. Precipitation was below normal at both fields for the year (Table 2), with 8 months below average. May and especially July were significantly above normal, with July rainfall 3 times greater than average. Most of the irrigation for corn was in June, much earlier than normal, with a total 4.2 inches for the corn. Soybeans were irrigated an average of 1.6 inches in August. The corn performance trials averaged 214 bu/a for the irrigated and 210 for the dryland. The soybean performance trials averaged 58.7 bu/a for the irrigated and 71 bu/a for the dryland. The sudden death syndrome foliar symptoms were first seen in early August in most fields in 2020, causing significant yield loss in soybeans in the irrigated trial due to the disease.

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

Month	2020	35-year avg.	Month	2020	35-year avg.
	---------------- in. ----------------			---------------- in. ----------------	
January	1.71	1.03	July	4.19	3.37
February	1.27	1.32	August	1.19	3.59
March	2.75	2.49	September	1.47	3.83
April	1.81	3.50	October	1.35	3.43
May	4.22	5.23	November	1.36	2.32
June	2.92	5.21	December	1.39	1.45
			Annual total	26.63	36.78

Table 2. Precipitation at the Kansas River Valley Experiment Field

	Rossville Unit		Paramore Unit	
Month	2020	30-year avg.	2020	30-year avg.
	-- in. --			
January	1.39	3.18	1.35	3.08
February	0.95	4.88	0.89	4.45
March	2.55	5.46	2.53	5.54
April	2.93	3.67	3.47	3.59
May	4.19	3.44	4.42	3.89
June	4.35	4.64	2.96	3.81
July	8.61	2.97	10.25	3.06
August	0.98	1.90	1.03	1.93
September	2.67	1.24	1.95	1.43
October	0.49	0.95	0.54	0.95
November	1.71	0.89	1.73	1.04
December	0.76	2.42	1.02	2.46
Total	28.65	35.64	32.14	35.23

Table 3. Precipitation at Ashland Bottoms, Belleville, and Beloit

	Ashland Bottoms		Belleville		Beloit	
Month	**2020**	**30-year average**	**2020**	**30-year average**	**2020**	**30-year average**
	------------------	------------------	------------------ in. ------------------	------------------	------------------	------------------
January	1.82	0.65	1.19	0.61	1.14	0.62
February	0.78	1.07	0.07	0.87	0.09	0.76
March	2.32	2.20	1.07	2.12	0.51	1.91
April	2.40	2.80	0.45	2.87	1.12	2.47
May	7.45	4.48	2.50	4.35	3.36	4.16
June	5.04	5.09	2.50	4.37	6.85	3.81
July	10.13	3.97	6.16	3.97	11.13	4.36
August	1.76	4.28	0.37	3.68	1.62	3.09
September	2.60	3.17	1.60	3.25	1.12	2.64
October	0.33	2.22	0.02	2.37	0.04	1.99
November	2.57	1.60	0.87	1.19	1.92	1.21
December	1.05	1.02	0.22	0.95	0.46	0.90
Annual	38.25	32.55	17.02	30.6	29.36	27.92
Last freeze	17-Apr-20		18-Apr-20		17-Apr-20	
First freeze	15-Oct-20		2-Oct-20		24-Oct-20	
Frost free days	181		167		190	
Days above 90°F	44		37		39	
Days above 100°F	1		2		0	
Days below 10°F	6		10		9	

30-year average = 1981–2010.

Table 4. Precipitation at Buhler (Hutchinson), Colby, and Conway Springs (Viola)

	Buhler (Hutchinson)		Colby		Conway Springs (Viola)	
Month	**2020**	**30-year average**	**2020**	**30-year average**	**2020**	**30-year average**
	----------------	----------------	---------------- in.	----------------	----------------	----------------
January	1.27	0.69	0.28	0.41	1.99	0.83
February	2.90	1.08	0.38	0.48	1.87	1.18
March	2.28	2.56	1.70	1.12	2.57	2.75
April	1.07	2.72	0.26	2.03	0.99	3.06
May	6.28	4.44	1.97	3.29	4.66	4.42
June	3.50	4.86	1.45	2.54	1.18	5.04
July	6.83	3.76	4.21	3.77	4.33	3.08
August	0.35	3.14	1.82	2.78	2.21	3.36
September	2.18	2.67	0.82	1.45	2.44	2.61
October	1.17	2.34	0.21	1.58	3.55	2.94
November	2.56	1.33	0.00	0.72	0.68	1.58
December	0.85	1.02	0.64	0.48	1.81	1.08
Annual	31.24	30.61	13.74	20.65	28.28	31.93
Last freeze	16-Apr-20		21-Apr-20		18-Apr-20	
First freeze	26-Oct-20		12-Oct-20		25-Oct-20	
Frost free days	193		174		190	
Days above 90°F	68		68		67	
Days above 100°F	0		0		2	
Days below 10°F	2		2		1	

30-year average = 1981–2010.

Table 5. Precipitation at Garden City, Goodland, and Greensburg

	Garden City		Goodland		Greensburg	
Month	**2020**	**30-year average**	**2020**	**30-year average**	**2020**	**30-year average**
	---------- in. ----------					
January	0.82	0.47	0.40	0.38	3.67	0.56
February	0.80	0.52	0.40	0.49	1.20	0.74
March	0.46	1.23	1.01	1.07	1.43	2.10
April	0.13	1.74	0.30	1.59	1.19	1.98
May	0.72	3.00	2.89	2.95	3.62	3.26
June	1.88	3.10	1.77	3.25	2.86	4.21
July	5.18	2.80	4.93	3.47	6.28	3.15
August	1.86	2.51	2.81	2.70	1.60	3.16
September	1.57	1.42	0.66	1.22	1.49	2.10
October	0.16	1.22	0.23	1.37	2.34	2.18
November	0.55	0.54	0.01	0.71	1.57	0.95
December	0.34	0.60	0.77	0.46	1.59	0.84
Annual	14.47	19.15	16.18	19.66	28.84	25.23
Last freeze	25-Apr-20		9-May-20		18-Apr-20	
First freeze	23-Oct-20		16-Oct-20		25-Oct-20	
Frost free days	181		160		190	
Days above 90°F	74		64		65	
Days above 100°F	9		2		3	
Days below 10°F	7		13		5	

30-year average = 1981–2010.

Table 6. Precipitation at Hays, Hutchinson 10SW, and Keats (Ashland Bottoms)

Month	Hays		Hutchinson 10Sw		Keats (Ashland Bottoms)	
	2020	30-year average	2020	30-year average	2020	30-year average
	------------------	------------------	------------------	in.	------------------	------------------
January	0.97	0.50	0.99	0.50	1.82	0.63
February	1.56	0.71	2.04	0.71	0.78	1.08
March	0.45	1.81	1.77	1.81	2.32	2.49
April	0.46	2.14	1.72	2.14	2.40	3.17
May	3.18	3.26	3.90	3.26	7.45	5.09
June	2.39	2.83	3.67	2.83	5.04	5.7
July	7.02	3.92	4.07	3.92	10.13	4.42
August	2.43	3.04	0.75	3.04	1.76	4.12
September	0.96	2.05	1.84	2.05	2.60	3.43
October	0.08	1.58	0.63	1.58	0.33	2.69
November	0.94	0.89	1.95	0.89	2.57	1.73
December	0.32	0.72	1.11	0.72	1.05	1.07
Annual	20.76	23.45	24.44	23.45	38.25	35.62
Last freeze	18-Apr-20		17-Apr-20		17-Apr-20	
First freeze	24-Oct-20		25-Oct-20		16-Oct-20	
Frost free days	189		191		182	
Days above 90°F	61		60		44	
Days above 100°F	3		1		1	
Days below 10°F	5		2		6	

30-year average = 1981–2010.

Table 7. Precipitation at Leoti, Manhattan (North Farm), and Marquette (Kanopolis Lake)

	Leoti		Manhattan (North Farm)		Marquette (Kanopolis Lake)	
Month	**2020**	**30-year average**	**2020**	**30-year average**	**2020**	**30-year average**
	in.					
January	0.23	0.42	0.67	0.63	1.47	0.64
February	1.04	0.53	0.79	1.08	2.17	0.95
March	0.60	1.38	2.53	2.49	0.89	2.13
April	0.07	2.00	1.94	3.17	1.32	2.49
May	0.64	2.57	5.56	5.09	3.53	4.03
June	3.01	2.58	3.50	5.70	3.55	4.16
July	3.23	2.90	6.63	4.42	7.48	3.72
August	2.68	2.79	1.79	4.12	1.02	3.62
September	0.35	1.57	2.15	3.43	2.04	2.48
October	0.02	1.47	0.66	2.69	0.10	2.13
November	0.00	0.65	2.37	1.73	2.21	1.09
December	0.11	0.57	0.96	1.07	0.89	0.78
Annual	11.98	19.43	29.55	35.62	26.67	28.22
Last freeze	17-Apr-20		17-Apr-20		18-Apr-20	
First freeze	19-Oct-20		16-Oct-20		24-Oct-20	
Frost free days	185		182		189	
Days above 90°F	75		47		54	
Days above 100°F	7		0		0	
Days below 10°F	7		6		3	

30-year average = 1981–2010.

Table 8. Precipitation at Mound Ridge (Newton), Ottawa, and Rock Springs

	Moundridge (Newton)		Ottawa		Rock Springs	
Month	**2020**	**30-year average**	**2020**	**30-year average**	**2020**	**30-year average**
	----------	----------	---------- in.	----------	----------	----------
January	1.30	0.78	1.71	0.63	1.31	0.80
February	2.77	1.12	1.27	1.08	1.18	1.11
March	3.47	2.71	2.75	2.49	1.89	2.51
April	1.85	2.84	1.81	3.17	2.12	3.32
May	7.00	4.45	4.22	5.09	4.46	4.98
June	1.94	4.95	2.93	5.70	1.89	5.04
July	5.65	3.63	4.18	4.42	7.57	4.01
August	0.62	3.45	1.19	4.12	3.16	4.05
September	2.20	3.07	1.47	3.43	2.33	3.16
October	1.07	2.60	1.35	2.69	0.72	2.48
November	1.14	1.81	1.36	1.73	1.71	1.74
December	1.44	1.04	1.39	1.07	0.82	1.14
Annual	30.45	32.45	25.63	35.62	29.16	34.34
Last freeze	16-Apr-20		18-Apr-20		17-Apr-20	
First freeze	26-Oct-20		15-Oct-20		2-Oct-20	
Frost free days	193		180		168	
Days above 90°F	75		45		59	
Days above 100°F	1		0		0	
Days below 10°F	3		4		6	

30-year average = 1981–2010.

Table 9. Precipitation at Rossville, Scandia, Silver Lake

	Rossville		Scandia		Silver Lake	
Month	**2020**	**30-year average**	**2020**	**30-year average**	**2020**	**30-year average**
	------------------------------ in. ------------------------------					
January	1.39	1.06	1.11	0.45	1.35	3.18
February	0.95	1.25	0.04	0.74	0.89	4.88
March	2.55	2.60	0.99	2.12	2.53	5.46
April	2.93	3.47	0.38	2.96	3.47	3.67
May	4.19	5.56	2.81	4.21	4.42	3.44
June	4.35	5.53	4.02	3.81	2.97	4.64
July	8.61	4.36	7.84	4.24	10.24	2.97
August	0.98	4.21	0.64	3.26	1.03	1.90
September	2.67	4.19	1.39	2.84	1.95	1.24
October	0.49	3.11	0.06	2.14	0.54	0.95
November	1.71	2.09	1.52	1.26	1.73	0.89
December	0.76	1.60	0.29	0.79	1.02	2.42
Annual	31.58	39.03	21.09	28.82	32.14	35.64
Last freeze	15-Apr-20		10-May-20		15-Apr-20	
First freeze	15-Oct-20		29-Sep-20		15-Oct-20	
Frost free days	183		142		183	
Days above 90°F	37		28		42	
Days above 100°F	0		0		0	
Days below 10°F	6		13		5	

30-year average = 1981–2010.

Effect of Late Planting Dates on Corn Yield

E.A. 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 2nd 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, and 2020. The experiment at Topeka was irrigated with irrigations totaling 9.5 inches applied June 8 through August 13, 2018; 3.5 inches June 30 through July 30, 2019; and 4.1 inches June 15 through August 17, 2020, via an overhead sprinkler irrigation system that 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; and April 10 to June 10 at Topeka and April 8 to June 8 at Ottawa in 2020. 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. The experiment utilized a randomized complete block design with four replications. Individual plots were 30-ft (12 rows) wide and 30-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

The 2018 results for ECK and KRV were initially reported in the Kansas Field Research Report *https://newprairiepress.org/kaesrr/vol5/iss6/2/*.

In 2019, there was a cool period in early May, then temperatures were closer to average for June and July, with August 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 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.

The 2018 and 2019 yield results from Ottawa were greatly influenced by the weather, specifically hot and dry periods in July when corn planted in early to mid-May was trying to pollinate (Figure 1). 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 (Table 1, Figure 3). 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 (Figure 2) 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 2, Figure 4). 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.

For all years at Topeka, the yield-limiting factor of moisture stress was greatly reduced by repeated irrigations (Figs. 5, 6), resulting in a more traditional yield response to planting date (Tables 3, 4). The highest yield was when corn was planted in the last half of April in 2018 and 2019 (Table 3, Figure 3). In 2020, the highest yield was with the April 10 planting date for both the short and full season hybrids (Table 4, Figure 7). The yield of the fourth planting date of June 11 was between 50 to 60% of the high yield each year. The full and shorter season hybrids' yields were almost equal when planted June 11. Similar to the results from Ottawa, switching from a full to a shorter season hybrid due to delayed planting did not increase yield.

Grain test weights were lower with the last planting dates at both locations for all years (Table 1-4). This reduction in grain test weight was related to the shorter grain fill period for the later planting dates.

The preliminary results from three 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.

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Table 1. Effect of planting date on dryland corn at the East Central Kansas Experiment Field, Ottawa, in 2019

Planting date	Grain moisture, %		Grain test weight, lb/bu		Grain yield, bu/a		Percent high yield, %	
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	
LSD (0.05)	1.1		1.7		9.7		8	

† 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 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	90.0	d	49	d
28-Apr	101	26935	16.1	e	55.5	ab	136.3	bc	74	bc
18-May	101	26862	17.5	d	55.2	a	146.2	b	79	b
8-Jun	101	26499	23.8	b	50.0	d	127.6	c	69	c
8-Apr	114	27007	17.5	d	56.3	a	153.0	b	83	b
28-Apr	114	27080	18.3	d	56.5	ab	179.7	a	98	a
18-May	114	27080	19.6	c	55.3	ab	179.1	a	97	a
8-Jun	114	27806	25.0	a	50.6	d	140.0	bc	76	bc
Pr>F		0.61	<0.0001		<0.0001		<0.0001		<0.0001	
LSD (0.05)		NS	0.9		1.2		15.7		8.3	

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

Table 3. Effect of planting date on corn under irrigation at the Kansas River Valley Experiment Field, Topeka, in 2019

Planting date	Plant population	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	
LSD (0.05)	NS	4.1		4.0		47		19	

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

Table 4. Effect of planting date on irrigated corn at the Kansas River Valley Experiment Field, Topeka, in 2020

Planting date	Hybrid rel. mat.	Plant population		Grain moisture		Grain test weight		Grain yield		Percent high yield	
	days	plants/a		pct		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 α = 0.05.

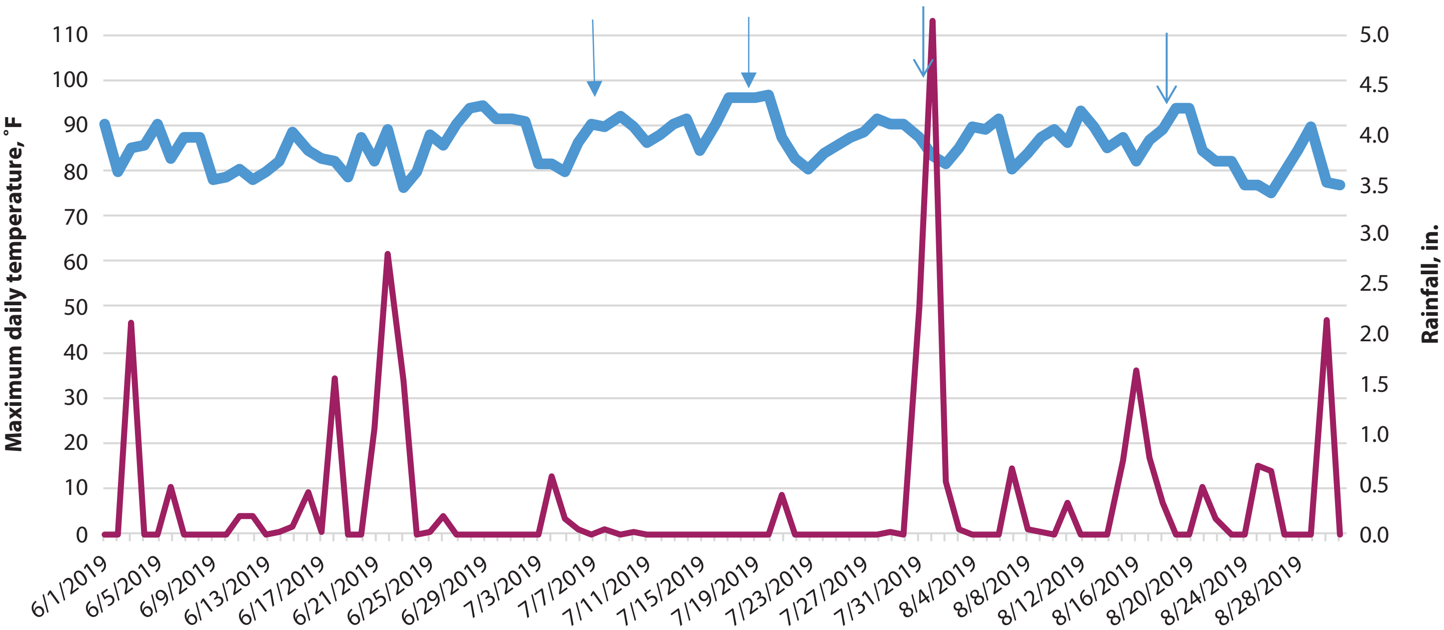

Figure 1. Daily maximum temperatures and daily rainfall at the East Central Kansas Experiment Field, Ottawa, in 2019. Arrows indicate tasseling for successive planting dates.

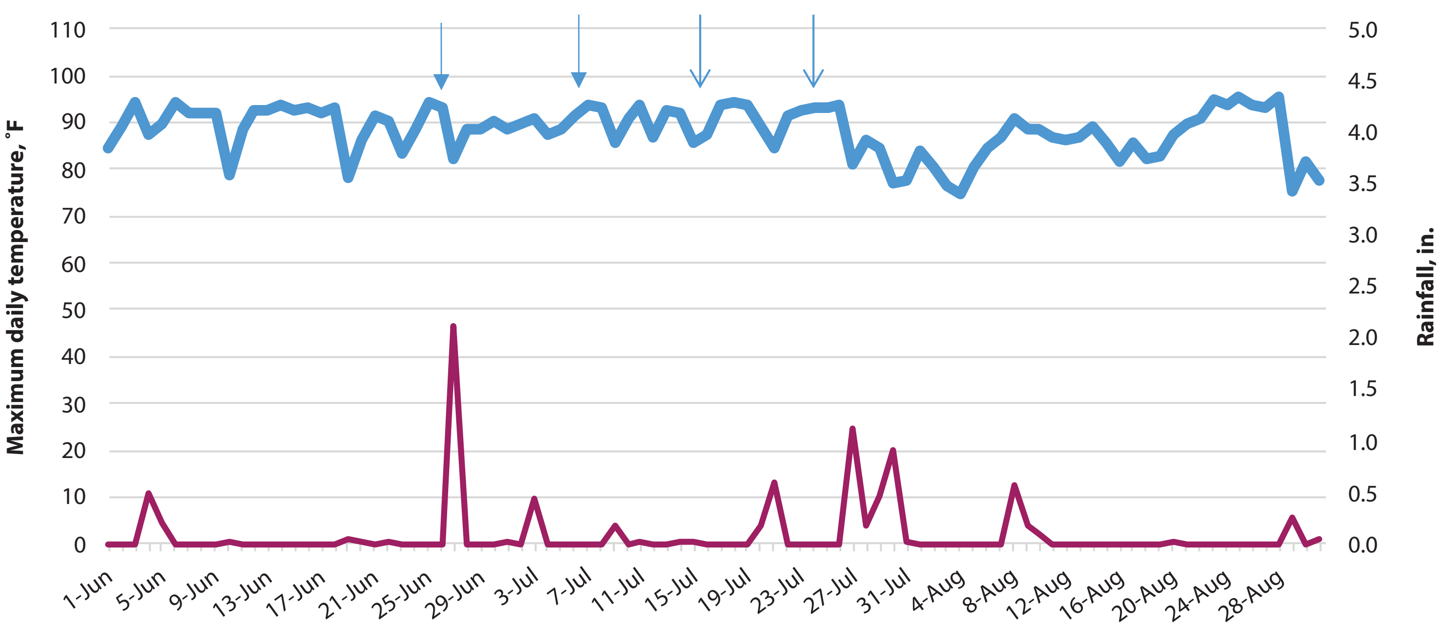

Figure 2. Daily maximum temperatures and daily rainfall at the East Central Kansas Experiment Field, Ottawa, in 2020. Arrows indicate tasseling for successive planting dates.

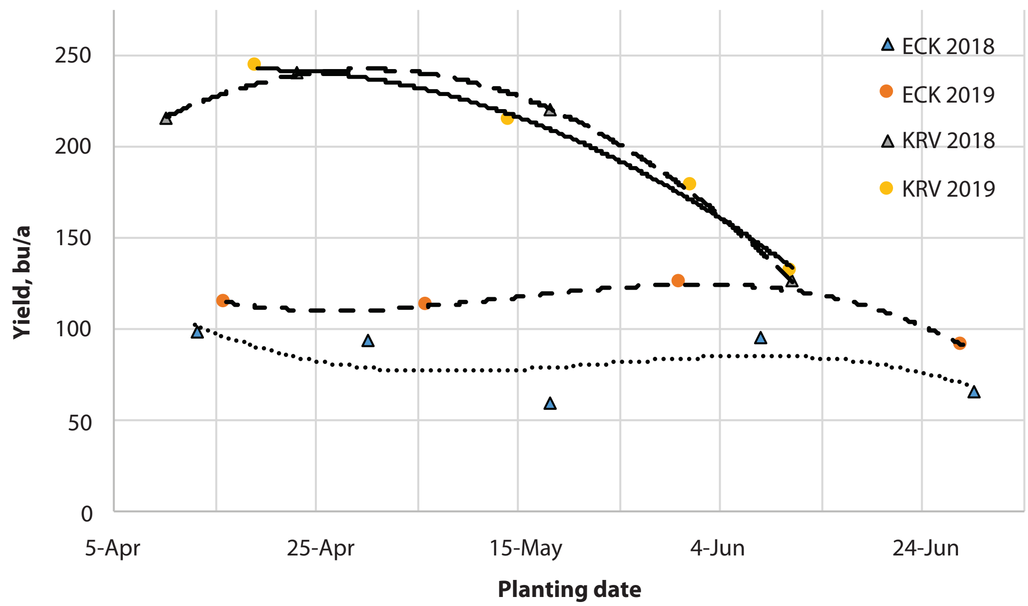

Figure 3. Yield response of corn to planting date at the East Central Kansas Experiment Field, Ottawa, and the Kansas River Valley Experiment Field-Topeka in 2018 and 2019.

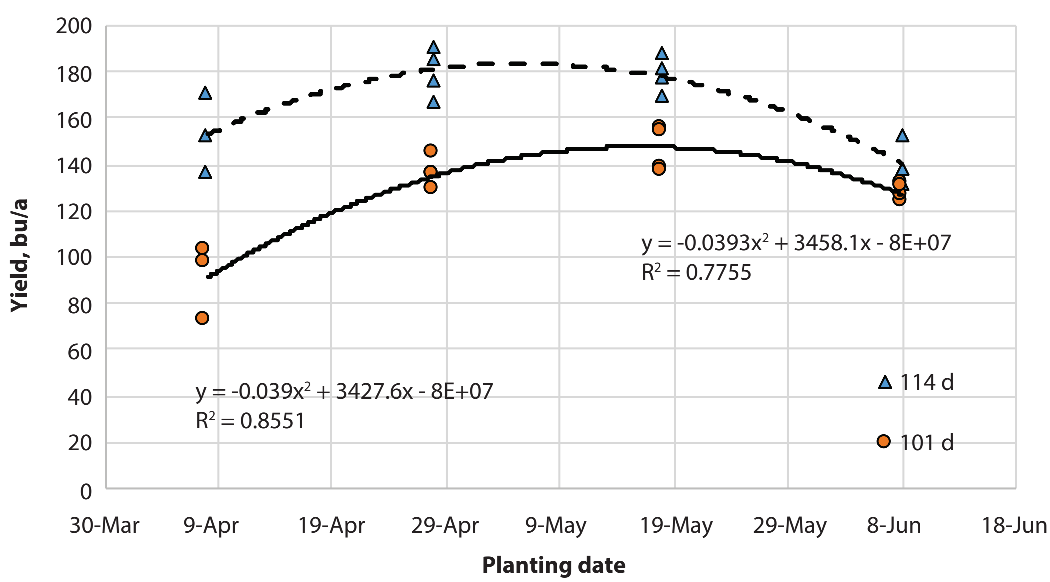

Figure 4. Yield response of full and short season corn to planting date at the East Central Kansas Experiment Field, Ottawa, in 2020.

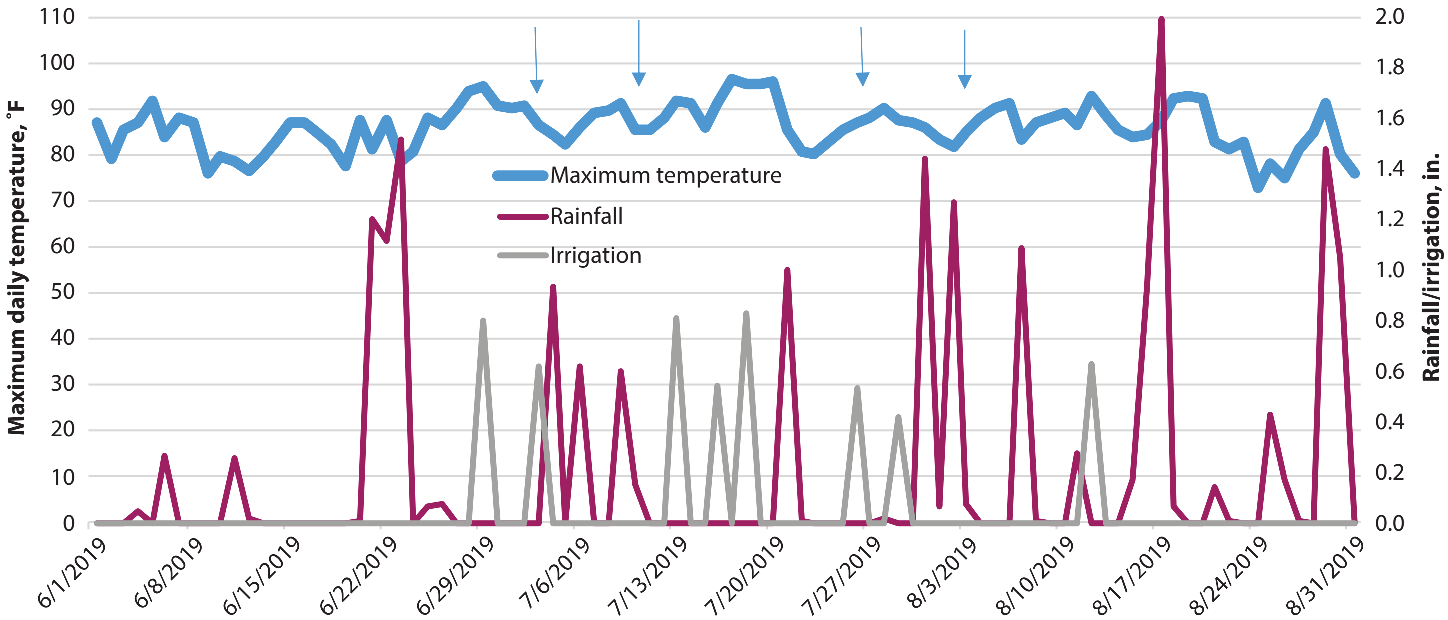

Figure 5. Daily maximum temperatures, daily rainfall and irrigation at the Kansas River Valley Experiment Field, Topeka, in 2019. Arrows indicate tasseling for successive planting dates.

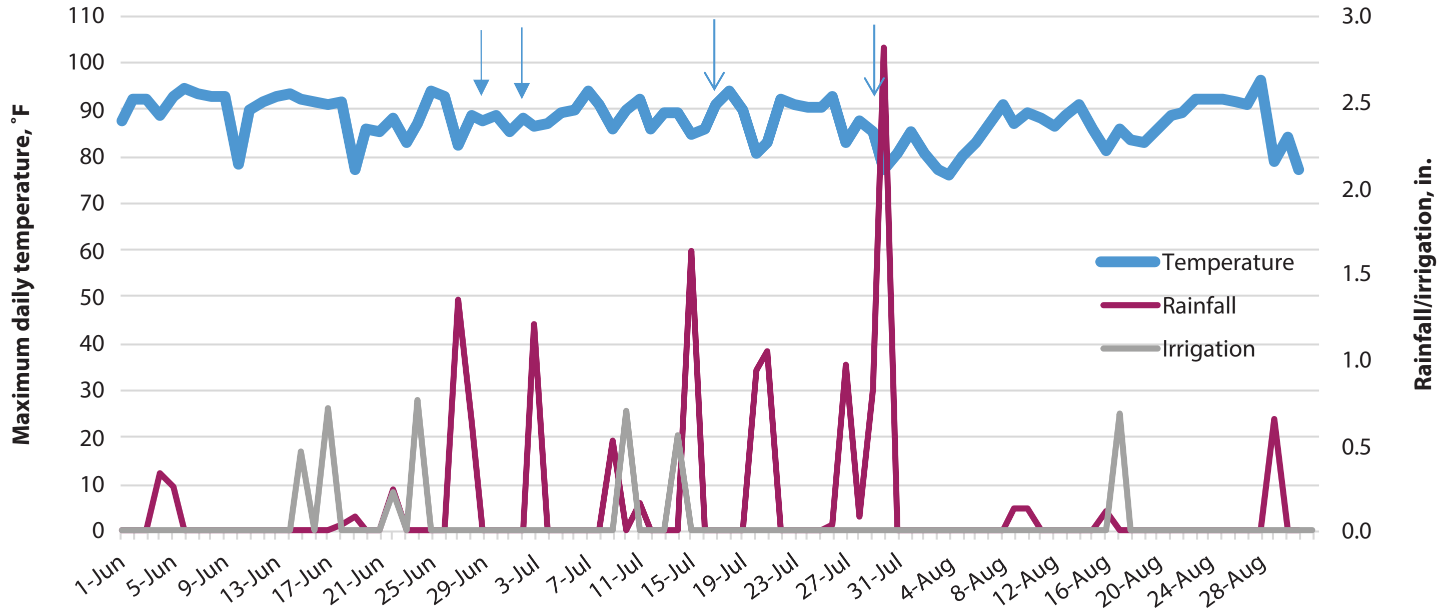

Figure 6. Daily maximum temperatures, daily rainfall and irrigation at the Kansas River Valley Experiment Field, Topeka, in 2020. Arrows indicate tasseling for successive planting dates.

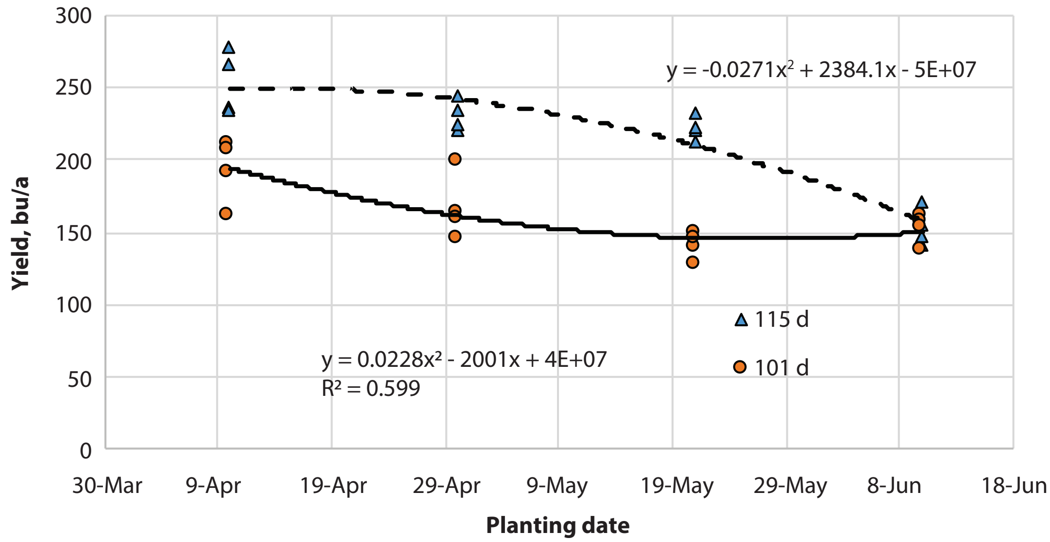

Figure 7. Yield response of short and full season corn under irrigation to planting date at the Kansas River Valley Experiment Field, Topeka, in 2020.

Comparison of Static and Active Downforce on Corn at the Kansas River Valley Experiment Field in 2020

E.A. Adee

Introduction

Uniformity of plant spacing and emergence have been shown to be significant contributing factors to increasing corn yields. Improved seed meters that offer very precise seed drop have been available on planters for a number of years. However, uniformity in plant emergence continues to be a challenge, especially with reduction of tillage and in fields with variable soils. Correct, consistent depth is critical for uniform corn emergence. By keeping the gauge wheels on the ground, consistent depth is achieved. An active downforce system, such as Precision Planting's DeltaForce, applies hydraulic downforce or lift to the row unit. With a Precision 20|20 planter monitor, load sensor readings of the downforce on the gauge wheels can be monitored and the target pressure adjusted from the monitor. The 20|20 display detects the load cell readings and adjusts the applied downforce or lift to maintain the gauge wheels' contact with the ground while also preventing compaction beyond what is necessary for creating a good furrow.

Procedure

A John Deere 7200 planter was equipped with a DeltaForce system at Kansas River Valley Experiment Field, near Topeka, KS. Connected to the Precision 20|20 planter monitor, the downforce could be set at any static (constant) pressure, or in the active downforce mode. The active downforce mode continues to monitor the pressure sensors on the gauge wheels of each row and calculate the percent of time the gauge wheels are in contact with the soil. The target pressure can be adjusted so the gauge wheels are in contact with soil, planting at the proper depth without unnecessary compaction around the seed.

Two studies were conducted in 2020 at Kansas River Valley Experiment Field (KRV) near Rossville (irrigated) and Kiro (dryland). Both fields were sub-soiled with a Blue-Jet in-line sub-soiler in the fall, and field cultivated prior to planting in the spring. The soil type at Rossville is Eudora silt loam, and at Kiro is Muir silt loam. The soil conditions at both fields were very mellow, especially at Rossville. Planting dates were April 21 and 23 at Kiro and Rossville, respectively. The treatments were 1) no downforce, 2) 125 lb static downforce, 3) 250 lb static downforce, 4) 375 lb static downforce, and 5) auto downforce. At Kiro the target downforce was set at 90 lb, and at Rossville the target force was set at 50 lb for the auto downforce treatments. Plots were 200-ft long at both locations. About 13 days after emergence, stand counts of 1/1000th of an acre, and number of plants at each leaf stage within each stand count were quantified from each plot at two sites at Rossville and four sites at Kiro.

Results

Stand counts taken May 29, 2020, show that the 375 lb static downforce reduced that stand by approximately 3000 plants/a compared to the other treatments (Table 1), which were not significantly different from each other. Within each stand count, there were very few plants at V2 and at V5, with no differences between treatments. The 250 and 375 lb treatments had more than 40% of the plants at V3, while the auto treatment had 94% of the plants at V4. As a result, the plants with the auto treatment were ahead in emergence and uniformity, as shown by the average leaf number, than the 250 and 375 lb treatments. The plants in the no downforce and 125 lb downforce treatments were between the two extremes. The yield results had a similar pattern, showing the highest yields with the auto, no downforce, and 125 lb downforce treatments. The yield with the 375 lb treatment was up to 36 bu/a less than with those three treatments.

Conclusions

These data show the negative impact of having too much down pressure on a row unit to keep the seed at the proper depth. The reduction in plant population, development, and uniformity with the higher down pressures in this very mellow seedbed contributed to the reduction in yield. In a situation with heavier soils and/or more residue cover, higher downforce pressures may be needed to maintain seed depth. However, when the firmness of soil or residue cover are variable, it would be challenging to select a static downforce that would work for all conditions. There are plans to compare the static vs. auto downforce in more variable conditions resulting from different tillage systems and amount of residue cover at the KRV fields.

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Table 1. Comparison of static and active downforce systems on planter units on plant population, plant uniformity and yield at Kansas River Valley Experiment Field in 2020

Treatment	Plant population		At v2	At v3		At v4		At v5	Avg leaf		Grain moisture	Test weight	Yield	
	------------------ plants/a May 29, 2020 ------------------								leaves/plt		pct	lb/bu	bu/a	
No downforce	28875	a*	0	8000	a	21250	b	880	3.79	b	16.8	59.7	202.1	a
125 lb	28187	ab	0	7800	a	21500	b	380	3.79	b	17.0	59.3	200.2	a
250 lb	27781	b	375	12000	a	17750	b	0	3.66	b	17.3	59.1	185.0	ab
375 lb	25135	c	0	10400	a	17380	b	500	3.72	b	17.2	58.7	168.0	b
Auto	28969	a	0	1500	b	27250	a	1880	4.01	a	16.7	59.6	204.2	a
PR>F	<.0001		0.42	0.04		0.02		0.69	0.04		0.5	0.25	0.02	

*Means followed by the same letter are not significantly different at $P = 0.05$.

Corn Grain Weight: Dependence upon Nitrogen Supply and Source-Sink Relations

J.A. Fernandez and I.A. Ciampitti

Summary

From a yield component perspective, final grain yield in corn (*Zea mays* L.) is the result of the number of grains per unit area and their final grain weight. The understanding of grain weight parameters, the rate and duration of grain growth, is critical to improve our rational design of management practices and breeding strategies. In this study, we attempted to determine the effect on grain weight and grain-filling parameters of source-sink modifications (i.e. the amount of assimilates available per grain) during linear grain fill under contrasting levels of nitrogen (N) fertilization in two commercially available US corn hybrids. Two hybrids (3394 and P1197) were evaluated under zero-N and two fertilized strategies at a N rate of 194 lb/a. Four levels of source-sink manipulations were implemented: 1) control; 2) reduced sink, with partially restricted pollination; 3) reduced source, with partial defoliation; and 4) both reduced sink and source. Final grain weight was significantly affected by N management and by modifications of the source-sink ratio during grain-filling. In addition, variations in grain filling rate were responsible for the major changes in grain weight. Results from this study suggest that grain weight is very responsive to reductions in the source capacity during grain-filling, but only marginally responsive to increments in the assimilate availability per seed during grain-filling.

Introduction

From a yield component perspective, final grain yield is the result of the number of grains per unit area and their final grain weight. While grain number per area is recognized as the most important component, grain weight is an important contributor to the final grain yield in corn. Grain weight parameters, the rate and duration of grain growth, have been studied under heat stress (Wilhelm et al., 1999), across planting dates (Melchiori and Caviglia, 2008), plant density (Borrás et al., 2003), and N fertilization (Melchiori and Caviglia, 2008; Fernandez and Ciampitti, 2019) to improve recommendations of best management practices and breeding strategies in corn.

The growth of corn grains can be separated into three key phases (Johnson and Tanner, 1972). After pollination, there is a short period of active cell division where the potential kernel size is defined, usually referred to as lag phase (Reddy and Daynard, 1983). The second growth phase, the linear grain fill, is characterized by a rapid dry matter accumulation and moisture decline (Ouattar et al., 1987). As starch is accumulated in the grain throughout this period, the grain milk line advances towards the tip through the dough stage. Water content continues to drop during the third and final phase, and grains are considered physiologically mature when they achieve their maximum dry weight. After this moment, grains continue to undergo a loss of water during the dry down period until harvest moisture (20-25%) is reached. From here, we can use a bi-linear model to effectively represent these three phases (Figure 1). Lag phase duration can be calculated as the period from flowering to the intersection of the curve with the x-axis, delineating the initiation of linear grain fill. The linear phase is described in terms of the grain filling duration and the rate of dry matter accumulation. Accordingly, the constant rate of water concentration decline can be assessed after grains enter the maturity state, referred to as dry down rate. The implementation of this simple approach to estimate physiological and harvest maturities is of value to both corn farmers and scientists.

The realization of the potential grain weight is determined by the balance between the post-flowering source capacity of the plant (i.e. assimilate production during the grain filling period) and the sink (i.e. total number of grains) (Reddy and Daynard, 1983; Jones et al., 1996). This balance represents the amount of assimilates available per grain during the linear grain fill and is commonly referred to as the source-sink ratio. A better understanding of the effect of source and sink limitations on grain growth in US hybrids, and thus on yield, is critical to outline and provide guidance toward adequate agricultural practices in corn. Therefore, the aim of this work was to determine the effect on grain weight and grain-filling parameters of source-sink modifications during linear grain fill under contrasting levels of N fertilization in two commercially available US corn hybrids.

Procedures

The study was conducted at the Ashland Bottoms Research Farm, Manhattan, KS, during the 2018 growing season. The soil pH was 6.13, soil organic matter (SOM) was 1.6%, and there was 48 ppm of phosphorus (P) (Mehlich) at the 6-inch soil depth, and available N was 54 lb/a at 24-inch soil depth.

Corn was planted on April 25, 2018, in plots of four rows, 30 in. apart, and 10-ft wide × 70-ft long. The previous crop was corn and furrow irrigation was applied using gated pipes. The experimental area was kept free of weeds, pests, and diseases during the growing season. The experimental design was a split-plot with factorial subplot structure, where hybrids were assigned to whole plots, and combinations of levels of N and source-sink treatment factors + a zero-n negative control were assigned to subplots. Two Pioneer (Corteva Agriscience, Johnston, IA, US) hybrids were evaluated [3394 and P1197, detailed description of hybrids in Fernandez et al. (2021) under zero-N and two fertilized strategies with an equal final N rate of 194 lb/a: 1) early N, split in two applications (50% planting and 50% V6); and 2) late N, split in three applications (50% planting, 20% V6, and 30% V12). Four levels of source-sink ratio were included (Figure 2): 1) control with normal pollination; 2) reduced sink, with partially restricted pollination; 3) reduced source, with partial defoliation; and 4) reduced both sink and source, combination of treatment 2 and 3. Reduced sink treatments were achieved using a bag to cover the entire ear when the silks were 2.5 cm long (Rajcan and Tollenaar, 1999). Partial defoliation was accomplished, two weeks after flowering, by removing the four topmost leaves. Lastly, a zero N (no N applied) with normal pollination was added as a negative control.

Grain filling was measured since blister stage (R2) of growth, collecting one ear per plot every week from each treatment combination, until harvest. Ten grains from the central portion of the ear were sampled to track changes in dry weight and water volume during the period. Grain filling rate and duration were estimated on a day-time basis from flowering to harvest maturity, fitting a bi-linear model [equations (1) and (2)] in each hybrid × nitrogen × source-sink treatment combination:

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

where x are the days after flowering, a is the y-intercept (mg grain^{-1}), b is the grain growth rate (mg grain^{-1} day^{-1}), and c is the total duration of grain filling (in days). In addition, the source/sink ratio during effective linear grain fill was calculated as the quotient of biomass accumulated from 15 days after flowering to physiological maturity and the total grain number per unit of land area.

The effect of treatments on all variables under study was determined through three-way analyses of variance (ANOVA). Multiple pairwise comparisons were performed using Fisher's least significant difference (LSD) method at a 5% level of significance. Relationships between variables were described through linear regression analysis.

Results

Final grain weight was significantly affected by N management and by modifications of the source-sink ratio during grain-filling ($P \leq 0.001$, Table 1). Under N fertilization, control treatments averaged 294 mg (hybrid 3394) and 304 mg (hybrid P1197) per grain. Small increments in grain weight were observed when pollination was restricted (i.e. source-sink ratio was increased), increasing up to 340 and 320 mg, respectively, for 3394 and P1197 hybrids. In contrast, when defoliations occurred (i.e. source-sink ratio was reduced), grain weight was dramatically impacted and averaged 231 and 251 mg, respectively, for 3394 and P1197 hybrids.

Furthermore, grain filling rate followed a similar behavior pattern as that observed for grain weight. A bi-linear relationship within these two variables showed that variations in grain filling rate were responsible for the major changes in grain weight until a plateau of 341 mg was achieved at a rate of 10.2 mg day^{-1} (Figure 3A). For grain filling rate, main effects for N fertilization and source-sink treatments were identified. While it is known that N deficiency produces a significant impact in the number of grains set (Fernandez et al., 2020), here we have also observed that N deficiency affects the source-sink ratio during grain-filling (Figure 3B). These results show that N stress impacted corn grain weight essentially through reductions on the grain filling rate.

In this study, we showed that grain weight, and in particular the rate of dry matter accumulation, is very responsive to reductions or deteriorations in the source capacity during grain-filling (Figure 3B). However, it also shows that grain weight (and thus crop yield) is only marginally responsive to increments in the assimilate availability per seed during grain-filling, plateauing at a source-sink ratio of 380 mg grain^{-1}. It is also critical to highlight the importance to maintain an adequate source strength with respect to the number of grains via adequate management practices (N supply), in particular, for the period around flowering in corn (Borrás et al., 2004).
We also revealed that grain moisture at maturity (%) was significantly modified across the evaluated treatments, but in a different manner in each genotype ($P \leq 0.001$, Table 1). The hybrid 3394 resulted in lower grain moisture of 32.4% when reductions

in the source capacity through defoliations were implemented. Instead, the P1197 hybrid showed lower plasticity for grain moisture when maturity was reached, ranging from 34.4 to 39.3% across all treatments. Lastly, the rate of post-maturity (maturity to harvest) dry down exhibited a decline or an increment in response to either source or sink reductions, respectively. However, modifications in the rate of dry down were less important than other variables, demonstrating that this period is highly dependent on the prevailing weather conditions—mainly related to humidity, temperature, and precipitation.

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Table 1. Analysis of variance and means for grain weight, grain filling rate and duration, moisture percentage at maturity, and dry down rate for two hybrids (H) and four source-sink treatments (SS) across three nitrogen (N) levels in 2018 field experiment

Hybrid	Source-sink	Nitrogen	Grain weight		Grain filling rate		Grain filling duration		Moisture at maturity		Dry down rate	
			mg		mg day^{-1}		days		%		% day^{-1}	
3394	Control	0N	257	cd	7.5	cd	43		36.6	c	-0.86	b
		Early 194N	297	b	8.8	bc	43		37.4	bc	-0.87	bc
		Late 194N	291	bc	8.6	bcd	43		39.2	abc	-0.9	bcd
	Restricted pollination	Early 194N	344	a	10.9	a	41		39.8	ab	-0.91	cd
		Late 194N	337	a	10.7	a	41		40	ab	-0.91	cd
	Defoliated	Early 194N	236	d	7.1	d	41		32.6	d	-0.81	a
		Late 194N	233	d	7.1	d	41		32.2	d	-0.81	a
	Restricted pollination + defoliation	Early 194N	336	a	9.9	ab	43		37.5	bc	-0.87	bc
		Late 194N	340	a	11	a	40		41.1	a	-0.92	d
P1197	Control	0N	235	c	6.6	e	43	ab	37.3	abc	-0.87	abc
		Early 194N	302	b	8.5	cd	44	a	36.5	abc	-0.86	abc
		Late 194N	306	b	9.1	bc	43	ab	38.7	ab	-0.89	bc
	Restricted pollination	Early 194N	320	ab	10.5	ab	40	bc	36.5	abc	-0.86	abc
		Late 194N	320	ab	10.2	ab	41	abc	35.6	bc	-0.85	ab
	Defoliated	Early 194N	251	c	7.5	de	42	ab	34.4	c	-0.83	a
		Late 194N	252	c	7.5	de	42	ab	36.7	abc	-0.86	abc
	Restricted pollination + defoliation	Early 194N	345	a	10.3	ab	42	ab	35.8	bc	-0.85	ab
		Late 194N	325	ab	11.3	a	38	c	39.3	a	-0.9	c
Sources of variation												
Hybrid (H)			ns		ns		ns		ns		ns	
Nitrogen (N)			***		***		ns		*		*	
Source-sink (SS)			***		***		+		***		***	
H × N			ns		ns		ns		ns		ns	
H × SS			ns		ns		ns		***		***	
N × SS			ns		ns		ns		+		+	
H × N × SS			ns		ns		ns		ns		ns	

Within each hybrid, different letters indicate significant differences at P ≤ 0.05.
+ Significant at $P \leq 0.1$; * significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; *** significant at $P \leq 0.001$.
Ns: non-significant.

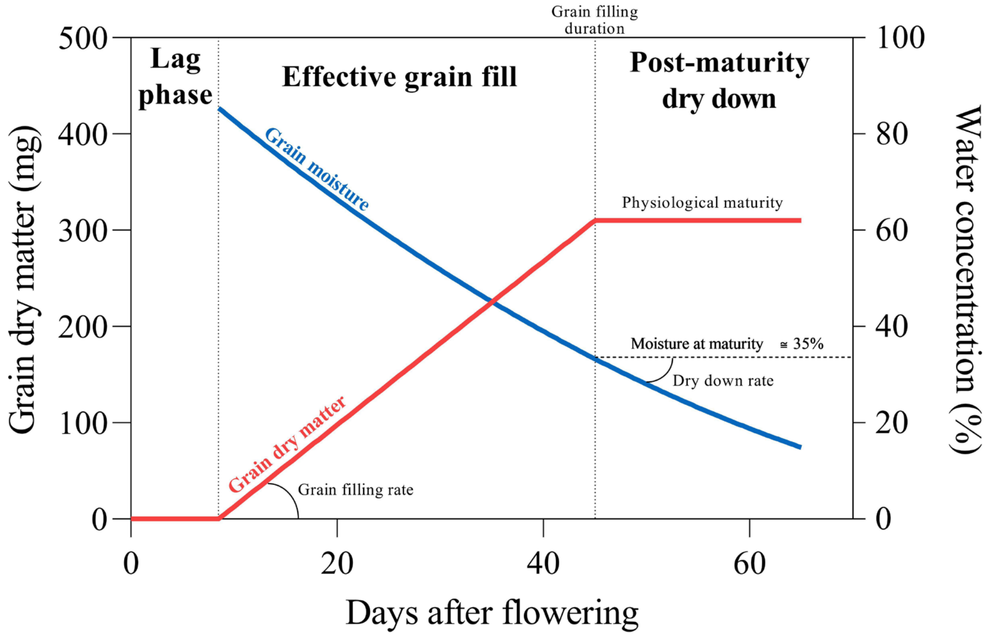

Figure 1. Graphical representation of the grain dry matter accumulation and water concentration decline on a day-time basis.

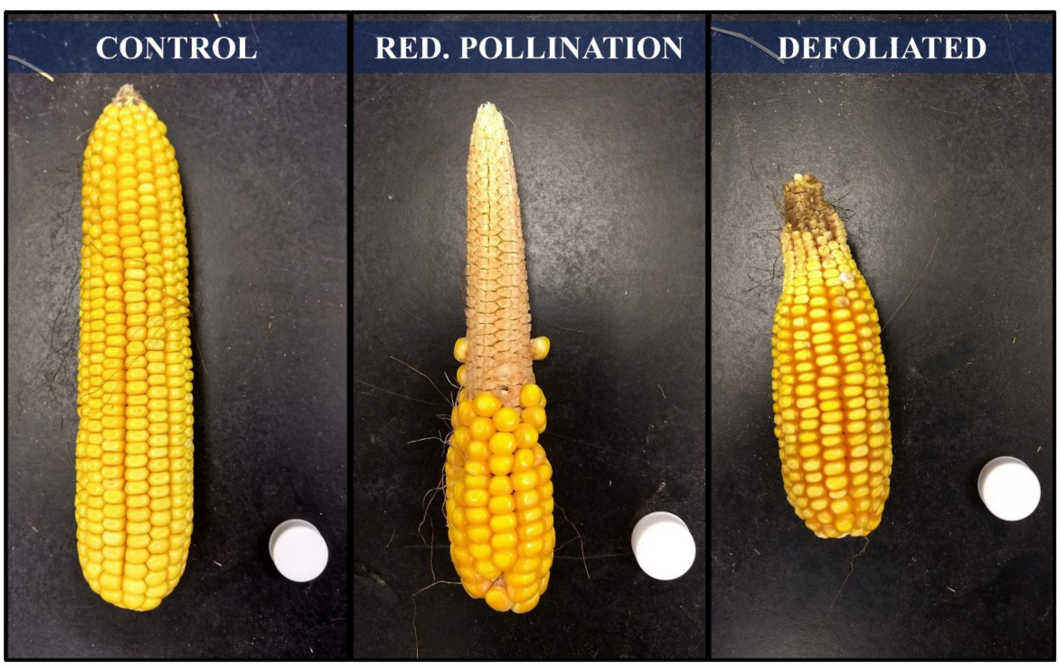

Figure 2. Picture of corn ears across three source-sink ratio manipulations evaluated in 2018 field experiment.

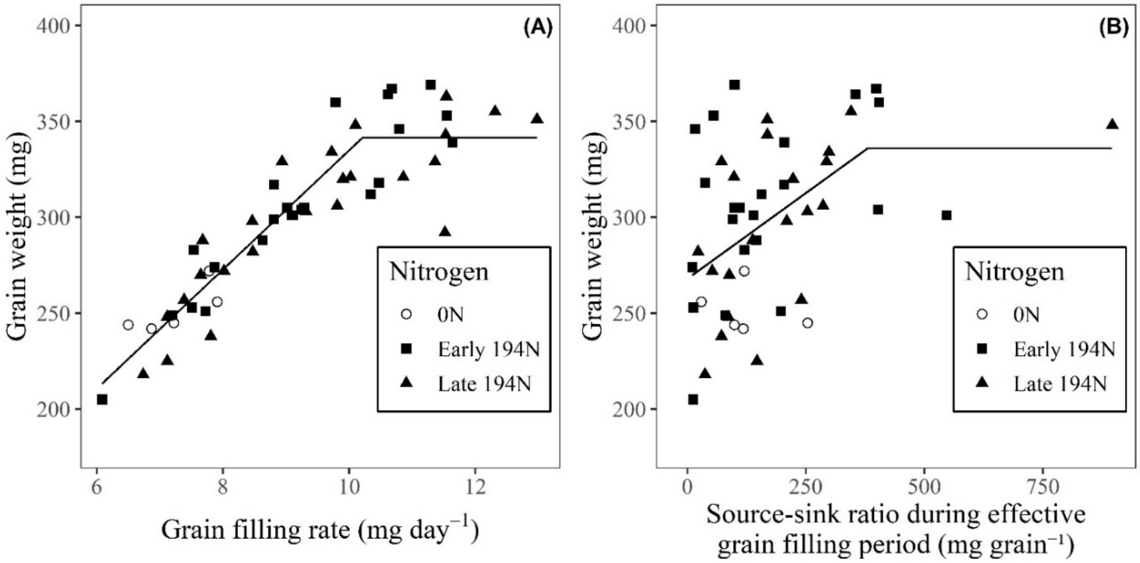

Figure 3. Relationship between grain weight and grain filling rate (A), and source-sink ratio during effective grain-filling (B). Symbols represent replicates across two hybrids, four source-sink treatments, and three nitrogen (N) levels in 2018 field experiment.

Corn Tiller Yield Contributions and Ear Development in Low Plant Densities

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Summary
Research in modern corn (*Zea mays* L.) hybrids investigating tiller contributions and ear development at low plant densities is scarce, particularly in water-limited environments. To fill this research gap, a second season of replicated experiments was conducted in 2020 at 7 sites across Kansas (Keats, Buhler, Greensburg, Garden City, Goodland, and two sites in Colby) evaluating two common, tiller-prone corn hybrids (P0805AM and P0657AM) at three target plant density levels (10000, 17000, and 24000 plants/a). Five of the listed sites also considered a tillering factor (tiller removal at development stage V10 [tenth-leaf] or tiller maintenance). Seasonal phenology, partitioned grain yield, harvested ear type characterizations, and environmental conditions were recorded and analyzed to quantify tiller contributions in each site. Results showed that intact tillers had either no effect or were able to boost yields. In the best environments, tillers were able to successfully compensate for losses of 60% in plant density. Five of the seven tested sites produced approximately 50% of total harvested ears as desirable tiller lateral ears in the 10000 plants/a target plant density. The highest percentage of undesirable tiller tassel ear development in the 10000 plants/a density was 13%. Future research will seek to find explanations of the ear type relationships on a deeper level and predict tiller yield contributions considering various environments and ear development outcomes.

Introduction
Tiller prolificacy in corn has been deemed undesirable since the beginning of the species domestication process. A main concern of farmers, agronomists, and breeders alike with these secondary vegetative shoots is their inability to produce grain with consumed plant resources, thus earning corn tillers the common name, "suckers." Modern corn hybrids are typically not tested by breeders at the very low plant populations employed in marginal environments, such as central and western dryland regions of Kansas. In these areas, having plant densities under 20000 plants/a is a key management component in conserving available soil moisture. However, when planting at this sparse density, conditions are prime for corn tiller development, which raises new questions about tiller impacts on yield and the plant water balance.

While corn tillers can develop typical axillary ears ("lateral ears"), this desirable situation is not always the case. Unproductive tillers may never reach reproductive stages or may produce apical ears (commonly "tassel ears") instead of desirable lateral ears. These development scenarios are likely key to understanding potential tiller contributions in various environments.

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The objectives of this study were to 1) determine the qualitative effect of corn tillers on yields considering differences in plant density, hybrid, and environment, and 2) evaluate corn tiller ear development resulting in each site as an indicator of tiller productivity.

Procedures

Data presented in this report were collected in the second year of a multi-year study (2019–2021) conducted across the state of Kansas (Veenstra et al., 2020). Location geographical coordinates and soil data are shown in Table 1. All plots were fertilized as necessary to avoid nutrient deficiencies and maintained with appropriate pesticides. Climatic data of interest downloaded with site coordinates from ClimateEngine are shown in Table 2 (Huntington et al., 2017).

Five sites were arranged in a split-split-plot design, with three factors evaluated: planting density with three levels as the whole plot, hybrid with two levels in the sub-plot, and tiller treatment with two levels in the sub-sub-plot (Table 1). That is, both levels of tiller (removal at the V10 [tenth-leaf] development stage [NT], or maintenance [YT]) were evaluated for both levels of hybrid (P0805AM and P0657AM [two Pioneer corn hybrids common in the region of study]) within each level of plant density (10000, 17000, and 24000 plants/a). Each site had at least three replications.

Two sites were arranged in a split-plot design, with two factors evaluated: planting density with three levels as the whole plot, and hybrid with two levels in the sub-plot (Table 1). That is, both levels of hybrid (P0805AM and P0657AM) were evaluated in each level of plant density (10000, 17000, and 24000 plants/a). Each site had three replications.

Measurements throughout the growing season included ear type characterization counts and partitioned grain yields. Ear characterization counts were conducted at harvest, and accounted for the number of harvestable ears in a plot that belonged to each of three predetermined categories—main plant ears (productive), tiller lateral ears (productive), and tiller apical ears (commonly “tassel ears,” unproductive). Partitioned grain yields were hand-harvested from the two central plot rows, separated by ear type category, and shelled by hand.

The selected experimental design structure allowed for quantification of the effect of corn tillers on yield. For analysis, data were classified into the following three partitions: full plant (main + tillers), main plant (main only), and tiller (tillers only). In addition, due to differences in yield goals, environmental conditions, and responses observed among sites, experimental sites were analyzed separately. Linear mixed models were fit to the data from each location and an analysis of variance (ANOVA) was performed to determine the significance of nested factors in the experimental design with regard to each yield partition as listed previously. All analyses, calculations, and figures were completed with the R software (R Core Team, 2020).

Results

Grain Yields

Full partitioned grain yields of sites considering the tiller removal factor (i.e., sites with split-plot-plot design structures) are shown in Figure 1. Each site is divided into factor combinations based on results from the performed ANOVA (data not shown). Yield potential for all fields was similar, with the exception of the Colby (B) location, which is a continuous-crop dryland site as indicated in Table 1.

Full yields in Keats were only affected by tiller removal in the 10000 plants/a density with the P0805AM hybrid. The P0805AM hybrid also out-yielded the P0657AM in this density when tillers were present. Planting density was a significant component of each treatment with regard to yield potential in this location, as the stepped effect of yields was obvious as target population increased. Tillers were unable to compensate for the presence of fewer plants at this site.

Garden City and Goodland full yields followed similar patterns. At both sites, tiller treatment was only significant in the 10000 plants/a, and plant density was only significant when tillers were not present. At these sites, the presence of tillers allowed statistically similar yields, even when comparing a plant density reduced to 40%. Tillers were able to successfully compensate for significantly fewer corn plants (up to 14000 plants/a) in these sites.

Yields at the Colby (A) site were only affected by tiller removal in the 10000 plants/a level. Plant density was only significant at the 10000 plants/a level when tillers were not present, and at all treatments at the 24000 plants/a level. Tillers were able to successfully compensate for a plant density lowered to 59%, but not to the impressive degree observed in the Garden City or Goodland sites.

Yields at the Colby (B) site were not affected by any factor or interactions included in this study.

In all tested sites, intact tillers either neutrally or positively influenced yields. In some cases, tillers successfully compensated for significantly fewer plants per acre.

Ear Development

Due to the nature of the data collected for ear development (i.e., lack of normality), only the ear type characterization as a percentage of the total ears harvested is provided in this report. The summary is shown in Figure 2.

Most sites produced approximately half of their total developed ears as tiller lateral ears in the 10000 plants/a target density, except for Buhler (33%) and Keats (13%). Keats produced the greatest percentage of tiller tassel ears of any location in the 10000 plants/a target density (19%). Buhler, Colby (A), and Greensburg produced 8%, 2%, and 6% of their ears as tiller tassel ears at this density, respectively.

Considering the 17000 plants/a that Keats and Colby (B) produced < 1% of their harvested ears on tillers. Tiller lateral ears were developed in Buhler (3%), Colby (A) (12%), Garden City (20%), Goodland (21%), and Greensburg (31%). Sites producing ≥ 1% of harvested ears as tiller tassel ears were Buhler (4%), Garden City (2%), and Greensburg (1%).

In the 24000 plants/a level, four sites produced tiller ears, and all of them (≥ 1%) were tiller lateral ears—Colby (A) (1%), Garden City (2%), Goodland (1%), and Greensburg (1%).

When summarizing ear development by hybrid across sites (data not shown), P0805AM produced the following harvested ear percentages for main ears, tiller lateral ears, and tiller tassel ears, respectively: 47%, 52%, and 1% (10000 plants/a); 83%, 16%, and 0% (17000 plants/a); and 98%, 2%, and 0% (24000 plants/a). For P0657AM, the main, tiller lateral, and tiller tassel harvested ear percentages were as follows: 54%, 37%, and 8% (10000 plants/a); 89%, 10%, and 1% (17000 plants/a); and 99%, 0%, and 0% (24000 plants/a).

Conclusions

The overall conclusion is that corn tillers do not reduce yields. In all sites, regardless of irrigation status or yield potential, tiller removal never had a positive influence on yields.

Effects of tiller removal are often tied to plant density in productive fields, as can be observed in the results shown from the 2020 season [See Figure 1; Colby (A), Garden City and Goodland]. In these cases, as plant density increases, tiller yield contributions decrease. Under certain circumstances, tillers have demonstrated potential to compensate for plant densities reduced by up to 60%. Although this relationship is certainly not always the case, it sparks imagination at the definite possibility of reducing plant densities while achieving similar yields in both marginal and adequate environments.

With regard to corn tiller yield relationships, a second key conclusion is the identified correlation between tiller ear development and yield outcomes. The specific environmental factors surrounding ear type determination remain unclear, but these processes appear to be a key part of predicting tiller outcomes and maximizing plant efficiency and productivity in low plant density corn fields.

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Table 1. Site geographical coordinates, sowing date, and soil characteristics of interest

Site	Latitude	Longi-tude	Sow date	pH	OM	NO_3-N	NH_4-N	P	CEC
	°N	°W		H_2O	% LOI	--------- ppm ---------		Mehlich, ppm	meq $100g^{-1}$
Keats, KS*	39.23	96.72	May-02	7.0	4.5	18.0	4.1	118.0	24.4
Buhler, KS**	38.14	97.73	Apr-29	6.4	2.9	17.9	4.8	24.0	23.1
Greensburg, KS**	37.58	99.37	May-05	5.4	2.6	37.1	13.6	84.9	18.9
Garden City, KS*	37.83	100.86	May-18	5.2	1.6	18.4	10.7	55.0	10.6
Goodland, KS*	39.25	101.78	May-07	5.8	3.8	36.9	17.9	106.0	24.0
Colby A, KS*	39.39	101.06	May-07	5.4	3.3	19.9	4.3	70.0	21.2
Colby B, KS*	39.38	101.06	May-15	6.5	3.2	43.5	36.4	31.0	24.0

OM = organic matter. CEC = cation exchange capacity.
* Site arranged in a split-split-plot design. ** Site arranged in a split-plot design.

Table 2. Site climatic data of interest for the 2020 growing season (April - August)

Site	Mean daily solar radiation	Mean maximum temperature	Mean minimum temperature	Seasonal water supply
	MJ m^{-2} day^{-1}	-------------------------- °F --------------------------		Precipitation + irrigation, in.
Keats, KS	22.5	79.0	58.3	20.3
Buhler, KS	23.4	82.4	58.6	19.0
Greensburg, KS	24.4	82.6	55.4	18.8
Garden City, KS	25.1	83.3	54.9	17.3
Goodland, KS	24.5	81.5	51.3	14.4
Colby, KS	24.4	81.0	51.6	10.7

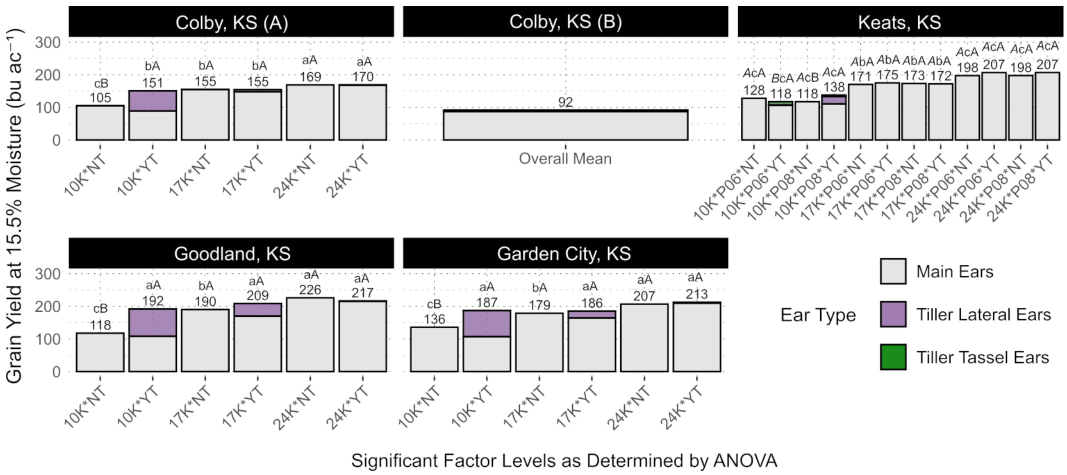

Figure 1. Mean full grain yields (adjusted to 15.5% standard moisture) and means comparisons (Tukey test) for each factor level deemed significant by ANOVA tests considering each location separately. (Lowercase letters are used to compare densities at a given factor level; uppercase letters are used to compare tiller treatments at a given factor level; uppercase italic letters are used to compare hybrids at a given factor level.) Only sites with tillering as a factor were considered (see split-split-plot sites in Table 1). Densities are denoted by 10K, 17K, and 24K; hybrids are denoted by P06 and P08; and tiller levels are denoted by NT (tillers removed) and YT (tillers maintained).

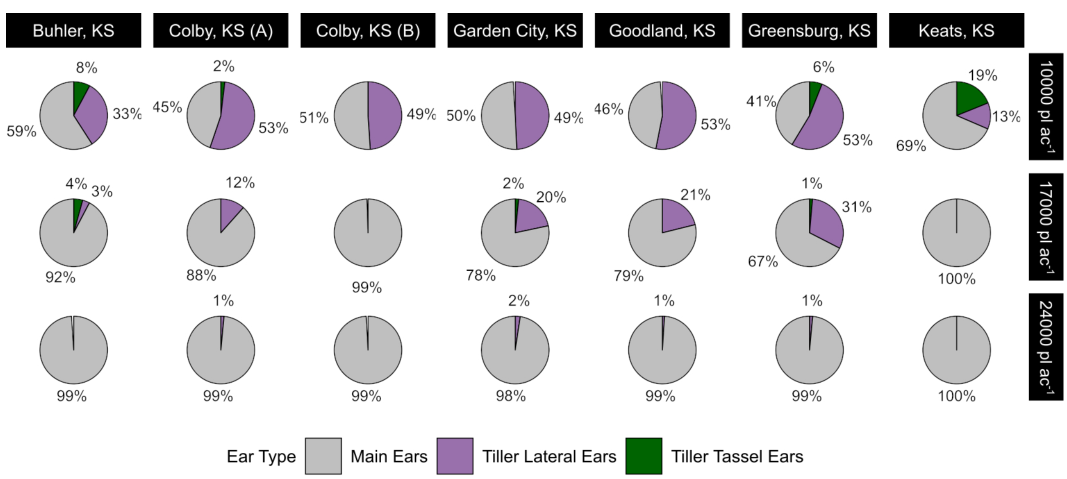

Figure 2. Ear development data by plant density, partitioned and shaded by ear type. Pie charts represent the total harvested ears, with slices representing the percentage of total ears belonging to each development category. Hybrids were averaged together and plots with tillers removed were not considered. All tested sites are shown.

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

E.A. 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 3.5% higher corn yields, and soybeans had up to a 2.9% 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. Nitrogen (150 lb in 2012 and 2013; 180 lb in 2014, 2015, 2016, 2017, 2018, and 2020; 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.

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 did 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 was very wet, with August near normal, resulting in average corn yields and very good soybean yields (no SDS symptoms). An analysis of data from 2013–2020 showed that corn yields were improved by deep tillage, and soybean yields improved 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 2014–2020 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 in the fall of 2020 to compare soil properties and soil health between tillage systems.

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 the Kansas River Valley Experiment Field

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

Table 2. Effects of tillage treatments on corn and soybean yields in 2012 at the 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 2013–2020 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	2013–2020	2014–2020
No-tillage	221	243	205 b*	183 b	226	206	218	207	214 b	32,313
Fall subsoil/spring field cultivate	223	259	215 a	202 a	236	214	228	212	223 a	31,938
Fall vertical tillage	196	259	207 b	189 b	226	210	219	211	215 b	31,982
Fall subsoil after sb/ vertical tillage after corn	214	256	211 ab	195 a	231	209	227	216	220 a	31,759
Pr>F#	0.14	0.27	0.05	0.005	0.46	0.7	0.22	0.36	0.001	0.43

*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 2013–2020 at Kansas River Valley experiment fields

	Soybean yield, bu/a								Average soybean yield
Tillage treatment	2013	2014	2015	2016	2017	2018	2019	2020	2013–2020
No-tillage	62.4	52.8	69.7	80.2	67.4	69.3	78.1	73.1	67.8
Fall subsoil/spring field cultivate	64.3	55.2	73.1	76.0	72.8	71.2	79.2	72.5	69.7
Fall vertical tillage	64.4	55.5	72.8	78.6	68.1	75.0	80.5	76.0	69.8
Fall subsoil after sb/ vertical tillage after corn	66.3	52.8	70.9	75.8	70.1	70.2	80.1	74.0	68.8
Pr>F#	0.52	0.40	0.23	0.12	0.098	0.51	0.87	0.54	0.07

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

Sorghum Grain Filling and Dry Down Dynamics for Hybrids Released Over the Past Six Decades in the US

P.A. Demarco, L. Mayor,[1] P.V.V. Prasad, C.D. Messina,[2] and I.A. Ciampitti

Summary
Sorghum (*Sorghum bicolor* L. Moench) is mainly grown in the Great Plains region of the United States, with the state of Kansas as the premier cropland for its cultivation. Over time, improvements in sorghum have been related to genetic and management interactions, however, scarcity of information on the grain filling and the dry down processes have been reported. This study characterizes grain filling and dry down dynamics for hybrids with different released years. Field trials were conducted during the 2018 and 2019 seasons in Kansas, testing 20 commercially available grain sorghum hybrids released between 1963 and 2017. Grain dry matter accumulation and reduction in grain moisture content were determined during the reproductive period, from grain filling to the physiological maturity of the crop. Across decades (hybrids), no changes in grain filling duration and rate were documented. Over the past 60 years, the rate of seed filling ranged from 0.56 to 1.34 mg grain/day, and the duration varied from 30 to 40 days for sorghum hybrids. The dry down duration ranged from 16 to 32 days and the rate of dry down ranged from -0.64 to -0.99% of moisture per day. Despite the lack of statistical differences in these grain filling traits, information about duration and rate are valuable guiding points for farmers in the US to better understand the potential fit of this crop into more intensified rotations.

Introduction
Sorghum (*Sorghum bicolor* L. Moench) is a widely cultivated crop in the central Great Plains region of the United States, with Kansas as one of the central states in terms of production and yields in the country (Rakshit et al., 2014; FAO, 2019). Over the past decades, improvements in grain yield due to genetic and management interactions have been reported for sorghum hybrids (Assefa and Staggenborg, 2010; Pfeiffer et al., 2019; Demarco et al., 2020). However, few details have been described regarding the grain filling and subsequent moisture loss (herein termed as "dry down") dynamics for US sorghum genotypes. After the critical period of the crop, which lasts for 10–15 days around flowering (Gambín et al., 2008), the period of grain filling, and then the water losses are of great importance for farmers due to the broader environmental factors that have an impact on the final yield. Identifying the duration and rate of these processes for genotypes from different years of release and maturity can help farmers to better understand the potential fit of this crop into more intensified rotations.

The grain filling and grain water loss occur consecutively in the plant. Generally, dry matter accumulation is divided into three phases (Bewley and Black, 1986). The first part consists of an active cell division phase with a higher water concentration in the

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grains. The effective grain filling constitutes the second phase, in which there is a continuous accumulation of biomass in the grains. Once the grains have achieved their final maximum weight, the biomass accumulation has ended, reaching the third phase known as physiological maturity. From this point, dry weight remains stable, and the grains continue losing moisture until the percentage of water content is acceptable to harvest the crop.

We hypothesized that different hybrids released over the last six decades in the US will present different duration and rates of grain filling and moisture loss. Our overall objective was to characterize the grain filling and dry down dynamics for commercially available sorghum hybrids with different years of release in the US.

Procedures

Experimental Conditions

Field studies were conducted at Corteva Agriscience research stations in Kansas, USA, during the 2018 and 2019 growing seasons. The experimental design was a randomized complete block design (RCBD), with 20 sorghum hybrids and three replications each season. Sorghum hybrids, all from Corteva Agriscience, spanned six decades of genetic selection (from 1963 until 2017). Plots were 17.4 ft long by 30-in. row spacing, the experimental layout was arranged in plots of two rows for 2018, and eight rows during the 2019 season. Specific details of sowing date, harvest date, plant density, and other management information from each year of study are presented in Table 1.

During the grain filling period, one plant per plot was collected in intervals of 4 to 5 days to characterize seasonal dynamics of grain dry matter and moisture content. The panicle was separated from the rest of the fraction (leaf + stem) by cutting 1 cm below the first branch and placed in plastic bags to conserve grain moisture. Phenology was tracked daily in these individual plants before flowering and during the reproductive period. At the laboratory, 40 grains per panicle were sampled inside a humidity chamber 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.

Statistical Analysis

Grain filling rate (GFR) and grain filling duration (GFD) were estimated fitting a bi-linear model [equations (1) and (2)] with grain dry weight modeled on a day-time basis from flowering to harvest maturity:

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

where d is the days after flowering, a is the y-intercept (mg/grain), b is the GFR (mg grain/day), and c is the total GFD (in days).

Dry down rate (DDR) and dry down duration (DDD) were estimated fitting a bi-linear model [equations (3) and (4)] with water content in percentage modeled on a day-time basis from physiological maturity (PM) to constant water content:

$$\text{Grain water content (\%)} = a + b * d \qquad \text{for } d<c \quad [3]$$
$$\text{Grain water content (\%)} = a + b * c \qquad \text{for } d>c \quad [4]$$

where d is the days after physiological maturity (PM), a is the y-intercept (WC %), b is the DDR (WC % per day), and c is the total dry down duration (DDD) in days.

Mixed-effects models were fitted with nlme (Pinheiro et al., 2018) package in RStudio (RStudio Team, 2016) for the traits measured.

Results

Over the last six decades, yield improvement in grain sorghum has been related mainly to increments in grain number per area rather than grain weight indicating that this physiological trait remained relatively stable across time (Demarco et al., 2020). Associated with grain weight, no changes in grain filling duration and rate were found for the years of release of our hybrids (Table 2). In our study, the grain-filling rate ranged from 0.56 to 1.34 mg grain/day, while the duration ranged from 30 to 40 days in length (Table 2). Likewise, Gizzi and Gambín (2016) reported no changes in grain weight for hybrids released from 1984 to 2014 and no changes in the duration of the seed filling period over time. This demonstrates that, as for maize (Otegui et al., 2015), there has not been a tradeoff between grain number and weight over time with yield selection in sorghum.

The rate of moisture content decline from physiological maturity to harvest did not present changes during the past decades, as well as the duration of the dry down period (Figure 1). Although the changes are not significant over time, the dry down duration ranged between 16 to 32 days and the rate of decrease in moisture content ranged from -0.64 to -0.99% of moisture per day (Table 2).

A comparison between hybrids from different decades is presented showing hybrids with a different rate but the same duration (Figure 2A and 2C), and different duration with similar rate (Figure 2B and 2D) of both dynamics under study. In panel 2A hybrids from 1981 and 1982 year of release present the same grain filling duration (36 days) but with a different rate, 1.02 mg grain/day for the hybrid from 1981 and 0.71 mg grain/day for the hybrid released 1982. Hybrids from 2007 and 2010 year of release, showed relatively the same grain filling rate (Figure 2B) 0.99 and 0.87 mg grain/day, respectively, but the duration was 34 for 2007 YR and 40 days after flowering for 2010 YR. The different durations between the two may be related to their relative maturity; the hybrid from 2007 is a mid-early relative maturity, while the 2010 hybrid is mid-late the difference to full bloom is 3 days, and 9 days for physiological maturity. In the dry down dynamics, hybrids from 1988 and 1997 are represented having similar dry down duration (22 and 23 days respectively from physiological maturity), and different rates (Figure 2C). Hybrids from 2007 and 2008 with similar rates of moisture lose approximately -0.70 grain WC % per day and have a difference of 9 days until the moisture content is constant.

Understanding how different sorghum hybrids reach their final grain weight is valuable not only for scientists, but also for farmers to select their genotypes and management strategies based on estimations of physiological maturity and dry down timings.

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Table 1. Field management and climate conditions during the 2018 and 2019 growing season

Location	Coordinates field trial	Year	Sowing date	Harvest date	Irrigation	Plant density	Max. Temp.	Min. Temp.	Precipitation
						plants/a	°F	°F	in.
Riley, KS	39°09'24.3"N 96°40'54.0"W	2018	6/7/2018	11/21/2018	Irrigated	70000	79.2	57.2	26.4
Riley, KS	39°09'12.1"N 96°40'03.7"W	2019	6/8/2019	11/8/2019	Dryland	70000	80.2	58.8	26.7

The minimum and maximum temperatures (Min. Temp. and Max. Temp., respectively) are the averages of minimum and maximum temperatures per day from planting to harvest for each site × year in Fahrenheit degrees (°F), respectively. The precipitation represents the accumulated rainfall from planting to harvest for all locations in inches. (Kansas Mesonet, 2017).

Table 2. Detailed results on grain filling rate (mg grain/day), and duration (days); dry down rate (WC % per day); and duration for all the hybrids under study

YR	Relative maturity	Days to FL	Days to PM	Grain filling rate	Grain filling duration	Dry down rate	Dry down duration
				mg grain/day	days	WC % per day	days
1963	Mid L	63	99	0.86	36	-0.70	26
1975	Mid	61	100	0.65	39	-0.69	22
1978	Mid	58	90	1.19	32	-0.95	18
1981	Mid	59	95	1.02	36	-0.65	27
1982	Mid L	63	99	0.71	36	-0.72	23
1983†	Mid	64	96	1.34	32	-0.66	32
1987	Mid L	67	105	0.56	38	-0.85	16
1988	Mid	61	97	1.07	36	-0.83	22
1989	Mid L	63	99	0.80	36	-0.67	26
1990	Mid E	58	93	0.82	35	-0.83	20
1992	Mid	60	92	1.16	32	-0.93	20
1997 A	Mid L	64	103	0.91	39	-0.68	23
1997 B	Mid E	57	87	0.93	30	-0.88	21
2003	Mid E	58	93	1.31	35	-0.99	19
2005	Mid	61	100	0.71	39	-0.64	24
2006	Mid L	62	94	1.22	32	-0.78	24
2007	Mid E	62	96	0.99	34	-0.70	29
2008	Mid	61	99	0.78	38	-0.69	20
2010	Mid L	65	105	0.87	40	-0.71	20
2013	Mid E	56	87	1.20	31	-0.77	24
2017‡	Mid	62	101	0.67	39	-0.71	19

†Hybrid included only in 2018 growing season.
‡Hybrid included only in 2019 growing season.
The YR represents the year of release of the hybrids, days to FL are the number of calendar days from planting to flowering; and the days to PM are the calendar days from planting to physiological maturity for all the hybrids.

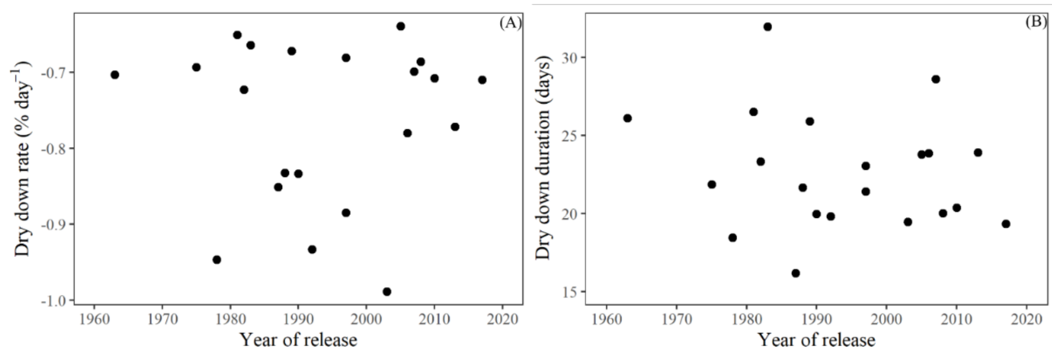

Figure 1. Grain dry down rate in water content percentage per day (A), and duration in days (B) related to the years of release of the hybrids.

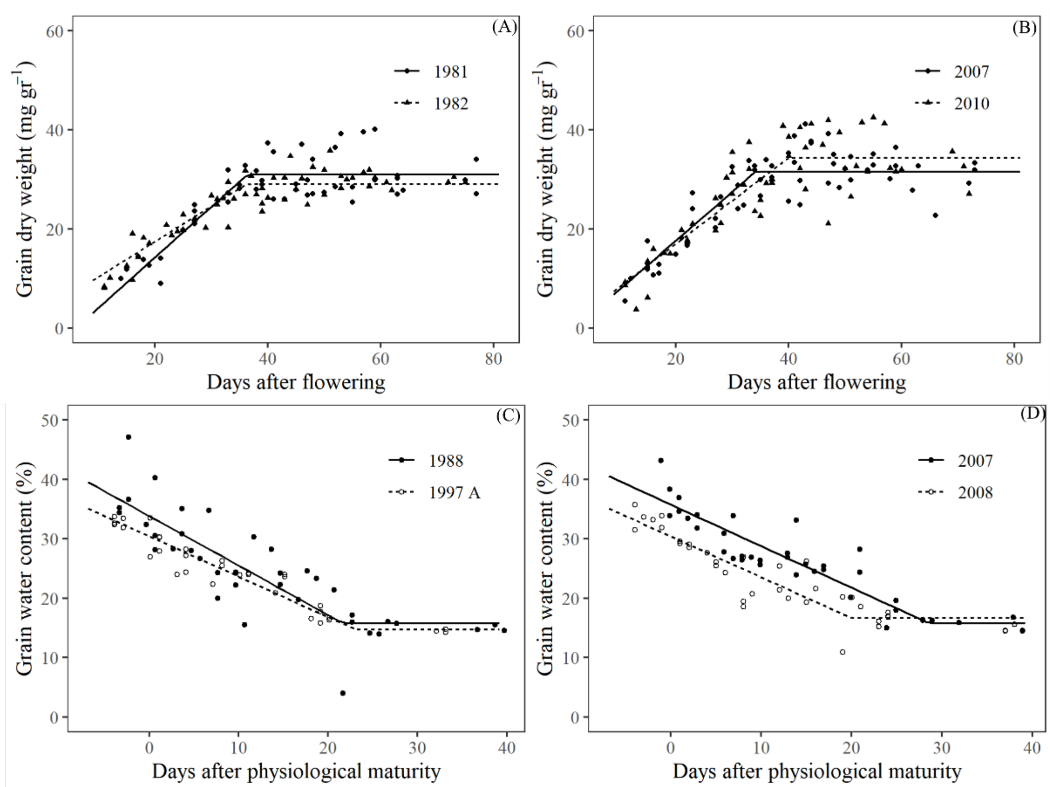

Figure 2. Grain filling dynamic in mg/gr of grain dry weight for different hybrids related to the days after flowering (A and B). Dry down dynamic in the percentage of grain water content in a relationship with the days after physiological maturity for hybrids from different years of release (C and D).

Macronutrient Fertility on an Irrigated Corn/Soybean in Rotation

E.A. Adee

Summary
Effects of nitrogen (N), phosphorus (P), and potassium (K) fertilization on a corn/soybean cropping sequence were evaluated from 2013 to 2020 (corn planted in odd years) from a study initiated in 1983. Corn yield was near optimum at 160 lb/a N. Phosphorus and K fertilization alone increased corn yield 31 and 7 bu/a, respectively; and soybean yields 22 and 1.7 bu/a, respectively. As N fertilization increased, the response to P increased corn yield from 13 to 40 bu/a. The best return on fertilizer investment was when the N and P needs were met for both crops.

Introduction
A study was initiated in 1972 at the Topeka Unit of the Kansas River Valley Experiment Field to evaluate the effects of N, P, and K on furrow-irrigated soybean. In 1983, the study was changed to a corn/soybean rotation with corn planted and fertilizer treatments applied in odd years. Study objectives were to evaluate the effects of N, P, and K applications to a corn crop on grain yield of corn, yield of the following soybean crop, and soil test values.

Procedures
The initial soil test in March 1972 on this silt loam soil was 47 lb/a available P and 312 lb/a exchangeable K in the top 6 in. of the soil profile. All fertilizer treatments were applied pre-plant before corn planting and incorporated. Nitrogen rates included a factorial arrangement of 0, 120, and 160 lb/a of N (with single treatments of 80 and 240 lb/a N). Three rates of P were 0, 30, and 60 lb/a of P_2O_5, and K treatments were 0 and 150 lb/a of KCl.

The planting date average was April 22 for corn and May 14 for soybean for the last four rotations, with herbicides applied pre-plant and postemergence each year. Plots were sprinkler irrigated with a linear move irrigation system. A plot combine was used for harvesting grain yields from the middle two rows of 15 (6 rows) × 30-ft plots.

The soil P ppm has decreased from the initial sampling when the study began as a corn/soybean rotation in 1983, with a study average of 55 ppm to 16 ppm in 2018. Soil K ppm has dropped from 320 to 242 K ppm, which is not as drastic as the P levels. For this reason, yield data from both crops for the last four rotation sequences are presented here to give a picture of the current yield level. Additionally, the seed planted in the last four crop rotations better represent the yield potential of current hybrids and varieties.

The income from fertilizer was calculated for each treatment in a crop rotation. Average yields of corn and soybeans were multiplied by the current grain price (January 2021) at $5.00 for corn and $13.60 for soybeans. Fertilizer cost was calculated using the following prices, N at $0.42/lb, P_2O_5 at $0.44/lb, KCl at $0.32/lb. The fertilizer cost of each treatment was subtracted from the gross income of a rotation of corn and soybeans since the fertilizer was applied only before corn. Then the gross of the check plot with no fertilizer was subtracted from each treatment in each replication for each year. This resulted in the income returned over fertilizer cost for comparison of fertilizer treatments.

Results

The average yield response of corn and soybean yields from 2013–2019 and 2014–2020, respectively, to the fertilizer treatments applied prior to corn planting are shown in Table 1. There were differences between the treatments for both crops. The factorial analysis at the bottom of the table explains the crops' response to each nutrient.

All three macronutrients increased corn yield, with corn responding most to N and P (Table 1). Yield responses of corn to N rates are shown in Figure 1, where the P and K rates were 30 and 150 lb/a, respectively, for all N rates. Nitrogen rate had the greatest influence on corn yield, as shown in Figure 1, especially to the first 80 lb of N. The yield response curve began to flatten as the N rate increased above 80 lb. The optimum economic N rate would probably be approximately 160 lb, which could vary depending on the price of corn and the cost of N.

Similarly, the first 30 lb of P_2O_5 resulted in the greatest yield increase (23 bu/a) for corn and continued to increase (8 bu/a) with an additional 30 lb of P_2O_5 (Table 1). The addition of 150 lb of KCl did increase the corn yield 6 bu/a, though probably not enough to be cost effective.

Soybean yields showed most response to the P left over after the corn, with a 13 bu/a increase for the first 30 lb of P_2O_5, with an additional increase of 9 bu/a at the 60-lb rate. A previous report from this study (Adee et al., 2016) showed that the severity of Sudden Death Syndrome (SDS) and subsequent yield loss in soybeans were related to lower soil P values. Long-term grain removal will reduce soil P levels, especially when fertilizer P levels do not meet maintenance levels. The severity of SDS and soybean yield response were very similar in 2016 and 2018. A variety more tolerant to SDS that was treated with ILeVO seed treatment greatly reduced the foliar symptoms of SDS in 2020. There was no significant yield benefit to the soybeans from additional N and K applied to the corn.

There was a significant return on fertilizer investment for N and P fertilizer and for the treatments that provided a more balanced fertility. The 150 lb of KCl (K) did not pay for itself, though a lower rate may have been more profitable. The highest income was with treatments of 120-60-0, 120-60-150, 160-60-0, and 160-60-150 of N-P-K (Table 1).

There was a significant interaction between N and P for both crops (Table 2). Basically, as corn yields increase with the increased N rate, more P is removed from the soil, as shown by the soil test data. As a result, both crops showed an increased yield response to P as the N rate increased, and an increased income over both years of the corn/soybean rotation (Table 1).

Conclusions

As was well documented for years, these data from a long-term study show that N is the most critical fertilizer for corn. The curve representing corn's yield response to N still shows that the optimum N rate is approximately 160 lb N/a. Phosphorus follows closely behind as a critical fertilizer for both crops. The best return for fertilizer investment is a balanced program that meets the needs of both crops in the rotation, and over the long term helps maintain or build fertility levels as needed.

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Table 1. Effects of nitrogen (N), phosphorus (P), and potassium (K) applications on corn yields in a corn/soybean cropping sequence, Kansas River Valley Experiment Field, Topeka Unit

Fertilizer[1]			Corn yield		Soybean yield		2-year Income return over fertilizer cost[4]	
N	P_2O_5[2]	K_2O	2013–2019		2014–2020			
------------- lb/a -------------			------------------ bu/a ------------------				$/a	
0	0	0	96.0	g[3]	37.7	f	0.00	j
0	0	150	99.8	g	38.1	ef	-66.49	j
0	30	0	122.2	f	53.6	c	326.43	efgh
0	30	150	98.1	g	55.7	bc	137.58	i
0	60	0	109.8	gf	62.8	a	363.57	efg
0	60	150	112.0	gf	65.5	a	314.72	efgh
120	0	0	157.2	e	43.8	ed	323.7	efgh
120	0	150	164.7	de	44.2	c	241.02	ghi
120	30	0	174.3	d	50.6	c	445.65	de
120	30	150	197.4	c	56.4	bc	544.02	cd
120	60	0	195.7	c	63.1	a	694.91	a
120	60	150	206.4	bc	64.1	a	667.26	ab
160	0	0	171.7	de	41.6	ed	302.72	fgh
160	0	150	169.5	de	43.5	ed	220.57	h
160	30	0	199.0	bc	55.7	bc	604.44	abc
160	30	150	205.8	bc	53.1	c	507.02	cd
160	60	0	200.5	bc	60.8	ab	654.02	ab
160	60	150	223.2	a	64.5	a	721.82	a
80	30	150	173.2	de	54.2	c	425.75	def
200	30	150	214.4	ab	55.4	bc	546.99	bcd
Prob>F			<0.0001		<0.0001		<0.0001	

continued

Table 1. Effects of nitrogen (N), phosphorus (P), and potassium (K) applications on corn yields in a corn/soybean cropping sequence, Kansas River Valley Experiment Field, Topeka Unit

Fertilizer[1]			Corn yield	Soybean yield	2-year Income return over fertilizer cost[4]
N	P_2O_5[2]	K_2O	2013–2019	2014–2020	
------------- lb/a -------------			------------------ bu/a ------------------		$/a
Nitrogen means					
0			106.3	52.2	179.30 b
120			182.6	53.7	486.09 a
160			195.0	53.2	501.77 a
Prob>F			<0.0001	0.38	<0.0001
Phosphorus means					
	0		143.2	41.4	170.25 c
	30		166.2	54.2	427.52 b
	60		174.6	63.5	569.38 a
Prob>F			<0.0001	<0.0001	<0.0001
Potassium means					
		0	158.5	52.2	412.83
		150	164.1	53.9	365.28
Prob>F			0.045	0.059	0.029

[1] Fertilizer applied to corn in odd years from 1983 to 2019.

[2] Phosphorus treatments not applied in 1997. Starter fertilizer of 10 gal/a of 10-34-0 was applied to all treatments in 1997 and 1998 (corn and soybean). Nitrogen and K treatments were applied to corn in 1997.

[3] Numbers followed by different letters are different at $P = 0.05$.

[4] 2-year income calculated using corn at $5.00, soybeans at $13.60, N at $0.42/lb, P_2O_5 at $0.44/lb, and KCl at $0.32/lb.

Table 2. Interaction of nitrogen (N) and phosphorus (P) fertilizer applied before corn in a corn-soybean rotation on soil phosphorus, corn and soybean yield at the Kansas River Valley Experiment Field, Topeka[1]

Nutrient		2018 soil test	Yield average	
N	P	P, ppm	2013–2019 Corn	2014–2020 Soybean
---------- lb/a ----------		0–6 in. depth	---------- bu/a ----------	
0	0	7.0	97.9 e[2]	37.7 d
0	30	16.7	110.1 d	54.7 b
0	60	42.9	110.9 d	64.2 a
120	0	4.2	161.0 c	44.0 c
120	30	13.2	185.9 b	53.5 b
120	60	32.8	201.0 a	63.6 a
160	0	3.9	170.6 c	42.5 c
160	30	8.4	202.4 a	54.4 b
160	60	24.3	211.8 a	62.6 a
Pr>F			0.005	0.03

[1] Fertilizer applied to corn in odd years from 1983 to 2019.
[2] Numbers followed by different letters are different at $P = 0.05$.

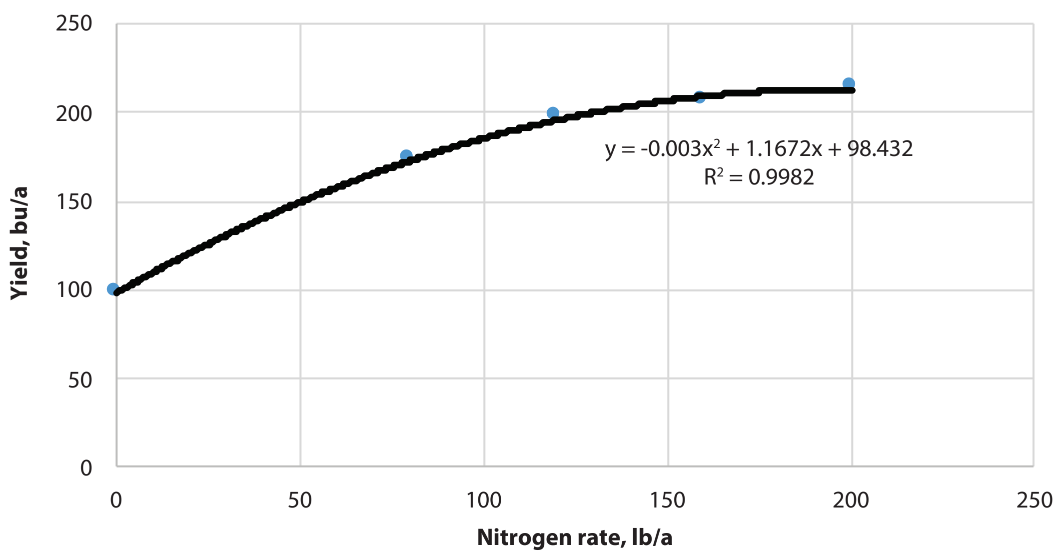

Figure 1. Average corn yield response from 2013 to 2019 to nitrogen rates applied with 30 and 150 lb of P_2O_5 and KCl, respectively, prior to the corn crop in long-term macronutrient fertility study at the Kansas River Valley Experiment Field, Topeka.

Does Grazing Cover Crops Impact Soil Properties?

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

Summary
Grazing of cover crops (CCs) by cattle could provide supplemental forage and additional revenue to offset grain yield losses when CCs are grown in semiarid rainfed cropping systems. However, grazing CCs could reduce the amount of residue retained on the soil surface and subsequently affect soil physical and chemical properties. This study evaluated effects of grazing CCs on soil bulk density, aggregate stability, and chemical properties using soil samples collected from three producer fields in west central Kansas that had paired grazed and non-grazed CC treatments, as well as adjacent native perennial pastures. Across sites, CC residue after grazing averaged 2650 lb/a compared to 3741 lb/a for the non-grazed CCs, representing a 29% decrease in CC biomass with grazing. Bulk density, aggregate size distribution, and mean weight diameter (MWD) were not different ($P > 0.05$) between grazed and non-grazed CCs. The MWD under perennial pasture was 0.148 in., approximately 2.9-fold greater than MWD with grazed (0.050 in.) or non-grazed CCs (0.051 in.). Soil pH and soil organic carbon (SOC) did not differ ($P > 0.05$) between the grazed and non-grazed CCs. Soil nitrate (NO_3-N), phosphorus (P), iron (Fe), manganese (Mn), and copper (Cu) concentrations with grazed or non-grazed CCs were greater than in pasture. Our findings showed grazing of CCs may be a management option to intensify NT cropping systems with little negative effects on soil bulk density, aggregate stability, or extractable nutrient concentrations.

Introduction
Integration of CCs into NT crop production has been recommended to regenerate soil properties degraded after many years of conventionally tilled, low-intensity cropping systems in the central Great Plains. Potential benefits of adopting CCs in NT cropping systems of west central Kansas include improved soil health through increased soil organic carbon, reduced compaction, enhanced soil nutrient cycling, as well as improved structure and water infiltration. However, subsequent crop yields following CCs have been mixed with CCs having either no effect or reducing yields in drier years in water-limited environments. This yield penalty presents a major barrier to adoption of CCs in the region. Notwithstanding, those few producers adopting CCs seek to overcome this economic loss through the incorporation of livestock to take advantage of supplemental forage provided by CCs. Value through grazing CCs may offset losses in subsequent crop yield in order to balance the goals of profitability and maintenance of soil health in dryland cropping. However, limited information exists on the effects of grazing CCs on soil properties. Concerns include reduced SOC accrual, increased soil compaction, and degraded soil structure with grazing, especially in NT production systems.

Previous research suggests grazing CCs may have nominal effects on soil properties and may be a good management option for the dryland producers of the central Great Plains. Still, on-farm research is needed to confirm the effect of grazing CC on soil properties in dryland NT cropping systems of this region. Therefore, the objective of this current research was to investigate CC grazing impacts on residue return, soil bulk density, aggregate stability, pH, and soil nutrient concentrations on producer fields in west central Kansas.

Procedures

This study was conducted on cooperative producer field located near Marquette in central Kansas and Hays in western Kansas for a total of two producer fields in the 2018–2019 growing season. The study was repeated on a different field in the 2019–2020 growing season near Marquette. The fields in Marquette were managed under a NT rainfed wheat-wheat-soybean (2018–2019) or wheat-sorghum-soybean (2019–2020) rotation. A winter CC mixture of triticale/rapeseed/radish was planted in the fall following the wheat phase ahead of soybean or sorghum in each rotation. The site near Hays was managed under a NT dryland wheat or triticale-sorghum-fallow rotation. Summer cover crops were planted immediately following triticale. The experiments at each study location had two treatments, grazed CCs and non-grazed CCs, in four replicated strips. The non-grazed CC treatments were fenced using electric wire fencing materials to prevent access to cattle during CC grazing. Cover crop grazing at Marquette in the 2018–2019 growing season occurred from December 17, 2018, through February 10, 2019, at a stocking rate of 5.4 animal unit months (AUM) per acre for 55 grazing days. Again, in 2019–2020, heifers grazed CCs from January 9 to February 17, 2020 with a stocking rate of 4.2 AUM/a for a total of 39 grazing days. At Hays, CC grazing spanned from August 24 to October 10, 2019, for 48 grazing days using lactating cows at a stocking rate of 5.2 AUM/a. Four locations within the grazed area, directly adjacent to each replicate of the fenced non-grazed CCs, were marked and used as four replicates (pseudoreplicates) for the grazed CC treatments. Prior to grazing, CC biomass was determined from two 6 ft^2 quadrats randomly placed in each replicated strip with all the aboveground CC biomass clipped at the soil surface. Freshly clipped sample weights were recorded, and samples were then dried at approximately 122°F in a forced-air oven until they reached a constant weight. These samples were then weighed to determine dry matter (DM). After termination of CCs, grazed and non-grazed CCs were sampled and DM was determined as described previously.

Soil samples were collected for the analysis of soil chemical and physical properties from the grazed and non-grazed CCs in the spring of 2019 and 2020 after termination of CCs and before soybean (Marquette, KS, in 2019) or sorghum planting (Marquette and Hays, KS, in 2020). Additional soil samples were taken from adjacent native perennial grass pastures in 2020 at both Hays and Marquette to compare soil properties to the CC treatments. Two intact soil cores of 6 inches in depth and 2 inches in diameter were randomly taken from each plot to determine soil bulk density. Samples were dried at 221°F for a minimum of 48 hours and bulk density was computed as mass of oven-dried soil divided by volume of the core. Ten additional 6-inch cores were collected randomly from each treatment for the determination of SOC and nutrient concentrations. Additional soil samples were collected from the 0- to 2-in. soil depth with a flat shovel for the determination of WSA. Samples were gently passed through sieves with 0.315- to 0.187-in. mesh and allowed to fully air-dry. Two sub-samples from each replicate were used to estimate WSA by the wet-sieving method.

Data analyses for CC biomass, bulk density, aggregate stability, SOC and available nutrient concentrations were performed using the PROC MIXED procedure in SAS v. 9.3 (SAS Institute, 2012, Cary, NC). Cover crop productivity data analysis was performed with CC management as a fixed effect while replication nested within location was considered random. For soil pH, bulk density, and available nutrient concentrations, CC management and sampling depth were considered fixed effects while replication nested within location was treated as a random effect in the model. Similarly, MWD were analyzed with CC management as a fixed effect and replication nested within location treated as a random variable in the model. The LSMEANS procedure of PROC MIXED was used for mean comparisons. Interactions and treatment effects were considered significant when F test P values were ≤ 0.05.

Results

In general, CC biomass post-grazing was less than non-grazed CCs. Averaged across sites, pre-grazed CC biomass was not different from post-grazed though both were less than the non-grazed CCs (Figure 1). This occurred because the annual grass CC species used in this study had significant regrowth after grazing, which resulted in additional growth to compensate for biomass removed by cattle consumption and trampling. Post-grazed CC biomass averaged 2650 lb/a compared to 3741 lb/a for the non-grazed treatment. This suggests that approximately 71% of the total available CC biomass produced was retained as residue on the soil surface after grazing. Therefore, careful grazing of CCs as done in this study could leave adequate residue cover to protect the soil and meet soil health goals.

A major drawback of CC grazing in NT systems is the potential for soil compaction, though this may depend on soil texture and, with some effects, alleviated by regular winter freeze-thaw cycles. Results from this study showed soil bulk density under grazed CCs was not different from the non-grazed CC treatment (Table 1). Soil bulk density was different ($P < 0.001$) among CCs and pasture (Table 1), possibly due to the remanent effects of past tillage operations before conversion to NT as well as the differences between temporary annual and permanent perennial rooting systems. Mean weight diameter of WSA and aggregate size distribution in the 0- to 2-in. soil depth was different among CCs and pasture. The MWD measured under perennial pasture was 2.9-fold greater than grazed or non-grazed CCs. Notwithstanding, the aggregate size distribution and MWD were not different ($P > 0.05$) between grazed and non-grazed CCs. Across sites, MWD averaged 0.050- and 0.051-in. with grazed and non-grazed CCs, respectively (Table 1).

Average soil pH under pasture was 6.71, which was greater than grazed (5.62) or non-grazed (5.76) CCs. Cattle grazing CCs had no negative effect on soil pH compared to the non-grazed treatment. The SOC concentration was not different between grazed or non-grazed CCs in this study. Across depths, SOC averaged 1.55% for grazed and 1.70% for non-grazed CCs, and both were less than that measured under pasture (Table 1). Similarly, soil fertility indicators including N, P, Fe, Mn, Zn, and Cu concentrations were unaffected by cattle grazing CCs compared to the non-grazed treatment. However, N concentrations measured under grazed or non-grazed CCs were 6-fold greater than in the pasture. Similarly, the P concentration was 4 times greater with CCs compared to the pasture. The significantly greater N and P concentrations measured in the annual production fields were expected due to regular applications of inorganic fertilizer (N and P) inputs compared to the non-fertilized perennial pastures. Despite the 1.5-fold greater SOC content measured in the pasture, micronutrients' (particularly Fe, Mn, and Cu) concentrations in the pasture were less than those measured in the grazed or non-grazed CCs. Based on these results, we conclude that grazing of CCs is a viable management option to intensify NT crop production to improve soil health and maintain or increase overall system profitability. Further research will be needed to determine the long-term effects of CC grazing in NT production systems.

Table 1. Soil physical and chemical properties in the 0- to 6-in. soil depth as influenced by cover crop management: no-till grain-based cropping systems with grazed cover crops, non-grazed cover crops, and perennial pasture

	Cover crop management		
Soil property	Grazed cover crops	Non-grazed cover crops	Pasture
pH	5.62 b[†]	5.76 b	6.71 a
Bulk density (g cm^{-3})	1.35 a	1.31 a	1.20 b
Total N (%)	0.15 c	0.17 b	0.23 a
SOC (%)	1.55 b	1.70 b	2.36 a
NO_3-N (ppm)	7.1 a	6.1 a	1.1 b
NH_4-N (ppm)	13.8 a	18.0 a	11.4 a
P (ppm)	48.2 a	46.6 a	13.4 b
Zn (ppm)	0.79 a	0.95 a	1.18 a
Fe (ppm)	56.8 a	53.3 a	33.4 b
Mn (ppm)	60.8 a	58.4 a	37.9 b
Cu (ppm)	1.3 a	1.3 a	1.0 b
Large macroaggregate (%)	29.2 b	32.2 b	68.9 a
Small macroaggregate (%)	43.1 a	43.4 a	21.8 b
Microaggregates (%)	27.7 a	24.5 a	9.3 b
MWD (inch)	0.050 b	0.051 b	0.148 a

[†]Means in a row followed by different letters indicate significant differences among cover crop management treatments at $\alpha < 0.05$.

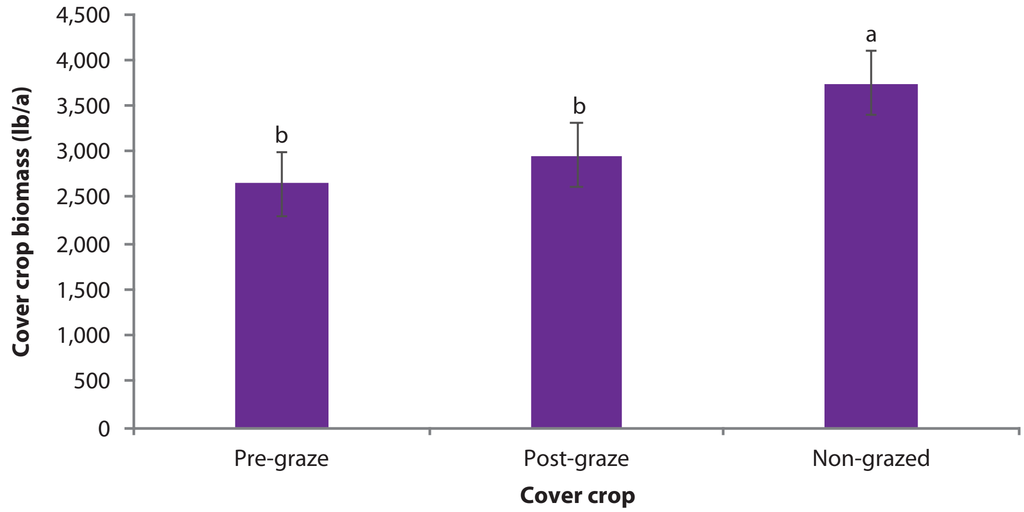

Figure 1. Cover crop productivity pre-grazing, post-grazing, and non-grazed, averaged across site-years. Means across site-years are averaged across 4 replications and 3 sites (n = 12). Different letters atop bars indicate significant differences among pre-graze, post-graze, and non-grazed cover crop biomass at $\alpha < 0.05$. Error bars represent standard error.

Using a Sprayable Biodegradable Polymer to Reduce Soil Evaporation in Greenhouse Conditions

J. Flory,[1] J. Grane, and A. Patrignani

Summary

Sprayable biopolymer membranes (SBM) is an emerging mulching alternative to increase horticultural and agricultural productivity by reducing soil erosion and evaporative losses. The SBM is usually applied in liquid form directly to the soil surface where the polymer molecules form a thin biodegradable film. In order to test this technology, an experiment was performed in greenhouse conditions with the goal of quantifying the impact on soil evaporation rate and biomass accumulation in winter wheat.

Introduction

About 60% of the annual water supply in agricultural systems of the southern Great Plains is lost as soil evaporation, making evaporative losses the single greatest loss of water (Warren et al., 2009). Previous micro-lysimeter studies have shown that evaporative losses can account for 30% of the growing season water supply losses for corn on sandy and silt loam soils in western Kansas (Klocke, 2004). Scientists and stakeholders alike have tested several management strategies that reduce soil water evaporation. Long-known alternatives include the use of nylon, sand, and gravel mulching, but these alternatives involve costly or heavy products that require specialized machinery, which can make applications over large fields impractical. A common management strategy to reduce soil water evaporation in extensive agricultural fields is the adoption of no-tillage, which consists of leaving crop stubble on the soil surface after harvesting the preceding crop. However, no-tillage has proven effective to reduce evaporative losses compared to bare soil only when >75% of the soil surface is covered with crop residue, a value hard to achieve and sustain in environments such as central and western Kansas. An evaporation study in a fallow field using micro-lysimeters near Garden City, KS, showed that corn residue covering 25 to 75% of the soil surface caused no reductions in soil evaporation (Klocke et al., 2009). Intensive cropping and horticultural systems have long solved this problem using plastic mulches, but the products generated much plastic waste, which contributes to environmental pollution.

Sprayable biopolymer membranes are an innovative technology with potential to minimize evaporative losses and increase soil water storage in both rainfed and irrigated cropland. The SBM has several advantages over similar methods of moisture loss prevention strategies, such as plastic mulch coverings that are disposed of in landfills, because of its ability to naturally degrade over time and offer a high ease of application (Adhikari et al., 2015). This experiment aims to quantify the reduction in soil water evaporation using SBM. We hypothesize that the SBM will reduce evaporative losses and that actively growing plants will be able to take advantage of soil water remaining

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longer in the soil profile to shift evaporative unproductive losses into transpirational losses.

Procedures

The study was conducted in winter wheat (*Triticum aestivum* L.) under greenhouse conditions. A total of 20 plastic containers with a volume of 16 L (4.2 gallons) were filled with a loam soil to reach a target bulk density of 1.1 g cm^{-3}. The experimental design consisted of a randomized complete block design with three treatments and four replications. Blocking was necessary to account for the effect of a small thermal gradient in the greenhouse caused by the refrigeration and ventilation system. The treatments consisted of a check without the SBM and two rates of biopolymer. The treatments consisted of a 2:1 ratio of water to polymer at a low rate (LR, 8 mg cm^{-2} of active ingredient) and high (HR, 21 mg cm^{-2} of active ingredient) application rates. After packing the soil, we applied a solution consisting of 3 L (0.8 gallons) of tap water with 18 g (0.04 oz) of all-purpose Miracle-Gro fertilizer (24-8-16) to each container. After watering the pots, the containers were left covered for 24 hours to allow soil moisture to redistribute in the soil. A total of 25 seeds of winter wheat were planted in a cross formation per pot. The day following planting, we applied the two treatments of the biodegradable polymer. The biopolymer was applied with a handheld sprayer equipped with an automatic pump that kept the pressure constant at 30 psi during the application. After the application of the biopolymer treatments, the plants were left to grow in the greenhouse environment with the initial soil water content. One soil moisture sensor (Teros 11, Meter Group Inc.) was installed in each treatment to monitor near-surface soil moisture conditions over the extent of the experiment. Downward-facing pictures were taken weekly to monitor and record the plant growth in each container. At a midpoint in the experiment, the number of weeds was recorded prior to their removal. The mass of the containers was also recorded periodically to track the amount of mass lost due to evaporation. The experiment was terminated when the plants of the check treatment were under severe water stress and had signs of premature senescence. Biomass was determined by clipping above-ground stems and leaves and then drying them at 60°C (140°F) for 48 hours.

Results

The total evapotranspiration ranged from 2.54 to 2.61 mm (approximately 1 inch) over the 35 days of the experiment. The total amount of above-ground dry biomass for the check was 1.12 g, while the LR resulted in 3.0 g of above-ground biomass and the HR treatment resulted in 3.3 g of above-ground biomass. Because the total water loss was similar, but the amount of biomass produced in pots treated with the biopolymer was significantly different ($P < 0.01$) than the check, the water use efficiency (WUE) of the LR treatment was 2.76 higher than the check, and the WUE of the HR treatment was 2.95 times higher than the check.

The plants that received the check treatment did initially grow at a faster rate, but they were not able to sustain that growth rate for the duration of the experiment like the polymer treated plants. Figure 1 shows pictures of the check treatment and the high rate single treatment at the time of harvest. Plants in the check pot show declining health, compared with the healthy plant growth seen in the polymer treated plot. As an additional advantage to the application of the polymer, we observed a lower number of weeds compared to the check (Table 1). The SBM may represent a physical barrier that helps suppressing weed emergence.

The soil moisture dynamics also showed how the HR treatment, in part, delayed the soil water depletion, likely by reducing the evaporative rate (Figure 2). The LR treatment exhibited a similar time series as the check, but despite similar changes in soil moisture, the water losses could have been attributed to different evapotranspiration partitioning.

Preliminary results show that the SBM has potential to shift evaporative unproductive water losses into productive transpiration that results in greater biomass. Our study was confined to greenhouse conditions and only explored biomass production during the early stages of winter wheat. Future research efforts will be focused on longer growing periods in both greenhouse and field conditions.

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Table 1. Average initial pot mass, final pot mass, above-ground biomass, evapotranspiration (ET), and water use efficiency (WUE) for the three different treatments

Biopolymer treatment	Initial pot mass	Final pot mass	Aboveground dry biomass	Weed count	Total ET	WUE†
	kg	kg	g	number	mm	g/mm
Check	16.6	15.4	1.12	4	2.57	0.43 a
Low rate	16.2	14.7	3.0	0	2.54	1.19 b
High rate	16.5	14.8	3.3	0	2.61	1.27 b

† Water use efficiency computed as the above-ground dry biomass divided by the total evapotranspiration. Letters represent treatments that have means significantly different at 1% level using Fisher's least significant difference.

Figure 1. Downward-facing images of a pot with the check treatment (left) and the high rate biopolymer treatment (right) on the day of harvest (December 8, 2020). Plant on the right resulted in greater biomass over the study period with the same amount of water as the check treatment plant.

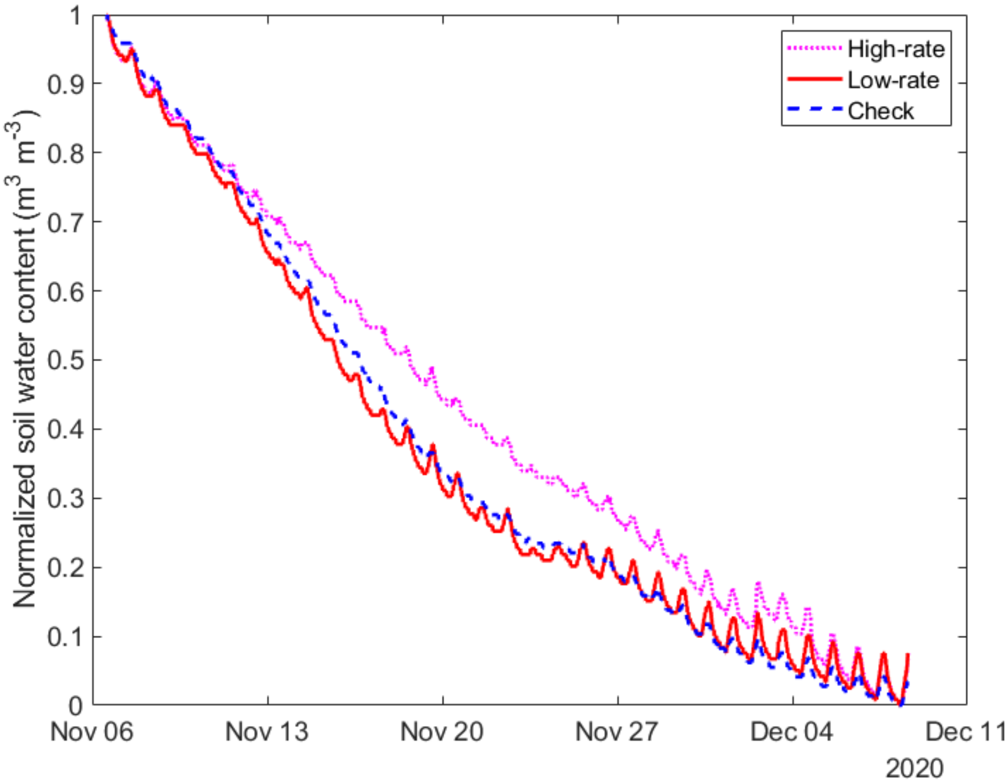

Figure 2. Normalized soil moisture dynamics for the check (no biopolymer), low application rate, and high application rate of the biodegradable polymer.

Laboratory Calibration of the Spectrum Field Scout TDR 300

W. Dyer,[1] D. Bremer,[1] P. Rossini, M. Stone,[2] and A. Patrignani

Summary
Soil moisture sensors (SMSs) are a useful tool that aid in data-driven water management decisions. However, default factory calibrations can be inaccurate and soil-specific calibrations are often required to obtain higher accuracy in the determination of soil water storage and plant available water. In this study, we conducted a lab calibration for the Field Scout TDR 300, which is a popular SMS used in the turfgrass industry. Five soils of different soil textural classes were packed in containers with known soil moisture for the laboratory calibration. The logarithmic model best fit the data for the course- and fine-textured soils, with a root mean square error (RMSE) value of 0.027 and 0.035 cm^3 cm^{-3}, respectively. These two calibration curves help to estimate volumetric water content more accurately for native and sand-based soils.

Introduction
Soil moisture sensors enable water managers and golf course superintendents to monitor soil water storage objectively, rather than to evaluate soil moisture content subjectively with touch and sight. Measurements of volumetric water content using SMSs provide a quantitative observation method that can lead to improved water use efficiency, conservation of water resources, and healthier plant conditions (Serena et al., 2020). Soil moisture sensors are effective tools that offer cost-effective and real-time measurements for data-driven water management decisions. The Field Scout TDR 300 (Spectrum Technologies Inc., Aurora, IL) is a popular hand-held instrument used in the turfgrass industry, most notably by golf course superintendents and athletic field managers. This handheld instrument allows turfgrass managers to guide irrigation decisions by identifying parts of the field that exhibit soil water deficits and by providing a surrogate soil water storage to determine the amount of irrigation water needed. In return, turfgrass managers have been able to cut down on cost, water inputs, and create more consistent playing conditions (O'Brien, 2014). However, a non-calibrated SMS may not accurately represent the soil water storage and soil moisture availability to plant roots, and this inaccuracy can lead to under- or over-watering irrigation events. Our objective was to develop a calibration curve for the Field Scout TDR 300 to help turfgrass managers to accurately estimate soil moisture content on native fine-textured soils often found in fairways, tees, and rough areas, and on engineered sand-based soils used on golf greens and many athletic field complexes.

Procedures
The Field Scout TDR 300 uses the principle of time domain reflectometry, in which the travel time that it takes for an electromagnetic signal to return to the sensor logger is directly related to the moisture content of the soil. In each measurement, the sensor

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sends an electric signal through a waveguide consisting of two parallel rods with a 7.6 cm (3.0 in.) length (Figure 1C) that are fully inserted into the soil.

The first step of the calibration process consisted of collecting soils of varying textural classes from different Kansas State University Research Experiment Station sites near Manhattan, KS. Each soil was dried at 105°C (221°F) for 48 hours, and then ground to pass through a 2 mm sieve. Ground soil was then packed into one-gallon plastic containers to a target bulk density of 1.4 g/cm^3 for fine-textured soils and a target bulk density of 1.7 g/cm^3 for the coarse-textured soil (Figure 1B). Each container was brought to a known volumetric water content spanning the range from air-dryness to saturated conditions. Then, each container was sealed with a plastic lid and left for 24 hours to allow for soil water redistribution within the soil in the container.

In each container, two measurements were made with the Field Scout TDR300 by inserting the sensor rods vertically. The two measurements were made at 90-degree angles from each other. For the two measurements we recorded the period average to be used for the curve fitting exercise. At the end of the experiment, all soils from the containers were placed in a drying-oven at 105°C (221°F) for 48 hours and then weighed to obtain the dry mass. The observed volumetric water content was calculated from the observed gravimetric water content and bulk density of each sample. The calibration consisted of a curve-fitting exercise using the observed volumetric water content as a function of the period average for each soil type. The fraction of sand, silt, and clay for each soil was determined using the hydrometer method using a solution of 50 g/L of sodium hexametaphosphate as a dispersing solution (Gavlak et al., 2005).

Results

Five textural classes were identified from four sites (Table 1), which provided a wide range of conditions for the calibration of the sensor. The commercial sand had the highest sand content of 100%, while the silty clay-textured soil had the highest clay content of 45.9%.

Calibration curves for fine-textured and coarse-textured soils were considered separately. The results for calibration (Figure 2) show a logarithmic model fit the data well for both sand ($r^2 = 0.93$, RMSE = 0.027) and the fine-textured soils ($r^2 = 0.95$, RMSE = 0.035). These two generated calibration curves help to estimate volumetric water content more accurately for native and sand-based turfgrass systems. Although the factory default calibration can be used and the sensor does not necessarily need to have site-specific calibration, absolute values can be greatly inaccurate if the sensor is left uncalibrated. Calibrated sensors increase the accuracy of the estimated soil water storage and can help end users make more-informed irrigation decisions. In this study, improvements of up to 0.02 cm^3 cm^{-3} were obtained by considering a custom calibration curve for the coarse-textured soil solely. These improvements can be valuable on sand-based turfgrass systems where soil water deficits need to be closely monitored. Value is also added for research purposes where accurately calibrated sensors should always be used.

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Table 1. Soil texture characterized by clay, silt, and sand

Soil sampling depth	Clay	Silt	Sand	Bulk density	Textural class
cm	-------------------------	%	-------------------------	g/cm^3	
Site 1:					
0–15	28.3	52.1	19.6	1.32	Silty clay loam
20–40	45.9	40.9	13.2	1.24	Silty clay
Site 2:					
0–15	20.7	59.1	20.2	1.39	Silt loam
Site 3:					
0–25	23.2	30.7	46.1	1.39	Loam
Site 4:					
Unknown	0	0	100	1.62	Sand

Figure 1. (A) Lab setup depicting the hydrometer method used for determining particle size analysis; (B) packed soil containers varying in moisture contents for sensor calibration (note that some containers show the marks of the two measurements at 90-degree angle); and (C) Field Scout TDR 300 depicted with 7.6-cm length rods attached.

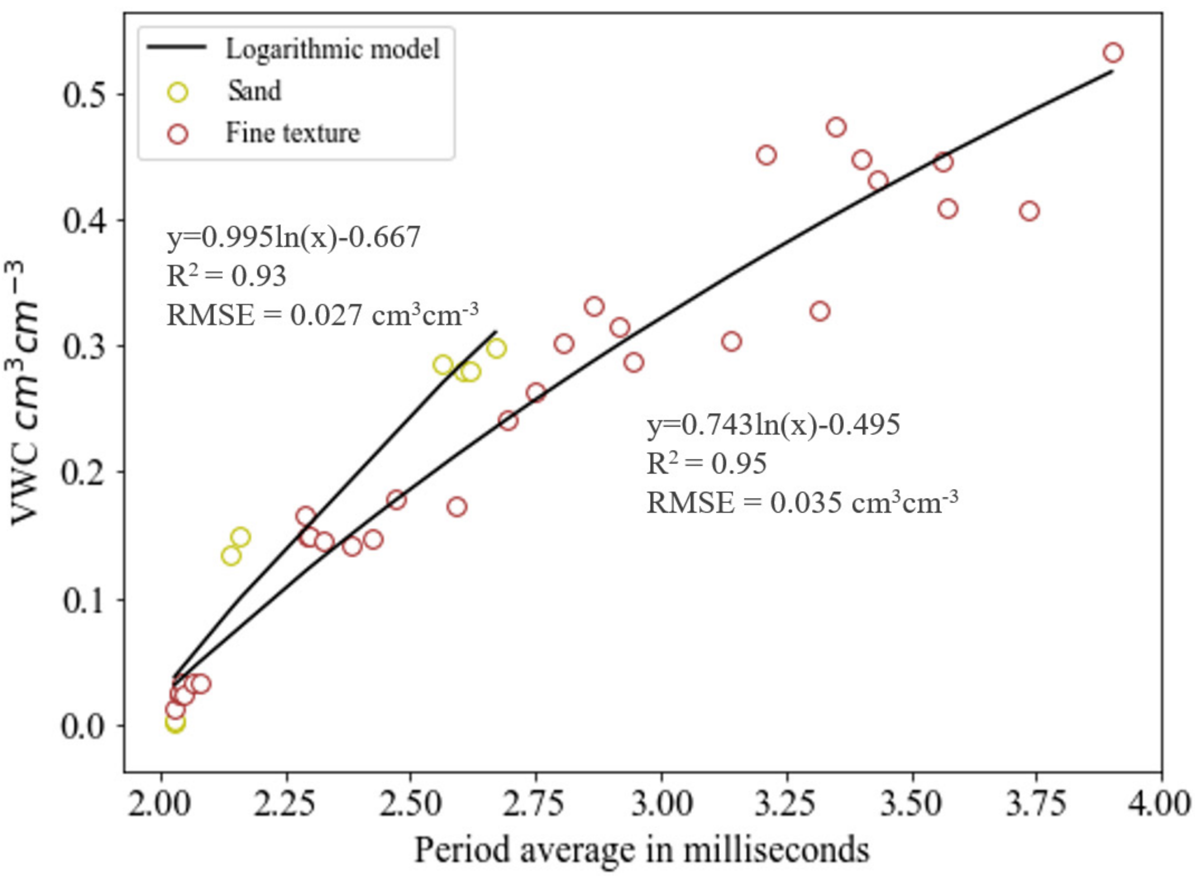

Figure 2. Volumetric water content as a function of period average using two calibration curves, grouped by sand and fine-textured soils. A logarithmic model was used to fit the data. VWC = volumetric water content.

Evaluating Traditional and Modern Laboratory Techniques for Determining Permanent Wilting Point

N. Parker and A. Patrignani

Summary
The permanent wilting point is often considered the lower limit for plant available water and can be measured in the laboratory using a pressure plate apparatus (traditional method) or a dewpoint water potential meter (modern method). However, recent evidence suggests substantial discrepancy between the soil moisture at the permanent wilting points derived from these two laboratory techniques. This preliminary study investigated the magnitude of the discrepancy between permanent wilting points derived from traditional and modern laboratory techniques and the concomitant effects on plant available water estimations. For the analysis, a total of 21 undisturbed soil samples were collected from the top 20 inches of the soil profile at 18 locations of the Kansas Mesonet. The soil moisture content at the permanent wilting point measured using the pressure plate apparatus was 22% higher in clay loam soils and 25% higher in the clay soils than the soil moisture values obtained using a dewpoint water potential meter. When using the pressure plate apparatus, the resulting plant available water capacity (PAWC) was 33% lower in clay loam soils and 57% lower in clay soils compared to the PAWC estimated using the dewpoint water potential meter. Only minor discrepancies of about 8 to 9% were observed in both the resulting permanent wilting point and the estimated PAWC in the silt loam and sandy loam soils.

Introduction
The concept of plant available water capacity describes the maximum amount of soil water that is available for root water uptake and is an important variable for making timely irrigation decisions. Plant available water capacity is computed as the difference between an upper limit commonly known as the "field capacity" and a lower limit known as the "permanent wilting point" (Figure 1). Field capacity refers to the soil water content retained after gravitational water has drained (Veihmeyer and Hendrickson, 1931). Permanent wilting point refers to the point at which plants cannot longer recover from soil water stress, and represents the point at which plant roots cannot longer extract water for the transpiration process (Briggs and Shantz, 1912). Field capacity and permanent wilting point are not considered soil physical properties, but are two concepts that have proven useful to farmers, water managers, and researchers. Field capacity and permanent wilting point can be measured either in the field or in laboratory conditions. Field observations tend to be more accurate, but can be laborious and usually require the span of an entire growing season. On the other hand, laboratory determination relies on small soil samples, but it allows researchers to process batches of soil samples from different fields and can substantially speed up the process. In laboratory conditions, field capacity and permanent wilting point are often measured by equilibrating soil samples at predetermined pressures of -1.5 psi (-10 kPa) and -217.6 psi (-1500 kPa), which represent specific levels of work expressed in units of energy per unit volume. Traditional methods for measuring field capacity and perma-

nent wilting point in the laboratory typically rely on multiple pieces of apparatus that use porous ceramic plates (e.g. tempe cells and pressure plates) (Richards and Fireman, 1943). These traditional methods have been used in research for almost a century and remain popular due to their ability to process large batches of soil samples in a single operation. However, recent evidence suggests that the traditional porous ceramic plate apparatus may be prone to measurement errors at pressures approaching the permanent wilting point in fine-textured soils (Solone et al., 2012). This study investigated the discrepancy between the permanent wilting point measured using pressure plate (traditional) and a dewpoint water potential meter (modern) techniques and the concomitant effects on plant available water capacity estimates.

Procedures

A total of 21 undisturbed soil samples with a volume of 3.3 fluid ounces (98 cm^3) were collected at 2, 4, 8, and 20 inch depths at 18 stations of the Kansas Mesonet (Patrignani et al., 2020) using a hand-held soil sampling kit (Eijkelkamp, The Netherlands). Soil samples were saturated in 5 mmol L^{-1} $CaCl_2$ solution and then field capacity was determined at -1.5 psi (-10 kPa) tension using a sandbox (Eijkelkamp, The Netherlands) (Figure 2A), and permanent wilting point was determined at -217.6 psi (-1500 kPa) tension using the traditional pressure plate apparatus (Soilmoisture Equipment Corp. Santa Barbara, CA) (Figure 2B). The water potential of the equilibrated samples from the pressure plate were verified with a modern dewpoint water potential meter (WP4C, Meter Group, Inc., Pullman, WA) (Figure 2C). After measuring the permanent wilting point, the soil samples were oven-dried at 221°F (105°C) for 48 hours, ground, and sifted through a 0.08 inch (2 mm) sieve, and then particle size analysis was determined using the hydrometer method (Gavlak et al., 2005). Plant available water capacity was computed as the difference between the volumetric water content at field capacity (-1.5 psi) and the permanent wilting point (-217.6 psi). The derived plant available water capacity was multiplied by the soil profile thickness to convert it to units of equivalent depth of soil water storage. The soil water storage measurements expressed in terms of inches of available water can be easier to compare to other components of the soil water balance such as evapotranspiration and precipitation, which are also measured in inches (or millimeters). In this study, we assumed a soil profile thickness of 4 feet to compute the equivalent depth of soil water storage in inches.

Results

The soils analyzed in this study had 3 to 70% sand, 17 to 61% silt, and 12 to 63% clay particle sizes (Table 1). Our soils captured seven out of the twelve U. S. Department of Agriculture soil textural classes, with silt loam soils making up 10 of the 21 total samples analyzed. The bulk density ranged from 1.33 to 1.83 g cm^{-3} with a corresponding porosity range of 31 to 50%. The soil moisture at the permanent wilting point registered higher when measured with the pressure plate apparatus than when measured with the dewpoint potential meter in all the soil textures except in the sandy loam, in which both techniques yielded the same water content at permanent wilting point (Table 2).

Assuming a soil profile that is 4 ft., the equivalent difference in water content at permanent wilting point between the pressure plate and dewpoint water potential ranges from 1 inch in the silt loam and silty clay loam to 4 inches in the clay soil. This measurement corresponds to 10 to 25% higher water content at permanent wilting point by the pressure plate technique compared to the dewpoint water potential meter.

In the fine-textured soils, measuring the permanent wilting point using pressure plate apparatus resulted in average plant available water capacity values that are 33% lower in clay loam and 57% lower in clay soils than the permanent wilting point measured using dewpoint water potential meter (Table 2). The silty clay and silty clay loam soils had almost the same plant available water capacity regardless of the method used.

In the coarse soil, the estimated plant available water capacity was almost the same for the pressure plate apparatus and the dewpoint potential meter in the sandy loam (9%) and silt loam (8%) soils, suggesting that both pressure plate and dewpoint water potential meter yield similar results in coarse-textured soils.

Our preliminary results indicate that measuring the permanent wilting point in the laboratory using traditional pressure plates could result in 22% higher water content at permanent wilting point in clay loam and 25% higher water content in clay soils than using modern dewpoint water potential meter techniques. This could lead to a difference of 33% plant available water capacity in clay loam and 57% difference in clay, depending on the laboratory method. Future research by the Kansas State University Soil Water Process laboratory will include detailed determination of field capacity and permanent wilting point using different methods covering a wider range of soils in Kansas.

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Table 1. Number of samples in each textural class and textural class mean of bulk density, total porosity, percent sand, percent clay, and verified matric potential from dewpoint water potential meter for pressure plate-equilibrated samples at -1500 kPa

Textural class	Number	Bulk density	Porosity	Sand	Clay
		$g\ cm^{-3}$	%		
Clay	1	1.33	50	3	63
Clay loam	2	1.45	46	26	34
Sandy clay loam	1	1.83	31	48	25
Sandy loam	2	1.70	36	70	12
Silt loam	10	1.43	46	15	23
Silty clay	3	1.34	49	7	46
Silty clay loam	2	1.50	44	15	31

Table 2. Textural class mean of field capacity (FC), permanent wilting point (PWP), derived from pressure plate (traditional), dewpoint water potential meter (modern) techniques, and the resulting plant available water capacity (PAWC) computed for a 4-feet soil profile

Textural class	FC	PWP-Trad	PWP-Modern	PAWC-Trad	PAWC-Modern
	inches				
Clay	25	18	14	7	11
Clay loam	18	12	9	6	9
Sandy clay loam	16	9	7	7	9
Sandy loam	15	3	3	12	12
Silt loam	20	8	7	12	13
Silty clay	22	13	11	9	11
Silty clay loam	20	10	9	10	11

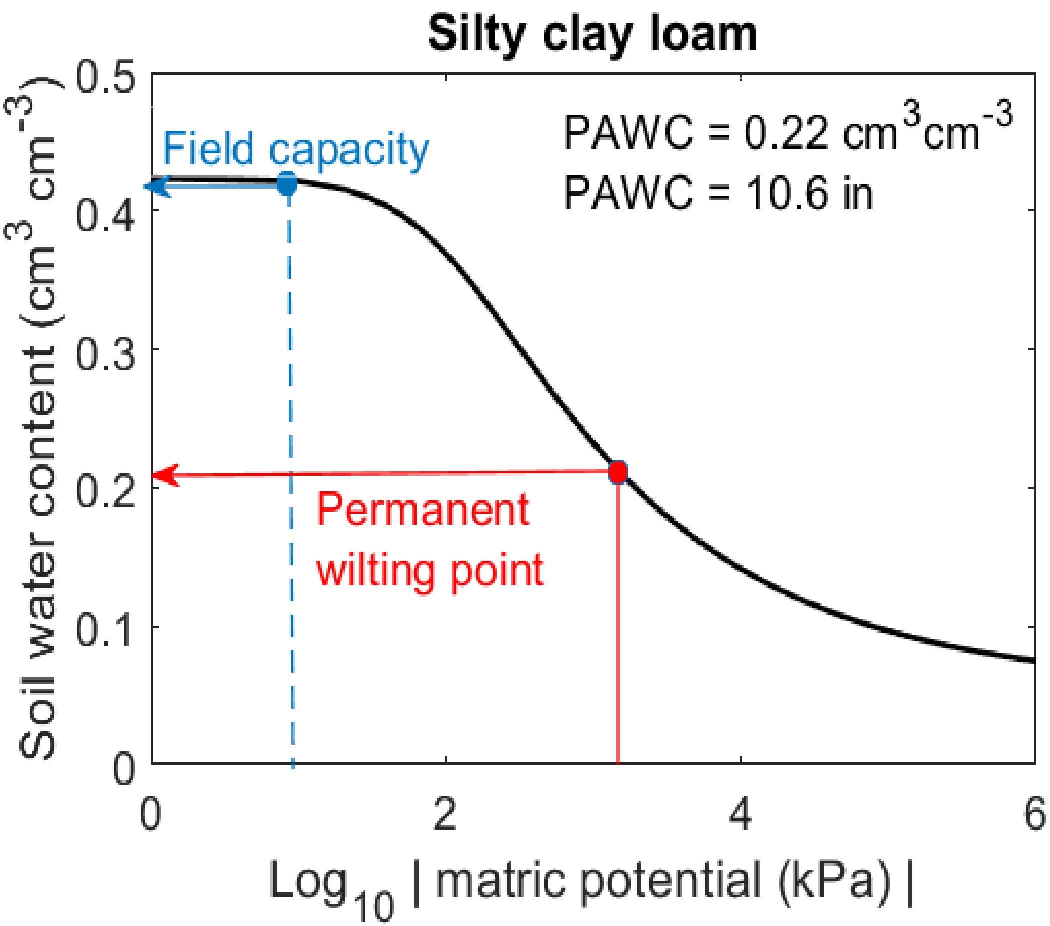

Figure 1. A soil water retention curve showing the field capacity (upper limit) and permanent wilting point (lower limit). Plant available water capacity (PAWC) is computed as the difference between soil water contents at field capacity and permanent wilting point. The PAWC (in volume fraction) is multiplied by the soil profile thickness to convert it to units of equivalent depth of soil profile water storage. Thus, assuming a soil profile thickness of 4 feet (48 in.) in this example, PAWC is 48 in × 0.22 cm^3 cm^{-3} = 10.6 in.

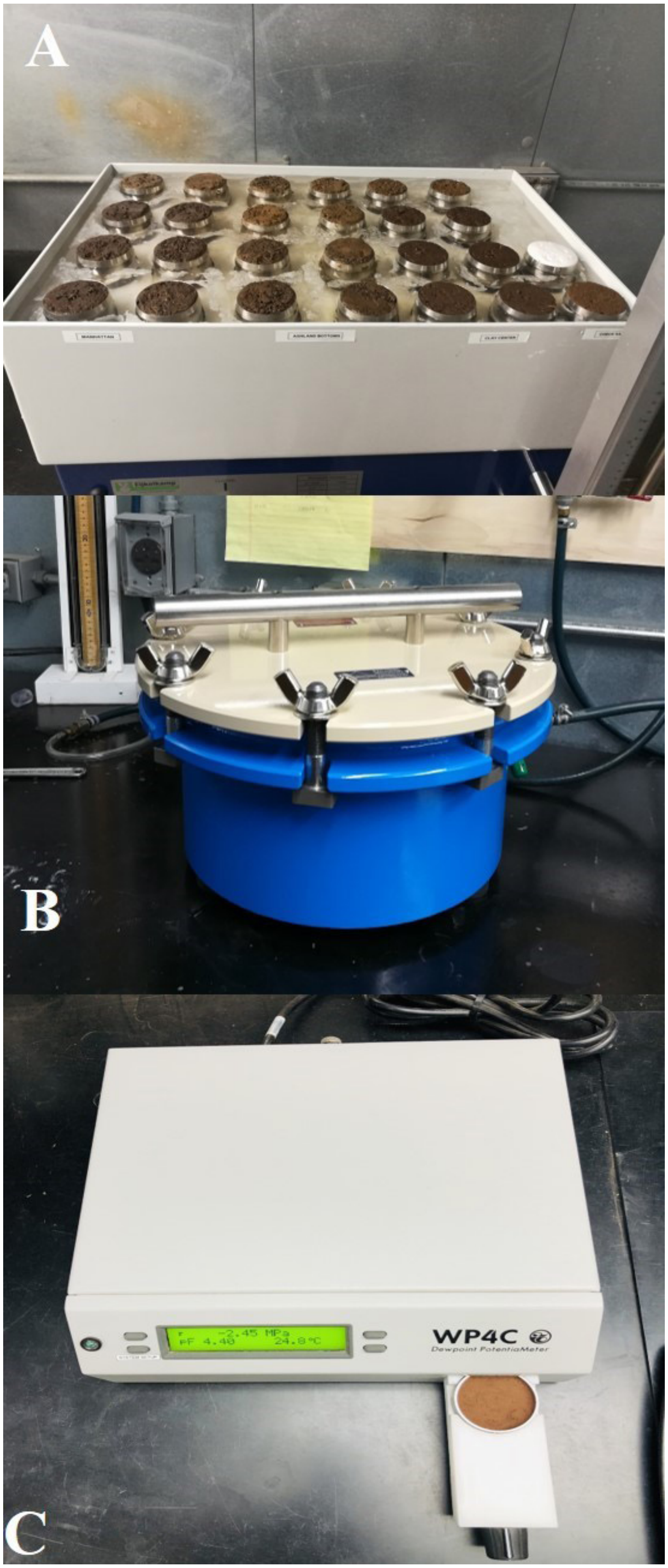

Figure 2. Measurements of field capacity using sandbox (a), and permanent wilting points using pressure plate apparatus (b; traditional technique), and dewpoint water potential meter (c; modern technique).

Preliminary Classification of Soil, Plant, and Residue Cover Using Convolutional Neural Networks

D. Nahitiya, M.N. Bisheh,[1] R.P. Lollato, and A. Patrignani

Summary
In agricultural fields, knowledge about the proportion of the soil surface covered with crop residue and vegetation canopy is key for improving soil and water conservation practices. In this study we trained a deep convolutional neural network to automate the classification of bare soil, crop stubble, and live vegetation from downward-facing images of agricultural fields. A comprehensive generic dataset, consisting of 3300 training and 645 test images, was collected from agricultural fields across Kansas State University Agricultural Experiment Stations and the Natural Resources Conservation Service Plant Material Center located near Manhattan, KS. Despite the intricate patterns and color textures resulting from different combinations of soil, canopy, and stubble the trained network showed good performance for automating the classification of land cover from images. The network achieved 87% accuracy over the training dataset and 84% accuracy over the test set.

Introduction
Soil cover by crop residue and actively growing vegetation is an important factor controlling soil erosion by wind and water. The combination of canopy and residue cover acts as an effective barrier intercepting and deflecting kinetic energy from raindrops that can lead to loss of soil aggregation, soil crusting, runoff, and soil erosion. Soil residue cover can also lead to improved soil moisture conditions by reducing soil evaporation (Flerchinger et al., 2003).

Agronomists and soil conservationists often need to estimate soil cover to determine the risk of soil erosion and the effectiveness of conservation practices. Over the years, several practical methods have been developed to quantify the soil cover in field conditions based on simple principles. The line transect method consists of an operator using a measuring stick or tape to count the number of one-foot marks intersecting stubble pieces and vegetation across the sample area (Sloneker et al., 1977). Line transects are selected at random and are often repeated several times to obtain an accurate average of soil cover values per field. Another common method often used to quantify soil residue and canopy cover is the use of reference photographs. In this method a trained operator uses a predefined set of images representing pre-calculated images of crop residue or green canopy cover for a specific crop to visually compare a selected area in the field to the set of reference images. With the advent of more powerful processors, new methods based on digital image analysis have enabled effective image color thresholding (Patrignani and Ochsner, 2015) and more sophisticated approaches using machine learning such as a random forest approach (Riegler-Nurscher et al., 2018). However, the classification of all three components—green canopy cover, crop stubble, and bare soil—still

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remains challenging because of the wide range of scenarios caused by the combination of soil types, crops, and soil moisture conditions in agricultural fields. The goal of this study was to quantify the fraction of green canopy cover, crop residue, and bare soil by using a deep neural network and a dataset of pixel-wise labeled images.

Procedures

The image dataset for training and testing the deep convolutional neural network consisted of 3300 downward-facing images collected across multiple cropland fields located in Research Experiment Stations of Kansas State University. Images were collected at about 5 ft from the ground and contained different combinations of bare soil, crop stubble, and green canopy cover. For this study, we trained a deep convolutional, neural network using semantic segmentation classification (SegNet model). The resulting trained model was evaluated by analyzing the confusion matrix and overall accuracy over the test dataset of labelled images. The confusion matrix describes how often the classifier is correct in predicting each class. To evaluate classification performance for each class, we used the F-1 score as a harmonic average on precision and recall for the model accuracy.

Results

The deep convolutional neural network effectively captured the fraction of the soil covered with crop residue, canopy cover, and bare soil (Figure 1). The trained network achieved 80% accuracy in the first 200 epochs, and after 1000 epochs achieved 87% validation accuracy over the training dataset and 84% accuracy over the test set. Among the three land covers, the trained model was able to identify canopy cover much more accurately. This is likely due to the excellent contrast between green canopy and the background represented by bare soil and residue cover. In most cases, the model was able to classify the strong features such as stems in stubble, but failed at classifying pieces of residue that had color and texture similar to that of bare soil. In this study, we demonstrated that deep neural networks have great potential as a tool for quantifying land cover components from images, which can be used to guide soil and water conservation practices. The group is now working on a web-based application to help field agronomists, farmers, and scientists to easily upload and quantify land cover from digital images.

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Table 1. Soil cover is identified as three key attributes of soil, stubble, and plants. This table indicates the distribution of the images.

Category	Number of images
Soil	212
Stubble	262
Soil and stubble	461
Soil and plant	410
Stubble and plant	112
Soil, stubble, and plant	1846
Total	3300

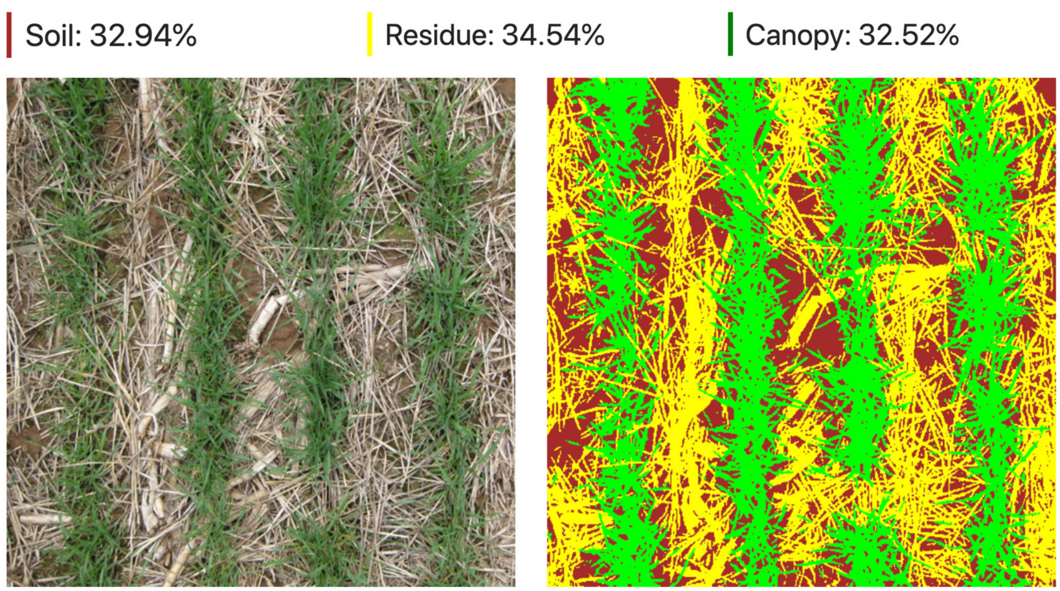

Figure 1. Original (left) and predicted (right) crop residue cover, green canopy cover, and bare soil using the trained model for residue cover in no-till winter wheat. Colors in classified images represent bare soil (brown), stubble (yellow), and green canopy (green).

On-Farm Assessment of AquaSpy Soil Moisture Sensors for Irrigation Scheduling

P. Rossini and A. Patrignani

Summary

The aim of this study was to compare a commercially-available radio-frequency (RF) spectroscopy soil moisture sensor with an array of calibrated research-grade soil water reflectometers in a no-till irrigated corn field from June to September 2020. The RF probe consisted of 12 sensors spaced at 4-inch intervals across 48 inches in length, while the array of soil water reflectometers consisted of four sensors deployed along the soil profile at 4, 12, 20, and 28 in. depth. Soil moisture sensors were installed at approximately 30-ft apart in two different regions within the same field characterized by contrasting soil textural classes. Hourly soil moisture and soil temperature were collected by both sensors and compared across the study period. The RF probe closely followed the soil moisture dynamics captured by the research-grade sensors. Preliminary results reveal that the tested RF sensor is useful for irrigation scheduling based on relative soil moisture values. Field-specific calibrations are required to translate the relative soil moisture measurements of the RF sensor into soil water storage in terms of volumetric water content or inches of water in the soil profile.

Introduction

In-situ soil moisture sensors provide farmers and water managers with field-specific and timely information to guide irrigation scheduling. Accurate observations of rootzone soil water are essential to quantify the amount of plant available water in the soil profile and determine the amount of irrigation needed to prevent plant water stress and the consequent decline in crop yield and/or quality (Evett et al., 2011). Previous research studies have shown that point-level soil moisture sensors can result in up to 50% irrigation water savings compared to fields without sensors (Hassanli et al., 2009), while still maintaining crop yield and profitability (Evans et al., 2013; Kukal et al., 2020). Several commercially-available point-level soil moisture sensors work based on the principles of time domain reflectometry (TDR), frequency domain reflectometry (FDR), and capacitance. All these methods rely on the radically different dielectric permittivity of water (approximately 80) compared to that of the dry mineral soil (about 2–3). Among these three technologies, capacitance is well-known for being affected by bulk electrical conductivity and soil temperature, to the extent that capacitance sensors may not provide the accuracy required for irrigation scheduling (Evett et al., 2011). In this study we investigated a new sensor based on radio-frequency spectroscopy widely used by producers in Kansas called AquaSpy (AquaSpy Inc., San Diego, CA) that has the potential to accurately measure rootzone soil moisture. The goal of this study was to compare the AquaSpy profile-level soil moisture sensor against an array of calibrated research-grade soil water reflectometers.

Procedures

The study was conducted in an irrigated no-till corn field of 54 acres located within the Flickner Innovation Farm near Moundridge, KS, from June to September 2020.

Co-located sensors were installed in two different portions of the field. A set of CS655 and AquaSpy sensors were installed in a region characterized by well-drained silt clay loam soils mapped as Crete soil series with <1% slopes, and the second pair of co-located sensors was installed in a region of the field characterized by sandy loam soils (sand 46% with fine gravel) mapped as Farnum soil series with slopes ranging from 1 to 3% (Figure 1A).

In this on-farm study we conducted a preliminary study of AquaSpy probes featuring 12 sensors spaced at 4-inch intervals across 48 inches in length that were specifically designed to cover the rootzone of common agricultural crops (Figure 1B). This sensor works based on radio-frequency spectroscopy attenuation to measure soil moisture. The AquaSpy sensor also provides soil temperature and bulk electrical conductivity measurements every 15 minutes. To test the ability of the AquaSpy sensor to capture the soil moisture dynamics in the irrigated field, observations obtained with the AquaSpy probe were compared with an array of four calibrated soil moisture sensors (CS655, Campbell Scientific, Logan, UT) deployed along the soil profile at 4, 12, 20, and 28 in. depth (Figure 1B). AquaSpy sensing depths beyond this point were not considered in the study. The CS655 sensors were deployed at about 30 ft from the capacitance sensor, and recorded hourly soil moisture, soil temperature, and bulk soil electrical conductivity. Because the AquaSpy probe provides relative soil moisture measurements following proprietary algorithms, the comparison of soil moisture dynamics between these two sensors was only performed in relative terms by scaling the average soil moisture in the top 28 inches of the soil profile by the minimum and maximum reading of each sensor during the period of study.

Results

The AquaSpy probes effectively captured changes in profile soil moisture as a consequence of irrigation and precipitation events, and rootzone soil moisture readings were comparable to those of the array of research-grade soil moisture sensors (Figure 2). In relative terms, the time series of profile-level soil moisture between the sensors was relatively good ($r^2 = 0.53$) for the management zone characterized by fine-textured soil and excellent ($r^2 = 0.83$) in the management zone dominated by coarse-textured soils (Figure 2). In both field management zones, the relative soil moisture dynamics exhibited little bias between sensing technologies. Minor discrepancies in the time series could be attributed to errors in either sensing technology, sensing volume, soil spatial variability, and even slight differences in sensor depths introduced during the installation process. A more rigorous analysis in controlled and standardized conditions would be required to accurately test the actual discrepancy between sensors.

To verify that the sensors were deployed at comparable depths we examined the soil temperature observations for both sensing technologies. As expected, soil temperature observations were not greatly affected by the type of sensor, with an average discrepancy of only 1.6°F in both fine- and coarse-textured soils (Figure 3). Further investigation across the different sensors along the soil profile showed an increased discrepancy in soil temperature at deeper layers in the coarse-textured soil, with differences as large as 4.2°F at 28-inch depth (Table 1). This difference in temperature at depth could be attributed to small offsets during the installation of either sensor, and to normal variations in the spatial distribution of soil temperature.

Our preliminary analysis suggests that the AquaSpy sensors closely followed the soil moisture dynamics of an array of research-grade soil moisture sensors in terms of relative soil moisture. Relative soil moisture trends can be useful for irrigation scheduling when supported by field observations of crop stress conditions and expert guidance from the manufacturing company to better interpret sensor readings. Producers who make in-season irrigation decisions based on the actual amount of soil water storage expressed in terms of volumetric water content or inches of water in the soil profile would require a site-specific calibration to translate relative soil moisture readings into actual soil water storage.

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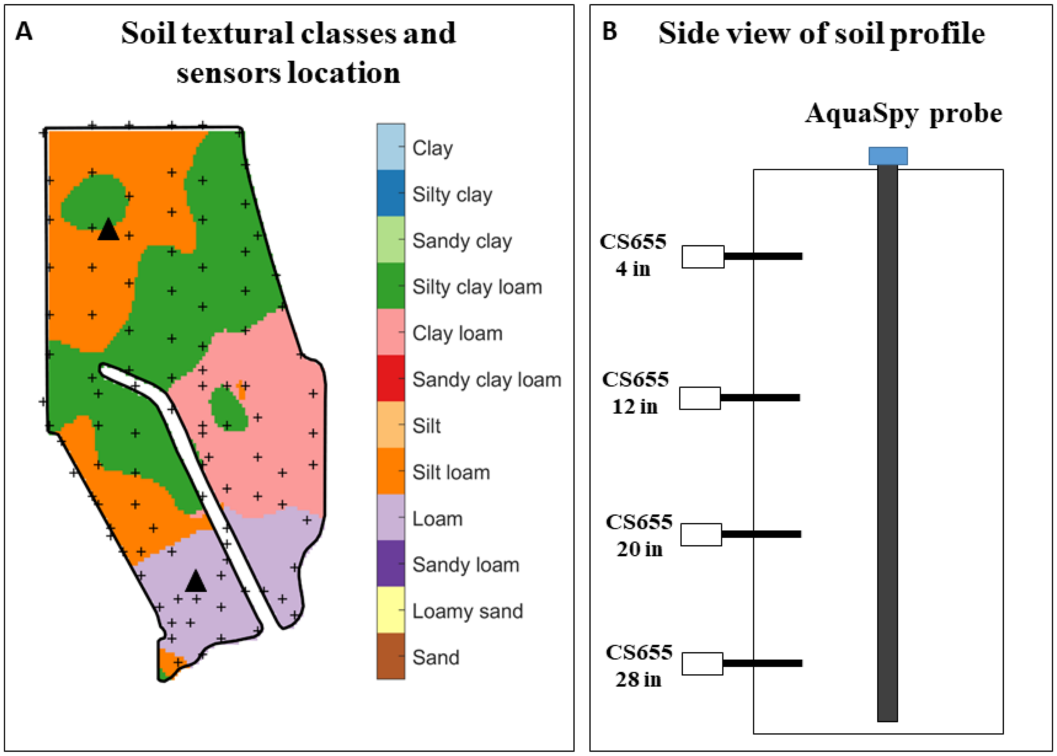

Figure 1. A) Soil textural class of the top 4 inches of the soil profile. Black crosses (+) represent soil sampling locations in which soil texture was determined in the laboratory using the hydrometer method. Solid black triangles represent the locations of the two co-located installations of the AquaSpy and soil water reflectometer sensors. B) Layout of the soil moisture sensors' location across the soil profile. At each location the two different sensors were deployed about 30 ft from each other.

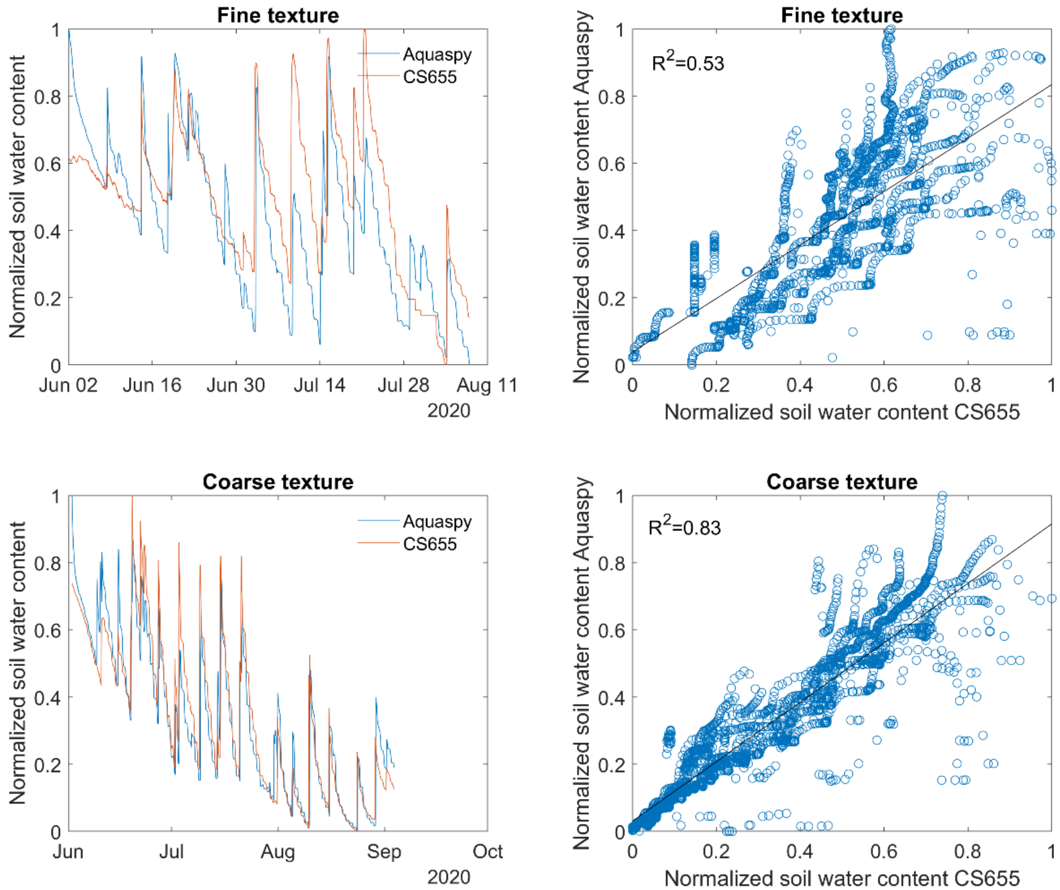

Figure 2. Comparison of profile (0 to 28 inches) soil water storage determined using the AquaSpy probe (blue line) and an array of four calibrated CS655 soil water reflectometers (red line) in a fine-textured soil (silty clay loam) and a coarse-textured soil (loam, 46% sand).

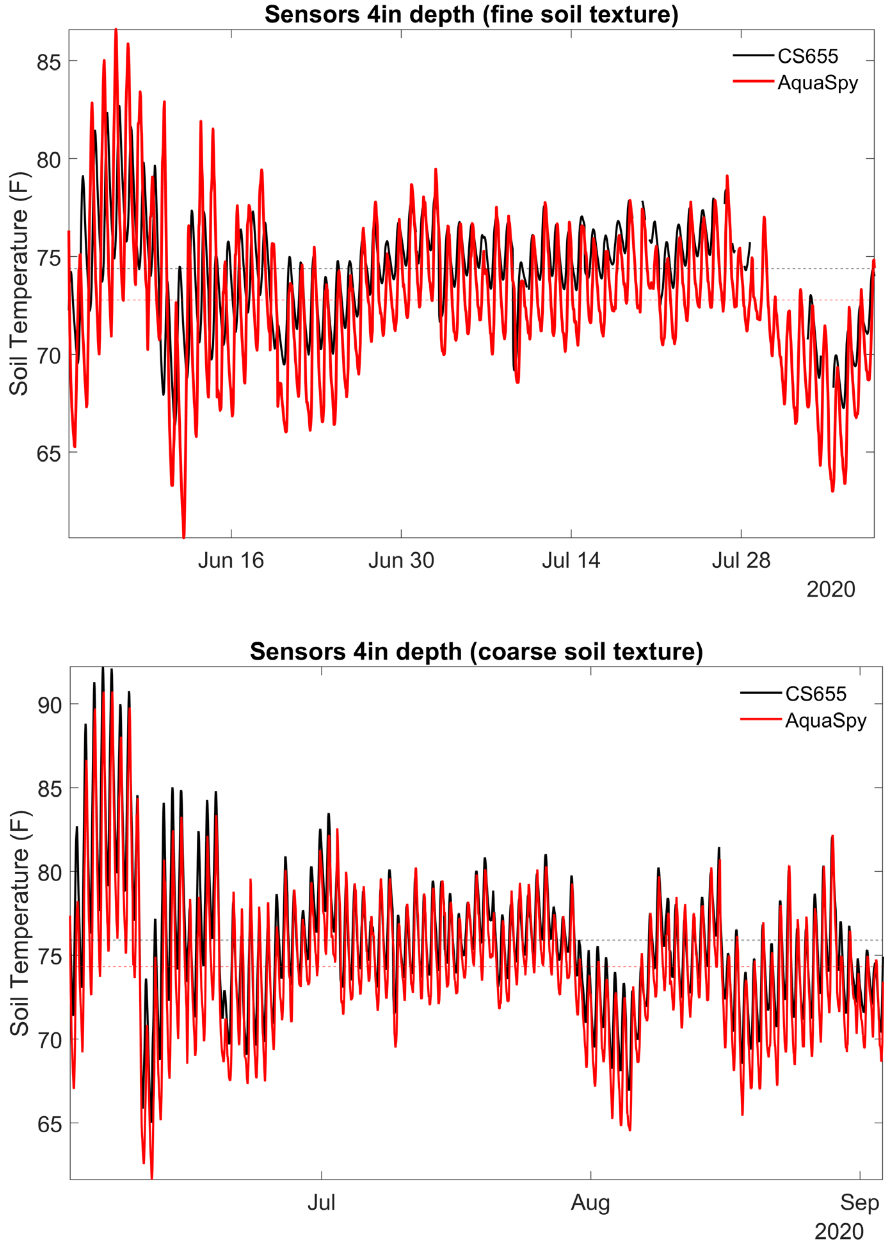

Figure 3. Surface soil temperature at 4-inch depth determined using the AquaSpy probe (red line) and an array of four calibrated CS655 soil water reflectometers (black line) for a fine-textured soil (top) and a coarse-textured soil (bottom). Dashed horizontal lines represent the average profile soil temperature for each sensor over the entire time series.

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

A.A. Correndo 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 2020 growing season, a corn-soybean rotation study was continued at Scandia, KS (USA), evaluating five N fertilizer rates in corn under both dryland and irrigated conditions. Average corn grain yields ranged from 110 to 206 bu/a for dryland, and from 198 to 221 bu/a for irrigated conditions. Under dryland, maximum corn yields were achieved with an apparent soil N supply level of 350 lb N/a (fertilizer N plus soil N); while removing the water limitations with irrigation resulted in corn grain yields maximized with ca. 250 lb N/a. Average soybean seed yields varied from 66 to 72 bu/a for dryland and from 72 to 79 bu/a for irrigated conditions. A lack of significant residual effect from previous corn N management was observed on soybean yields.

Introduction
The objective of this study was to continue the assessment, under both rainfed and irrigated conditions in north central Kansas, of the response of corn (*Zea mays* L.) grain yield to N fertilizer and the residual effects of the N fertilization practice on this crop on the following soybean crop.

Procedures
A second year of a long-term study under a corn-soybean rotation was continued in the 2020 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 Argiustoll). At corn planting time (April 27, 2020), 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 by testing for pH, soil organic matter (SOM, %), soil texture (%), extractable (M-3) phosphorus (P, ppm), potassium (K, ppm), 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. Seasonal weather data were gathered from the Kansas Mesonet (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 served as the previous crop for corn plots. Under the same design, the N rate management on the previous corn crop (2019) was used as treatment for the

2020 soybean crop. Corn was planted on April 27, 2020, and soybean on May 15, 2020. Corn plots were mechanically harvested using a combine on September 30, 2020 from the two central rows then scaled to bu/a. Corn yields were corrected to 15.5% moisture content. Soybean plots were mechanically harvested using a combine on October 13, 2020, from the two central rows then scaled to bu/a. Soybean seed yields were corrected to 14% moisture content.

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 factor and block as the random factor. When 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 (ca. 3%), medium soil P, and high K. Initial soil N availability at 0–24 inches (NO_3-N plus NH_4-N) were high in both cases ranging from 98 to 133 lb/a and from 115 to 132 lb/a for dryland and irrigated areas, respectively. In both cases, at least two thirds of N was in the NO_3 form.

Weather

The total precipitation during the planting-maturity period (May-September) was about 16 inches (Figure 1A). The precipitation distribution pattern denoted a dry period at the beginning of the season (< 3 in. during the first month). More regular and abundant precipitation events were registered during June-July, ending with a dry August but with very good radiation levels during the post-flowering period. No days with heat stress risks ($T_{max} > 95^{o}F$) were registered (Figure 1B).

Corn Grain Yield

In spite of the high initial soil N availability, corn grain yield significantly responded to N fertilizer rate under dryland conditions (Figure 2). In contrast, no significant yield response to N was observed under irrigation, presumably due to a better soil N mineralization synchrony with crop N demand, possibly more limited due to water stress under rainfed management. Following adjusted N-response curves, the maximum yields were achieved at 214 lb N/a under dryland conditions, while approximately 110 lb N/a were enough to maximize yields under irrigation (Figure 2A). When initial soil N availability was added to the N rate, the apparent N supply to achieve maximum yields resulted ca. 350 lb N/a under dryland, while ca. 250 lb N/a under irrigation. The latter denotes a higher use efficiency of the initial N supply related to the better water conditions for the crops, but also presumably due to greater levels of soil N mineralization during the season (Figure 2B).

Soybean Seed Yield

Soybean yields varied from 66 to 71 bu/a for dryland and from 72 to 79 bu/a under irrigation (Figure 3). Negligible effects of the corn N management from the previous season were evident for both water scenarios for soybean seed yield.

References

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Table 1. Soil fertility (0–6 inches) at planting of corn and soybean crops at irrigated and dryland areas in Scandia, KS, for the 2020 cropping season

Crop	0–6 in. depth	pH	SOM	Clay	Silt	Sand	P	K	$N\text{-}NO_3$	$N\text{-}NH_4$
		-	%				ppm			
Corn	Dryland	5.8	3.1	28	60	12	14.9	510	15.4	5.9
	Irrigated	6.3	2.8	24	58	18	17.9	490	29.9	7.5
Soybean	Dryland	5.8	3.0	23	59	18	11.3	511	17.4	8.5
	Irrigated	6.1	2.8	22	59	19	16.9	488	20.8	5.6

SOM = soil organic matter.

Table 2. Crop management practices for corn and soybean crops at Scandia, KS, for the 2020 cropping season

Practices	Corn		Soybean	
Irrigation	Dryland	Irrigated	Dryland	Irrigated
Tillage	No-till			
Planting date	04/27/2020		05/15/2020	
Genotype	P1197YHR		P39A58X (RR2-Xtend)	
Seeding rate	29,000 seeds/a	35,000 seeds/a	110,000 seeds/a	140,000 seeds/a
Row spacing	30 in.			
P fertilization	23 lb P/a			
N fertilization	0, 53, 107, 161, 214 lb N/a		---	

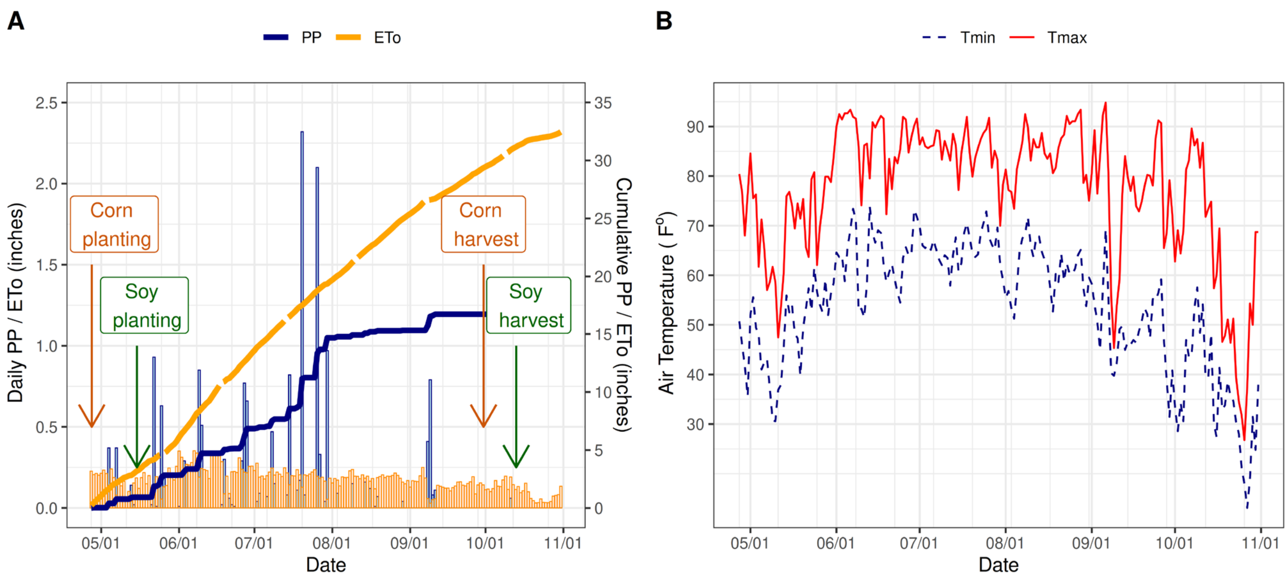

Figure 1. A: Daily and cumulative precipitation (PP) and reference evapotranspiration (ETo); B: daily minimum and maximum air temperature, on the right, for the 2020 cropping season at Scandia, KS.

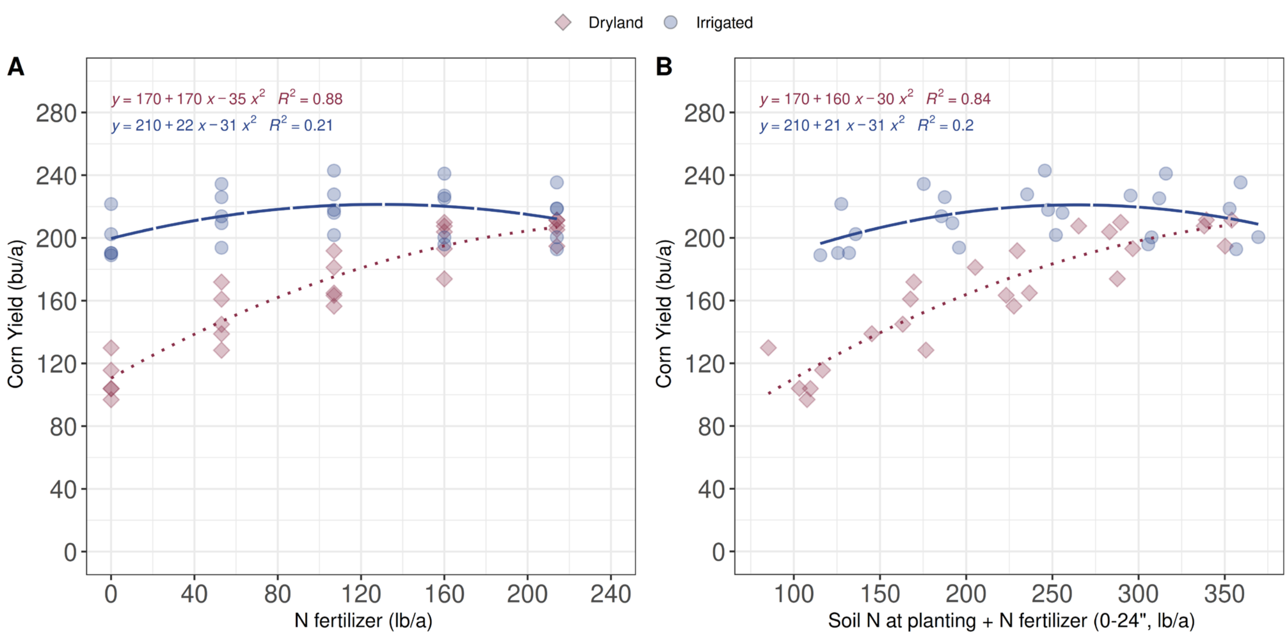

Figure 2. A: Corn grain yield (bu/a) versus nitrogen (N) fertilizer rate treatments; B: versus N availability as soil NO_3-N and NH_4-N (0–24 inches, lb/a) plus N fertilizer (applied as urea at V5 stage).

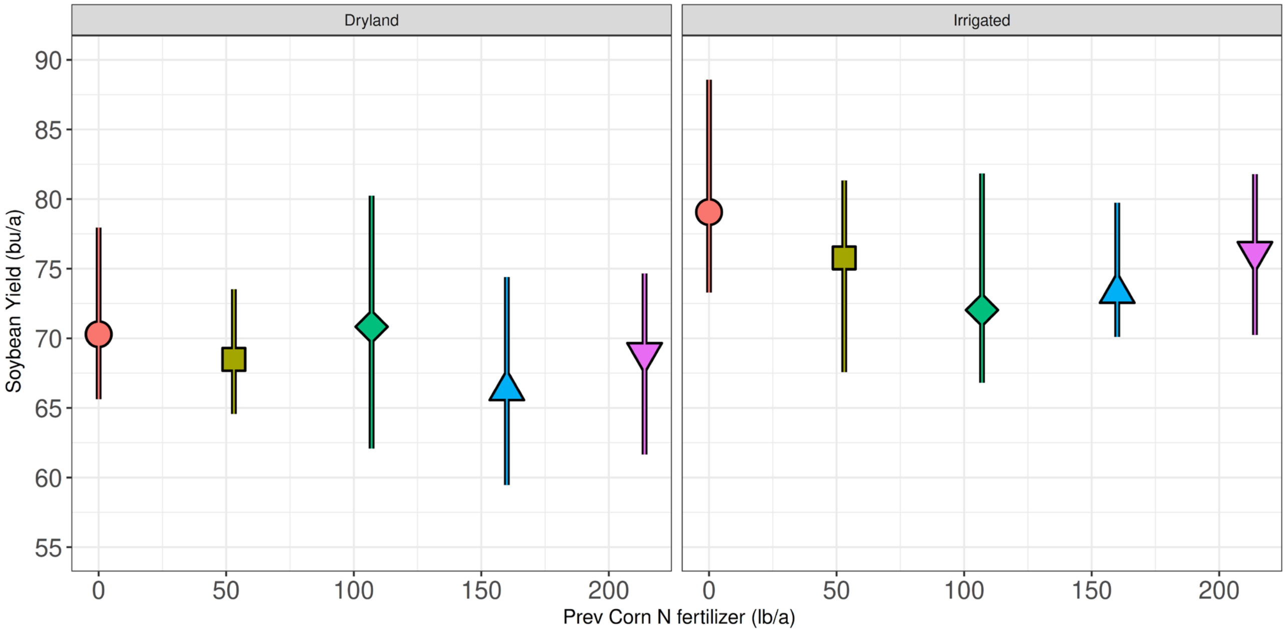

Figure 3. Soybean seed yield (bu/a) versus previous corn nitrogen (N) fertilizer rate treatments. Overlapping error bars indicate the absence of statistical differences (Tukey LSD 5%).

Forage Accumulation of Spring and Summer Cover Crops in Western Kansas

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

Summary

Intensification of no-till dryland cropping systems in western Kansas with cover crops (CCs) may provide important ecosystem services while also supplying annual forage for livestock. Two experiments were initiated in 2015 and 2016 near Brownell, KS, to determine the forage production potential of spring and summer CCs in a winter wheat-grain sorghum-fallow crop rotation. Cover crops were mechanically harvested as hayed forage to a height of 6 inches or mob-grazed with yearling heifers (weighing approximately 1000 lb each) stocked at 3 head/acre/day. Forage accumulation was determined for the hayed treatment using a small plot forage harvester, and samples of the grazed treatment were hand-clipped before and after grazing every year from 2015 to 2020. Results showed forage accumulation of spring CCs grown in place of fallow following grain sorghum averaged 2231 lb/a dry forage mass and ranged from 1427 to 2871 lb/a. Similarly, forage accumulation of summer CCs planted after wheat harvest averaged 2513 lb/a dry forage mass and ranged from 956 to 3718 lb/a. In 2017, summer CCs failed to produce a harvestable yield. Results suggest that CCs may provide desirable annual forage for livestock. However, forage accumulation of both spring and summer CCs was variable in this study. In years that spring CCs were planted early (before March 15), yields tended to be higher (>2200 lb/a) due to less susceptibility to heat and moisture stress. Summer CCs performed best when planted immediately following wheat harvest to take advantage of summer rains and to produce as much forage mass (>3000 lb/a in favorable years) as possible before the first killing frost or about October 15 for most of western Kansas.

Introduction

Conventional dryland crop rotations in western Kansas typically produce either one crop in two years or two crops in three years with long periods of fallow in between the harvest of one crop and the planting of another. As a water conservation practice, fallow has been utilized to store soil moisture and stabilize subsequent crop yields. However, water storage efficiencies are typically low (about 30%), even with reduced or no-till tillage. Some producers have looked to intensify such crop rotations by replacing fallow with cover crops (CCs) or annual forages. As less water is necessary to produce forage compared to grain, such CCs may be successfully integrated into dryland crop rotations for increased soil cover and potentially greater income per acre when hayed or grazed as annual forages.

Two periods that exist for integrating CCs in conventional western Kansas crop rotations include 1) fallow ahead of winter wheat planting, or 2) fallow following winter wheat harvest. Replacement of fallow ahead of wheat planting presents an opportunity to take advantage of spring precipitation and cool temperatures for spring annual forage production. However, there is much greater risk associated with summer CCs following wheat harvest when soil moisture levels are frequently low and summer rainfall is erratic. The objective of this study was to determine the forage accumulation of either spring or summer CCs in place of fallow in a no-till dryland cropping system.

Procedures

Two experiments were initiated in 2015 (spring CCs) and 2016 (summer CCs) at the Kansas State University HB Ranch near Brownell, KS, to investigate CC management strategies for dryland cropping rotations in western Kansas. Cover crops were compared to chemically-controlled no-till fallow in a winter wheat-grain sorghum-fallow crop rotation. Spring CCs were a two-species mixture of oats and triticale at a seeding rate of 32 and 38 lb/a for oats and triticale, respectively. Spring CCs were planted into grain sorghum residues near the third week of March each year as field conditions would allow. Summer CCs were a four-species mixture of forage sorghum, pearl millet, sunn hemp, and cow pea at seeding rates of 7.5, 2.5, 5, and 20 lb/a, respectively. Summer CCs were planted into wheat stubble shortly after harvest as field conditions would allow. Both spring and summer CCs were mechanically harvested to a height of approximately 6 inches or mob-grazed with yearling heifers. Both studies were designed as split-plot randomized complete blocks. Main plots were the three crop phases of the wheat-sorghum-fallow crop rotation, and split-plots included hayed CCs or grazed CCs in place of fallow before or after winter wheat.

Cover crop grazing and haying generally coincided with grass crop heading stages. Prior to grazing, available forage mass was determined from samples that were hand-clipped to ground level in two areas of 3 ft × 2 ft from each plot. Fresh weights were recorded and samples were oven-dried at 122°F for a minimum of 48 hours or until a constant weight was reached. Grazed CCs were stocked with yearling heifers (weighing approximately 1000 lb each) stocked at 3 head/acre/day, on average, to utilize approximately 30 to 40% of the available forage mass. Following grazing, CC residue retained was measured as previously described. Hayed CC treatments were harvested from a 3 ft × 100 ft strip in the middle of each plot using a Carter small-plot forage harvester (Carter Manufacturing Company, Brookston, IN). Whole plot weights were recorded in the field with sub-samples collected and weighed. Sub-samples were oven-dried at 122°F to determine dry matter (DM) yield. This report summarizes forage accumulation of spring and summer CCs across years and management strategies. Statistical analysis was completed using PROC GLIMMIX of SAS ver. 9.3 (SAS Institute, 2012, Cary, NC) with year and treatment considered fixed and replication considered random. Differences were considered significant at $P \leq 0.05$. Coefficient of variation was determined for spring and summer CCs using PROC MEANS of SAS.

Results

On average, spring CC forage accumulation averaged 2231 lb of DM per acre with a high of 2871 lb/a in 2017 and a low of 1427 lb/a in 2019 (Figure 1a). Substantial variation in forage accumulation occurred across years in this study (coefficient of variation = 41.33), mostly due to differences in CC planting and harvest dates as field conditions would allow. From 2015 to 2018, favorable conditions supported DM production >2200 lb/a each year. However, low yields (<1500 lb/a) were observed in 2019 due to cool, wet conditions that delayed CC planting (Table 1). Further, in 2020, although CCs were planted on time, dry conditions that persisted through late spring limited vegetative growth early in the growing season. Across years, it was observed that once warm summer temperatures developed, spring CCs ceased vegetative growth and began to mature rapidly. On average, hayed CCs yielded 2299 lb/a of dry forage mass (Figure 1b). Following CC grazing, 1861 lb/a of residue was retained. This indicated a forage utilization rate of 26% compared to the 2532 lb/a available forage at the start of grazing.

Post-wheat summer CC forage accumulation averaged 2516 lb/a with substantial variation across years (coefficient of variation = 53.17). A high of 3718 lb/a was observed in 2018 with a low of 956 lb/a in 2019 (Figure 2a). Drought conditions in 2017 (Table 1) severely limited CC establishment and resulted in no harvestable yield. Favorable conditions in 2016 and 2018 supported DM production >3000 lb/a. In this study, timely rainfall in July and August was critical for adequate summer CC establishment following wheat harvest. Averaged across years, hayed CCs yielded 2423 lb/a of dry forage (Figure 2b). Following CC grazing, 1769 lb/a of residue was retained. This indicated a 39% forage utilization rate compared to the 2905 lb/a available at the start of grazing.

Results from this study suggest that spring CCs may produce about 2230 lb/a available forage in similar environments in western Kansas. Early planting dates (March 15 or earlier) will be essential for spring-planted cool-season CCs to take advantage of early spring precipitation as well as to develop as much vegetative growth as possible when temperatures are cooler. When planted post-wheat, successful summer CC establishment will depend upon timely rainfall in July and August. Planted immediately following wheat harvest, summer CCs may take advantage of all mid-summer rainfall and develop as much vegetative growth as possible (>3000 lb/a in favorable years) before the first killing frost, or approximately October 15, for most of western Kansas.

Table 1. Monthly precipitation from 2015 to 2020 near Brownell, KS

	Precipitation						
Month	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**30-yr avg.**
	---------- inches ----------						
January	0.67	0.35	1.14	0.04	0.51	0.98	0.47
February	0.16	0.20	0.08	0.04	0.31	1.57	0.87
March	0.04	0.43	1.30	0.31	0.71	0.43	1.02
April	0.83	6.93	5.31	0.67	0.91	0.47	2.44
May	6.02	2.72	3.94	3.62	7.76	3.19	3.74
June	0.63	3.15	1.57	3.70	1.57	2.40	3.27
July	4.02	3.11	1.54	7.83	0.94	7.01	2.52
August	0.39	4.65	3.23	5.59	12.48	2.44	2.72
September	0.39	1.30	1.85	3.43	1.57	0.94	1.69
October	1.69	0.63	2.01	3.07	1.50	0.08	1.77
November	1.50	1.14	0.08	0.47	0.39	0.94	0.75
December	1.14	0.39	0.00	1.69	2.32	0.31	1.02
Annual	17.52	25.00	22.01	30.51	31.06	20.75	22.28

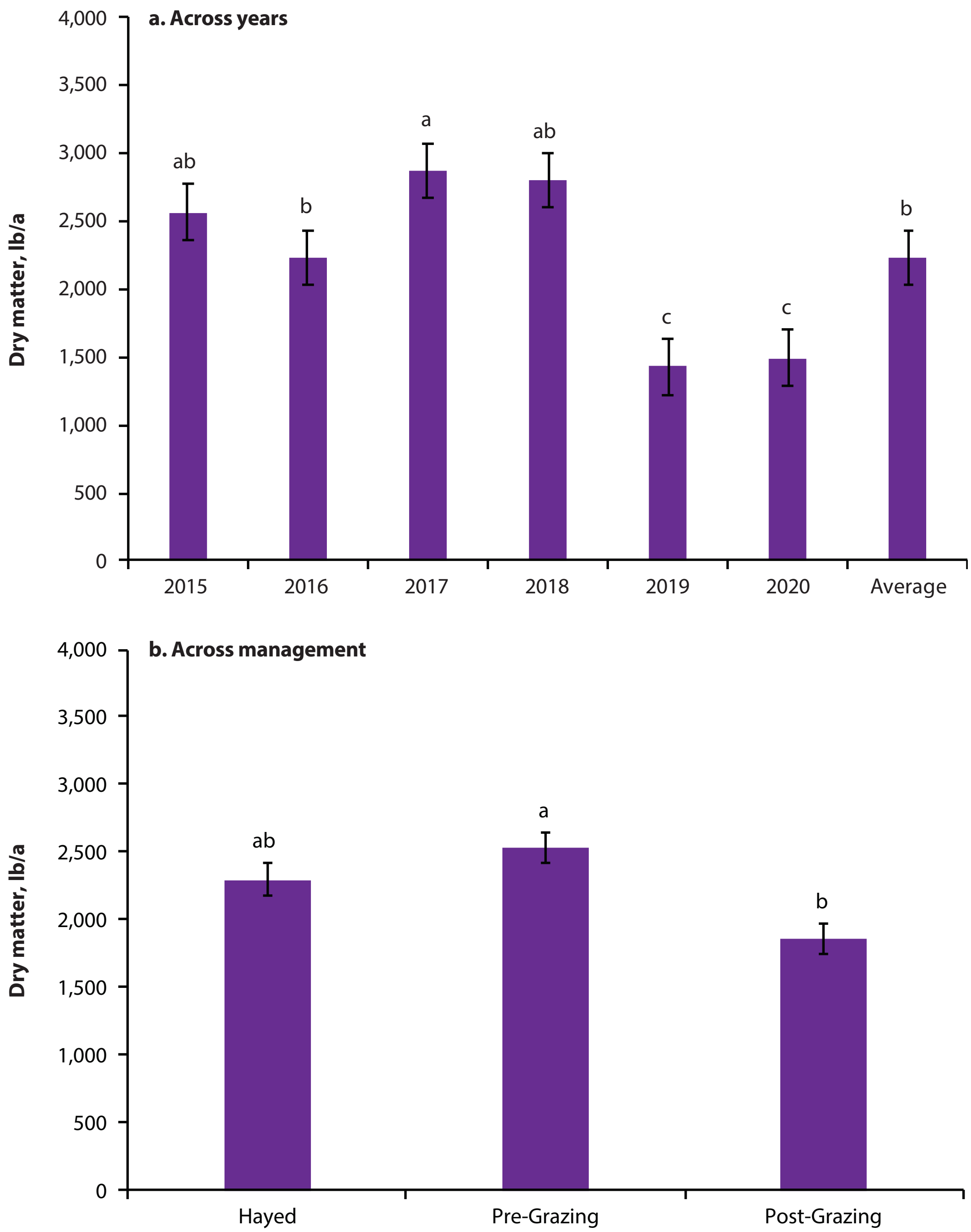

Figure 1. Spring cover crop forage accumulation across years (a) and management strategy (b) near Brownell, KS. Error bars indicate standard error ($\alpha = 0.05$) and bars with the same letter are not significantly different ($\alpha = 0.05$).

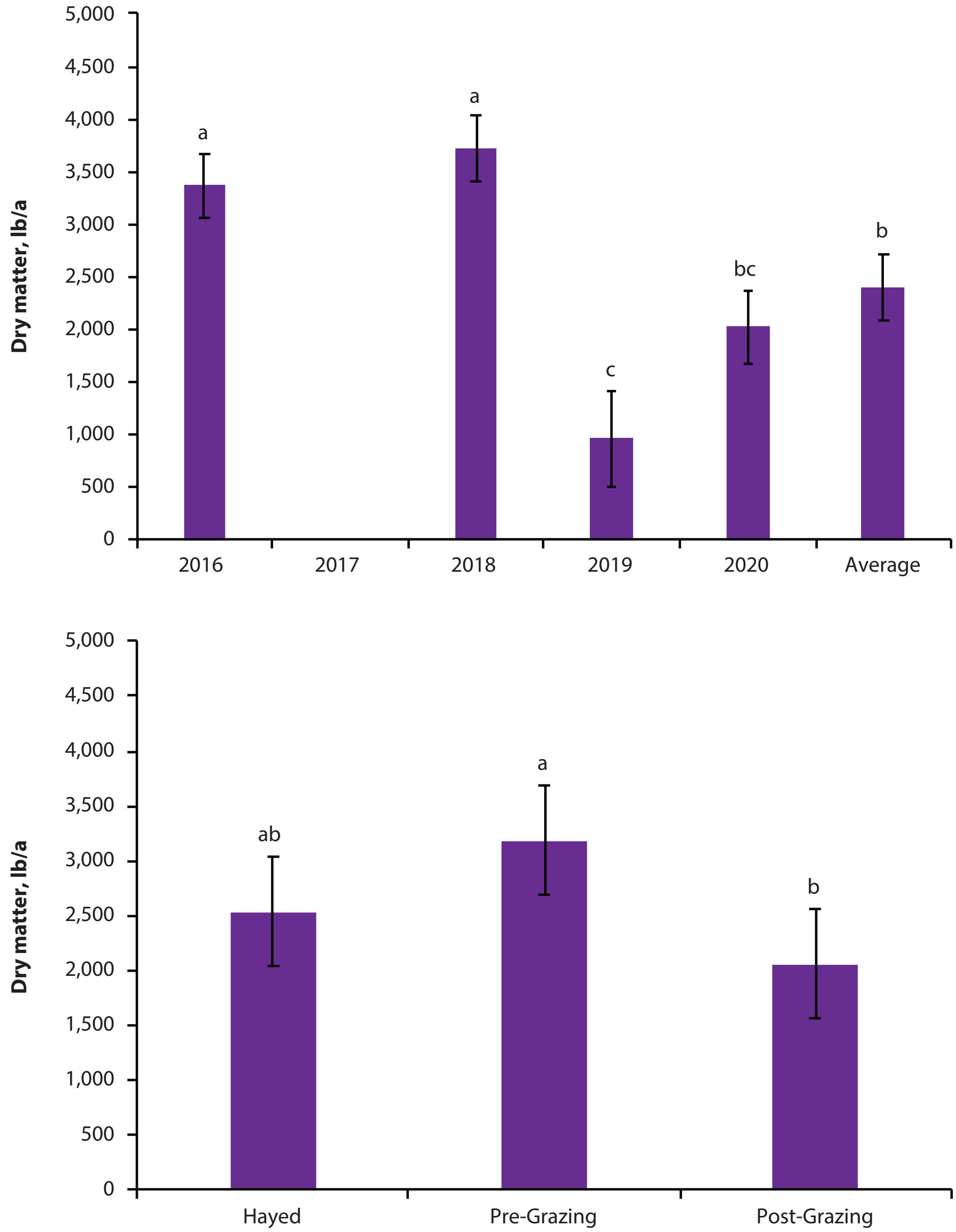

Figure 2. Summer cover crop forage accumulation across years (a) and management strategy (b) near Brownell, KS. Error bars indicate standard error ($\alpha = 0.05$) and bars with the same letter are not significantly different ($\alpha = 0.05$).

Dual-Purpose Cover Crop Effects on Soil Health in Western Kansas No-Till Dryland Cropping

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

Summary
Increasing interest in soil health has led producers in western Kansas to consider cover crops (CCs) for increased soil cover and improved soil properties. However, grain yield reductions following CCs in dryland cropping systems necessitate dual-purpose forage harvest to balance goals of environmental and economic sustainability. This study was initiated in 2015 near Brownell, KS, to investigate the effects of dual-purpose CC management in place of fallow on selected soil chemical and physical properties in a no-till winter wheat-grain sorghum-fallow cropping system. Mixed oat and triticale cover crops were either mechanically harvested as hayed forage to a height of 6 inches, mob-grazed with yearling heifers (weighing approximately 1000 lb each) stocked at 3 head/acre/day, or left standing (unharvested). Cover crop treatments were compared to chemically-controlled no-till fallow. Soil samples were collected following CC termination, but before winter wheat planting in 2019 and 2020. Results indicate that dual-purpose CCs had no effect on soil bulk density or porosity relative to unharvested CCs or the fallow treatment. Soil organic carbon was similar for standing and grazed CCs though carbon stocks were less for the hayed treatment. All CC treatments were similar to fallow. Indicators of soil structure—including mean weight diameter and large macroaggregates—were greater, while small macroaggregates were less for all CCs compared to fallow. These results suggest that dual-purpose CCs in no-till dryland cropping may replace fallow to provide forage for livestock while improving soil health. Still, careful management will be necessary to ensure adequate CC residues are retained such that, when CC growth is limited, grazing of CCs may be more desirable than haying in order to maintain soil properties.

Introduction
Integrating cover crops (CCs) to replace fallow in no-till dryland cropping systems in western Kansas has the potential to improve soil health by increasing soil carbon, reducing compaction, and enhancing soil structure. However, subsequent grain yield penalties due to reduced soil moisture following CCs represent a major barrier to adoption. Dual-purpose CCs may provide annual forage for livestock, which may offset losses in subsequent crop yield in order to balance goals of environmental and economic sustainability in dryland cropping. To our knowledge, limited information exists on the effects of dual-purpose use of CCs on soil properties. Concerns include reduced soil organic carbon (SOC) accrual, increased soil compaction, and degraded soil structure with CC haying and grazing, especially in no-till production systems.

Limited research findings from regions outside of western Kansas suggest that the effects of dual-purpose CCs on soil properties may be minimal. These results are promising and suggest that CC haying and grazing may be a good strategy for the dryland producers of this region. The objective of this experiment was to determine the effects of dual-purpose CCs on soil bulk density and porosity, organic carbon, as well as water stable aggregates (WSA).

Procedures

This study was initiated in 2015 at the Kansas State University HB Ranch near Brownell, KS, to investigate the effect of dual-purpose CCs in place of fallow on soil properties in a no-till dryland winter wheat-grain sorghum-fallow cropping system. Cover crops were a two-species mixture of oats and triticale at a seeding rate of 32 and 38 lb/a, respectively. The CCs were either mechanically harvested as hayed forage to a height of approximately 6 inches, mob-grazed with yearling heifers (weighing approximately 1000 lb each) stocked at 3 head/acre/day, or left standing. All CCs were chemically terminated by approximately the third week of June using glyphosate and 2,4-D in 2015, and with paraquat and carfentrazone thereafter from 2016 to 2020. This study was designed as a split-plot randomized complete block. Main plots were the three crop phases of the wheat-sorghum-fallow crop rotation, and split-plots were CC treatments. Hayed, grazed, and standing CCs were compared to chemically-controlled no-till fallow for a total of four treatments.

Soil samples were collected in 2019 and 2020 in the time following CC termination, but before winter wheat planting. Two intact soil cores of 2 inches in depth and 2 inches in diameter were randomly taken from each plot to determine soil bulk density and porosity. Bulk density was determined as mass of oven-dried soil divided by volume of the core, and porosity was determined using a constant particle density of 2.65 g/cm^3. Ten additional 2-inch cores were collected randomly throughout each plot for the determination of SOC concentration. Soil samples were mixed in the field, allowed to air-dry, and ground to pass through a steel sieve with 0.08-inch openings. Subsamples were ground to pass through a 0.01-inch screen, and SOC concentrations were determined by dry combustion after pretreating samples with 10% (v/v) hydrochloric acid to removed carbonates. Carbon stocks were calculated by multiplying concentrations by soil bulk density and the thickness of the soil layer. Additional samples were collected from the 0- to 2-inch soil depth with a flat shovel for the determination of WSA, an indicate of soil structure and erodibility. Samples were gently passed between sieves with 0.315- to 0.187-mm mesh and allowed to air-dry completely. Two sub-samples from each plot were used to estimate WSA by the wet-sieving method. Aggregate fractions were separated into large macroaggregates (>0.08-inch), small macroaggregates (0.08- to 0.01-inch), as well as microaggregates (<0.01-inch) and values were used to determine mean weight diameter. This report will summarize dual-purpose CC effects on selected soil chemical and physical properties averaged across the 2019 and 2020 sampling times. Statistical analysis was completed using PROC GLIMMIX of SAS ver. 9.3 (SAS Institute, 2012, Cary, NC) with treatment considered fixed and replication considered random. Differences were considered significant at $P \leq 0.05$.

Results

Haying and grazing of CCs had no effect on soil bulk density (Figure 1a) or porosity (Figure 1b) in the 0- to 2-inch soil depth compared to standing CCs or fallow in this no-till dryland cropping system. Soil near-surface bulk density averaged 1.13 g/cm^3 and porosity averaged 60.0%. This indicates that haying and grazing of CCs at similar cutting heights and stocking rates may have no effect or minimal effects on soil compaction in similar no-till systems. Soil organic carbon concentrations (Figure 2a) and stocks (Figure 2b) in the 0- to 2-inch soil depth with hayed CCs (1.51% or 3.66 ton/a) were less compared to the standing treatment (1.65% or 4.18 ton/a) and both were similar to fallow (1.52% or 3.86 ton/a). The grazed CCs (1.64% or 4.11 ton/a) were similar to standing CCs or fallow, and carbon stocks were greater compared to the hayed treatment. This indicates that grazing CCs may maintain or accrue SOC similarly to standing CCs in comparable dryland systems. However, mechanical forage harvest may have detrimental effects on SOC concentrations and stocks due to the limited residue retained following CC forage removal.

Mean weight diameter of WSA in the 0- to 2-inch soil depth was greater with all CCs (standing, grazing, or hayed) compared to fallow (Figure 3a). Mean weight diameter was 0.11 inch for the standing CCs, 0.10 inch for the hayed CCs, 0.12 inch for the grazed CCs, and 0.07 inch for fallow. This indicates that CCs have the ability to increase soil aggregation similarly when standing, hayed, or grazed. Additionally, all CCs were found to increase the proportion of large macroaggregates (>0.08 inch) compared to fallow (Figure 3b). The opposite was observed for small macroaggregates (0.08 to 0.01 inch) when all CCs had a lower proportion relative to the fallow treatment. Small macroaggregates were greater for standing CCs compared to the grazed CCs and both were similar to the hayed treatment. Microaggregates (<0.01 inch) were less for standing CCs compared to fallow. Hayed and grazed CCs were similar to standing CCs and fallow. These results of WSA indicate that hayed and grazed CCs have the potential to enhance soil structure and reduce erodibility in similar no-till dryland cropping systems.

In this study, dual-purpose CCs were found to have no effect on near-surface soil bulk density or porosity. However, mean weight diameter and the proportion of large macroaggregates were increased with all CCs treatments compared to fallow. Soil organic carbon stocks were less with hayed CCs relative to the grazed or standing treatments. These findings indicate that such dual-purpose strategies where CCs are grazed or mechanically harvested as hayed forage may provide similar benefits to soil health as unharvested standing CCs. Still, careful management will be critical such that when CC growth is limited, grazing CCs will be most beneficial compared to haying in order to maintain soil properties.

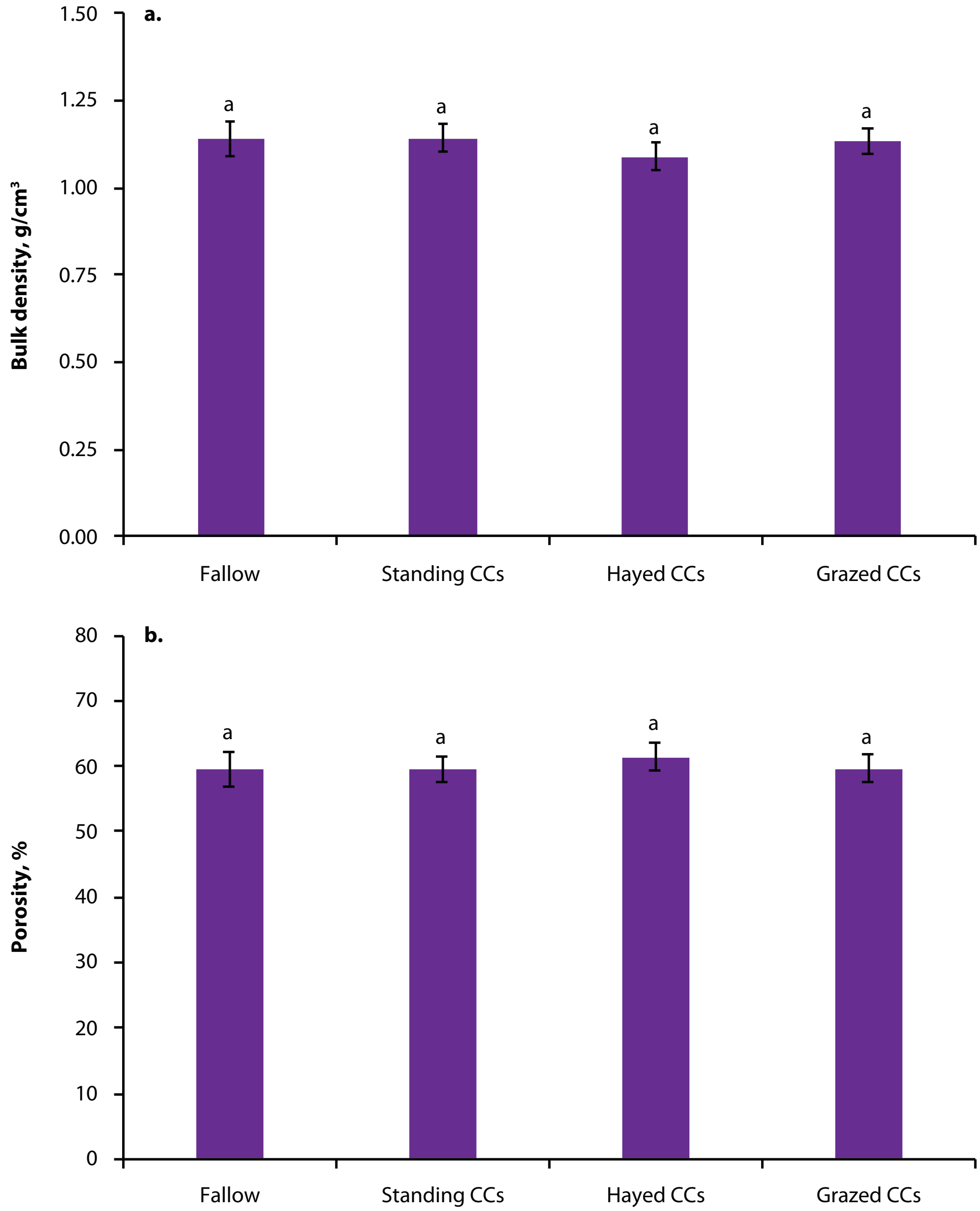

Figure 1. Cover crop (CC) management effect on soil bulk density (a) and porosity (b) in the 0- to 2-inch soil depth in a dryland cropping system in western Kansas. Error bars indicate standard error ($\alpha = 0.05$) and bars with the same letter are not significantly different ($\alpha = 0.05$).

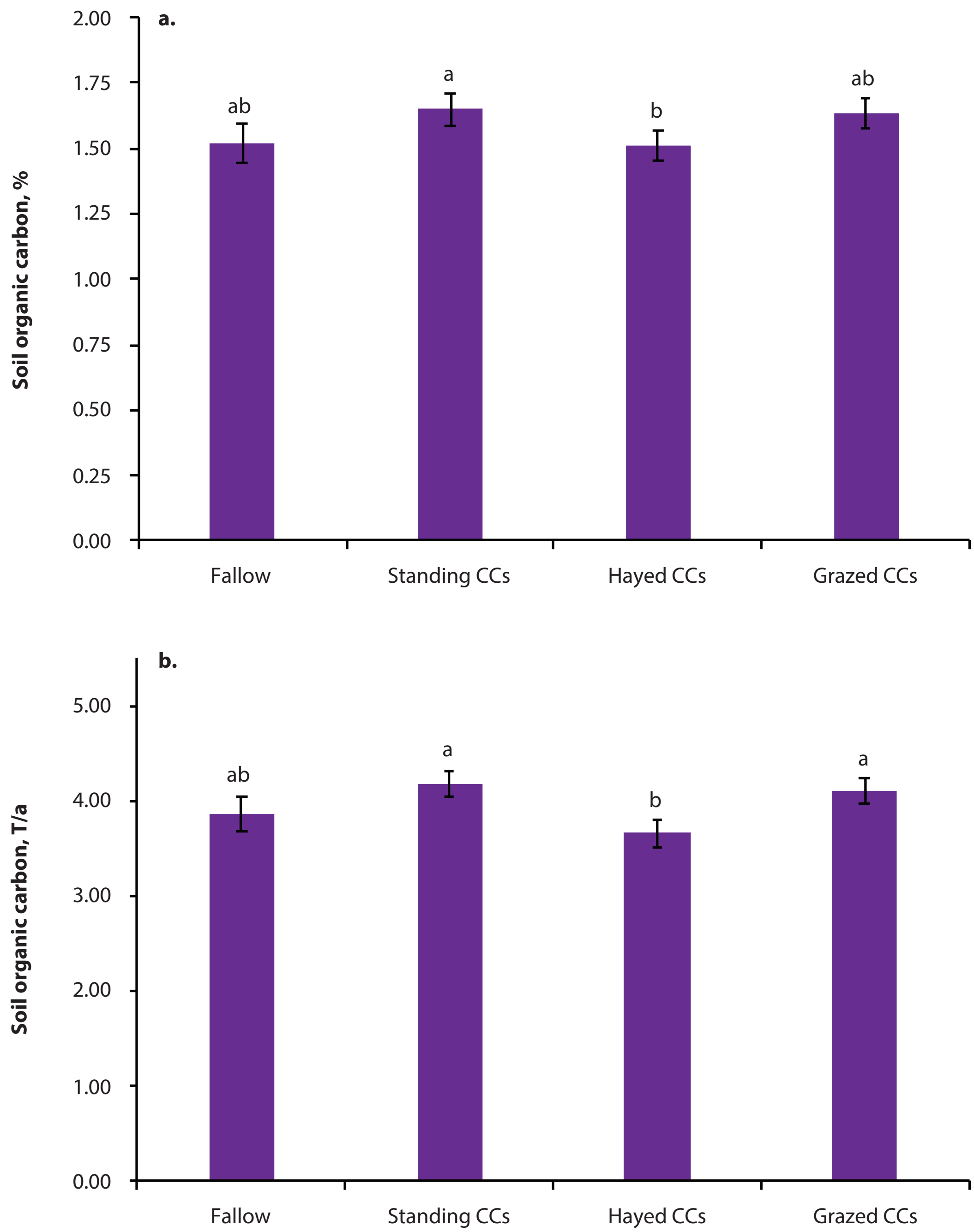

Figure 2. Cover crop (CC) management effect on soil organic carbon concentrations (a) and stocks (b) in the 0- to 2-inch soil depth in a dryland cropping system in western Kansas. Error bars indicate standard error (α = 0.05) and bars with the same letter are not significantly different (α = 0.05).

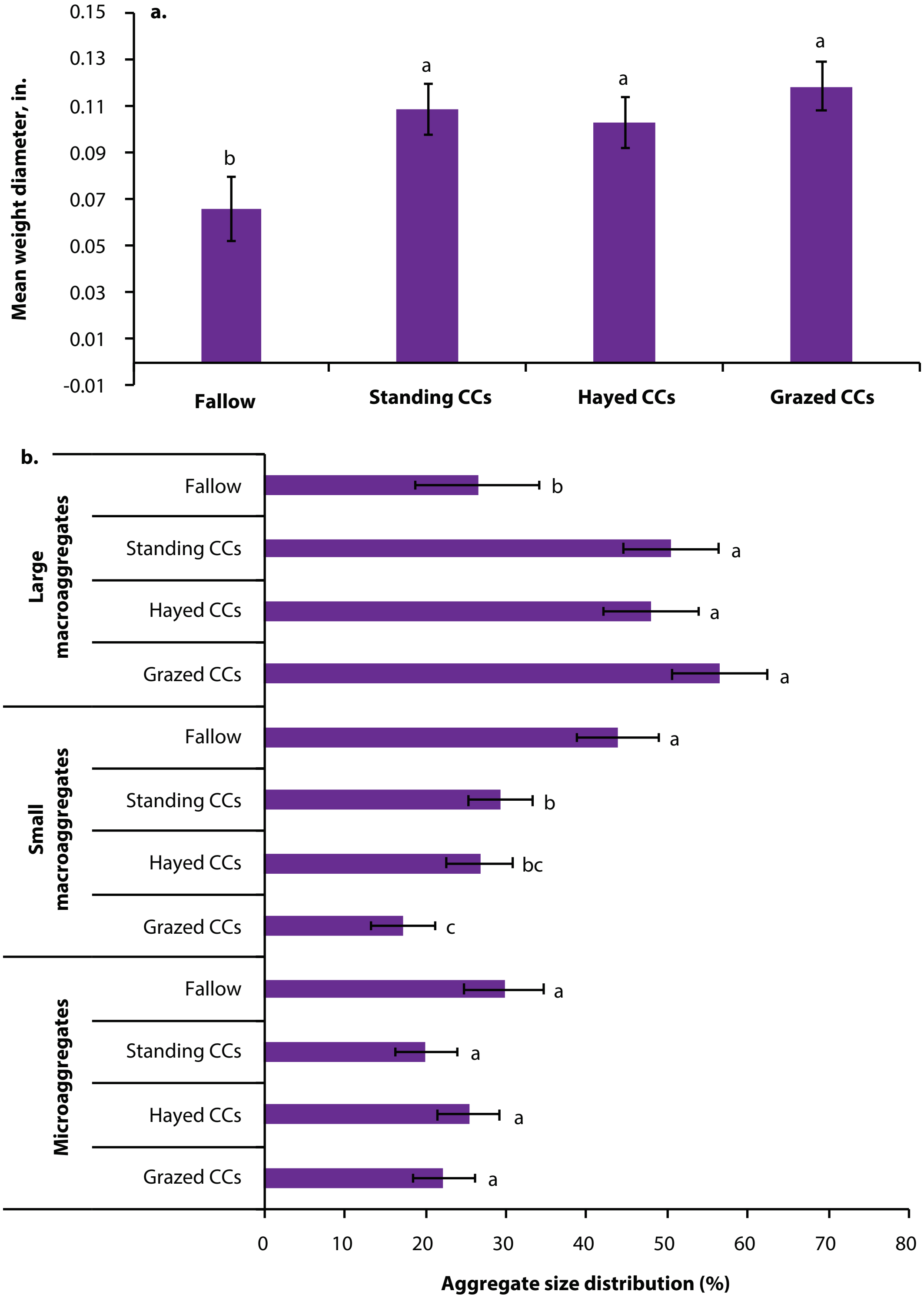

Figure 3. Effects of cover crop (CC) management on mean weight diameter (a) and distribution of large macroaggregates (>0.08 in.), small macroaggregates (0.08 to 0.01 in.) and microaggregates (<0.01 in.) (b) in the 0- to 2-inch soil depth in a dryland cropping system in western Kansas. Error bars indicate standard error (α = 0.05) and bars with the same letter are not significantly different (α = 0.05) within aggregates size fractions.

Kansas Soil Health Partnership

C.B. Pires, I.A. Ciampitti, D.A Ruiz Diaz, M.V.M Sarto, and C.W. Rice

Summary
This study was part of a farmer-led initiative that fosters transformation in agriculture through improved soil health, benefitting farmer profitability, supporting a stable food supply, and preserving the environment. This study's objective was to measure the effect of soil management strategies on the soil microbial community distribution and activity. Four farmers in Kansas were accepted into the program to conduct on-farm comparisons of a standard farm practice and an improved practice. This was ongoing research, and for this field research report, we are presenting the study at one of the selected farms. This site was located near Bucyrus, Miami County (38°44'30" N, 94°42'30" W, elevation: 1109 ft), with a Grundy silt loam. The improved practice was the incorporation of cover crops into a long-term no-till corn-soybean rotation. The experimental design was four replicated strips of the farmer standard practice and the improved practice. Soil samples were taken on a GPS coordinated grid at 0 to 2 inches soil depth before implementing the cover crops (baseline), and at the third year of the study. Soil biological health indicators included soil organic matter, soil microbial biomass, total fungi, total bacteria, and β-glucosidase (βG) activity. Soil organic matter and βG activity were compared between initial and third-year. Interpolated maps evaluated the spatial distribution of the soil microbial community. Two years of cover crops increased enzyme activity. Soil microbial biomass and soil organic matter were significantly ($P < 0.001$) correlated. Our results suggest that soil organic matter was a key driver of the spatial distribution of the soil microbial community.

Introduction
Soil health is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (Doran and Zeiss, 2000; Lehmann et al., 2020). Healthy soils are critical for supporting crops, but also ecosystem services, such as climate regulation, nutrient cycling, flood regulation, carbon sequestration, water purification, and habitats for microorganisms (Rinot et al., 2019). Soil health includes soil attributes associated with the soil microbiome and the range of functions they perform (Doran et al., 1996). Promoting and monitoring soil health is the basis for sustainable agriculture. According to Karlen and Rice (2015), the most promising strategies to mitigate soil degradation are improving soil management practices, which improves soil health by enhancing soil biological activity and increasing soil organic matter. Soil microbial communities regulate carbon and nutrient cycling in soils. For agricultural soils, the use of cover crops may ultimately increase crop production, carbon sequestration, microbial biomass and activity, and soil health (Bonini Pires et al., 2020; Chavarría et al., 2016). With the purpose of testing different soil management practices, a Kansas soil health network was created between the Kansas State University Soil Microbial Agroecology Lab, Kansas Corn, and the Kansas Soil Health Partnership. The partnership was a farmer-led initiative that fosters transformation in agriculture through improved soil health, benefitting farmer profitability, supporting a stable food supply, and preserving the environment. The objective of this study was to measure the effect of the farmer soil management practice and an improved practice on the soil microbial community distribution and activity.

Procedures

This research project was initiated in 2018 and conducted at four commercial farms across Kansas (Figure 1). This is ongoing research, and for this field report, we are presenting the study at one of the selected farms. This site was located near Bucyrus, Miami County (38º44'30" N, 94º42'30" W, elevation: 1109 ft), on a Grundy silt loam soil. This study consisted of two treatments: an improved practice, which was the addition of cover crops (CC) in a long-term no-till corn-soybean rotation; and the standard practice (NC) was the same rotation, without cover crops. The cover crop planted in 2018 was rye (broadcast), and in 2019 a mix of rye, oats, barley, peas, and vetch. The experimental design was four replicated strips of 6.5 acres each of the farmer's standard practice and the improved practice (Figure 2), for a total of 52 acres. Soil samples were taken on a 1-acre GPS coordinated grid at 0 to 2 inches depth before implementing the cover crops (baseline-2018) and at the third year of the study (2020). Soil samples for microbial properties were kept in a cooler (39°F) and frozen (-4°F) within 2 hours after sampling and stored until analysis. Samples for soil organic matter analysis were cleaned of roots, air-dried, ground, and sieved (2 mm). Soil organic matter (SOM) was analyzed by loss-on-ignition (LOI). Soil microbial community composition was assessed by phospholipid fatty acid analysis (PLFA). The PLFA was performed with modifications to the original procedure (White and Ringelberg, 1998). A total of 30 biomarkers were identified for all samples. Microbial groups were assigned based on characteristics of the biomarkers. Any PLFA abundance was reported as nmol per gram of dry soil (nmol PLFA g^{-1} soil). Total bacteria were the sum of Gram-positive bacteria, Gram-negative bacteria, and actinomycetes. Microbial biomass was the sum of all PLFA biomarkers. The Fungal:Bacterial ratio (F:B ratio) was total fungi divided by total bacteria. The βG activity was measured following a modified fluorometric method using fluorometric substrate 4-methylumbelliferone (Zeglin et al., 2013). Potential βG activity was reported as nanomoles activity per gram of dry soil per hour ($nmol^{-1}$ hr^{-1} g^{-1} soil). As ongoing research, no statistical analyses were performed. All figures presented in this field report are exploratory and preliminary.

Preliminary Results

Soil Microbial Community and Soil Organic Matter Spatial Distribution

Spatial patterns and drivers of soil microbial communities have not yet been well documented (Song et al., 2018); however, the spatial distribution of plants and soil chemical properties have been documented for a long period. Technological advances in precision agriculture have made soil mapping an economically feasible practice for farmers in the last couple of decades. Global positioning system (GPS) equipped machinery allows the collection of georeferenced data, which can generate maps via several interpolation techniques when coupled with a geographic information system (GIS). The interpolated soil microbial community maps (Figure 3A, 3B, and 3C) suggest a correlation between soil microbial biomass, total fungi, and total bacteria, hereinafter referred to as soil microbial community with soil organic matter (Figure 4). This correlation was confirmed through a simple linear regression between soil microbial biomass and soil organic matter, which had a P-value < 0.001 and coefficient of determination (R^2) of 0.43 (Figure 5). Overall, all microbial groups had a similar spatial distribution. Likewise, F:B ratio (Figure 3D) had a similar spatial pattern of their base microbial groups. Intensively managed agricultural soils often have lower F:B biomass ratios compared to more extensively managed soils due to tillage, high rates of fertilization, and decreasing

C:N ratio favoring bacteria (Sinsabaugh et al., 2013). A higher F:B ratio is linked to an increased abundance of fungi in the soil, which indicates a higher carbon storage potential and greater aggregations (Malik et al., 2016).

Soil Organic Matter

Soil organic matter is the key driver to improved soil health, to increase yields, and minimize environmental damage (Oldfield et al., 2019). Thus, SOM is crucial to conserve, regenerate, and increase productive soils' resilience. The use of conservation practices such as cover crops, one of the mainstays of conservation agriculture (Pittelkow et al., 2015), is essential to increase SOM and enhance microbial diversity and activity. Although still preliminary, our results indicate a slight increase in SOM levels for the cover crop treatment when comparing the baseline and third-year data (Figure 6). The SOM remained unchanged for the no cover crop treatment.

β-Glucosidase Activity

β-Glucosidase is a hydrolytic enzyme linked to the soil carbon cycle (Bonini Pires et al., 2020). For these reasons, βG has been used as an indicator of soil health due to its rapid response to soil management changes. Our preliminary results had increased βG activity for the CC treatment compared with NC (Figure 7). The cover crop residue is likely to have increased βG activity. Shifts in βG activity in response to management changes have been reported previously in different systems (Sarto et al., 2020), highlighting the sensitivity of enzyme activity as a soil health indicator.

Final Considerations and Next Steps

This study is part of a 5-year on-farm soil health project. The ultimate goal is to generate data-driven recommendations that Kansas farmers can use to improve their farms' productivity and sustainability. With our still-growing georeferenced dataset, we will also evaluate the effect of soil health on crop yield and develop strategies to mitigate yield-limiting factors while increasing soil resilience.

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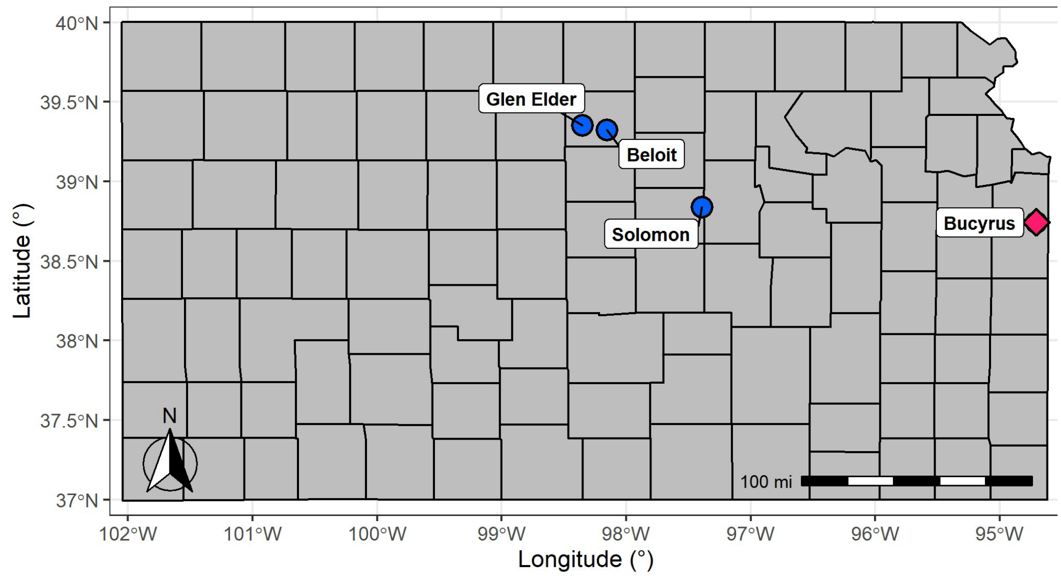

Figure 1. Kansas Soil Health Partnership Network.

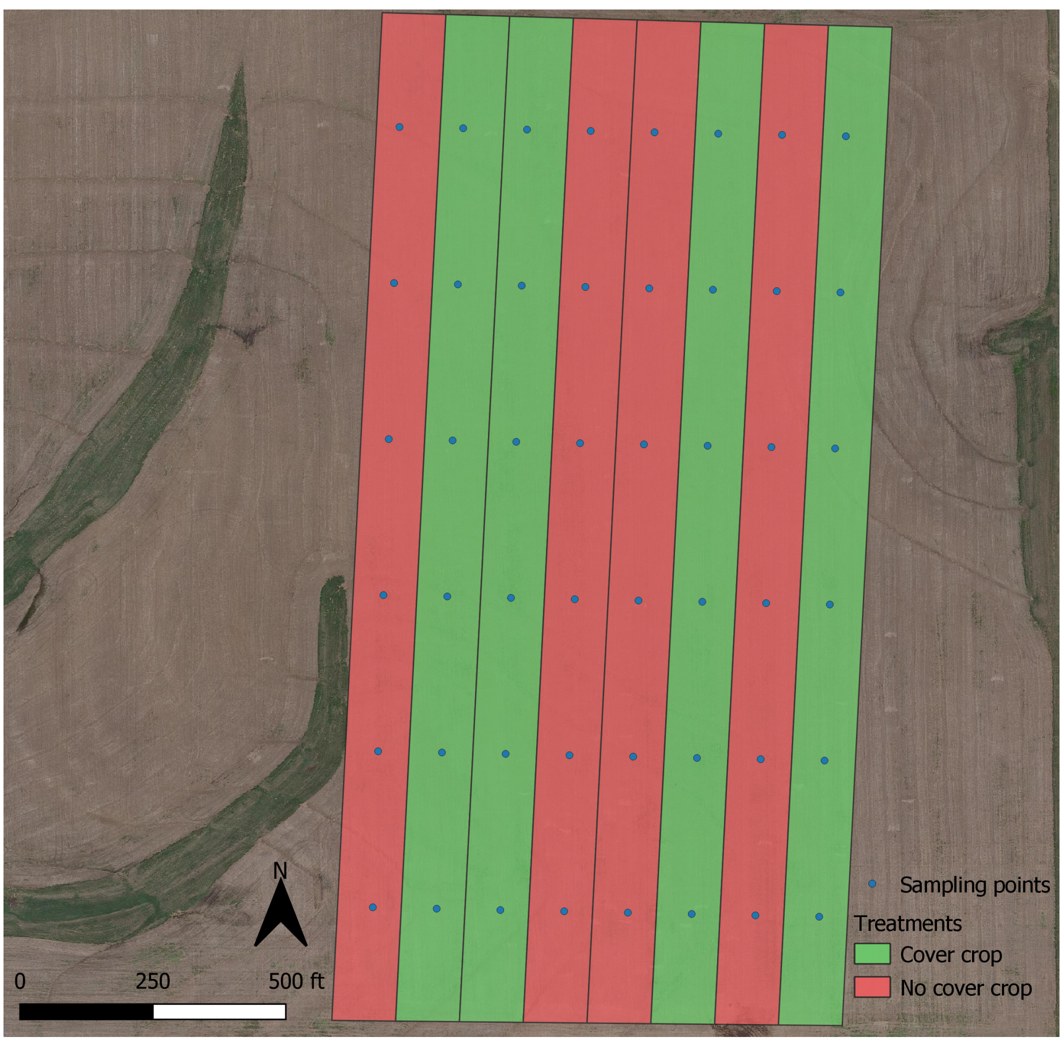

Figure 2. Experimental design and soil sampling scheme.

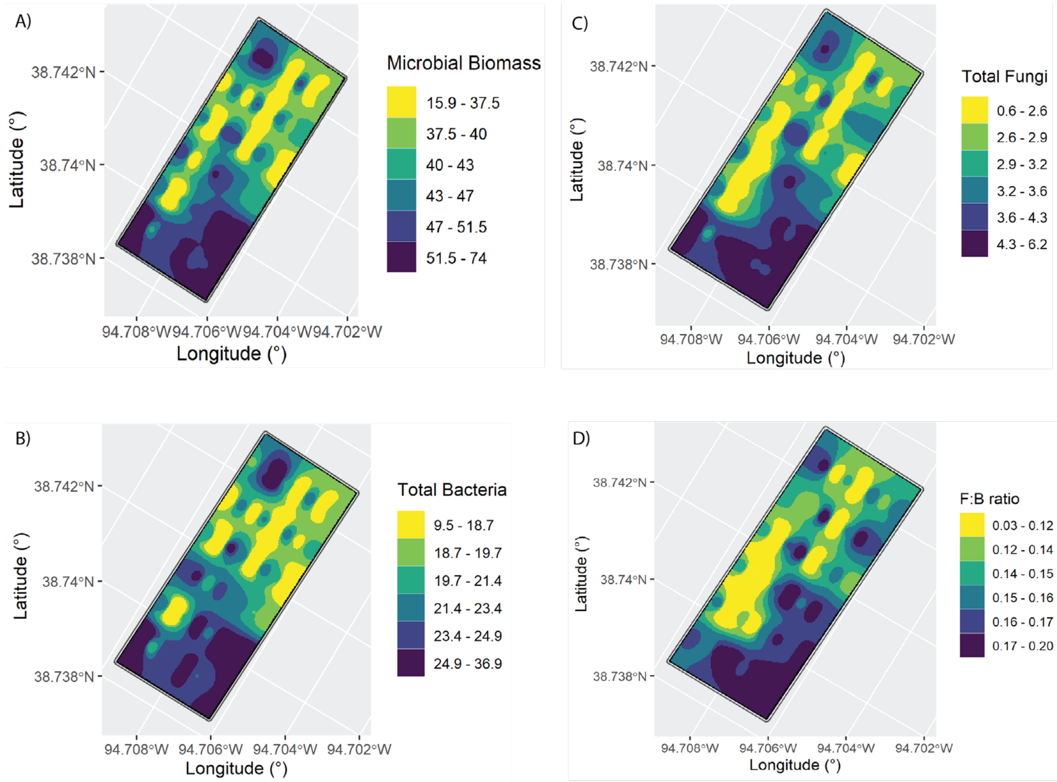

Figure 3. Spatial distribution: (A) microbial biomass, (B) total fungi, (C) total bacteria, and (D) fungal:bacterial ratio. Data are presented in nmol PLFA g^{-1} soil.

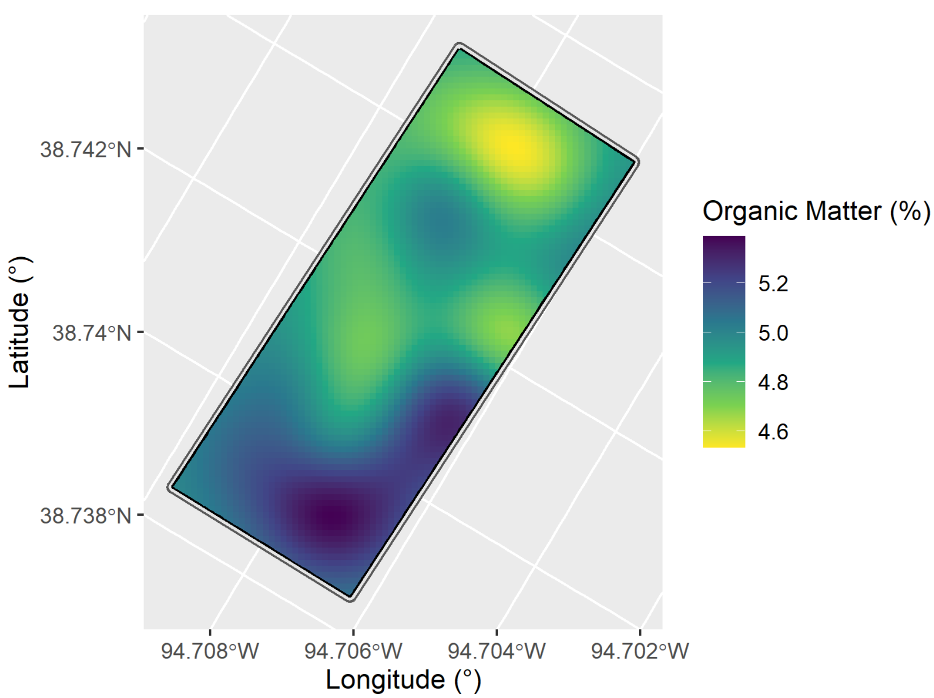

Figure 4. Soil organic matter spatial distribution.

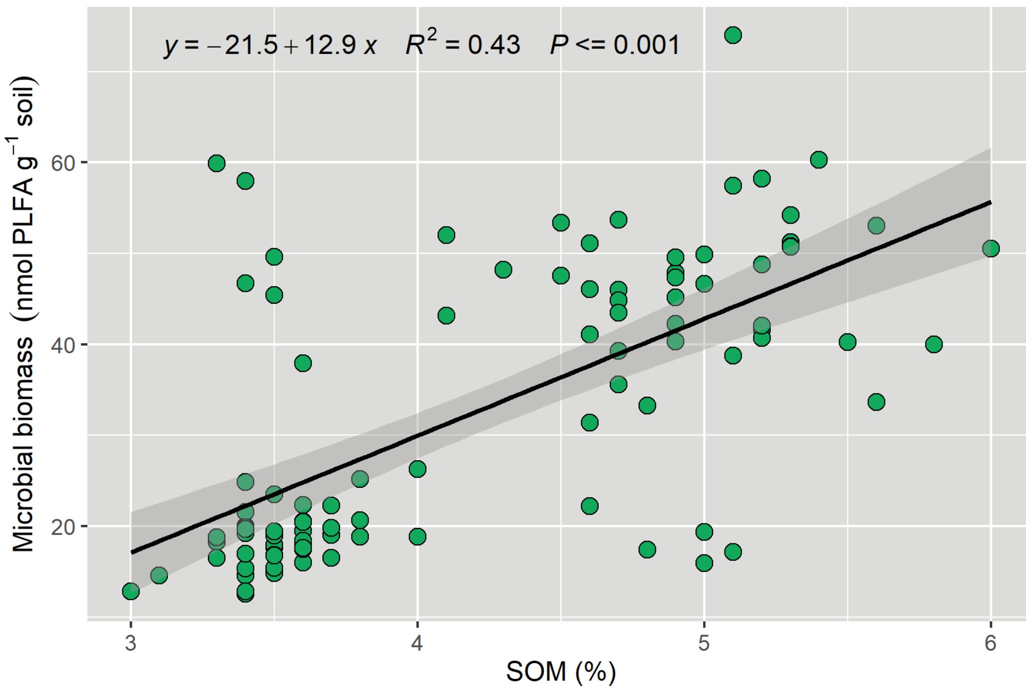

Figure 5. Linear regression between soil organic matter and microbial biomass.

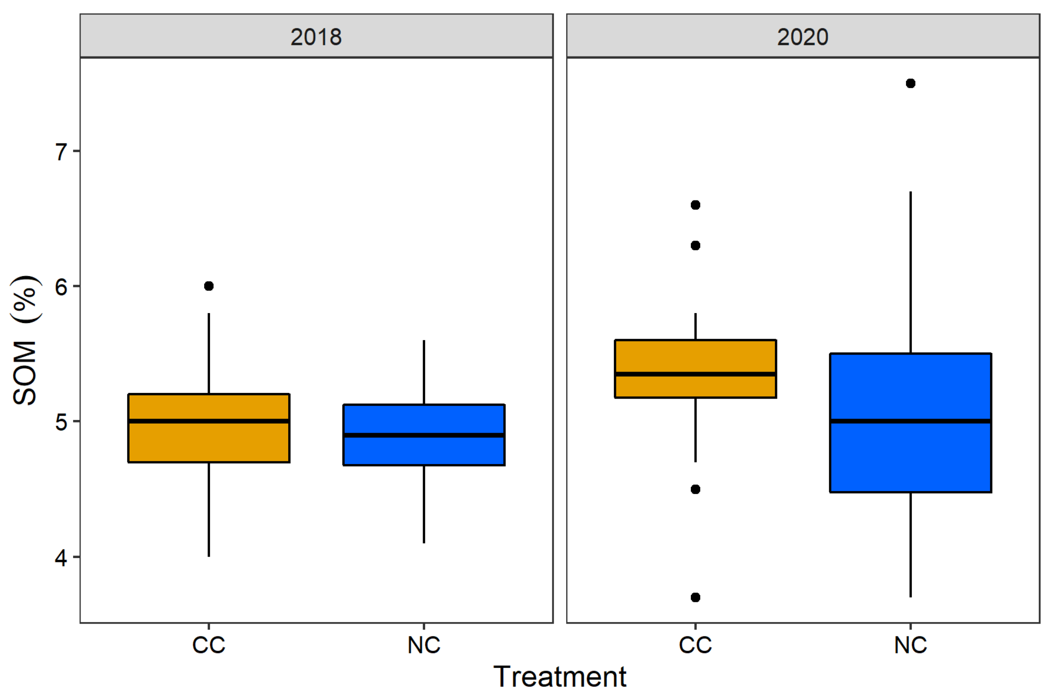

Figure 6. Soil organic matter by loss-on-ignition (LOI). CC = cover crops. NC = standard practice.

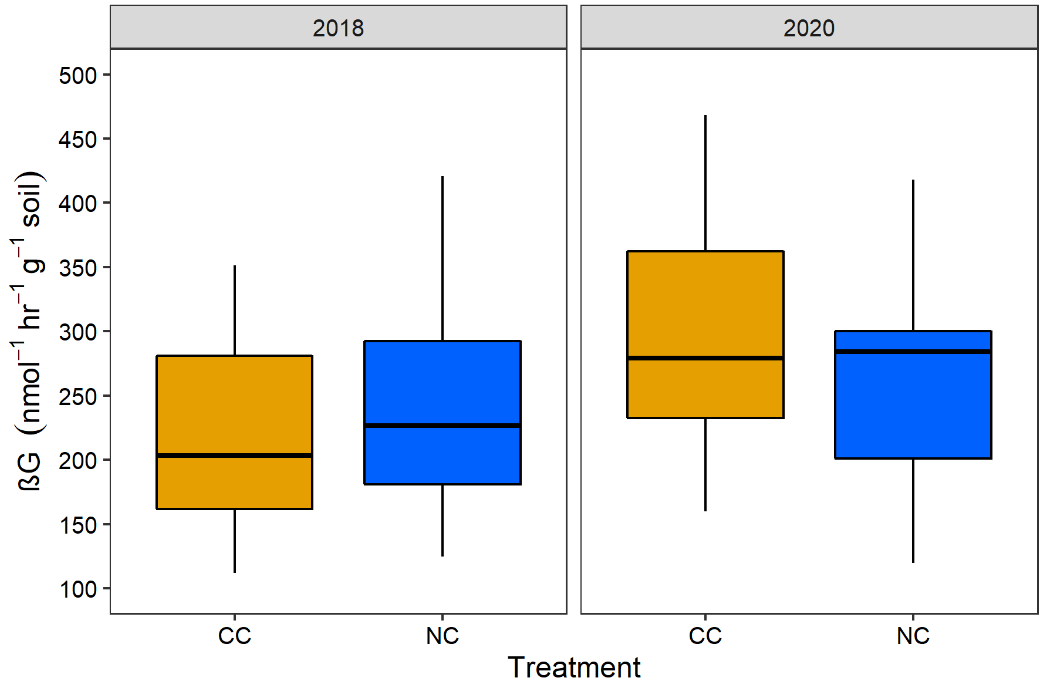

Figure 7. β-Glucosidase activity. CC = cover crops. NC = standard practice.

Co-Inoculation and Sulfur Fertilization in Soybeans

L.H. Moro Rosso, A.F. de Borja Reis, S.L. Naeve, and I.A. Ciampitti

Summary

Soybeans [*Glycine max* (L.) Merr.] rely on large nutrient uptake, especially nitrogen (N), to produce seeds with high nutritional value. Biological N fixation (BNF) supplies most of the plant N demand and enhancement of this process might improve cropping systems' sustainability. Although seed inoculation with *Bradyrhizobium* spp. for soybean crop is a well-known management practice, co-inoculation with the free-living N-fixer *Azospirillum brasilense* has not been deeply investigated in the US, to our knowledge. Thus, this research explores the effect of co-inoculation with *A. brasilense* on soybean yield and seed nutritional quality (protein, oil, essential and sulfur (S) amino acids concentration) under contrasting fertilizer S rates. Two-way factorial experiments were conducted in Manhattan and Topeka (KS, US) during the 2019 growing season. Sulfur rates of 0 and 20 lb/a were combined with four inoculation strategies: 1) non-inoculated, 2) seed inoculation with *Bradyrhizobium japonicum*, 3) *A. brasilense*, and 4) co-inoculation using both bacteria. The proportion of BNF was estimated via the relative abundance of ureide-N (RAU) at the R5 stage (beginning seed filling). Shoot dry mass was also assessed at R5, as well as seed yield and seed size (1000-seed weight) at harvest time (R8 stage). Dry basis concentration of seed components was also determined (protein, oil, essential and sulfur amino acids). None of the treatment factors significantly ($P < 0.05$) influenced any observed trait. Overall, RAU averaged 80%, seed yield 65 bu/a, protein 42%, and oil 20%. Future research is necessary to eventually capture effects from co-inoculation and S fertilization in soybeans.

Introduction

Soybean [*Glycine max* (L.) Merr.] produces a great amount of protein and oil in the seeds, which highlights its worldwide importance for human nutrition. However, the high nutritional value depends on large nutrient uptake, especially N. Biological N fixation is a crucial process to enhance seed yield and protein, along with a relatively small contribution from soil N supply. However, the bacteria responsible for BNF (*Bradyrhizobium* spp.) must be introduced in agricultural soils (Albareda et al., 2009). In addition, *Bradyrhizobium* spp. is not the only organism capable of fixing N and benefiting the cropping system sustainability.

Azospirillum brasilense is not hosted in root nodules but can fix and release N close to the root surface. Moreover, this species is associated with root growth, which improves nutrient uptake in deeper soil layers; resistance to biotic and abiotic stresses; and potential increase in shoot dry mass and seed yield (Fukami et al., 2018). Therefore, A. brasilense is classified as a plant growth promoting rhizobacteria (PGPR). The process of combining traditional *Bradyrhizobium* spp. inoculation with a PGPR is called co-inoculation and shows promising results in South America (Barbosa et al., 2021). However, little is known about the effect of co-inoculation on yield and seed composition in the US, or the influence on underlying processes such as BNF and S uptake. This research aims to investigate the effect of co-inoculation with *A. brasilense* on soybean yield and nutritional quality (seed protein, oil, essential and sulfur amino acids) under contrasting fertilizer S rates in Kansas.

Procedures

Sites and Measurements

Field experiments were conducted during 2019 at the Ashland Bottoms Agronomy Farm (39.14° North, 96.63° West, Manhattan) and Kansas River Valley Experimental Field (39.07° North, 95.77° West, Topeka). Sowing date was June 7, 2019, in Manhattan and May 17, 2019, in Topeka. Both locations received the genotype AG39X7 (maturity group 3.9) at 140,000 seeds/a. A characterization of the soil (prior to sowing) and weather parameters (from sowing to harvest) are presented in Table 1. At emergence (VE stage) (Fehr et al., 1971), two S fertilization rates were applied: 1) zero (unfertilized control); and 2) 83 lb/a of ammonium sulfate (AMS, with 21% N and 24% S), supplying a total of 20 lb S-SO_4 per acre. Before sowing, liquid inoculants (TerraMax, Eagan, MN) were applied to the seeds as: 1) non-inoculated (control); 2) *Bradyrhizobium japonicum*; 3) *A. brasilense*; and 4) both bacteria (co-inoculation).

The treatment structure was a two-way factorial in a randomized complete block design (RCBD) with four repetitions. Experimental units (plots) were composed of four rows of 40 feet length spaced 30 inches apart. During early seed filling (R5 stage), shoot fresh mass (lb) was sampled from a 25 ft^2 area, avoiding border rows at each plot. From the fresh sample, a 10-plant subsample was randomly selected in order to estimate water content (%), and thereafter dry mass in lb/a. Another subsample was collected, considering only 10 main stems. Whole plant and main stems were allowed to dry in a forced-air oven (150°F) until constant weight.

Main stems were ground in a micro mill (60-mesh screen) and subjected to ureide and nitrate (NO_3) analysis (Hungria and Araujo, 1994). Concentration of stem extracts (ureide and NO_3) was used to calculate the relative abundance of ureide-N (RAU), a proxy of BNF (Unkovich et al., 2008). At harvest time (R8 stage), the two central rows were combine harvested to estimate seed yield (13% moisture basis), excluding biomass sampling gaps. From the combine, a 2 lb sample was collected to measure seed size (1000-seed weight, lb) and seed nutritional quality (protein, oil, essential and sulfur amino acids) via near-infrared spectroscopy (NIR) (Pazdernik et al., 1997). The concentration of all seed components is expressed in dry mass basis (%).

Statistical Analysis

A linear mixed model for each observed variable was fitted with the lme4 package (Bates et al., 2015) in the R software (R Core Team, 2021). The model accounted for S fertilization (2 levels), inoculation strategy (4 levels), and its interaction, as fixed effect factors. Site (Manhattan and Topeka), block, and block nested in site, were included as random effect factors. Type III analyses of variance (ANOVA) were performed using the car package (Fox and Weisberg, 2018). Tukey test was performed for means comparison in case fixed effects were significant ($P < 0.05$). Finally, least square means (LSMEAS) were extracted for all eight treatments and variables were subjected to a principal components analysis (PCA) with the factoextra package (Kassambara and Mundt, 2020). The PCA was intended to show the overall relationship among all observed variables (seed yield, size, dry mass, RAU, and seed components).

Results

Neither inoculation nor S fertilization influenced any observed variable (Table 2). Therefore, treatment LSMEANS are reported without means comparison (Figure 1). Yield averaged 65 bu/a, protein and oil concentration were ca. 42% and 20%, respectively. The RAU values reached ca. 80%, indicating BNF was the main N source in early seed filling (R5). Overall, seed yield was negatively correlated with oil concentration and positively associated with dry mass and seed size (Figure 2). The weak positive correlation between yield and protein is noteworthy. Protein concentration was strongly correlated with essential and sulfur amino acids. Future research should explore co-inoculation and S fertilization under contrasting growing conditions (e.g., low and high soil pH) and increase the number of treatment repetitions.

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Table 1. Site description for Manhattan and Topeka, KS. Soil parameters were measured prior to sowing from a 6-inch depth layer; except for soil SO_4 and NO_3, measured from a 24-inch depth layer. Weather data were summarized from sowing to harvest (140 days) at each location and obtained from DAYMET (Thornton et al., 2020).

Soil	Manhattan	Topeka	Weather	Manhattan	Topeka
Water pH	6.5	7.1	Radiation, MJ m^{-2} day^{-1}	4733	5343
SOM [a], %	1.4	1.7	Max. temperature, °C	28.4	27.7
Clay, %	8	22	Min. temperature, °C	16.6	16.9
Sand, %	47	11	Mean temperature, °C	22.5	22.3
Silt, %	45	67	Precipitation, mm	668	825
P[b], mg dm^{-3}	30	18	Precipitation SDI [d]	0.65	0.71
CEC [c], $cmol_c$ dm^{-3}	7.5	9.5	Evapotransp. [e], mm	650	683
NO_3, mg dm^{-3}	2.8	3.2	Relative humidity, %	72	76
SO_4, mg dm^{-3}	0.9	1.7	VPD [f], kPa	121	111

[a] Soil organic matter via loss-on-ignition (LOI).
[b] Phosphorus via Mehlich-3.
[c] Cation exchange capacity.
[d] Shannon diversity index of precipitation (Bronikowski and Webb, 1996); values range from zero to one, with one representing evenly distributed precipitation.
[e] Reference evapotranspiration (ET_0).
[f] Vapor pressure deficit.

Table 2. Analysis of variance (ANOVA) results for shoot dry mass (R5 stage), seed yield, seed size (1000-seed weight), relative abundance of ureide-N (RAU), seed protein, oil, essential and sulfur amino acids (%, dry basis). Sulfur fertilization, inoculation strategy, and their interaction were considered as fixed effects while site and block were random. Values between parentheses represent degrees of freedom, followed by the *P*-value (F-test).

Variable	Intercept	Inoculation	Sulfur	Interaction
Dry mass	(1) 1.99e-03 **	(3) 1.37e-01	(1) 8.33e-01	(3) 6.41e-01
Seed yield	(1) 2.84e-08 ***	(3) 8.09e-01	(1) 4.53e-01	(3) 4.32e-01
Seed size	(1) 3.13e-02 *	(3) 4.39e-01	(1) 1.41e-01	(3) 1.28e-01
RAU (R5)	(1) 4.27e-04 ***	(3) 3.65e-01	(1) 9.34e-01	(3) 6.38e-01
Protein	(1) 1.08e-02 *	(3) 6.44e-01	(1) 9.64e-01	(3) 9.43e-01
Oil	(1) 1.23e-02 *	(3) 6.11e-01	(1) 8.23e-01	(3) 2.34e-01
Amino acids				
Essential [a]	(1) 7.40e-03 **	(3) 3.37e-01	(1) 9.45e-01	(3) 9.57e-01
Sulfur [b]	(1) 3.82e-04 ***	(3) 7.33e-02	(1) 8.99e-01	(3) 6.84e-01

[a] Essential amino acids: isoleucine, leucine, histidine, phenylalanine, valine, lysine, cysteine, methionine, threonine, and tryptophan.
[b] Sulfur amino acids: cysteine and methionine. Amino acid groups were generated based on Pfarr et al. (2018).
* Significant at the 0.05 probability level. ** *P*-value < 0.01. *** *P*-value < 0.001.

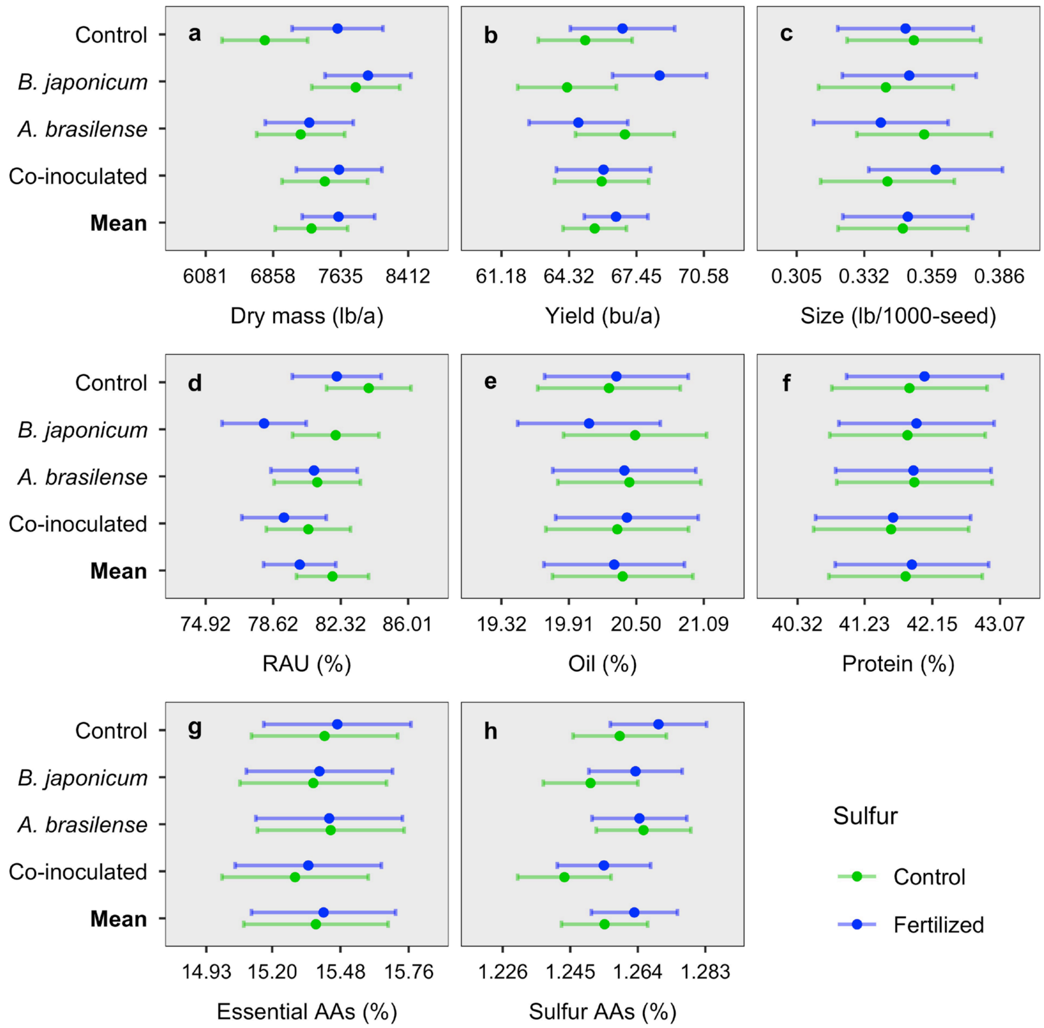

Figure 1. Least square means (LSMEANS) for R5 shoot dry mass (a); seed yield (b); seed size (c); relative abundance of ureide-N (RAU) (d); seed oil (e); protein (f); essential (g); and sulfur amino acids (h) concentration. No significant differences (*P* < 0.05) were observed among treatment factors; therefore, no means comparison was performed. Essential amino acids (AAs) correspond to the sum of isoleucine, leucine, histidine, phenylalanine, valine, lysine, cysteine, methionine, threonine, and tryptophan. Sulfur AAs correspond to cysteine and methionine. Error bars represent the standard error from the linear mixed models.

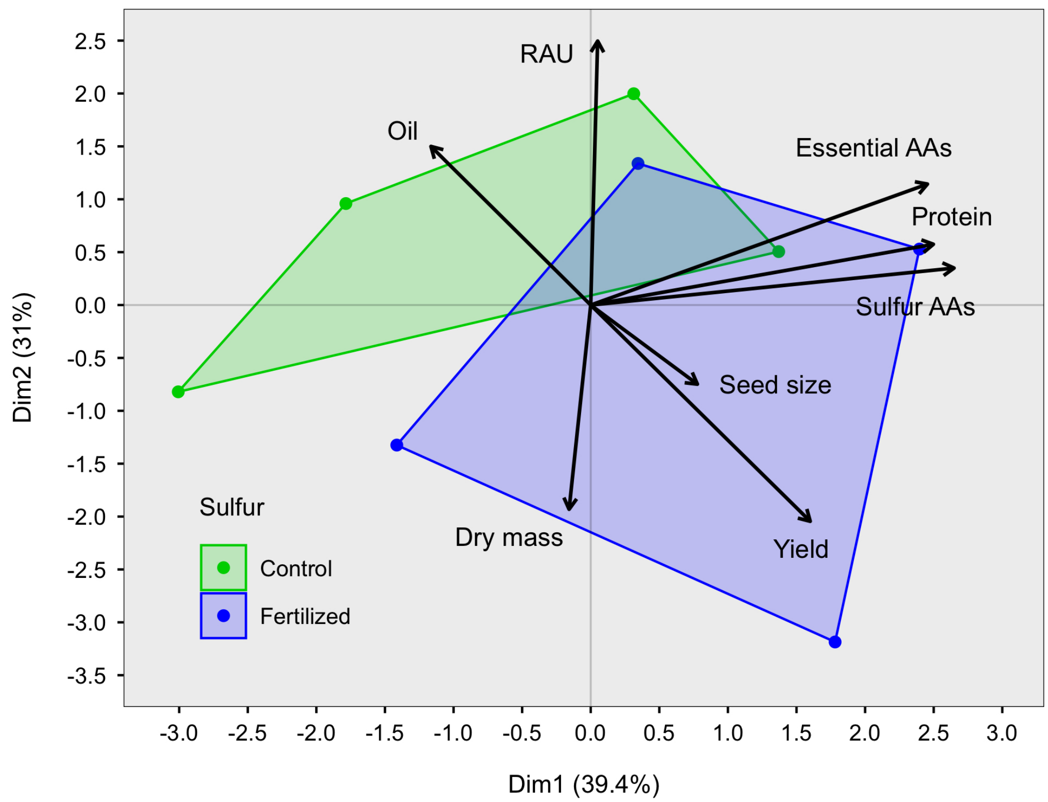

Figure 2. Principal component analysis (PCA) displaying the relationship among least square means (LSMEANS) of observed variables. With only eight variables, the first two dimensions (Dim) account for most of the treatment variation. Arrows pointing in the same directions indicate positive Pearson's correlation, otherwise negative correlation. Perpendicular arrows show no correlation between variables. The treatment LSMEANS were not significantly different in the analysis of variance (ANOVA), with *P* < 0.05.

Foxtail Management in Smooth Brome Hay Meadows

S.R. Lancaster and S.R. Duncan

Summary
Three different herbicides were applied at early bromegrass greenup and at post hay harvest to assess their effectiveness in controlling foxtail at two producer hay meadow sites in Pottawatomie (PT) and Dickinson (DK) counties. Pendimethalin applied early resulted in the greatest foxtail control, but control did not extend through the season to reduce late-summer infestations. Metsulfuron applied early resulted in approximately 30% visible brome injury. The injury was associated with 77 and 48% brome hay losses when compared to the untreated check, at the PT and DK sites, respectively. Injury from the early spring treatments was exacerbated by six freeze events and cool, dry conditions for three weeks following application. Metsulfuron and pendimethalin applied post-harvest also resulted in visible brome injury, but dry matter yields were not measured. This study will be continued in 2021 without the metsulfuron treatments, but with the addition of sequential pendimethalin treatments.

Introduction
Smooth bromegrass (*Bromus inermis*) is a major hay and pasture crop in eastern Kansas, occupying approximately 1.2 million acres (Figure 1), and yielding up to three tons or greater of dry matter (Lamond et al., 1992) per growing season with good rainfall and adequate fertilization. Since 2007, a perceived or noted decline in smooth bromegrass yield as well as increased foxtail [primarily yellow (*Setaria pumila*) and giant (*S. faberi*)] competition in the summer months has been observed. Two field studies in the spring of 2020 evaluated and compared (1) the efficacy of spring and post-harvest applied herbicides, (2) their effect on the smooth bromegrass, and (3) their control of foxtail species in established smooth bromegrass hay meadows.

Procedures
The effects of early spring and post hay harvest applications of pendimethalin (Prowl H2O), *S*-metolachlor (Dual II Magnum), and metsulfuron (Escort XP) on smooth bromegrass injury, yield, and foxtail and other weed control/suppression were evaluated. Site descriptions and conditions at the time of herbicide application are listed in Table 1. The seven treatments in each experiment were arranged in a randomized complete block design with three replications. Herbicide treatments (Table 2) were applied using a CO_2 backpack sprayer with a 4-nozzle boom with 8002ER nozzles at 35 psi delivering 20 gallons/a of solution. Individual plots were 10- × 25-ft and the treated area was the center 7 × 25 ft of the plot. Crop injury (CI) and foxtail suppression (%) were assessed approximately every 10-14 days after herbicide applications. Two 18- × 18-in. quadrats were clipped from each plot at 3 in. in height on June 5, weighed on an electronic scale, and placed in a dryer at 104°F for 48 hours. Samples were removed and weighed immediately on the same electronic scale. Dry matter percentage was calculated and used to calculate forage dry matter yields/a.

Results

Dry matter yield response trends to treatments were similar, so forage yields from the two sites were combined for analysis (Figure 2). Foxtail control and brome injury responses were also similar at both locations (Figure 3). Prowl H2O applied early in the spring resulted in 97% foxtail control, compared to only 47% and 34% control provided by Dual II Magnum and Escort XP, respectively. Post-harvest herbicide applications provided minimal, non-significantly different levels of foxtail control (Figure 3). When data collection ceased in early September, foxtail suppression was unacceptable in all plots (data not shown).

Escort XP applied in early spring (Figure 3) resulted in 28% visual injury to the brome, minimal foxtail control, and 62% less dry matter production compared to the untreated check (Figure 2). Smooth brome injury was likely exacerbated by below-average temperatures, including six freeze events that occurred the week after spring application (http://mesonet.k-state.edu/).

With the exception of early spring-applied pendimethalin, herbicides did not adequately control foxtail in the short term and caused visible, but not always statistically significant smooth brome injury.

Herbicides did not reduce the late-summer foxtail infestation, despite apparent suppression eight weeks after the early spring application.

Future Research

Based on these results, this work will be repeated in 2021 with refinement of treatments. Prowl H2O will be applied per labeled rates either at greenup or at greenup and after cutting. Smooth bromegrass injury from the Escort XP treatment was unacceptable on cooperators' hay meadows and will be dropped from this study.

Acknowledgments

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Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

Table 1. Site description and conditions when herbicides were applied to plots in Pottawatomie and Dickinson counties

			Temperature				Wind
Site	Soil	Dates of application	Air	2-in. Soil depth	4-in. Soil depth	Relative humidity	speed and direction
			------------- °F -------------			%	mph
PT	Pawnee clay loam	March 26	52	50	50	85	NE – 8
		June 22	68	70	72	78	W – 5
DK	Irwin silty clay loam	March 25	55	57	54	85	S – 6
		June 22	70	70	70	80	W – 3

Table 2. Herbicides and application rates applied in early spring and post brome hay harvest in Pottawatomie and Dickinson counties

Herbicide	Product	Rate, product/a
Metsulfuron†	Escort XP	1 oz/a
Pendimethalin	Prowl H2O	4 pt/a
S-metolachlor	Dual II Magnum	1 pt/a

† Metsulfuron was applied with 0.25% v/v crop oil concentrate.

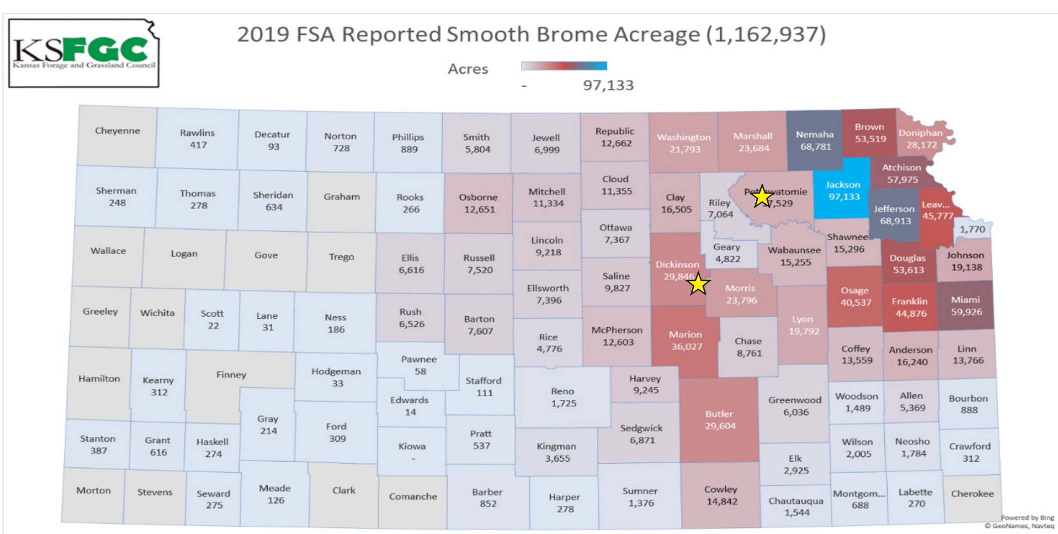

Figure 1. Location of plots (gold stars) and reported acreage by county. Map produced by Kansas Forage and Grasslands Council with Kansas Farm Service Agency data.

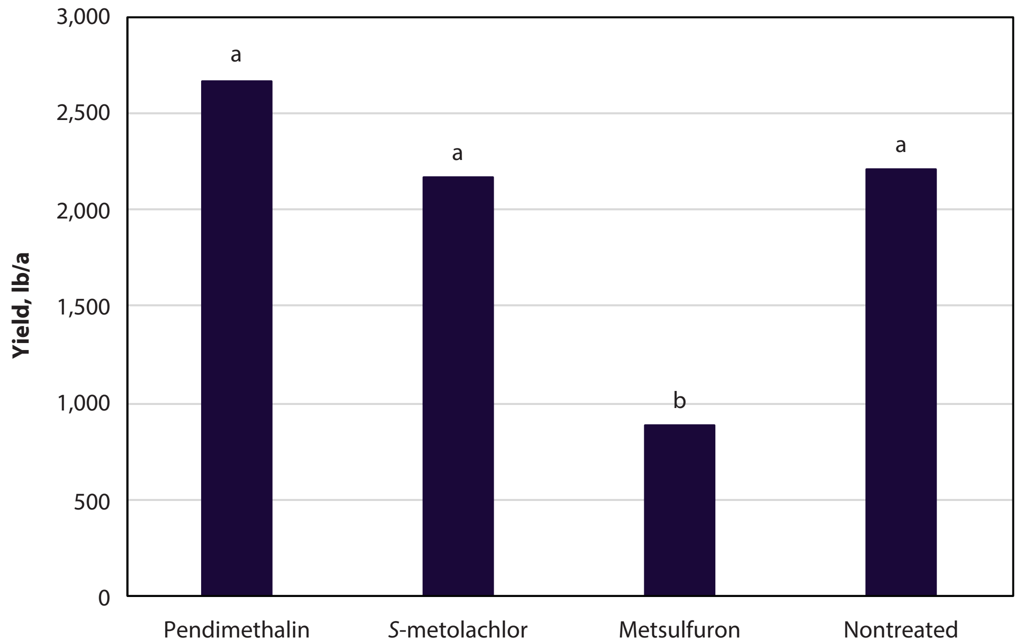

Figure 2. Smooth bromegrass hay yield at 8 weeks after spring herbicide application. Values followed by the same letter are not significantly different at $P = 0.05$.

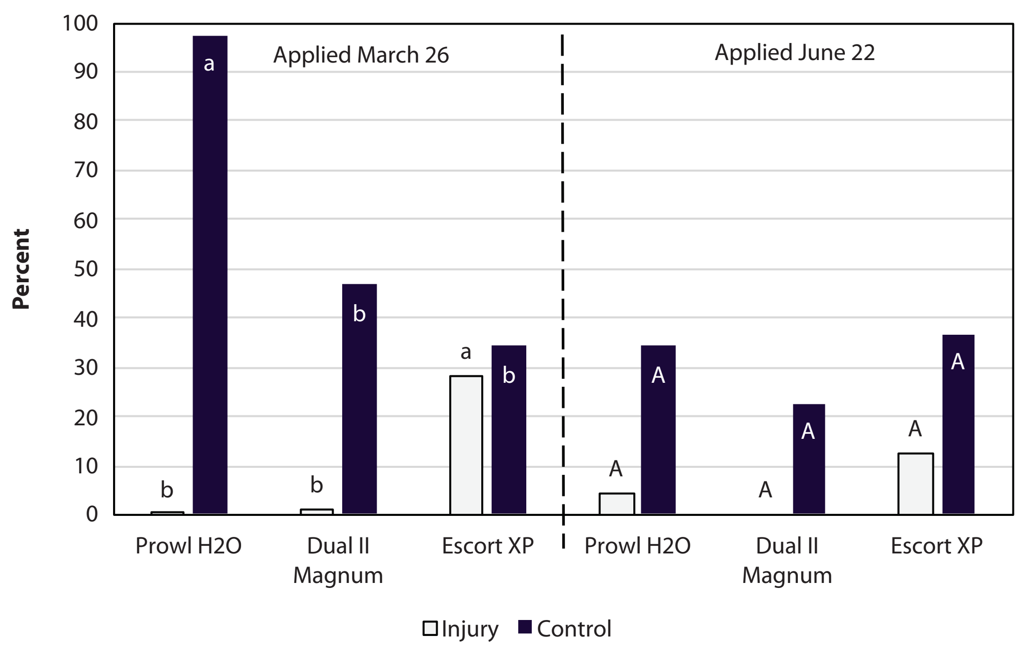

Figure 3. Foxtail control and brome injury at 8 weeks after herbicide application. Means within an application date followed by the same letter are not significantly different at $P = 0.05$.

Efficacy of Imiflex, Zest, and Assure II on Green Foxtail Control

V. Kumar, I. Effertz, T. Lambert, R. Liu, and B. Bean[1]

Summary
Grass weeds pose a serious management challenge in grain sorghum. Recent development of three herbicide-tolerant grain sorghum technologies such as Inzen, Igrowth, and DoubleTeam will provide the opportunity for producers to use nicosulfuron (Zest), imazamox (Imiflex), and quizalofop-p-ethyl (FirstAct) for grass weed control, respectively. The main objectives of this research were to (1) determine the effectiveness of Imiflex applied preemergence (PRE) on green foxtail control in comparison to commonly used group 15 herbicides; (2) compare the efficacy of Zest, Imiflex, and Assure II applied early- or late-POST at two different rates; and (3) determine the tank-mix compatibility of Zest, Imiflex, Assure II, and Select Max (clethodim) with 2,4-D (Weedar 64) and dicamba (Clarity) on green foxtail control. Field experiments were conducted in fallow ground with a natural infestation of green foxtail at Kansas State University Agricultural Research Center in Hays, KS. PRE herbicide programs, including Imiflex, Dual II Magnum, Warrant, and Outlook were tested. Imiflex, Zest, and Assure II were tested in early- or late-postemergence (POST) timings. The early POST treatments of Imiflex, Assure II, Zest, and Select Max alone or in tank-mixture with Weedar 64 and/or Clarity were also tested in a separate study. Among PRE programs, Imiflex tested at both rates provided an excellent control (89 to 94%) of green foxtail up to 50 days after PRE (DAPRE), whereas control did not exceed more than 51% with any of the group 15 herbicides. Among early POST programs, Assure II at 10 fl oz/a provided 95% green foxtail control at 28 days after early POST (DAEPOST). Green foxtail control with early POST treatments of Imiflex, Zest, and Assure II (6 oz/a) was moderate and ranged from 77 to 83% at 28 DAEPOST. Green foxtail control with late POST treatments of Imiflex, Zest, and Assure II was inadequate and ranged from 14 to 31% at 21 days after late POST (DALPOST). In a separate study, tank-mixing Weedar 64 or Clarity with Assure II reduced the efficacy by >50% on green foxtail control compared to Assure II alone treatment. These results suggest that PRE applied Imiflex (6 or 9 oz/a) can provide excellent residual activity for early season control of green foxtail. Furthermore, Assure II applied early POST at a higher rate can provide effective control of green foxtail; however, the efficacy will significantly decline if Assure II is tank-mixed with Weedar 64 or Clarity.

Introduction
Controlling grass weeds in grain sorghum is a serious challenge for Kansas producers. Season-long interference of grass weed species such as barnyardgrass, Johnsongrass, shattercane, Texas panicum, and foxtail (yellow or green) can reduce sorghum grain yields by 42% to 100% (Bean, 2020). Lack of effective herbicide options further exacerbate the problem of grass weed control in grain sorghum. Currently, there is no over-the-top (POST) selective herbicide labeled for grass weed control in sorghum. Main objectives of this research were to (1) determine the effectiveness of Imiflex applied PRE on grass weed control in comparison to commonly used group 15 herbicides; (2) compare the

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

efficacy of Zest, Imiflex, and Assure II applied early- or late-POST at two different rates; and (3) determine the tank-mix compatibility of Zest, Imiflex, Assure II, and Select Max with Weedar 64 and Clarity for green foxtail control.

Procedures

Two separate field experiments were conducted in the 2020 growing season at the Kansas State University Agricultural Research Center near Hays, KS. Experiments were conducted in fallow ground (corn stubble) and the study site had a natural infestation of green foxtail. PRE herbicide programs, including Imiflex (6 and 9 fl oz/a), Dual II Magnum (24 oz/a), Warrant (64 oz/a), and Outlook (18 fl oz/a) were tested. Imiflex (6 and 10 fl oz/a), Zest (0.9 and 1.33 oz/a), and Assure II (6 and 10 oz/a) were tested in early- or late-POST timings. PRE treatments were applied on April 16, 2020, whereas early POST and late POST treatments were applied on June 4, 2020 (on 3- to 4-inch tall green foxtail), and June 24, 2020 (on 12-inch tall green foxtail), respectively. In a separate study, the early POST treatments of Imiflex (6 fl oz/a), Assure II (8 fl oz/a), Zest (1.33 oz/a), and Select Max (16 oz/a) alone or in tank-mixture with Weedar 64 (16 fl oz/a) and/or Clarity (8 fl oz/a) were also tested. Assure II and Select Max treatments included nonionic surfactant (NIS) at 0.25% v/v, whereas, Imiflex and Zest treatments included crop oil concentrate (COC) at 1% v/v. All treatments were applied using a CO_2-operated hand-held sprayer equipped with AIXR 110015 nozzles. Experiments were conducted in a randomized complete block design with 4 replications (each plot size of 10-ft wide × 30-ft long). Data on percent visible control of green foxtail were recorded at biweekly intervals throughout the growing season. 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 least significant difference test at $P < 0.05$.

Results

Results indicated that PRE applied Imiflex at 6 or 9 oz/a provided an excellent control (89 to 94%) of green foxtail up to 50 days after PRE (DAPRE), whereas control did not exceed more than 51% with any of the group 15 herbicides tested (Figure 1A; Figure 2). Furthermore, green foxtail control with PRE applied Imiflex ranged from 51 to 61% at 77 DAPRE. Among early POST programs, Assure II at 10 fl oz/a provided 95% green foxtail control at 28 days after early POST (DAEPOST) (Figure 1B). Green foxtail control with early POST treatments of Imiflex, Zest, and Assure II (6 oz/a) was moderate and ranged from 77 to 83% at 28 DAEPOST. Green foxtail control with late POST treatments of Imiflex, Zest, and Assure II was inadequate and ranged from 14 to 31% at 21 days after late POST (DALPOST) (Figure 1C). In separate study, tank-mixing Weedar 64 or Clarity reduced the efficacy of Imiflex, Zest, Assure II, and Select Max herbicides (Figure 3). For instance, tank-mixing Weedar 64 or Clarity with Assure II reduced the efficacy by >50% for green foxtail control compared to the Assure II alone treatment (Figure 3 and 4).

Conclusions

Results suggest that PRE applied Imiflex (6 or 9 oz/a) can provide an excellent residual activity on green foxtail control. Furthermore, early POST treatment of Assure II at a higher rate can provide effective control of green foxtail; however, the efficacy will significantly decline if Assure II will be tank-mixed with Weedar 64 or Clarity.

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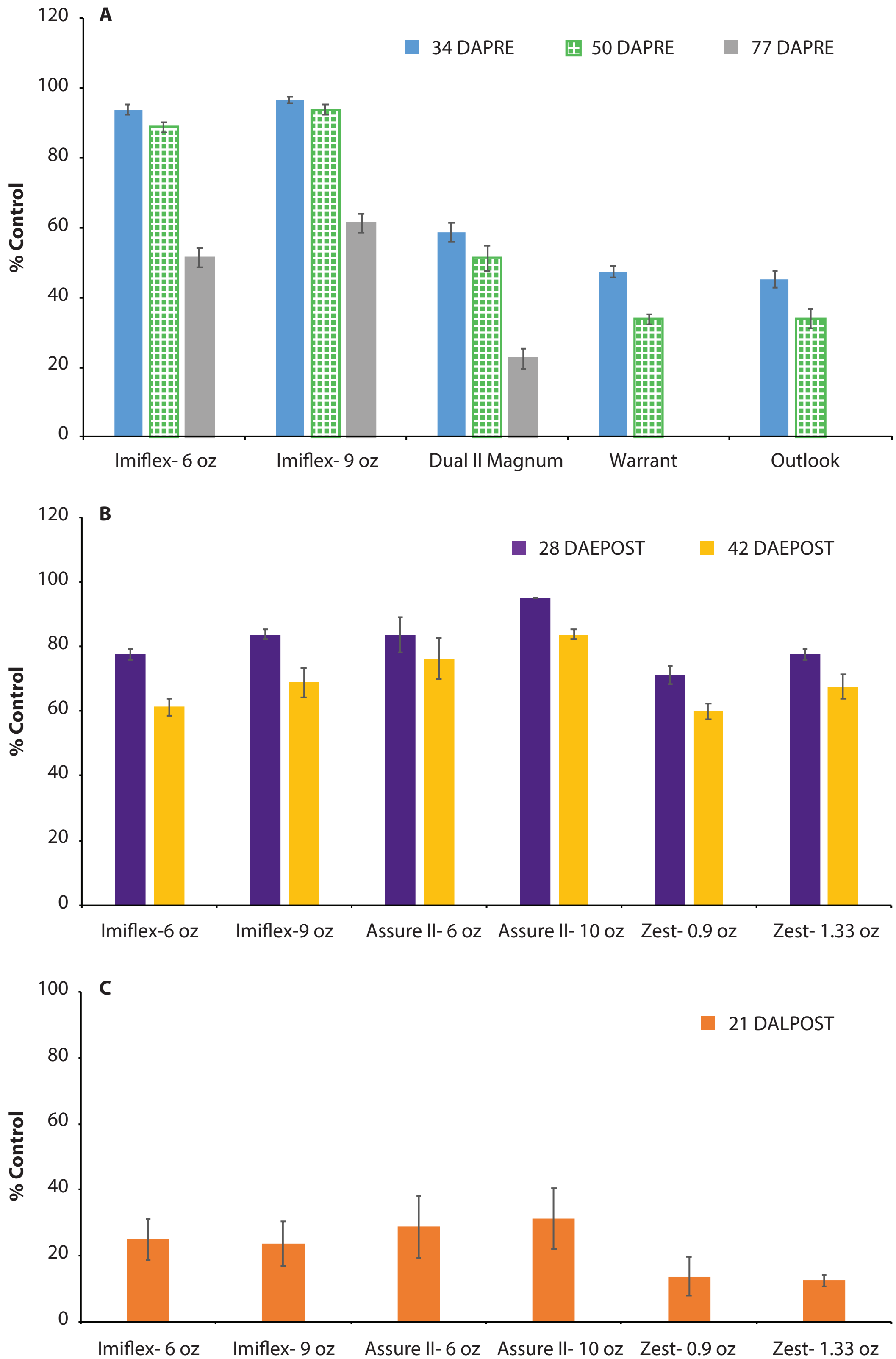

Figure 1. Green foxtail control with PRE (A), early POST (B), and late POST (C) herbicide programs at the Kansas State University Agricultural Research Center near Hays, KS.

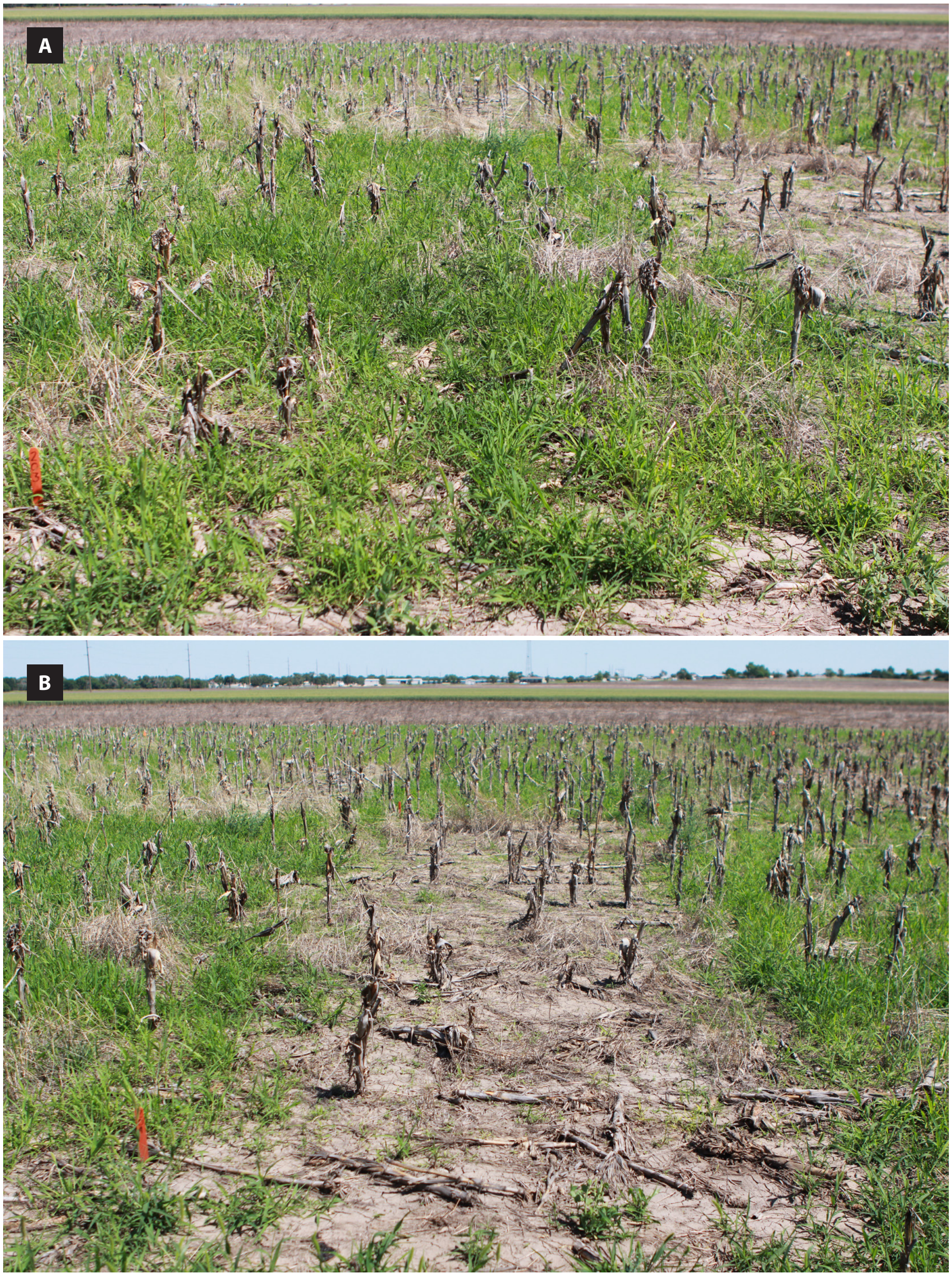

Figure 2. Comparison of green foxtail control in nontreated weedy check (A) and Imiflex (B) applied PRE at 9 oz/a at 50 days after PRE (DAPRE).

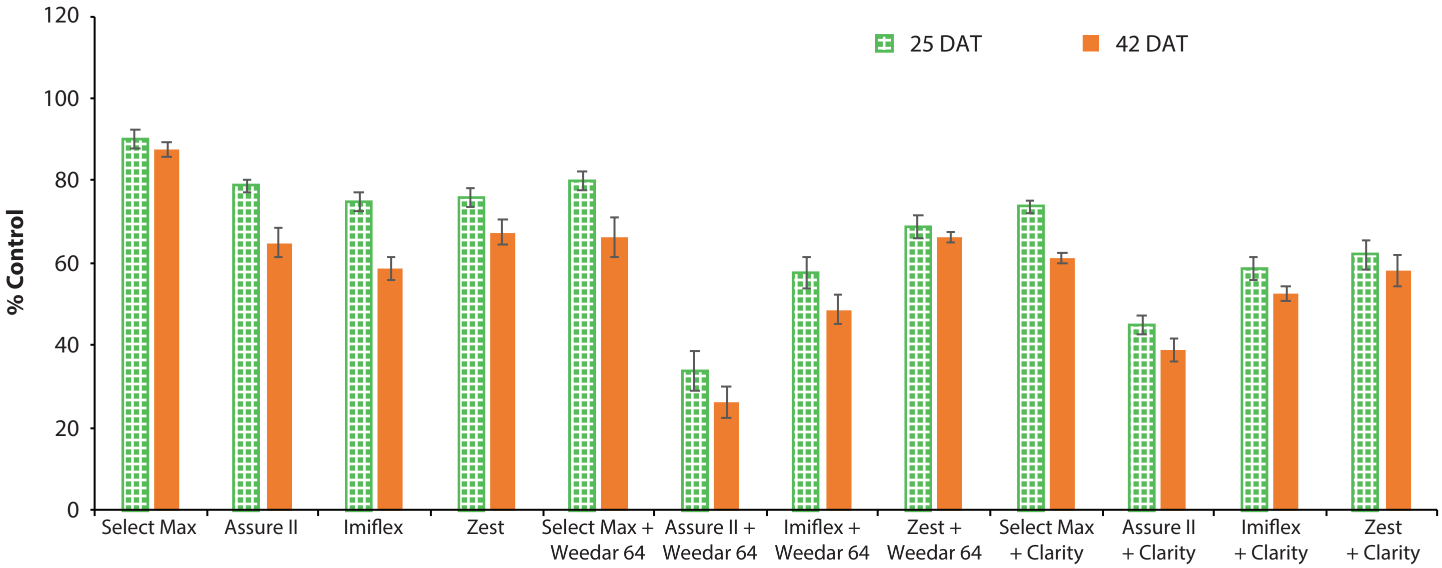

Figure 3. Green foxtail control with early POST treatments of Imiflex, Assure II, Zest, and Select Max alone or tank-mixed with Weedar 64 or Clarity at 25 and 42 days after treatment (DAT).

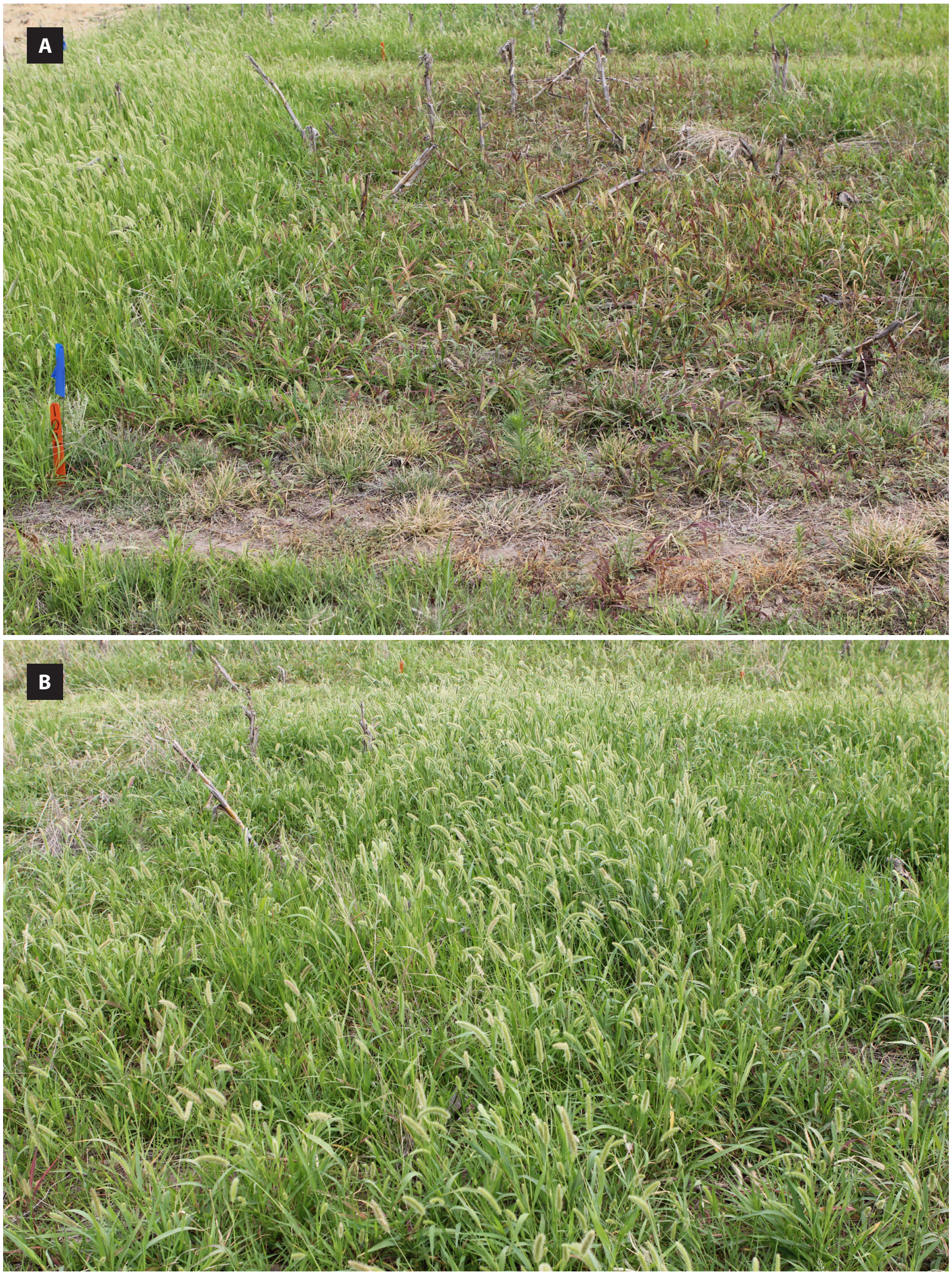

Figure 4. Green foxtail control with early POST treatment of Assure II (A) and Assure II + Weedar 64 (B) at 25 days after treatment (DAT).

Auxinic Herbicide Mixtures for Controlling Multiple Herbicide-Resistant Kochia in Fallow

V. Kumar, T. Lambert, R. Liu, R.S. Currie, and P.W. Stahlman

Summary
Kochia resistant to glyphosate (Roundup), chlorsulfuron (Glean), and dicamba (Banvel or Clarity) has become quite common in the U.S. Great Plains, whereas multiple resistance to additional herbicides, including fluroxypyr (Starane Ultra), atrazine (AAtrex), and metribuzin (Sencor) has also been reported recently. Effective management of these multiple herbicide-resistant (MHR) kochia populations warrants the need of alternative herbicide strategies. The main objective of this research was to investigate the efficacy of auxinic herbicides, including Duplosan (dichlorprop-p), Weedone (2,4-D), Clash (dicamba), and/or Pixxaro (premix of halauxifen and fluroxypyr) alone or in various combinations for controlling MHR kochia. Separate greenhouse and field experiments were conducted at the Kansas State University Agricultural Research Center (KSU-ARC) in Hays, KS. Greenhouse studies included an MHR kochia population (resistant to glyphosate, dicamba, fluroxypyr, chlorsulfuron, atrazine, and metribuzin) from Garden City, KS, and a susceptible (SUS) kochia population from Hays, KS. The postemergence (POST) applied herbicide programs, including Clash Weedone, Duplosan alone or in tank-mix combinations were tested. Field experiments were conducted in a fallow field at KSU-ARC with a natural infestation of kochia population with multiple resistance to glyphosate and dicamba. Herbicides, including Duplosan, Weedone, Clash, and Pixxaro were tested alone or in tank-mix combinations. Results from greenhouse study indicated that Clash, Duplosan, and Weedone applied alone provided inadequate control (5 to 42%) of MHR kochia at 21 days after treatment (DAT). In contrast, control of SUS population was 83 to 92% with Clash and Duplosan alone treatments. Tank-mixing Duplosan with Clash and/or Clash + Weedone significantly improved visible control (72 to 90%) of MHR kochia as compared to Duplosan, Clash, or Weedone alone treatments. Similarly, tank-mixing Clash to Duplosan or Pixxaro (two-way mixtures) and to Duplosan + Weedone, Pixxaro + Duplosan or Pixxaro + Weedone (three-way mixtures), provided an excellent control (91 to 97%) of MHR kochia compared to Clash, Pixxaro, Weedone, and Duplosan alone treatments in a field study. Altogether, these results suggest that tank-mixing Clash with Duplosan and/or Pixxaro can potentially provide synergistic effect in controlling MHR kochia in fallow fields.

Introduction
Multiple herbicide-resistant (MHR) kochia is an ever-increasing challenge for producers in the U.S. Great Plains, including Kansas (Kumar et al., 2019). The widespread resistance to glyphosate and acetolactate synthase (ALS) inhibiting herbicides has been reported among kochia populations in the region (Heap, 2021). Growers are relying extensively on dicamba applications (both preemergence and POST) for controlling glyphosate and ALS inhibitor-resistant kochia. Unfortunately, dicamba resistance in kochia populations has also been evident in several states in the region

(Kumar et al., 2019; LeClere et al., 2018). In addition to glyphosate, ALS inhibitors, and dicamba resistance, multiple resistance to fluroxypyr, atrazine, and metribuzin has also been reported in a single kochia population in western Kansas (Kumar et al., 2021). Increasing cases of MHR kochia populations in the region warrant implementation of alternative herbicide strategies for their effective management. The main objective of this research was to investigate the effectiveness of auxinic herbicides, including Duplosan, Weedone (2,4-D), Clash (dicamba), and/or Pixxaro (halauxifen + fluroxypyr) herbicides alone or in various combinations for controlling MHR kochia.

Procedures

Greenhouse Study

A greenhouse study was conducted at the KSU-ARC in Hays, KS, by using an MHR kochia population (resistant to glyphosate, dicamba, fluroxypyr, chlorsulfuron, atrazine, and metribuzin) from Garden City, KS, and a susceptible (SUS) population from the Hays research farm. Kochia plants from both populations were grown in 4-inch square plastic pots containing commercial potting mixture under greenhouse conditions. Actively growing kochia plants (3- to 4-inch tall) from both populations were separately treated with Clash (8 fl oz/a), Weedone (8.5 fl oz/a), Duplosan (16 fl oz/a) alone or in tank-mix combinations using a cabinet spray chamber. All herbicide treatments included a nonionic surfactant (NIS) at 0.25% v/v. Data on percent control of MHR and SUS plants were visually assessed at 21 days after treatment (DAT). The shoot dry biomass of each treated plant was also determined at 21 DAT.

Field Study

A field study was conducted in the 2020 growing season at KSU-ARC in a fallow field (soybean stubble) with natural infestation of a kochia population resistant to glyphosate and dicamba. The study was laid out in a randomized complete block design with 4 replications. Each plot size was 10-ft wide × 30-ft long. Herbicide programs, including Duplosan (16 fl oz/a), Weedone (16 fl oz/a), Clash (16 fl oz/a), and Pixxaro (6 fl oz/a) were tested alone or in various tank-mix combinations (2- or 3-way). All herbicide treatments were applied to 3- to 4-inch tall kochia plants using a CO_2-operated backpack sprayer equipped with AIXR 110015 nozzles. All treatments included nonionic surfactant (NIS) at 0.25% v/v. Data on kochia control were visually assessed at biweekly intervals throughout the growing season.

Statistical Analyses

All data collected in the greenhouse and field studies were subjected to analysis of variance (ANOVA) using PROC MIXED in SAS 9.3 (SAS Inst. Inc., Cary, NC). Means were separated using Fisher's protected LSD test ($\alpha = 0.05$).

Results

Greenhouse Study

Results indicated that Clash, Duplosan, and Weedone applied alone provided inadequate control (5 to 42%) of MHR kochia at 21 DAT (Figure 1A). In contrast, the Clash and Duplosan alone treatments provided 83 to 92% control of SUS population. Tank-mixing Duplosan with Clash and/or Clash + Weedone provided 72% to 90% control of MHR kochia as compared to the Duplosan, Clash or Weedone alone treatments (Figure 1A). Consistent with visible control, tank mixture of Duplosan + Clash or Duplosan + Clash + Weedone significantly reduced shoot dry biomass of MHR kochia (Figure 1B).

Field Study

Results from the field study also indicated that control of MHR kochia with Clash, Pixxaro, Weedone, or Duplosan alone treatments was inadequate (10 to 66%) throughout the growing season (Figure 2). However, tank-mixing Clash with Duplosan or Pixxaro (two-way mixtures), and to Duplosan + Weedone, Pixxaro + Duplosan or Pixxaro + Weedone (three-way mixtures), provided an excellent control (91 to 97%) of MHR kochia at 6 and 9 weeks after treatment (WAT) (Figure 2 and 3). Control of MHR kochia with all other tank-mix combinations (both two and three ways) was moderate and ranged from 53 to 81% at 6 and 9 WAT (Figure 2).

Conclusions

Results from these studies suggest that tank-mixing Clash with Duplosan, Pixxaro, Duplosan + Pixxaro, Duplosan + Weedone, or Pixxaro + Weedone can potentially provide synergistic effects in controlling MHR kochia in fallow fields.

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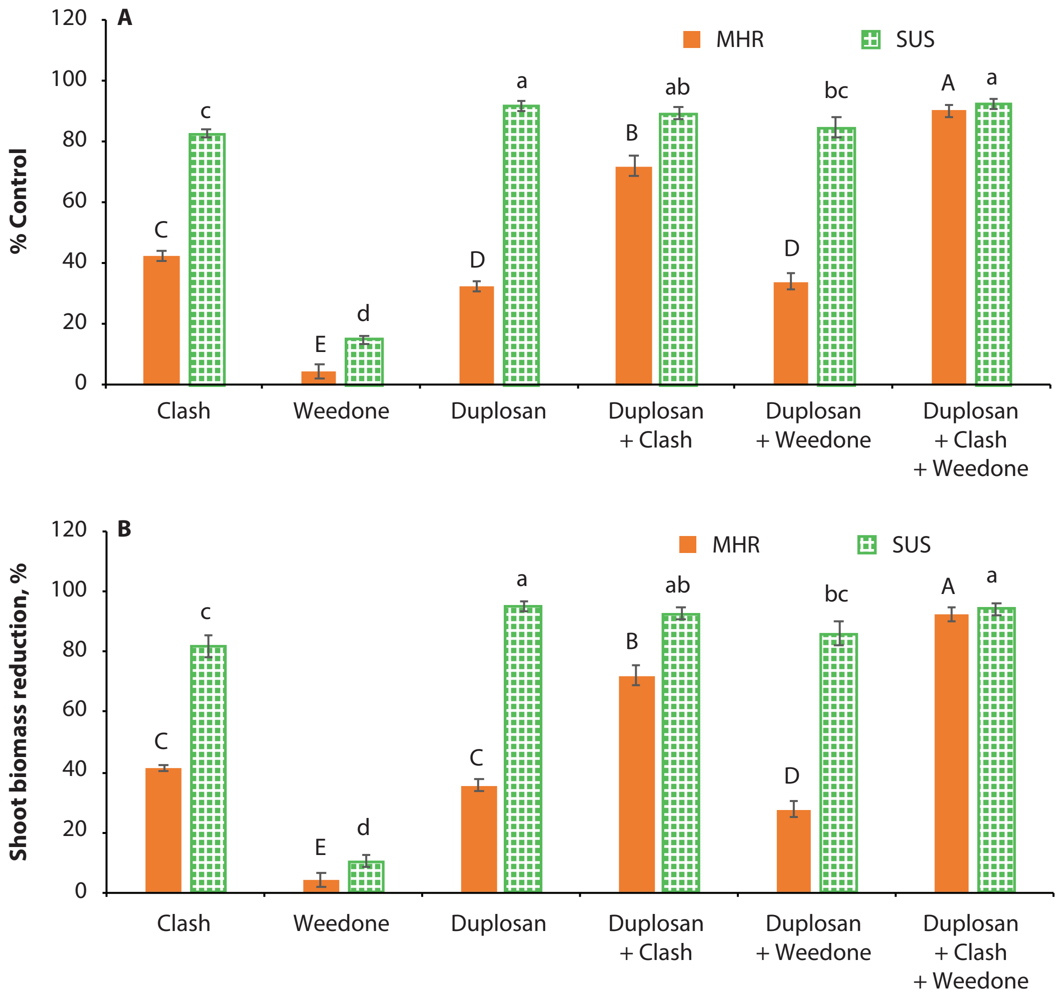

Figure 1. Multiple herbicide-resistant (MHR) and susceptible (SUS) kochia control (A) and shoot dry biomass reduction (B) 21 days after treatment with Duplosan, Clash, and Weedone alone or in tank-mix combinations at the K-State Agricultural Research Center in Hays, KS. Means for SUS population followed by similar lowercase letters are not significantly different based on Fisher's protected LSD test at $P < 0.05$; means for MHR population followed by similar uppercase letters are not significantly different based on Fisher's protected LSD test at $P < 0.05$.

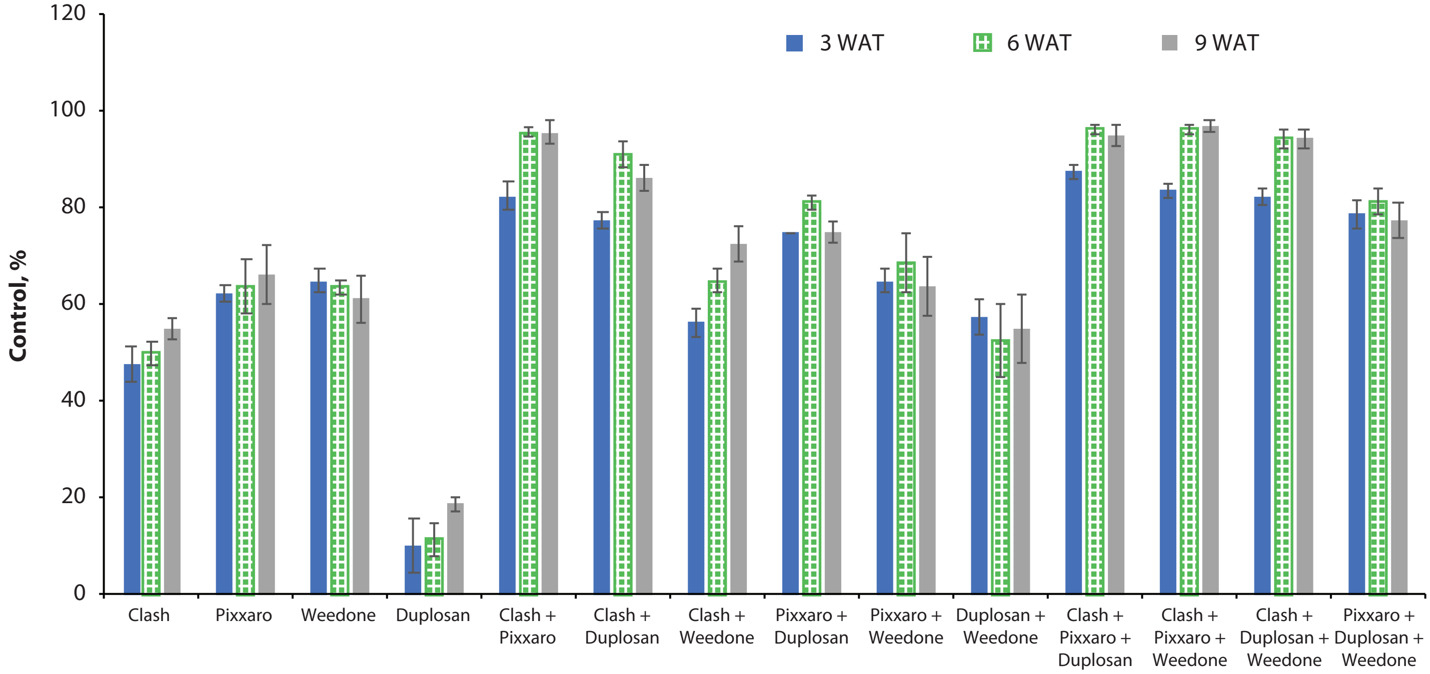

Figure 2. Multiple herbicide-resistant (MHR) kochia control with Clash, Pixxaro, Weedone, and Duplosan alone or in various tank-mix combinations at 3, 6, and 9 weeks after treatment (WAT) in fallow at K-State Agricultural Research Center in Hays, KS.

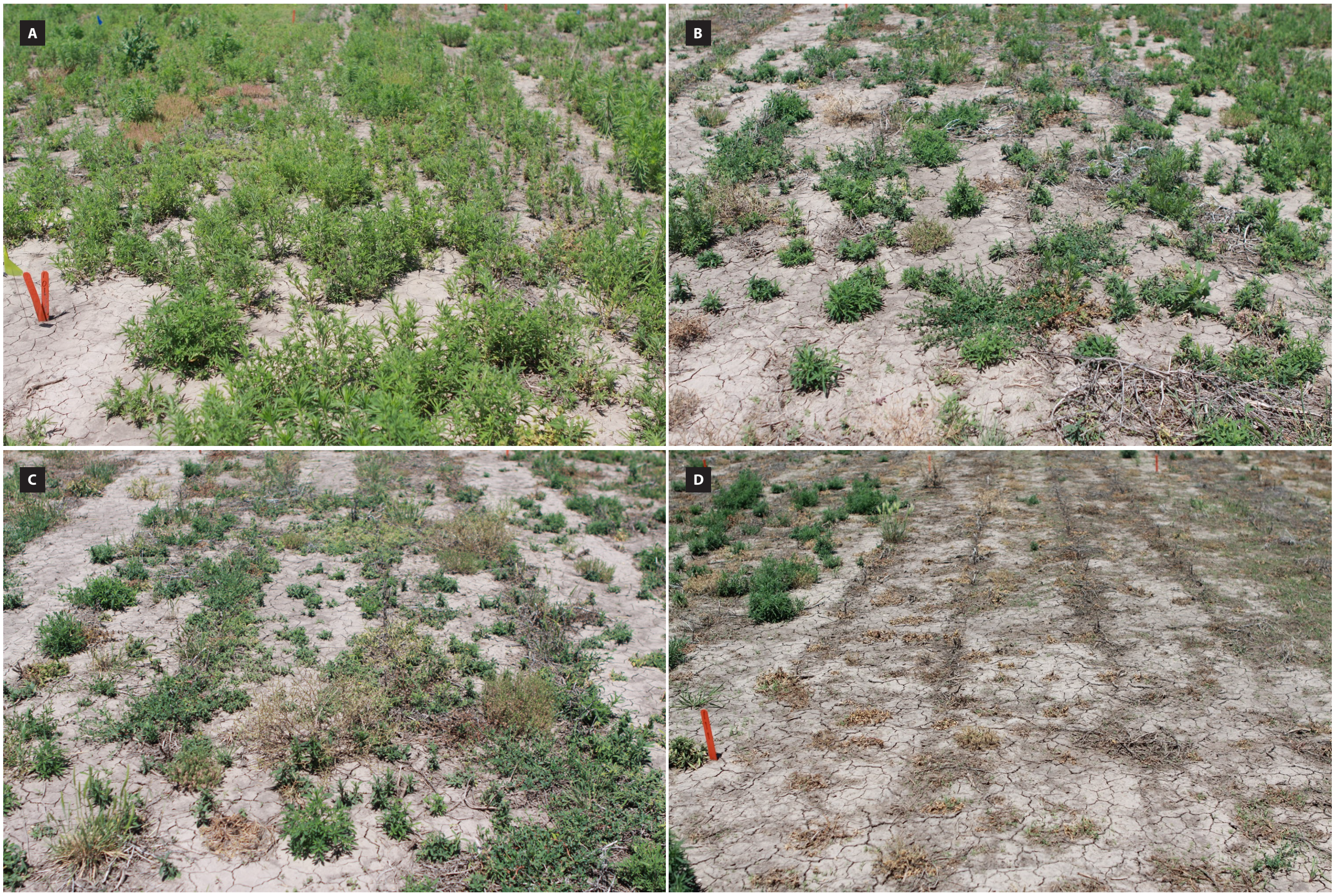

Figure 3. Multiple herbicide-resistant (MHR) kochia control at 6 weeks after treatment (WAT) in fallow field at the K-State Agricultural Research Center in Hays, KS: Nontreated weedy check (A), Duplosan (B), Pixxaro (C), and Clash + Duplosan + Weedone (D).

Interaction of 2,4-D with Glyphosate or Graminicides on Grass Weed Control in Enlist E3 Soybeans

R. Liu, I. Effertz, T. Lambert, A. Jhala,[1] and V. Kumar

Summary
The introduction of Enlist E3 soybean allows growers to use postemergence (POST) applications of low-volatile formulations of 2,4-D choline (Enlist One) for in-season control of glyphosate-resistant weeds. The POST applications of Enlist One and glyphosate (Roundup PowerMax) mixture can be tank-mixed with clethodim (Select Max) or quizalofop (Assure II) for both grass and broadleaf weed control. However, reduced control of grass weed species has previously been reported when graminicides (Select Max or Assure II) are tank-mixed with auxinic herbicides (2,4-D or dicamba). The main objective of this research was to determine the effectiveness of Enlist One, Roundup PowerMax, Select Max, and/or Assure II alone or in various combinations on grass weed control in Enlist E3 soybean. Field experiments were conducted during the 2020 growing season at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS, and the University of Nebraska near Lincoln, NE (UNL). The dominant grass species at the KSU-ARC site were southwest cupgrass and green foxtail. The predominant grass species at the UNL site were giant foxtail, hairy cupgrass and fall panicum. Herbicide treatments, including Select Max, Assure II, and Roundup PowerMax applied at V3-V4 soybean stage alone or in combination with Enlist One; and sequential treatments of Enlist One followed by (separated by 5 days) Select Max, Assure II and/or Roundup PowerMax, and vice-versa were investigated. Results from the KSU-ARC site indicated that sequential treatment of Enlist One at 5 days prior to the application of Assure II provided the highest control (87% to 90%) of southwest cupgrass and green foxtail at 28 days after treatment (DAT). In contrast, control of both grass species did not exceed 78% with the rest of the treatments. Soybean grain yields ranged from 7 to 16 bu/a for the majority of the treatments. Results from UNL site showed that the addition of Enlist One to Select Max or Assure II or applied in sequential treatments at 5 days after the application of these graminicides reduced control of giant foxtail (69% to 79%), hairy cupgrass (70% to 79%), and fall panicum (69% to 79%) at 28 DAT compared to graminicides alone (93 to 97%). Furthermore, an addition of Roundup PowerMax to tank-mixtures of Enlist One with Select Max or Assure II improved the control of all three weed species. Soybean grain yields ranged from 21 to 55 bu/a for the majority of the treatments. In conclusion, these results support the hypothesis that Enlist One can compromise the efficacy of Select Max or Assure II; however, addition of Roundup PowerMax to these tank-mixtures can help to optimize grass weed control in Enlist E3 soybean.

Introduction
The introduction of Enlist E3 soybean has stacked tolerance to glyphosate (Roundup PowerMax), glufosinate (Liberty), and 2,4-D (Enlist One), which allows growers to

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use Enlist One for in-season weed control, especially for managing glyphosate-resistant weeds. Acetyl-CoA-Carboxylase (ACCase) (Group 1) inhibiting herbicides (also known as graminicides) can provide effective control of a wide range of annual and perennial grass species. The POST application of Enlist One can be tank-mixed with Roundup PowerMax and/or graminicides (Select Max or Assure II) for broad spectrum weed control in Enlist E3 soybean. However, tank-mixing Enlist One may antagonize the efficacy of glyphosate (Roundup PowerMax) or graminicides for grass weed control. The main objective of this research was to determine the effectiveness of Roundup PowerMax, Select Max and/or Assure II alone or in various tank-mix combinations with Enlist One on grass weed control in Enlist E3 soybean.

Procedures

Field experiments were conducted at the KSU-ARC and UNL sites to evaluate the effectiveness of Roundup PowerMax, Assure II, and/or Select Max alone or in various combinations with Enlist One for grass weed control in Enlist E3 soybean. An Enlist E3 soybean variety AG34X7 was planted at 156,900 seeds/a on May 20, 2020, at the KSU-ARC site, and on May 11, 2020, at the UNL site. The main grass weed species targeted at KSU-ARC were southwest cupgrass and green foxtail, whereas giant foxtail, hairy cupgrass and fall panicum were predominant grass weed species at the UNL site. Experiments were established in randomized complete block design with 3 replications. A total of 14 herbicide programs including a non-treated weedy check were tested (Table 1). All herbicide treatments were applied with CO_2-operated backpack sprayer using TTI11003 spray nozzles calibrated at 15 gallons per acre at 40 PSI. At harvest, data were collected on percent visual control of each grass species at 14, 28, and 54 days after treatment (DAT), aboveground shoot dry biomass (g) at the end of the season, as well as soybean grain yield (bu/a). All data were subjected to ANOVA using PROC MIXED in SAS v. 9.0 (SAS Inst. Inc., Cary, NC). Means were separated using Fisher's protected LSD test ($\alpha = 0.05$).

Results

Grass Control

Results from the KSU-ARC site indicated that an application of Enlist One followed by (*fb*) 5 days after POST (5 DAP) of Select Max provided the highest grass control (87 to 90%) of both grass weed species at 28 DAT (Figure 1A). Control of both grass species did not exceed 78% with the rest of the treatments. Assure II applied alone or tank mixed with Enlist One had poor grass control; however, an addition of Roundup PowerMax to the tank-mixture of Enlist One and Assure II improved the control of both grass weed species (Figure 1A). At the UNL site, results indicated that tank-mixture of Enlist One with Select Max or Assure II reduced the control of all three grass species compared to Select Max or Assure II applied alone at 28 DAT (Figure 1B). An addition of Roundup PowerMax to the tank-mixtures of Enlist One with Select Max or Assure II restored the efficacy of both graminicides on all three grass species (Figure 1B).

Shoot Dry Biomass

Among all treatments, Roundup PowerMax alone or in tank-mixture with Enlist One or Enlist One plus Assure II, tank-mixtures of Enlist One with Assure II or Select Max, and sequential treatments of Roundup PowerMax *fb* Enlist One or Enlist One *fb* Roundup PowerMax provided the highest reductions (65 to 80%) in shoot dry biomass of both grass weed species at the KSU-ARC site (Figure 2A). At the UNL site, Select Max or Assure II applied alone or tank mixed with Enlist One plus Roundup PowerMax, and sequential treatment of Enlist One *fb* Assure II had the highest total shoot dry biomass reductions (88 to 96%) (Figure 2B).

Enlist E3 Soybean Yield

Enlist E3 soybean yield at the KSU-ARC site ranged from 7 to 16 bu/a, and 21 to 55 bu/a at the UNL site (Figure 3).

Conclusions

These preliminary results suggest that tank-mixing Enlist One with Select Max or Assure II can compromise the grass weed control in Enlist E3 soybean. The addition of Roundup PowerMax to tank-mixtures of Enlist One with Assure II or Select Max could restore the efficacy on grass weed control.

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Table 1. Herbicide programs tested at the Kansas State University Agricultural Research Center near Hays, KS, and the University of Nebraska near Lincoln, NE, sites in Enlist E3 soybean

Trt	Herbicide programs[1]	Rate	Timing
		fl oz/a	
1	Non-treated	-	-
2	Select Max[2]	16	EPOST
3	Assure II[2]	8	EPOST
4	Roundup PowerMax[3]	32	EPOST
5	Select Max[2] + Enlist One	16 + 32	EPOST
6	Assure II[2] + Enlist One	8 + 32	EPOST
7	Roundup PowerMax[3] + Enlist One	32 + 32	EPOST
8	Roundup PowerMax[3] + Select Max[2] + Enlist One	32 + 16 + 32	EPOST
9	Roundup PowerMax[3] + Assure II[2] + Enlist One	32 + 8 + 32	EPOST
10	Enlist One *fb* Roundup PowerMax[3]	32 *fb* 32	EPOST *fb* 5 DAEP
11	Enlist One *fb* Select Max[2]	32 *fb* 16	EPOST *fb* 5 DAEP
12	Enlist One *fb* Assure II[2]	32 *fb* 8	EPOST *fb* 5 DAEP
13	Roundup PowerMax[3] *fb* Enlist One	32 *fb* 32	EPOST *fb* 5 DAEP
14	Select Max[2] *fb* Enlist One	16 *fb* 32	EPOST *fb* 5 DAEP
15	Assure II[2] *fb* Enlist One	8 *fb* 32	EPOST *fb* 5 DAEP

[1] All treatments were applied using a CO_2-operated backpack sprayer equipped with Turbo Teejet TTI11003 nozzles.
[2] Nonionic surfactant (NIS) at 0.25% v/v was included.
[3] Ammonium sulfate (AMS) at 2% wt/v was included.
EPOST = early postemergence. *fb* = followed by. DAEP = days after early postemergence.

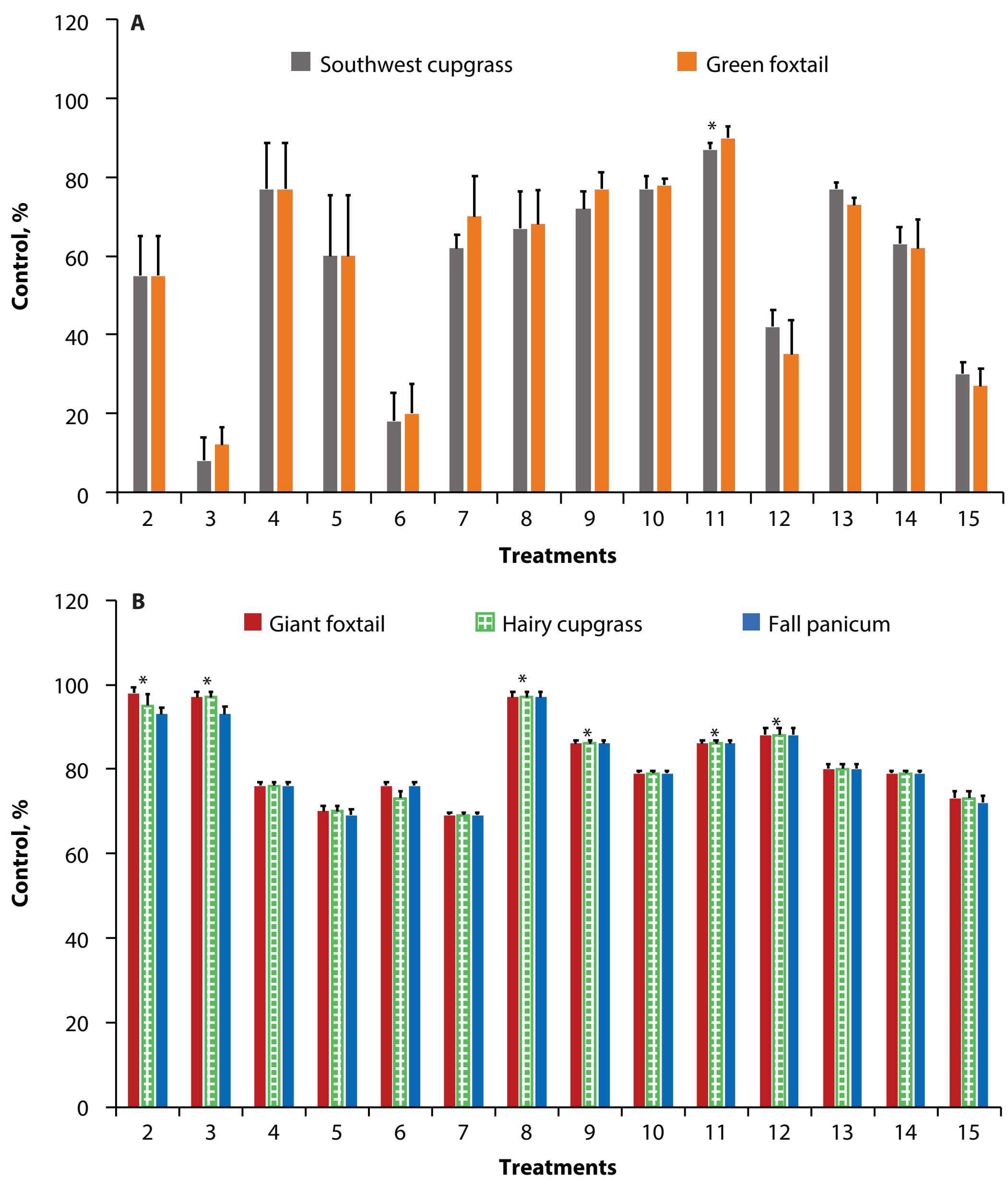

Figure 1. Effect of selected herbicide treatments on grass weed control (%) at 28 days after treatment (DAT): A) Kansas State University Agricultural Research Center near Hays, KS; B) University of Nebraska near Lincoln, NE. *Indicates significant differences from other treatments.

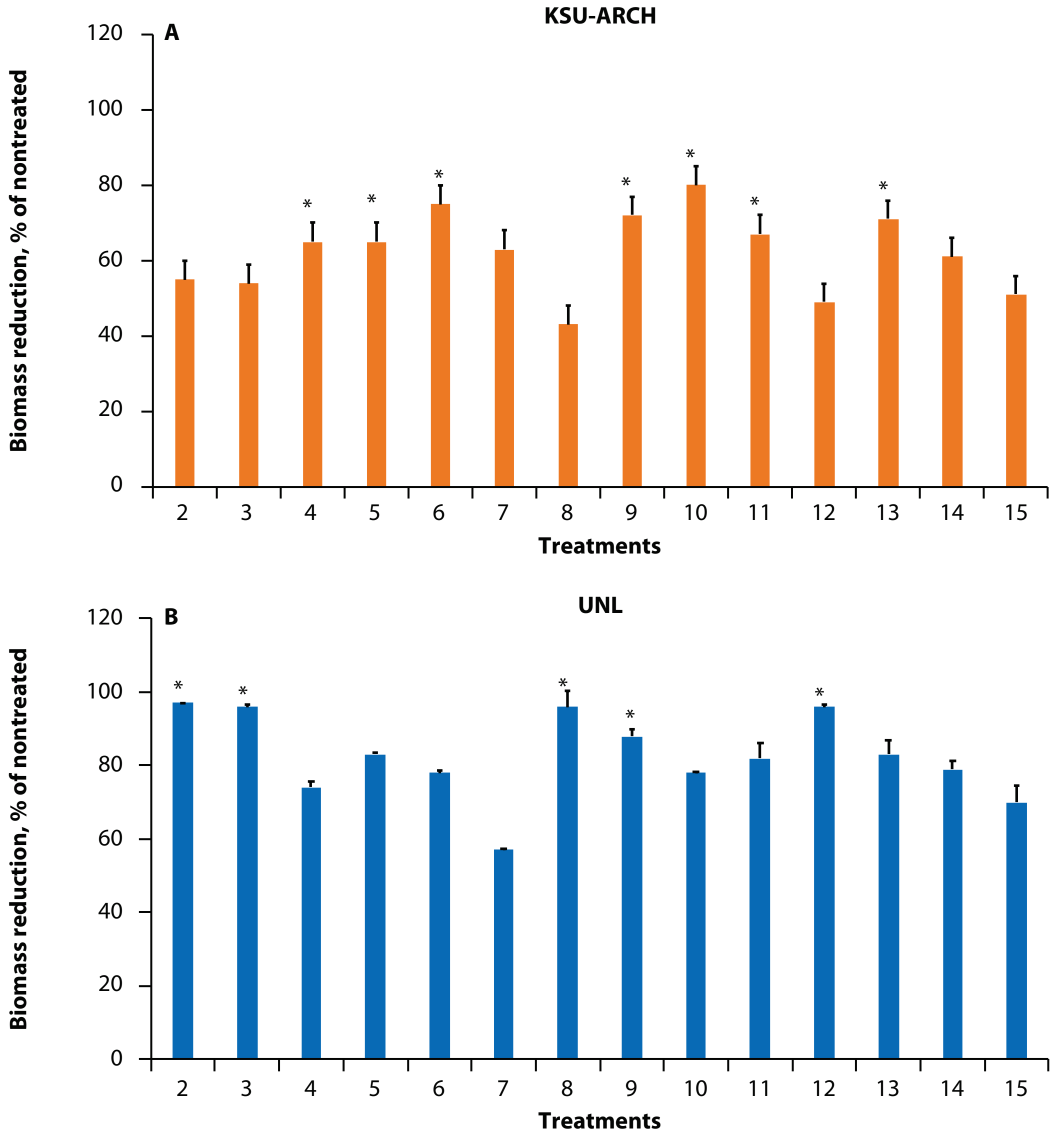

Figure 2. Effect of selected herbicide treatments on total shoot dry biomass reduction (% of nontreated) of grass species at A) Kansas State University Agricultural Research Center near Hays, KS; B) University of Nebraska near Lincoln, NE. *Indicates significant differences from other treatments.

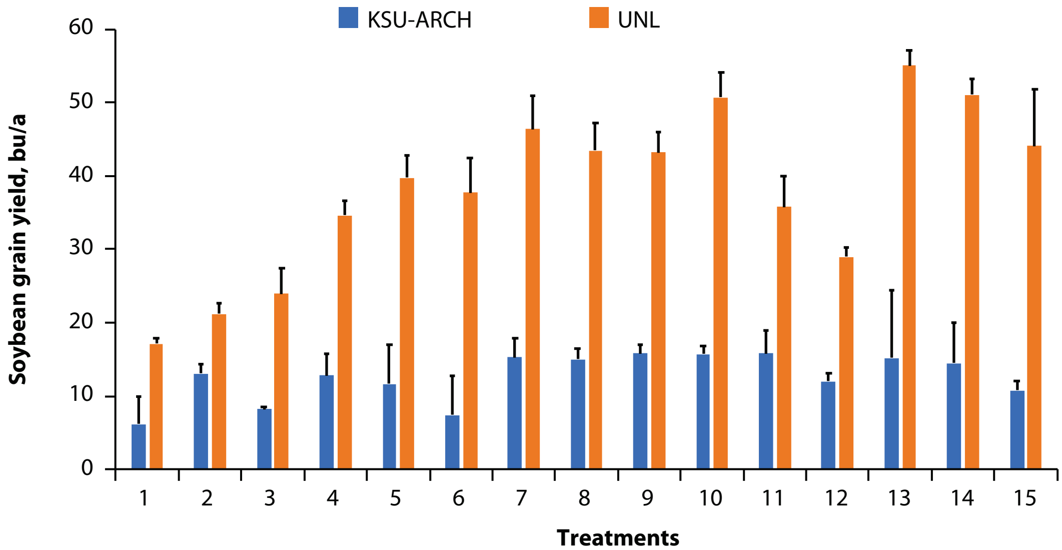

Figure 3. Effect of selected herbicide treatments on Enlist E3 soybean grain yield at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS, and the University of Nebraska near Lincoln, NE (UNL).

Effect of Tank-Mixing Glyphosate, Dicamba, and Graminicides on Grass Weed Control in Roundup Ready 2 Xtend Soybeans

R. Liu, I. Effertz, T. Lambert, A. Jhala,[1] and V. Kumar

Summary
The adoption of Roundup Ready 2 Xtend soybean allows growers to use dicamba (Xtendimax or Engenia) in mixtures with glyphosate (Roundup PowerMax) or graminicides (Select Max or Assure II) for broad spectrum weed control. However, anecdotal evidence suggests that Xtendimax may cause antagonism when applied with Select Max and/or Assure II herbicides. The main objective of this study was to determine the effectiveness of Roundup PowerMax, Select Max, and/or Assure II alone or in tank-mixtures with Xtendimax for grass weed control in Xtend soybean. Field studies were conducted in 2020 at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS, and at the University of Nebraska, Lincoln, NE (UNL). The dominant grass species at the KSU-ARC site were southwest cupgrass and green foxtail. The dominant grass weed species at the UNL site were giant foxtail, hairy cupgrass, and fall panicum. Treatments, including Select Max, Assure II, and Roundup PowerMax applied as early post-emergence (EPOST; V3-V4 soybean growth stage) alone, or in combination with Xtendimax were tested (see Table 1 for details). Results from the KSU-ARC site indicated that Roundup PowerMax applied alone and in sequential treatments at 5 days prior to or after the application of Xtendimax provided ≥ 85% control of both grass species, whereas the rest of the treatments provided ≤ 71% control. The highest soybean grain yield (13 to 17 bu/a) was observed with Roundup PowerMax alone or in tank-mixtures with Select Max, Assure II and/or Xtendimax. In contrast, tank-mixing Xtendimax to Select Max or Assure II, or Xtendimax applied 5 days prior to the application of Select Max or Assure II, reduced giant foxtail (64 to 82%), and hairy cupgrass (71 to 82%) control at the UNL site. The addition of Roundup PowerMax to tank-mixtures of Xtendimax with Select Max or Assure II restored the efficacy of both Select Max and Assure II on all three grass species. Soybean grain yield (64 to 77 bu/a) did not differ for the majority of treatments at UNL site. These results suggest that addition of Xtendimax with Select Max or Assure II can potentially compromise the efficacy of graminicides, and Roundup PowerMax should be added in these mixtures to optimize grass control in Roundup Ready 2 Xtend soybean.

Introduction
The introduction of Roundup Ready 2 Xtend soybean has provided stacked tolerance to both glyphosate and dicamba, which allows growers to use low-volatile formulations of dicamba (Xtendimax or Engenia) for in-season weed control, especially for controlling glyphosate-resistant weeds. Acetyl-CoA-Carboxylase (ACCase) (Group 1)

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inhibiting herbicides (Select Max or Assure II) are commonly used for effective control of a wide range of annual and perennial grass species. Xtendimax is usually tank-mixed with Roundup PowerMax or graminicides (Select Max or Assure II) for controlling both grass and broadleaf weed species in Roundup Ready 2 Xtend soybean. However, previous studies have shown that antagonism may occur between auxinic herbicides and graminicides when applied in tank-mixtures. For instance, it was reported that grass control was reduced by 7 to 38% when a tank-mixture of dicamba with sethoxydim (Poast) was applied. The main objective for this research was to determine the effectiveness of Roundup PowerMax, Select Max or Assure II alone, or in various combinations with Xtendimax on grass weed control in Roundup Ready 2 Xtend soybean.

Procedures

Field experiments were conducted in the 2020 growing season at the KSU-ARC near Hays, KS, and the UNL near Lincoln, NE. Roundup Ready 2 Xtend soybean variety AG34X7 was planted at 156,900 seeds/a on May 20, 2020, at the KSU-ARC site, and NK S29-K3X was planted at 140,000 seeds/a on May 11, 2020, at the UNL site. Grass weed species at the KSU-ARC site included southwest cupgrass and green foxtail. The dominant grass weed species at UNL site were giant foxtail, hairy cupgrass, and fall panicum. Experiments were established in a randomized complete block design with 3 replications. A total of 15 herbicide programs, including a non-treated weedy check, were tested (Table 1). All herbicide treatments were applied with a CO_2-operated backpack sprayer equipped with TTI11003 nozzles. Data were recorded on percent visual control of each grass weed species at 14, 28, and 54 days after treatments (DAT), and aboveground shoot dry biomass (g) at the end of the season, as well as soybean grain yield (bu/a). All data were subjected to ANOVA using PROC MIXED in SAS v. 9.0 (SAS Inst. Inc., Cary, NC). Means were separated using Fisher's protected LSD test ($\alpha = 0.05$).

Results

Grass Control

Results from the KSU-ARC site indicated that Roundup PowerMax applied alone or in sequential treatments at 5 days prior to or after Xtendimax applications provided ≥ 85% control of both grass weeds at 28 DAT (Figure1A). Control of both species did not exceed 72% with the rest of the treatments (Figure 1A). Tank-mixing Assure II with Xtendimax significantly reduced control of both grass species; however, an addition of Roundup PowerMax to this tank-mixture restored the efficacy of grass weed control (63 to 67%) at 28 DAT (Figure 1A). Results at the UNL site indicated that tank-mixing Xtendimax with Select Max or Assure II, and sequential treatment of Xtendimax followed by (*fb*) Select Max or Assure II had comparatively lower control of giant foxtail (64 to 82%), hairy cupgrass (71 to 82%), and fall panicum (72 to 88%) at 28 DAT compared to standalone treatments of Roundup PowerMax, Select Max and Assure II (Figure 1B). An addition of Roundup PowerMax to the tank-mixtures of Xtendimax with Select Max or Assure II restored the efficacy of both graminicides on all the three grass species (Figure 1B).

Soybean Grain Yield

The highest grain yield (13 to 17 bu/a) at the KSU-ARC site was observed with Roundup PowerMax alone or in tank-mixtures with Select Max or Assure II and Xtendimax applied EPOST, or Roundup in sequential application at 5 days prior to or after Xtendimax application treatments (Figure 2). Soybean grain yield at UNL site did not differ for the majority of the treatments and ranged from 64 to 77 bu/a (Figure 2).

Conclusions

These preliminary results suggested that adding Xtendimax with Select Max or Assure II can compromise the grass weed control in Roundup Ready 2 Xtend soybean. Roundup PowerMax should be added in these tank-mixtures to optimize grass weed control.

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

Table 1. List of herbicide programs tested in Roundup Ready 2 Xtend soybean at the Kansas State University Agricultural Research Center near Hays, KS, and the University of Nebraska near Lincoln, NE, sites

Trt	Herbicide programs[1]	Rate	Timing
		fl oz/a	
1	Non-treated	-	-
2	Select Max[2]	16	EPOST
3	Assure II[2]	8	EPOST
4	Roundup PowerMax[3]	32	EPOST
5	Select Max + Xtendimax[4]	16 + 22	EPOST
6	Assure II + Xtendimax[4]	8 + 22	EPOST
7	Roundup PowerMax[3] + Xtendimax[4]	32 + 22	EPOST
8	Roundup PowerMax[3] + Select Max[2] + Xtendimax[4]	32 + 16 + 22	EPOST
9	Roundup PowerMax[3] + Assure II[2] + Xtendimax[4]	32 + 8 + 22	EPOST
10	Xtendimax[4] *fb* Roundup PowerMax[3]	22 *fb* 32	EPOST *fb* 5 DAEP
11	Xtendimax[4] *fb* Select Max[2]	22 *fb* 16	EPOST *fb* 5 DAEP
12	Xtendimax[4] *fb* Assure II[2]	22 *fb* 8	EPOST *fb* 5 DAEP
13	Roundup PowerMax[3] *fb* Xtendimax[4]	32 *fb* 22	EPOST *fb* 5 DAEP
14	Select Max[2] *fb* Xtendimax[4]	16 *fb* 22	EPOST *fb* 5 DAEP
15	Assure II[2] *fb* Xtendimax[4]	8 *fb* 22	EPOST *fb* 5 DAEP

[1]All treatments were applied using a CO_2-operated backpack sprayer equipped with Turbo Teejet TTI11003 nozzles.
[2] Nonionic surfactant (NIS) at 0.25% v/v was included.
[3] Ammonium sulfate (AMS) at 2% v/v was included
[4] Intact at 0.5% v/v was included.
EPOST = early postemergence. *fb* = followed by. DAEP = days after early postemergence.

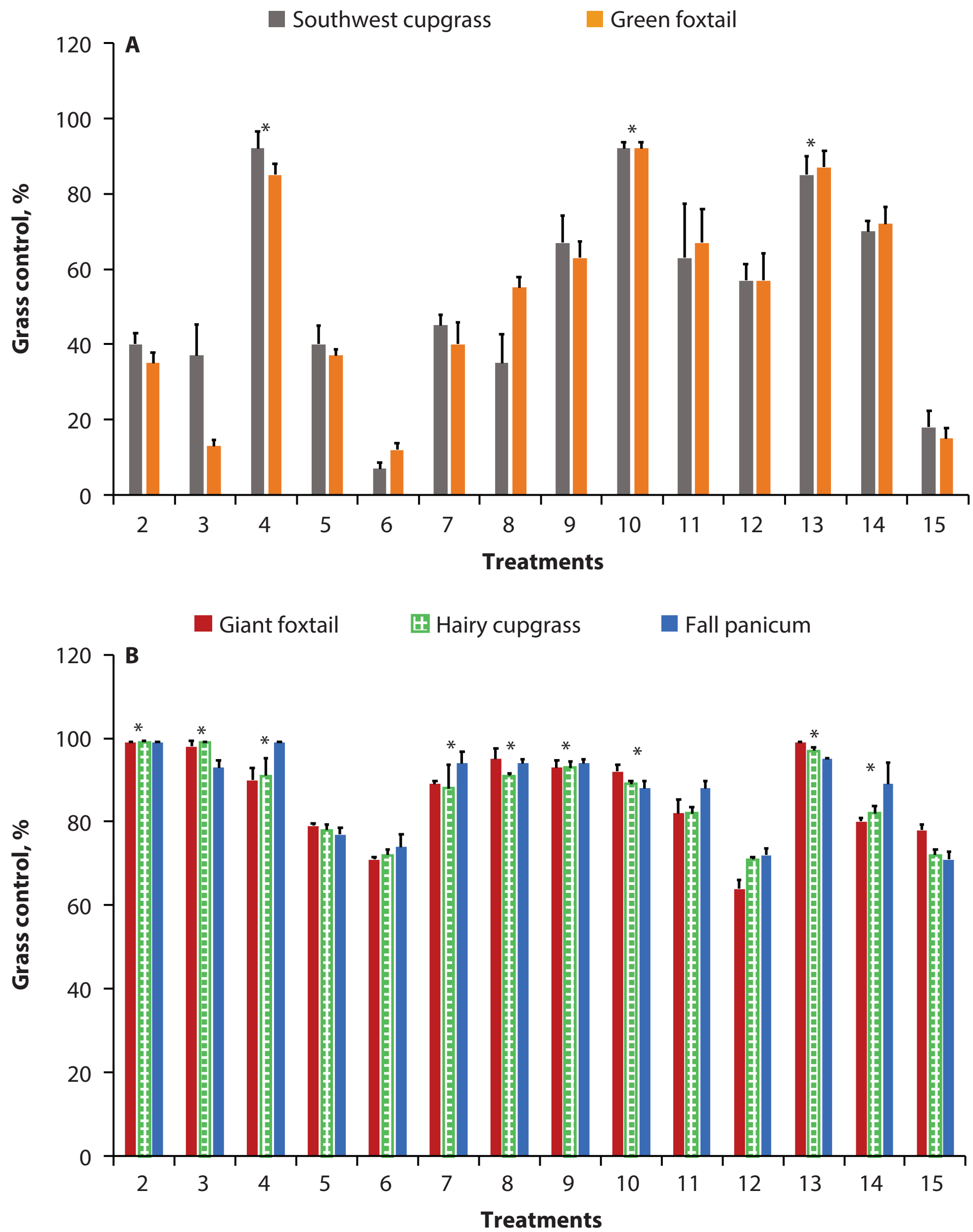

Figure 1. Effect of selected herbicide treatments on grass weed control (%) at 28 days after treatment (DAT): a) Kansas State University Agricultural Research Center near Hays, KS; b) University of Nebraska near Lincoln, NE. * Indicate best performing herbicide treatments.

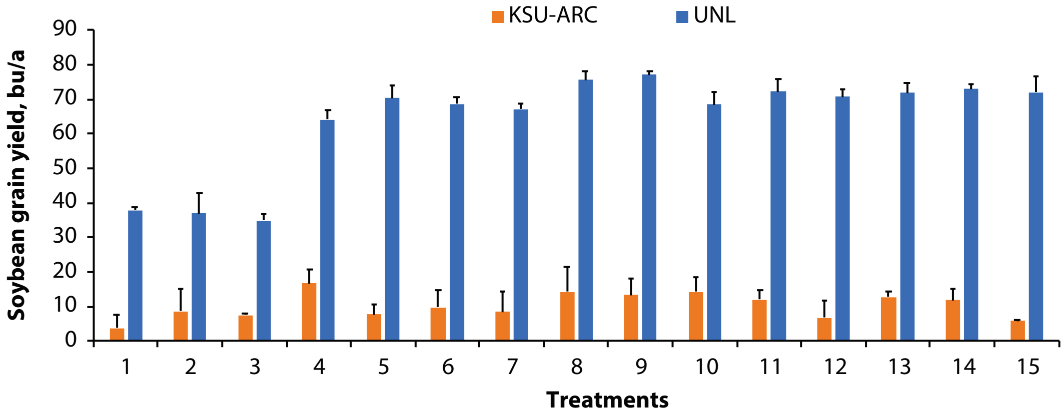

Figure 2. Effect of selected herbicide programs on Roundup Ready 2 Xtend soybean grain yield at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS; and at the University of Nebraska, Lincoln, NE (UNL).

Control of Volunteer Enlist Corn in Enlist E3 Soybean

R. Liu, I. Effertz, T. Lambert, and V. Kumar

Summary
Recent development of Enlist corn allows the use of 2,4-D choline (Enlist One), glyphosate (Roundup PowerMax), glufosinate (Liberty), and aryloxyphenoxypropionate (FOPs) herbicides for controlling grass and broadleaf weeds. However, volunteer Enlist corn plants can cause infestation in subsequent Enlist E3 soybean (resistant to 2,4-D, glyphosate, and glufosinate) in areas where a corn-soybean rotation is commonly practiced. The main objective of this research was to determine the effectiveness of cyclohexanedione (DIMs) herbicides alone or in tank-mixtures with Enlist One for Enlist corn control in Enlist E3 soybean. A field study was conducted in the 2020 growing season at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS. Enlist corn hybrid DKC62-53 was planted at 17,420 seeds/a on May 13, 2020. Enlist E3 soybean variety P30T92E was planted at 152,000 seeds/a in a perpendicular direction to corn on May 20, 2020. Herbicide treatments, including clethodim (Select Max) and sethoxydim (Poast Plus) were tested alone or in tank-mixtures with Enlist One as early POST (EPOST, 8- to 12-inch tall corn), or late postemergence (POST) (12- to 30-inch tall corn). Results indicated that Select Max applied EPOST alone provided an excellent, season-long control (95 to 99%) and highest biomass reduction (up to 100%) of volunteer Enlist corn in Enlist E3 soybean. However, volunteer corn control was significantly reduced when Enlist One was tank-mixed with Poast Plus. Volunteer corn control was low to moderate (50–85%) with all late postemergence (LPOST) programs tested. Soybean grain yield did not differ among EPOST treatments (39 to 44 bu/a), while grain yield was significantly lower (~ 34 bu/a) for LPOST treatments. These results suggested that the EPOST application of Select Max and Poast Plus can effectively control volunteer Enlist corn infestation in Enlist E3 soybean. However, adding Enlist One could compromise the efficacy of Poast Plus herbicide.

Introduction
Herbicide-resistant (HR) crops have provided growers flexibility for weed management. For instance, HR corn comprises 90% of the total corn production, and HR soybean comprises 94% of the total soybean production in the United States. However, the increased adoption of HR corn resulted in volunteer HR corn being a problem for soybean production in areas where a corn-soybean rotation is practiced. Enlist crop technologies are new stacked traits developed by Corteva Agriscience. Enlist E3 soybean can tolerate 2,4-D choline (Enlist One), glyphosate (Roundup PowerMax), and glufosinate (Liberty); whereas Enlist corn can also tolerate aryloxyphenoxypropionate (FOPs) herbicides in addition to 2,4-D, glyphosate, and glufosinate. The objective for this study was to determine the effectiveness of Select Max and Poast Plus applied at two different timings for volunteer Enlist corn control in Enlist E3 soybean.

Procedures

A field study was conducted at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS. Enlist corn hybrid DKC62-53 was planted at 17,420 seeds/a on May 13, 2020, and Enlist E3 soybean variety P30T92E was planted at 152,000 seeds/a in a perpendicular direction to corn on May 20, 2020. The experiment was conducted in a randomized complete block design, with 4 replications. Two application timings included V3-V4 stage of volunteer corn (8- to 12-inch, EPOST) and V7-V8 stage (12- to 30-inch, LPOST). A total of 10 herbicide programs, including a nontreated weedy check and a handweeded check were tested (Table 1). All treatments were applied using a backpack sprayer equipped with Turbo Teejet TTI11003 nozzles using a spray volume of 15 gallons per acre. Data were recorded on percent visible control (%) of volunteer corn at 14, 28, 42, 56, and 98 days after treatment (DAT), corn aboveground shoot dry biomass at the end of season, and soybean grain yield (bu/a). All data were subjected to ANOVA using PROC MIXED in SAS v. 9.0 (SAS Inst. Inc., Cary, NC). Means were separated using Fisher's protected LSD test ($\alpha = 0.05$).

Results

Results indicated that Select Max applied EPOST alone provided an excellent, season-long control (95 to 99%) and the highest biomass reduction (up to 100%) of volunteer Enlist corn in Enlist E3 soybean (Figures 1 and 2). Volunteer corn control with Poast Plus and a tank-mixture of Select Max with Enlist One was moderate to excellent and ranged from 80 to 97% throughout the growing season (Figure 1). In contrast, volunteer corn control and shoot dry biomass was significantly reduced when Enlist One was tank-mixed with Poast Plus compared to the Poast Plus alone treatment (Figures 1 and 2). Volunteer corn control was low to moderate (50 to 85%) with all LPOST treatments (Figure 1). Soybean grain yield did not differ among EPOST treatments (39 to 44 bu/a), while grain yield was significantly lower (~ 34 bu/a) for LPOST treatments (Figure 3).

Conclusions

Select Max and Poast Plus alone applied EPOST can effectively control infestation of volunteer Enlist corn in Enlist E3 soybean. An addition of Enlist One in a tank-mixture with Poast Plus compromised the efficacy of Poast Plus on volunteer corn control. In addition, Select Max and Poast Plus should be applied early in the season in order to achieve better control of volunteer Enlist corn in Enlist E3 soybean.

Table 1. List of herbicide treatments tested for controlling Enlist corn in Enlist E3 soybean at the Kansas State University Agricultural Research Center near Hays, KS

Treatments	Herbicide programs[1]	Rate (fl oz/a)	Timing
1	Select Max[2]	16	EPOST
2	Poast Plus[3]	24	EPOST
3	Select Max[2] + Enlist One	16 + 32	EPOST
4	Poast Plus[3] + Enlist One	24 + 32	EPOST
5	Select Max[2]	16	LPOST
6	Poast Plus[3]	24	LPOST
7	Select Max[2] + Enlist One	16 + 32	LPOST
8	Poast Plus[3] + Enlist One	24 + 32	LPOST
9	Nontreated	-	-
10	Handweeded	-	-

[1] All treatments were applied using a backpack sprayer equipped with Turbo Teejet TTI11003 nozzles.
[2] Nonionic surfactant (NIS) at 0.25% v/v was included.
[3] Crop oil at 1% v/v, and ammonium sulfate (AMS) at 2% wt/v was included.
EPOST = early postemergence. LPOST = late postemergence.

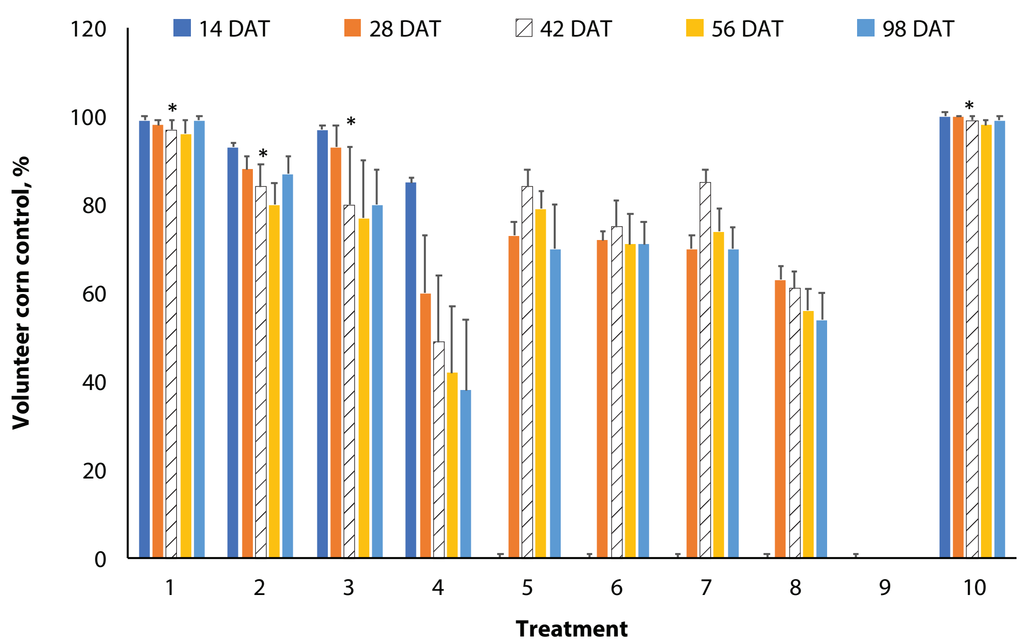

Figure 1. Effect of herbicide treatments on volunteer Enlist corn control in Enlist E3 soybean at the Kansas State University Agricultural Research Center near Hays, KS, at 14, 28, 42, 56, and 98 days after treatment (DAT). *Indicates significant differences from other treatments.

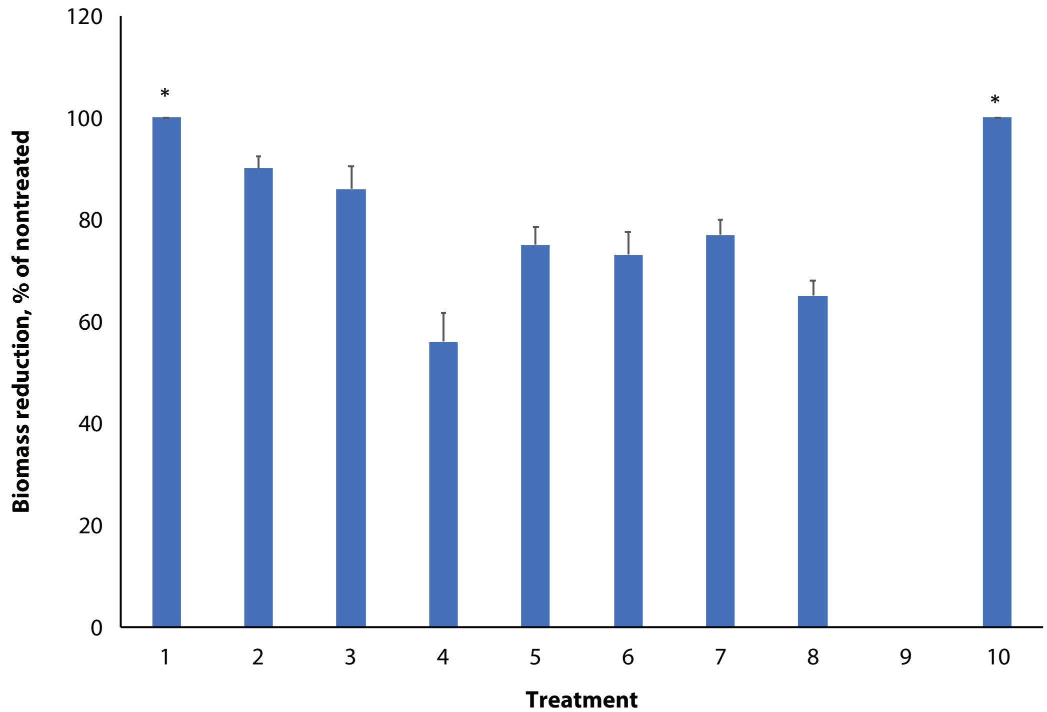

Figure 2. Effect of herbicide treatments on total shoot dry biomass reduction (% of nontreated) of volunteer Enlist corn in Enlist E3 soybean at the Kansas State University Agricultural Research Center near Hays, KS. *Indicates significant differences from other treatments.

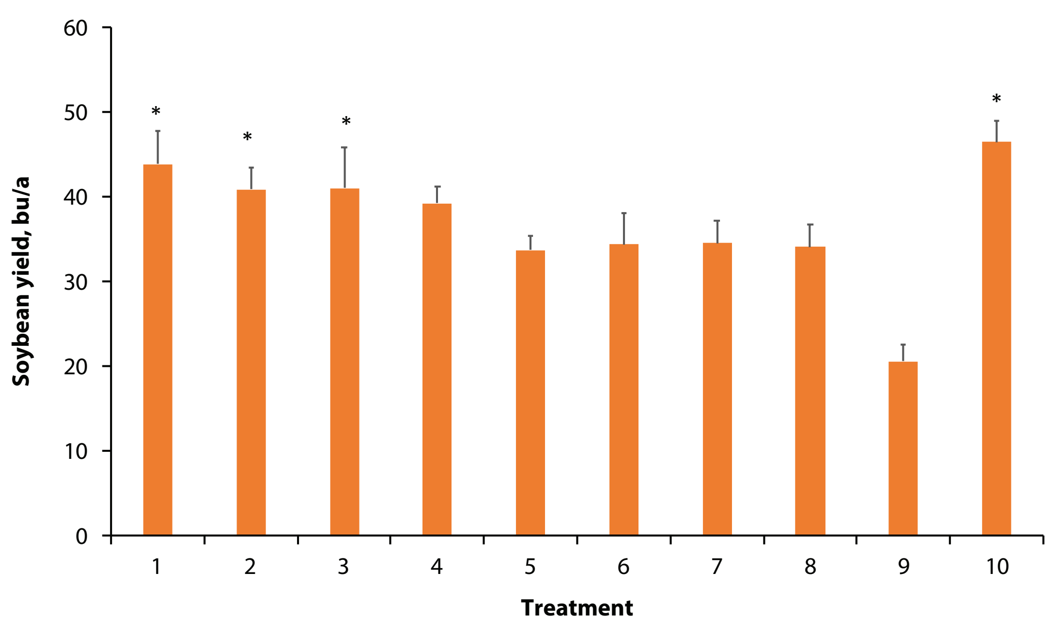

Figure 3. Effect of herbicide treatments on Enlist E3 soybean grain yield at the Kansas State University Agricultural Research Center near Hays, KS. *Indicates significant differences from other treatments.

Winter Wheat Response to Different Fungicide Management (Products and Timing of Application) During the 2019–2020 Growing Season

G. Cruppe,[1] B.R. Jaenisch, and R.P. Lollato

Summary
Foliar fungicides can improve wheat grain yield in Kansas, but there is limited information on the efficacy of different products as well as the timing of application. We conducted a field study in five Kansas locations to evaluate the yield, test weight, and protein responses of WB-Grainfield to different commercial fungicides applied at different times during the growing season. The trial was conducted in a randomized complete block design to evaluate (1) a non-treated control; Topguard applied at 5 ounces per acre at (2) jointing, (3) heading, and (4) jointing plus heading; (5) Delaro applied at 6 oz/a at jointing; (6) Absolute Maxx applied at 5 ounces per acre at heading; (7) Delaro at jointing plus Absolute Maxx at heading at the rates previously specified; and (8) Nexicor applied at 13 oz/a at heading. The study was conducted near Conway Springs, Great Bend, two sites near Hutchinson (optimum- and late-sowing date), and Leoti. Grain yield across locations ranged from 36 to 72.9 bushels per acre. A significant fungicide by location interaction on grain yield resulted from two locations showing no response to fungicide; two locations resulting in the highest yield when fungicide at heading was presented in the evaluated treatment; and one location showing all fungicide treatments outyielding the control. Similar results were obtained for test weight, where fungicides at heading seemed to benefit test weight at all locations except at the driest one. There were no consistent effects of foliar fungicide management on wheat grain protein concentration. This research is an initial step in determining the benefits of foliar fungicide to winter wheat yield and to date, a preliminary conclusion highlights the usefulness of a heading fungicide application when precipitation is not a limiting factor to yields, without consistent differences among the evaluated products.

Introduction
The application of foliar fungicides has been associated with increased wheat yields in Kansas (de Oliveira Silva et al., 2020a; Jaenisch et al., 2019; 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), even though some intensive production systems maximizing wheat yield have used a dual-fungicide system (Lollato and Edwards, 2015; Lollato et al., 2019; Jaenisch et al., 2019).

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 the development of such diseases. There is a

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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); thus, 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 to different fungicide management strategies and products in Kansas.

Procedures

One field experiment was conducted in five Kansas locations during the 2019–2020 winter wheat growing season, including near Conway Springs, Great Bend, two sites near Hutchinson, and Leoti. The two locations near Hutchinson differed in their previous crop and sowing date, as one was sown under optimal conditions following a conventional tilled canola crop; and the other was sown late no-tilled after a soybean crop. The experiments were established in a randomized complete block design with eight treatments and anywhere from four to eight replications, depending on location. Treatments included (1) a non-treated control; Topguard applied at 5 oz/a at (2) jointing, (3) heading, and (4) jointing plus heading; (5) Delaro applied at 6 oz/a at jointing; (6) Absolute Maxx applied at 5 oz/a at heading; (7) applying Delaro at jointing plus Absolute Maxx at heading at the rates previously specified; and (8) Nexicor applied at 13 oz/a at heading. All treatments were applied with a non-ionic surfactant. The winter wheat variety evaluated at all locations was WB-Grainfield. A Massey Ferguson XP8 small-plot, self-propelled combine was used for harvesting. Plot ends were trimmed at harvest time to avoid border effect. Measurements included grain yield (corrected for 13% moisture content) and grain test weight, and grain protein concentration at harvest maturity (corrected for 13% moisture content). Statistical analysis was performed using a two-way ANOVA in PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC) 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 6.7 to 16.8 inches of precipitation during the growing season, with corresponding crop reference evapotranspiration of 30.8 to 41.7 inches (Table 1). These precipitation and atmospheric water demand values resulted in water supply:water demand ratios of 0.16 to 0.49, suggesting that water deficit was certainly limiting wheat yields in two locations (Leoti and Hutchinson late) and likely may have also limited yields at the other three locations (Patrignani et al., 2014; Lollato et al., 2017).

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 (Table 2). The two driest locations studied were Great Bend and Leoti with average yields of 36 and 43 bu/a, where there were no differences among the treatments evaluated, even when compared to the untreated control. In Hutchinson—the trial sown at the optimum date after canola, with the highest yield potential (average 72.9)—the treatment receiving both Delaro at jointing plus Absolute Maxx at heading resulted in the highest grain yield (84 bu/a), which was statistically greater than any other treatment. For the late-planted trial in Hutchinson (average 57.9 bu/a), Topguard applied at heading or at jointing and heading had the greatest yields, which were statistically similar to those attained by Nexicor at heading and Delaro at jointing plus Absolute Maxx at heading (59.7 to 62.7 bu/a). In Conway Springs, all fungicide treatments yielded more than the control (52.4 versus 61.1 bu/a), with no statistical differences among fungicide treatments.

Grain Test Weight

Similarly 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 Great Bend, all treatments receiving foliar fungicides, regardless of timing or product, resulted in greater test weight than the untreated control (57.1 versus 55.9 pounds per bushel). For the trial in Conway Springs and for both trials in Hutchinson, the general trend was that treatments receiving foliar fungicide around heading, regardless of product, had greater test weight than those only receiving fungicide at jointing or than the control (62.9 versus 61.8 lb/bu in Conway Springs; 55.7 versus 54.0 lb/bu in the optimum sowing date; 61.1 versus 59.7 lb/bu in the late sowing date). There was no fungicide effect on wheat test weight in Leoti (Table 2).

Grain Protein Concentration

Grain protein concentration as affected by fungicide treatment showed a weaker interaction with location than grain yield or test weight ($P < 0.05$) (Table 2). This interaction resulted from a few random treatments having lower protein concentration in Great Bend (Topguard at jointing) and Hutchinson optimum (Delaro at jointing); or a few random treatments having greater protein concentration in Hutchinson late (Topguard at heading and Delaro at jointing), while there was no treatment effect on Leoti or Conway Springs (Table 2). These greater or lower protein concentrations didn't seem to follow a pattern. We note that the increase in grain yield resulting from fungicide application did not decrease grain protein concentration, perhaps due to an extended duration of nitrogen uptake and translocation into the grain, which determines protein (de Oliveira Silva et al., 2020b; Lollato et al., 2019b, 2021).

Preliminary Conclusions

Results suggest that the optimum fungicide management strategy depended on geographic location. In locations with limited precipitation, the application of foliar fungicides improved grain test weight in half of the cases; and showed no improvement in grain yield. For locations where precipitation amount was less limiting, fungicides applied at heading had the greatest yield two-thirds of the time; while the simple presence of fungicide (regardless of timing) resulted in the greatest yield in the remaining third. So far, we don't have enough data to conclude on the efficacy of different fungicide products and their efficiency in terms of grain yield, as the ranking of products changed depending on location.

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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 the growing season at the five study locations during 2019–2020

Location	Tmax	Tmin	Precip.	ETo	WS:WD
	------------ °F ------------		---------- inches ----------		
Conway Springs	61.9	39.4	16.4	35.9	0.46
Great Bend	60.9	36.0	16.3	36.3	0.45
Hutchinson (optimum)	61.7	37.2	16.8	34.5	0.49
Hutchinson (late)	59.4	34.6	13.6	30.8	0.44
Leoti	61.6	32.7	6.7	41.7	0.16

Table 2. Winter wheat grain yield, test weight, and protein concentration as affected by the interaction of fungicide management and location at the five study-sites conducted during the 2019–2020 growing season. Timing of fungicide application is referred to as growth stage in the Feekes scale of cereal development (FK6 = jointing; FK10 = heading)

Fungicide product	Timing	Great Bend	Hutchinson (optimum)	Hutchinson (late)	Leoti	Conway Springs
		------------------------- Grain yield (bu/a) -------------------------				
No		33.8	62.9	51.8	42.4	52.4
Topguard	FK 6	34.2	66.4	53.9	42.3	**57.7**
Topguard	FK 10	34.3	72.3	**61.1**	44.3	**62.7**
Topguard	FK6+FK10	36.6	73.4	**62.7**	45.0	**62.3**
Delaro	FK6	38.4	68.1	53.9	44.7	**60.6**
Absolute Maxx	FK 10	36.2	77.3	57.9	42.3	**62.0**
Delaro + Absolute Maxx	FK6+FK10	37.8	**84.0**	**59.7**	42.6	**61.9**
Nexicor	FK 10	36.7	79.1	**61.9**	43.2	**60.3**
Treatment effect		ns	< 0.01	< 0.01	ns	< 0.05
		--------------------- Grain test weight (lb/bu) ---------------------				
No		55.9	53.4	59.8	56.3	61.6
Topguard	FK 6	**57.3**	53.7	59.9	56.1	61.9
Topguard	FK 10	**56.3**	54.9	**61.3**	55.9	**63.1**
Topguard	FK6+FK10	**57.3**	**55.5**	**61.1**	56.2	**62.4**
Delaro	FK6	**57.1**	54.3	59.4	56.0	62.0
Absolute Maxx	FK 10	**57.5**	**55.5**	**61.3**	56.4	**62.8**
Delaro + Absolute Maxx	FK6+FK10	**56.9**	**55.7**	**60.8**	56.4	**62.9**
Nexicor	FK 10	**57.0**	**56.1**	**61.3**	56.2	**63.0**
Treatment effect		< 0.05	< 0.01	< 0.01	ns	< 0.05
		--------------------- Protein concentration (%) ---------------------				
No		**13.2**	**12.0**	10.9	10.5	10.1
Topguard	FK 6	12.3	**11.8**	11.5	10.7	10.0
Topguard	FK 10	**12.9**	**12.1**	**11.9**	10.7	10.0
Topguard	FK6+FK10	**12.9**	**12.0**	11.7	10.5	10.0
Delaro	FK6	**12.8**	11.6	**12.3**	10.6	9.7
Absolute Maxx	FK 10	**13.3**	**12.1**	11.7	10.5	10.1
Delaro + Absolute Maxx	FK6+FK10	**12.9**	**12.2**	11.7	10.5	10.2
Nexicor	FK 10	**13.0**	**12.0**	11.5	10.5	10.3
Treatment effect		< 0.05	< 0.05	< 0.05	ns	ns

Winter Wheat Variety Response to Flag Leaf Foliar Fungicide Application in 2019–2020

G. Cruppe,[1] B.R. Jaenisch, and R.P. Lollato

Summary
Foliar fungicide can be an important tool in improving wheat yields, but its effectiveness is season- and variety-dependent. To evaluate the yield, test weight, and protein responses of different commercial winter wheat varieties to one foliar fungicide application around heading, we conducted a trial combining four winter wheat varieties and two fungicide management treatments in Manhattan during 2019–2020. The control treatment consisted of no fungicide application, and the alternative treatment consisted of 5 oz/a Absolute Maxx + NIS applied at heading. Varieties evaluated were Bob Dole, Larry, WB4269, and Zenda. The study was conducted under no-tillage practices following a previous soybean crop. Grain yield across varieties averaged 47.8 bushels per acre in the control and 51.3 bu/a in the fungicide treatment. Zenda was the highest yielding variety (51.3 bu/a), followed by Larry (48.9 bu/a), and WB4269 and Bob Dole (~45.5 bu/a). The statistical analysis suggested that all varieties responded similarly to the fungicide application, but we hypothesize that this was because we did not have enough observations to build statistical power. Grain test weight and protein concentration were only impacted by variety and showed no fungicide effect (both were usually greater in Bob Dole and Larry as compared to Zenda or WB4269). These results suggest that the yield increase due to fungicide application did not result in protein dilution, likely due to an extended period for nitrogen (N) uptake and remobilization into the grain. Further research is needed to statistically detect significant differences among varieties in their response to foliar fungicide.

Introduction
Fungal foliar diseases often reduce wheat yield in Kansas, with losses as large as 22% (Hollandbeck et al., 2019) and foliar fungicide has been associated with increased wheat yields in long-term variety performance trials (Munaro et al., 2020). The benefits of foliar fungicides to susceptible varieties are well documented and could account for as much as 15–20 bu/a in seasons with high disease incidence (Jaenisch et al., 2019; Sassenrath et al., 2019). However, this benefit might be insignificant in dry seasons with low disease pressure (Cruppe et al., 2017). Because of the variability in growing conditions and disease pressure in Kansas, the breakeven probability of foliar fungicides is highly variable. Thus, genetic resistance has been the main strategy used in the region to mitigate yield losses resulting from diseases in historical time scales (Kelley, 2001).

Recent evidence suggests that even resistant varieties might benefit from foliar fungicides in seasons when disease pressure is high (de Oliveira Silva et al., 2020a). In fact, a recent evaluation of intensively managed wheat fields suggested that foliar fungicides were among the most important factors contributing to the increased wheat yields in Kansas (Lollato et al., 2019a), and are often used in intensified wheat management systems (Lollato and Edwards, 2015).

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Given the importance of foliar fungicide management to maximizing wheat yields, and its dependence on variety, the objective of this study was to evaluate how different wheat varieties responded in terms of grain yield and grain test weight to one foliar fungicide application around heading time in Kansas.

Procedures

One field experiment was conducted in Manhattan, KS, during the 2019–2020 winter wheat growing season. The experiment was sown using a Great Plains NT606 drill and was conducted under no-tillage practices after soybeans in a complete two-way factorial treatment structure arranged in a split-plot design and six replications. Fungicide applied at heading was the whole plot (either presence or absence), and four commercial winter wheat varieties with contrasting genetic resistance to the different predominant diseases were the sub-plot. Fungicide management consisted of 5 oz/a of Absolute Maxx + NIS applied at heading. The winter wheat varieties included in this study were: Bob Dole, Larry, WB4269, and Zenda. A Massey Ferguson XP8 small-plot, self-propelled combine was used for harvesting. Plot ends were trimmed at harvest time to avoid border effect. Measurements included grain yield (corrected for 13% moisture content), grain test weight, and grain protein concentration at harvest maturity (corrected for 13% moisture content).

Statistical analysis was performed using a two-way ANOVA in PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC) where variety, fungicide, and their interactions were considered fixed effects, and replication was treated as a random effect in the analysis of variance.

Results

Weather Conditions

The study location received 18.4 inches of precipitation during the growing season (Table 1), which is enough to suggest that there was no water limitation to grain yields (Patrignani et al., 2014; Lollato et al., 2017). Precipitation was well distributed according to the different water needs depending on the crop's stage of development, with ~3.4 inches in the fall, ~4.0 inches in the winter, and ~11 inches in the spring. These moisture levels, combined with relatively cool spring temperatures, led to the development of stripe rust and later, leaf rust (visual observations only).

Grain Yield

Grain yield was affected by fungicide and by variety individually ($P < 0.01$), but the evidence for variety-specific response to fungicide was weak ($P = 0.15$) (Table 2). In the treatments receiving foliar fungicide, grain yield averaged 51.3 bu/a as compared to 47.8 bu/a in the treatments not receiving fungicides. Zenda was the highest yielding variety (58.1 bu/a) and was followed by Larry (48.9 bu/a), which yielded more than Bob Dole and WB4269 (average 45.5 bu/a). This trial was planted beside an early-planted wheat trial, which increased the incidence of barley yellow dwarf virus in the study. This can help explain the much greater yield in Zenda as compared to the other varieties. While there was no variety × fungicide interaction, we note that there was a range in the differences in treated versus untreated depending on variety, with Bob Dole showing no yield gain from fungicide, while the other three varieties evaluated gained 4–6 bu/a. The lack of significance in this study might be because it was conducted in one location and therefore, had only a few observations. Perhaps more observations could have improved the power of this analysis and detected these differences among varieties in their response to fungicide – if a difference truly existed.

Grain Test Weight

Grain test weight differed among varieties but was not impacted by fungicide management or by the interaction between fungicide and variety (Table 2). Bob Dole and Larry had the greatest test weights, whereas Zenda and WB4269 had the lowest.

Grain Protein Concentration

Similarly to test weight, grain protein concentration differed among varieties but was not affected by fungicide or its interaction with variety (Table 2). All varieties differed from each other ($P < 0.01$), with Bob Dole having greater protein than Larry, which had greater protein than WB4269, which had greater protein than Zenda. It was interesting to note that the increase in grain yield resulting from fungicide application did not decrease grain protein concentration, as expected due to a dilution effect associated with greater yields. This might have occurred due to the extended green leaf area resulting from fungicide treatment (Jaenisch et al., 2019), possibly extending the duration of N uptake and translocation into the grain, which determines protein (de Oliveira Silva 2020b; Lollato et al., 2019b; 2021).

Preliminary Conclusions

Results suggest that both fungicide and variety impacted grain yield, but varieties responded similarly to fungicide management. Nonetheless, we hypothesize that with a single site year, there were not enough observations to build statistical power and detect these differences. Our results also showed that grain yield increases due to fungicide did not dilute grain protein concentration, similar to results by Kelley (2001). We hypothesize that the extended green leaf area resulting from the fungicide (Jaenisch et al., 2019) increases the duration of N uptake and translocation to the grain, compensating for increased yield levels.

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Table 1. Average maximum (Tmax) and minimum (Tmin) temperatures, and cumulative precipitation and grass evapotranspiration (ETo) during the fall (October 1 – December 31), winter (January 1 – March 31), and spring (April 1 – June 30) at the study location during the 2019–2020 growing season. The ratio of water supply (WS) over water demand (WD) is also shown.

Season	Tmax	Tmin	Precip.	Eto	WS:WD
	--------------- °F	---------------	---------------- in.	----------------	
Fall	54.0	31.5	3.4	6.5	0.52
Winter	48.2	28.0	4.0	6.4	0.63
Spring	75.6	53.3	11.0	17.0	0.65
Total	59.3	37.6	18.4	29.9	0.62

Table 2. Mean grain yield, grain test weight, and grain protein concentration as affected by fungicide, variety, and fungicide × variety for the trial conducted in Manhattan, KS, during the 2019–2020 winter wheat growing season. F-test probabilities are also shown. Values less than 0.05 indicate statistical significance.

	Grain yield (bu/a)			Grain test weight (lb/bu)			Grain protein concentration (%)		
Variety	Control	Fungicide	Mean	Control	Fungicide	Mean	Control	Fungicide	Mean
Bob Dole	45.4	45.3	45.3 c	57.7	57.3	57.5 a	12.1	12.2	12.2 a
Larry	46.0	51.7	48.9 b	57.4	57.4	57.4 ab	11.7	11.8	11.8 b
WB4269	43.8	47.9	45.9 c	57.0	57.1	57.1 bc	11.5	11.5	11.5 c
Zenda	56.0	60.3	58.1 a	56.8	56.9	56.8 c	10.7	10.7	10.7 d
Mean	47.8 b	51.3 a		57.2	57.2		11.5	11.6	
Fixed effects	--- Pr > F ---								
Fungicide (F)		<0.01			0.83			0.25	
Variety (V)		<0.01			<0.01			<0.01	
F × V		0.15			0.46			0.96	

Wheat Variety-Specific Response to Seeding Rate Under Intensive Management Conditions in Western Kansas in 2019–2020

R.P. Lollato and B.R. Jaenisch

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. One experiment evaluating the response of the wheat varieties Joe, WB-Grainfield, Langin, and LCS Revere to seeding rates ranging from 200,000 to 1,000,000 seeds per acre was established in a field managed by growers that consistently win state and national wheat yield contests near Leoti, KS. The trials were established on September 25, 2019, after a long fallow. The growing season was extremely dry, with only 6.3 inches of cumulative precipitation (corresponding only to 15% of atmospheric water demand). Stand count increased with increases in seeding rate but final population was closer to the target under low populations. Varieties differed statistically in grain yield but all varieties responded similarly to seeding rate. The lowest yield was recorded across varieties in the treatment with 200,000 seeds/a, with the treatments ranging from 400,000 to 1,000,000 seeds/a all resulting in the same yield level. The variety WB-Grainfield underperformed the other varieties, likely due to more damage from a spring freeze occurring in April 2020. These results suggest that wheat grain yield responses to seeding rate were not dependent on variety, with optimum seeding rates as low as 400,000 seeds/a. We note that increasing seeding rates past this point led to numerical, but not statistical, increases in yield.

Introduction

Wheat responses to seeding rate are inconsistent, ranging from quadratic (Holliday, 1960) to positive linear, quadratic-plateau, plateau-negative linear, and even inexistent (Whaley et al., 2000; Lloveras et al., 2004; Jaenisch et al., 2019; Fischer et al., 2019; Lollato et al., 2019). The quadratic response suggests that there is an optimum population below which the crop is limited by less than optimum plants (Whaley et al., 2000) and above which it is limited by disease pressure, insects, lodging, or insufficient resources such as fertility (Lloveras et al, 2004). 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 (above 90 bushels per acre) where the crop is not limited by resources (these including fertility levels but also temperature 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/ft^2 (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.

The majority of the studies evaluating wheat yield response to seeding rate were performed under standard management conditions i.e., 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 at understanding wheat response to seeding rate in a high resource availability scenario. This is relevant in a context in which increases in food production are needed to feed an increasing global population, especially in regions characterized by actual yields well below the potential yield such as in Kansas and neighboring states (Lollato and Edwards, 2015; Lollato et al., 2017; 2019; Patrignani et al., 2014). Considering that 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 2019–2020 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, Byrd, 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., 2019). The experiments were planted on September 25, 2019, after a long summer fallow in sorghum residue, and were the second crop after manure application (5 tons per acre, providing about 150 pounds of N and phosphorus). Management of the field consisted of 80 pounds of nitrogen (N) per acre plus 13 lb of sulfur per acre in December, 3.5 ounces per acre Rave herbicide in February, and 13.7 oz/a of Miravis Ace once the flag leaf was fully emerged. Combined with the soil fertility available at sowing, all the manageable stresses were likely reduced. A Massey Ferguson XP8 small-plot, self-propelled combine was used for harvesting.

A total of 15 individual soil cores (0–24 in. depth) were collected from each location and divided into 0–6 in. and 6–24 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 (SAS Inst. Inc., Cary, NC). Linear and non-linear regression analyses were used to test the grain yield response to plant population. Replication was treated as a random effect in the analysis of individual locations.

Results

Weather Conditions

The 2019–2020 growing season was extremely dry in Leoti. Total precipitation during the growing season was 6.3 inches, which compared to 41 inches of crop water demand (Table 2), meaning that water supply only accounted for 15% of water demand. Despite very dry growing season conditions, sowing was followed by ~0.6 inches of precipitation, which allowed for good emergence and tiller production during the fall.

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 per acre resulted in 197,684 plants/a; while the target of 1,000,000 plants/a resulted in 642,306 plants/a. This is usually observed in seeding rate studies (Bastos et al., 2020). As expected, there was no variety effect on final stand establishment.

Grain yield was affected by seeding rate and by variety independently, but there was 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 41.4 bu/a in the 200,000 plants/a seeding rate, to anywhere from 47.6 to 51.3 bu/a in the seeding rates ranging from 400,000 to 1,000,000 seeds/a, with no significant statistical differences among the latter seeding rates. The variety WB-Grainfield had the lowest grain yield (40.5 bu/a) as compared to the remaining varieties, which ranged from 49.1 to 52.2 bu/a (with no significant yield differences among Joe, LCS Revere, or Langin). The lower grain yield measured in WB-Grainfield was likely due to its early release from winter dormancy, being well advanced in maturity when a harsh spring freeze occurred in April, causing severe burn-back and tiller loss particularly in this variety.

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 32.7 and 57.3 bu/a, wheat response to seeding rate was independent of variety and yield, maximized at 400,000 seeds/a. Yield increases reported for seeding rates beyond 400,000 seeds/a, while numerically present (~10%), were not statistically significant.

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Table 1. Initial soil fertility measured at wheat sowing during the 2019–2020 growing season for the trial conducted near Leoti, KS

Depth	OM	pH	CECS	NO_3-N	NH_4-N	P	K	Ca	Mg	Mn	Na	Cu	Zn	Fe	S	Cl	Sand	Silt	Clay
in.	%		meq/100 g	ppm													%		
0 to 6	2.9	6.6	18.3	30.9	3.7	155.0	864.0	2,433.9	460.3	13.6	19.2	1.4	19.4	27.4	4.9	9.4	16.0	58.0	26.0
6 to 14	1.9	7.6	31.1	15.6	7.8	67.2	747.4	4,845.7	582.2	6.7	21.9	1.1	4.4	15.6	3.8	8.7	14.0	52.0	34.0

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 2019–2020 growing season. The water supply (WS) to water deficit (WD) ratio is also shown.

Season	Tmax	Tmin	Precip.	Eto	WS:WD
	---------------- °F ----------------		---------------- in. ----------------		
Fall	57.8	28.8	0.7	10.3	0.07
Winter	50.1	23.9	1.9	8.4	0.23
Spring	76.4	45.3	3.6	22.5	0.16
Total	61.4	32.6	6.3	41.0	0.15

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 per acre. The significance of fixed effects resulting from the ANOVA is also shown.

	Variety					Variety				
Seed rate	WB-Grainfield	Joe	LCS Revere	Langin	Mean	WB-Grainfield	Joe	LCS Revere	Langin	Mean
	---------------- Stand count (plants/a) ----------------					---------------- Grain yield (bu/a) ----------------				
200,000	167732	191693	239617	191693	197684 e	32.7	41.7	47.5	43.8	41.4 b
400,000	346113	330139	394036	306177	344116 d	44.3	50.0	50.8	45.4	47.6 a
600,000	362087	484558	505857	391374	435969 c	38.4	49.7	52.1	57.3	49.4 a
800,000	585730	535144	569755	521832	553115 b	42.6	51.1	57.0	54.5	51.3 a
1000000	788073	657615	537806	585730	642306 a	44.7	53.3	53.5	52.3	51.0 a
Mean	449947	439830	449414	399361		40.5 b	49.2 a	52.2 a	50.7 a	
Fixed effects	-- Pr > F --									
Seeding rate (R)			< 0.01					< 0.01		
Variety (V)			0.36					< 0.01		
R × V			0.11					0.41		

Wheat Variety Response to Seeding Rate Across a Range of Kansas Environments in 2019–2020

R.P. Lollato and B.R. Jaenisch

Summary
Due to the inconsistencies of wheat response to seeding rate, we conducted an experiment in seven Kansas locations during the 2019–2020 winter wheat growing season with the objectives of determining whether higher yielding environments warrant lower seeding rates than lower yielding environments, and whether this response depends on wheat variety. The wheat varieties 'Larry,' 'SY Monument,' 'Tatanka,' and 'WB4303' were seeded at 200,000, 400,000, 800,000, and 1,600,000 seeds per acre at Ashland Bottoms, Belleville, Conway Springs, Great Bend, Hutchinson, Leoti, and Manhattan. Growing season rainfall in the studied locations ranged from 6.7 to 24.2 inches, which corresponded to anywhere from 16 to 80% of the reference evapotranspiration. Stand count increased with increases in seeding rate but final population was dependent on the location: in Great Bend, the range in population evaluated was only from 248,270 to 464,590 due to an extremely dry period following wheat sowing; while at the other locations there was a larger range in populations evaluated. Regarding grain yield, plant population also interacted with location: grain yield increased linearly with increases in seeding rate in the five lowest yielding environments, and plateaued at 800,000 seeds/a in the two highest yielding environments. Likewise, varieties interacted with the location so that in two locations there were no varietal effects; while in five locations the difference between the lowest and highest yielding varieties ranged from 5.2 to 9.9 bushels per acre. These results suggested that wheat grain yield responses to seeding rate were dependent on location, and that varieties yielded differently by location but the response of the different varieties to seeding rate was similar.

Introduction
Recent evidence suggested that wheat might not respond to seeding rate in high yielding environments (>90 bu/a; Bastos et al., 2020) or that at least, very low seeding rates are already sufficient to maximize yields (Fischer et al., 2019; Lollato et al., 2019). This contrasts with previous evidence suggesting that responses are usually quadratic (Holliday, 1960) or of other forms (Whaley et al., 2000; Lloveras et al., 2004; Jaenisch et al., 2019). The Bastos et al. (2020) study also suggested that the optimum plant population depends on a given variety's tillering potential. Variety selection and seeding rate are among the first management decisions a grower takes during the growing season. Improved management can allow for the reduction of yield gaps, especially in regions such as Kansas, where current yields are lower than the potential yield (Lollato and Edwards, 2015; Lollato et al., 2017, 2019; Patrignani et al., 2014). Given the contrasting and inconsistent results of wheat grain yield response to seeding rate, and whether it depends on variety, this research investigated (1) what is the lower limit of plant population above which grain yield does not respond to increases in seeding rate; and (2) whether this response depends on the wheat variety.

Procedures

Seven field experiments were conducted during the 2019–2020 winter wheat growing season across the state of Kansas, including: Ashland Bottoms, Belleville, Conway Springs, Great Bend, Hutchinson, Leoti, and Manhattan. A two-way factorial treatment structure was established in a completely randomized block design and evaluated four commercial wheat varieties (i.e., Larry, SY Monument, Tatanka, and WB4303) and four seeding rates (200,000, 400,000, 800,000, and 1,600,000). All seeds were treated with insecticide and fungicide seed treatment to avoid potential stand losses due to pests (Pinto et al., 2019). The research plots comprised of seven 7.5 in.-spaced rows wide and were 30-ft long. A total of 15 individual soil cores (0–24 in. depth) were collected from each location and divided into 0–6 in. and 6–24 in. increments for initial fertility analysis (data not shown). These data were used to guide management of N rate, which was based on a yield goal of 70 bu/a and considered initial soil NO_3-N at sowing as well as credits from organic matter. All experiments received a foliar fungicide around heading. A Massey Ferguson XP8 small-plot, self-propelled combine was used for harvesting.

In-season measurements included stand count (measured approximately 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 the PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC). Replication was treated as a random effect in the analysis of individual locations.

Results

Weather Conditions

The weather conditions had great contrasts among the seven locations where this trial was conducted during the 2019–2020 growing season (Table 1). Total precipitation ranged from 6.7 inches in Leoti to 24.2 inches in Ashland Bottoms, with reference evapotranspiration (ETo) ranging from 29.9 inches in Manhattan to 41.7 inches in Leoti. These conditions resulted in ratios of precipitation over reference ETo (an estimate of the water supply over water demand) that ranged from 0.16 in Leoti to 0.80 in Ashland Bottoms.

Seeding Rate and Variety Effects on Stand Establishment and Grain Yield

There was a significant seeding rate by location effect on final stand establishment (Figure 1). Overall, increases in seeding rate increased plant population; however, the increase in population as affected by increases in seeding rate depended on location. The two most contrasting examples were Great Bend and Belleville. In Great Bend, where wheat planting was followed by a substantial dry spell, increasing the seeding rate from 200,000 to 1,600,000 seeds/a only increased plant population from 248,270 to 464,590 plants per acre. Meanwhile, in Belleville, where sowing was followed by ideal conditions for crop establishment, the same increase in seeding rate increased plant population from 421,326 to 1,377,130 plants/a.

Grain yield was affected by the interaction between seeding rate and location, as well as by the interaction of variety and location; but there were no variety by seeding rate interactions; suggesting that varieties responded similarly to increases in seeding rate. Overall, there were quadratic increases in grain yield with increases in seeding rate at all locations, but the two highest yielding locations (Hutchinson and Conway Springs) maximized yields at approximately 800,000 seeds/a, while the lowest yielding locations showed increases in yield with increases in seeding rate until 1,600,000 seeds/a (Great Bend, Manhattan, Leoti, Belleville, and Ashland Bottoms). Likewise, varieties ranked differently in each study location (Table 3). For example, varieties did not differ statistically in Belleville (mean yield: 49 bu/a) and in Conway Springs (mean yield: 63 bu/a), where differences between the highest and lowest yielding varieties were approximately 2.5 bu/a. In the other locations, the yield difference between the lowest and the highest yielding varieties ranged from 5.2 to 9.9 bu/a (Table 3).

Preliminary Conclusions

In response to the two objectives of this project, we found that wheat yield maximized at a lower seeding rate at the two highest yielding environments as compared to lower yielding environments. Likewise, the first year of this trial failed to provide evidence for variety-specific information on wheat response to seeding rate, suggesting that all varieties responded similarly.

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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 seven study locations during 2019–2020

Location	Tmax	Tmin	Precip.	ETo	WS:WD
	--------------- °F	---------------	------------- inches	-------------	
Ashland Bottoms	59.3	37	24.2	30.3	0.80
Belleville	57.7	33.7	12.5	31	0.40
Conway Springs	61.9	39.4	16.4	35.9	0.46
Great Bend	60.9	36	16.3	36.3	0.45
Hutchinson	61.7	37.2	16.8	34.5	0.49
Leoti	61.6	32.7	6.7	41.7	0.16
Manhattan	59.3	37.6	18.4	29.9	0.62
Average	60.1	35.5	15	34.2	0.45
Max	61.9	39.4	24.2	41.7	0.80
Min	57.7	31.5	6.7	29.9	0.16

Table 2. Grain yield as affected by wheat variety at the seven study locations during the 2019–2020 growing season. Means followed by the same letter do not differ statistically for comparisons within location.

	Variety			
Location	Larry	SY Monument	Tatanka	WB4303
Ashland Bottoms	52.5 b	56.0 a	58.4 a	56.6 a
Belleville	48.7 a	49.2 a	48.8 a	46.8 a
Conway Springs	63.3 a	61.9 a	64.3 a	64.6 a
Great Bend	31.5 ab	29.1 b	34.3 a	33.4 a
Hutchinson	67.9 b	72.9 a	70.6 ab	63.0 c
Leoti	49.0 a	45.9 b	51.8 a	49.6 a
Manhattan	41.2 bc	43.5 b	47.0 a	40.4 c

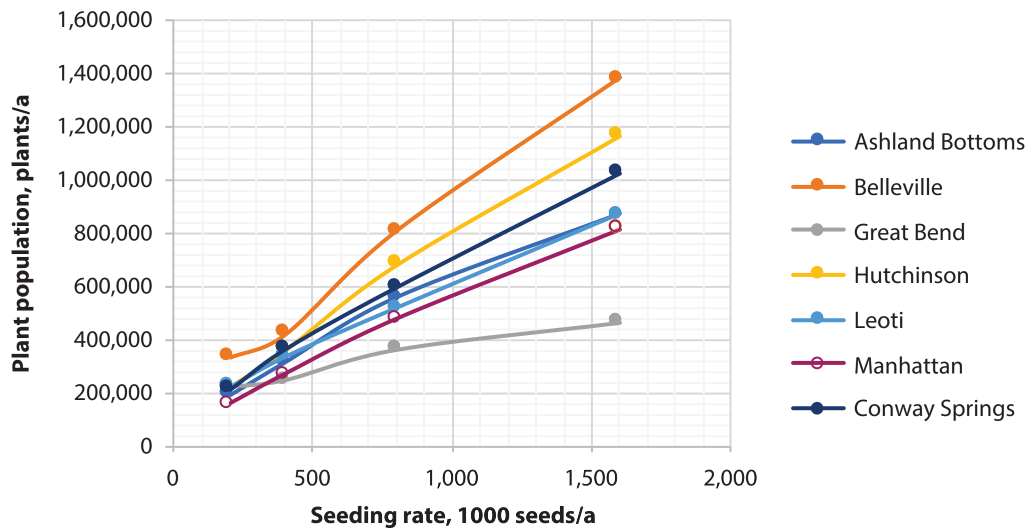

Figure 1. Winter wheat plant population as affected by seeding rate and its interaction with location during the 2019–2020 growing season in Kansas.

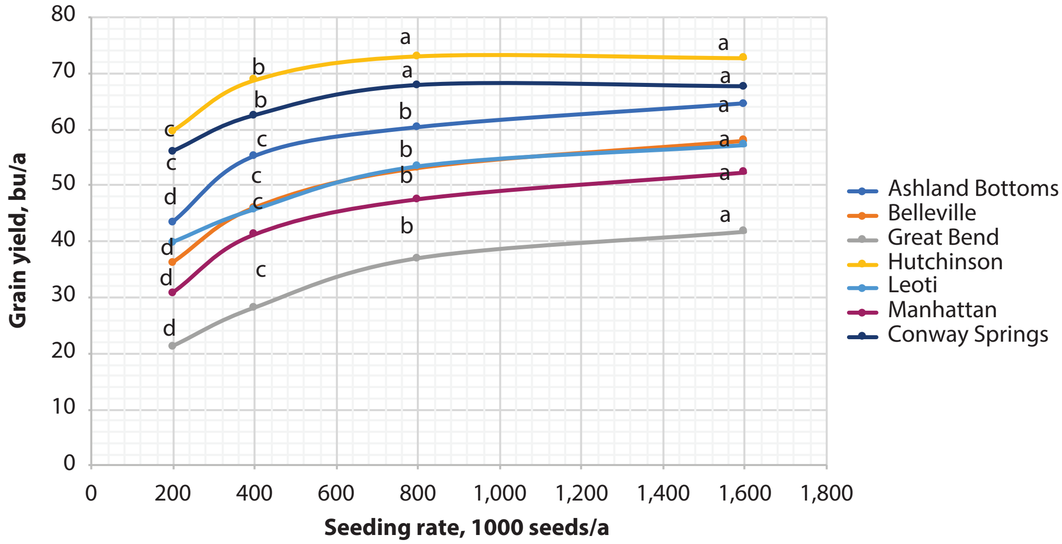

Figure 2. Winter wheat grain yield as affected by seeding rate and its interaction with location during the 2019–2020 growing season in Kansas. Means followed by the same letter do not differ statistically for comparisons within the same location.

Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2019–2020 Growing Season in Kansas

R.P. Lollato, B.R. Jaenisch, and L. Haag

Summary
The objective of this project was to evaluate winter wheat stand count and grain yield responses to seeding rate and its interaction with seed cleaning and seed treatment in Kansas during the 2019–2020 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 enough to be generalized across locations. The average plant population across treatments ranged from ~285,000 to 620,000 plants per acre, with the low populations occurring either in sites where severe freeze damage caused winterkill or in sites where sowing was followed by extremely dry periods. Grain yield across treatments ranged from 25 to 75 bushels per acre. Across locations, both stand count and grain yield increased with increases in seeding rate, with improvements in seed cleaning, and with the presence of a fungicide plus insecticide seed treatment across locations. 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 was study derived from commercial seed production fields (i.e., high quality seed) and not from commercial grain production fields, which are usually the case for bin-run seed.

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 approximately 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 with a field study evaluating improved management practices (de Oliveira Silva et al., 2020). 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 the population in high-yielding environments such as high fertility

fields sown at the appropriate timing, where tillering is abundant. Meanwhile, higher seeding rates were required in lower-yielding environments where the crop did not have as much time to tiller (Bastos et al., 2020). Similar results were reported by 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.

Not all planted seeds become emerged plants. 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; Pinto et al., 2019). 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 second year of a three-year project. The first year of data was reported by Lollato et al., 2020.

Procedures

Field experiments were conducted in ten locations during the 2019–2020 winter wheat growing season: Ashland Bottoms, Beloit, Belleville, Colby, Conway Springs, Great Bend, Hutchinson (optimum sowing time, conventional till after canola), Hutchinson (late sowing, no-till after soybeans), Leoti, and Manhattan (Table 1). 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 (hereafter referred to as 'None'), after air screening, and on the top of the gravity table. 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. A Massey Ferguson XP8 small-plot, self-propelled combine was used for harvesting.

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 (SAS Inst. Inc., Cary, NC). Replication was treated as a random effect in the analysis for individual locations, while location and replication nested within location were random effects in the analysis across locations. Random effects also accounted for the statistical design of the experiment (i.e., seeding rate nested within replication, and seed cleaning nested within seeding rate nested within replication).

Results

Weather Conditions

The ten locations evaluated during the 2019–2020 winter wheat growing season provided very contrasting environments for the evaluation of the different treatments (Table 1). Growing season mean maximum temperatures ranged from 57.7°F in Belleville to 61.9°F in Conway Springs and mean minimum temperatures ranged from 31.5°F in Colby to 39.4°F in Conway Springs. Growing season precipitation ranged from 6.7 inches in Leoti to 24.4 inches in Ashland Bottoms, with corresponding grass reference evapotranspiration (ETo) ranging from 29.9 inches in Manhattan to 41.7 inches in Leoti. The corresponding water supply (WS) to water demand (WD) ratios ranged from 0.16 in Leoti to 0.80 in Ashland Bottoms.

Overall Treatment Significance on the Measured Variables

Table 2 shows the results from the analysis of variance for each location individually, as well as for the combined analysis across locations. At the 0.05 probability level, seeding rate affected stand count in nine locations and in the combined analysis; seed cleaning affected stand count in seven locations and in the combined analysis; and seed treatment impacted stand count in two locations and in the combined analysis. Grain yield was affected by seeding rate in seven locations plus the combined analysis; by seed cleaning in six locations and in the combined analysis; and by seed treatment in four locations plus in the combined analysis.

Stand Count

Across all treatments, stand count ranged from ~285,000 plants/a in Colby and Great Bend, to ~620,000 plants/a in Hutchinson (optimal sowing) (Table 3). The very low average population in Colby was a result from the harsh April freeze that increased winterkill, and in Great Bend it was due to extremely dry conditions for several months following the sowing of the wheat crop. Despite some small differences in response to the treatments among locations (Table 2), these responses were uniform enough to be discussed across locations. Across locations, increasing seeding rates increased plant population linearly, as the 600,000 seeds/a rate averaged 362,009 plants/a; the 900,000 seeds/a rate averaged 489,480 plants/a; and the 1,200,000 seeds/a rate averaged 574,350 plants/a rate. Seed cleaning also had a significant impact on final population, with a special advantage resulting from the gravity table in comparison to the other treatments: the average population for the unclean seed was 438,812 plants/a, which is statistically the same as that resulting from air screen (452,914 plants/a). Gravity table, however, increased the final plant population to 534,113 plants/a. Likewise, there was a significant effect of seed treatment on plant population, as the treated seed averaged 490,046 plants/a as compared to 460,514 plants/a in the untreated seed.

Grain Yield

The ten locations was this experiment were conducted during the 2019–2020 growing season provided a large range in yielding conditions. Average grain yield across all treatments ranged from 25 bu/a in Colby to 75 bu/a in Hutchinson (optimal planting). Similar to the plant population, grain yield across locations was affected by the main effects of seeding rate, cleaning, and treatment, individually (Table 3). Each increase of 300,000 seeds/a in the seeding rate increased grain yield by ~3 bu/a, for average grain yields of 46.6, 50.9, and 53.5 bu/a for the three seeding rates evaluated. Likewise, there were significant yield increases resulting from the seed cleaning process, with the unclean seed treatment averaging 48.7 bu/a; the air screen treatment averaging 50.5 bu/a; and the gravity table treatment averaging 51.9 bu/a. Finally, the fungicide plus insecticide seed treatment increased grain yield by 0.5 bu/a (from 49.6 bu/a in the untreated control to 51.1 bu/a with seed treatment).

Preliminary Conclusions

Winter wheat population establishment and grain yield responses to seeding rate, seed cleaning, seed treatment, and their interactions were dependent on environmental conditions. Despite some location-specific responses due to different yield levels, our results showed a clear benefit from increases in seeding rate, improvements in seed cleaning, and 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, which are usually the case for bin-run seed. This was the second year of this research, and the results from the first year are published in Lollato et al., 2020. This research will continue for one more growing season so that we can establish probabilities of yield gain and breakeven on seeding rate, seed cleaning, and seed treatment.

Acknowledgments

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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 the growing season at the ten study locations during 2019–2020

Location	Tmax	Tmin	Precip.	ETo	WS:WD
	------------- °F -------------		---------- inches ----------		
Ashland Bottoms	59.3	37.0	24.2	30.3	0.80
Beloit	59.5	34.9	17.0	33.5	0.51
Belleville	57.7	33.7	12.5	31.0	0.40
Colby	60.1	31.5	7.9	38.4	0.20
Conway Springs	61.9	39.4	16.4	35.9	0.46
Great Bend	60.9	36.0	16.3	36.3	0.45
Hutchinson (optimum)	61.7	37.2	16.8	34.5	0.49
Hutchinson (late)	59.4	34.6	13.6	30.8	0.44
Leoti	61.6	32.7	6.7	41.7	0.16
Manhattan	59.3	37.6	18.4	29.9	0.62
Average	60.1	35.5	15.0	34.2	0.45
Max	61.9	39.4	24.2	41.7	0.80
Min	57.7	31.5	6.7	29.9	0.16

Table 2. Significance of seeding rate (R), seed cleaning (C), seed treatment (T) and their interactions on stand count and grain yield at ten Kansas locations where the trial was conducted, as well as the analysis combined across sites, during the 2019–2020 growing season

Effect	Ashland Bottoms	Beloit	Belleville	Colby	Conway Springs	Great Bend	Hutch. (optimum)	Hutch. (late)	Leoti	Manhattan	Combined
	-----	-----	-----	-----	-----	Stand count	-----	-----	-----	-----	-----
R	0.15	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
C	0.11	0.16	< 0.01	< 0.01	< 0.01	0.34	< 0.01	< 0.01	0.03	0.02	< 0.01
T	0.17	0.03	0.45	< 0.01	0.25	0.61	0.74	0.36	0.09	0.77	< 0.01
R × C	0.61	0.54	0.44	0.95	0.52	0.48	0.93	0.05	0.85	0.94	0.51
R × T	0.18	0.57	0.77	0.99	0.04	0.65	0.42	0.64	0.38	0.71	0.17
C × T	0.41	0.85	0.97	0.46	0.81	0.43	0.49	0.91	0.09	0.14	0.86
R × C × T	0.49	0.92	0.82	0.09	0.76	0.19	0.83	0.01	0.04	0.63	0.03
	-----	-----	-----	-----	-----	Grain yield	-----	-----	-----	-----	-----
R	0.02	< 0.01	< 0.01	< 0.01	0.36	0.02	0.16	< 0.01	0.21	< 0.01	< 0.01
C	0.35	< 0.01	< 0.01	0.02	0.08	0.02	0.39	< 0.01	0.59	0.01	< 0.01
T	0.91	< 0.01	< 0.01	< 0.01	0.09	0.05	0.11	0.17	0.28	0.39	< 0.01
R × C	0.69	0.87	0.43	0.39	0.37	0.62	0.79	0.88	0.07	0.27	0.28
R × T	0.76	0.18	0.17	0.14	0.96	0.36	0.15	0.14	0.29	0.83	0.76
C × T	0.28	0.31	0.61	0.72	0.15	0.09	0.34	0.68	0.65	0.23	0.44
R × C × T	0.22	0.15	0.47	0.96	0.34	0.44	0.34	0.87	0.23	0.84	0.68

Table 3. Effects of seeding rate, seed cleaning method, and seed treatment on plant population and grain yield across 10 Kansas locations during the 2019–2020 winter wheat growing season

Effect		Plant population		Grain yield	
		------ plants/a ------		----- bu/a -----	
Seeding rate (seeds/a)	600,000	362,009	c	46.6	b
	900,000	489,480	b	50.9	ab
	1,200,000	574,350	a	53.4	a
Seed cleaning	None	438,812	b	48.7	c
	Air screen	452,914	b	50.4	b
	Gravity table	534,113	a	51.8	a
Seed treatment	None	460,514	b	49.5	b
	Treated	490,046	a	51.1	a

Means followed by a common letter are not significantly different by the Tukey test at the 5% level of significance.

Testing Efficacy of Plant Growth Regulator Products for Enhanced Winter Wheat Grain Yield and Quality

R.M. Aiken

Summary
Experimental plant growth regulator compounds are expected to improve wheat grain yield by extending the duration of green leaf area and altering remobilization of stored carbohydrates. In order to evaluate this, plant growth regulator materials supplied by a commercial third party were applied to Tatonka hard red winter wheat during the mid-grain fill development stage. Overall, crop productivity increased. Compared to the control treatment, two of the treatment combinations had increased grain yield (13%, machine harvest; 31%, hand harvest); increased above-ground biomass (AGB, 8%); and increased harvest index (HI, 22%). Yield components also increased, including seeds/a (21%) and seed mass (7%). Variation in chlorophyll content during the grain filling period was positively related to variation in these and other response variables.

Introduction
Plant growth regulators are integral to agronomic management of crops, such as cotton, and can modify development of cereal crops. Field studies demonstrate yield benefits of growth regulators applied to wheat. For example, lodging and plant height were reduced for irrigated wheat when two growth regulators (ethephon and chlormequat chloride) were applied at flag leaf stage (Ramburan and Greenfield, 2007). Flag leaf duration of winter wheat was extended and seed yield increased with application of 6-benzylamino-purine, a cytokinin plant growth regulator (Luo et al., 2018). The research objective of this study was to evaluate effects of proprietary plant growth regulators on productivity of winter wheat.

Procedures
Tatonka hard red winter wheat was drilled (70 lb/a., 7.5-in. row spacing) on September 27, 2019. The previous crop at this site was a biomass sorghum, harvested in fall 2018 and subsequently managed with minimum-tillage. Power Flex HL (Pyroxsulam, 2 oz/a) with Preference nonionic surfactant adjuvant (32 oz/100 gal) was applied on April 1, 2020. Solid set irrigation sprinklers were installed (30-ft. centers); irrigation (1.6 in.) was applied on May 23, 2020 (Feekes 10.4, 80% heading), then the system was removed.

Plots (10- × 50-ft) were established with three sampling locations within each plot; treatment assignments were randomized. Treatments were applied on June 11, 2020 (mid-grain fill) using TT11002 nozzles with a spray boom that had 20-in. spacing, 1.5-ft above crop canopy, and operating at 22 psi at 3 mph.

Flag leaf chlorophyll content was measured using a SPAD meter; readings were taken from five flag leaves at each three sampling locations on June 11, 2020 (Chl_1) and June 16, 2020 (Chl_2). Leaf chlorophyll content was calculated from Chl (μmol/m2)

= 10 ^(M^0.265), where M is SPAD reading (Markwell et al., 1995). On June 23, 2020, triplicate samples (12-in. row lengths) were harvested and measured for AGB, grain mass, HI, and components of yield. Hand harvest occurred on June 23, 2020, and machine harvest was conducted using a plot combine on July 4, 2020.

Data were analyzed as randomized complete block experimental design, with covariate analysis.

Results

Hot conditions with some strong winds prevailed during the June grain filling period (Figure 1), delaying the application of treatments to June 11, 2020. The crop reached 80% heading (Feekes 10.4) on May 22, 2020, early flowering on May 26, 2020, and flowering (Feekes 10.5.3) on 6/1 2020.

Mean responses to experimental treatment means were adjusted for linear effects of significant covariates. In summary, relative to the control treatment (1), treatments 5 and 6 increased above-ground biomass; and grain yield (hand harvest) (Figure 2); harvest index; the yield components seeds/a; and seed mass. Treatment 5 resulted in greater yield (machine harvest), seeds per head, and increased the moisture content of above-ground biomass. No differences among experimental treatments were detected in chlorophyll content.

Variation in flag leaf chlorophyll during grain fill was positively related to variation in above-ground biomass, grain, harvest index, seeds per head, seeds/a, seed mass, and biomass moisture. Canopy extent at grain fill was positively related to variation in seeds per head and seeds/a. Grain N was negatively related to seeds/a.

Next Steps

This study is being conducted in Colby, KS, to repeat the field trial for a second growing season to confirm treatment responses.

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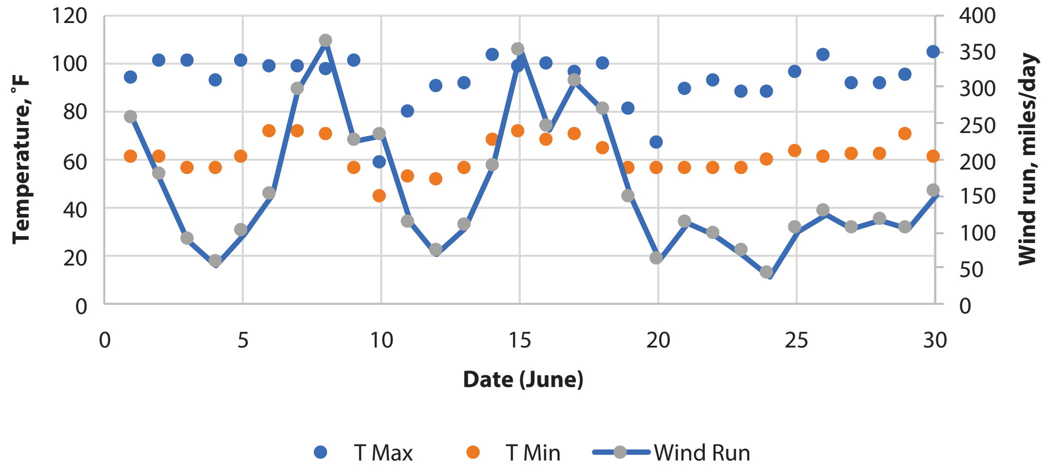
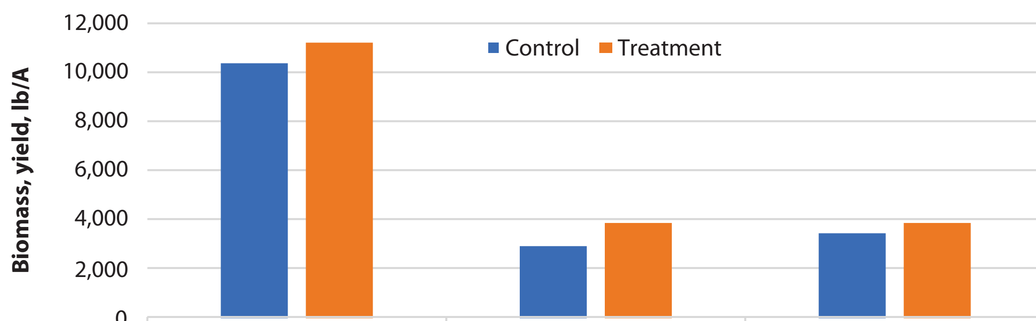


Figure 1. Temperature and wind conditions during the grain filling period at the Northwest Research-Extension Center, Colby, KS (June 2020).



	AGB	G_HH	G_CH
Control	10,357	2,911	3,418
Treatment	11,161	3,830	3,853

Figure 2. Effects of an experimental growth regulator treatment on productivity of winter wheat: Above-ground biomass (AGB), hand-harvested grain yield (G_HH) and combine-harvested grain yield (G-CH).

Winter Wheat Variety Response to Timing and Number of Fungicide Applications During the 2019–2020 Growing Season in Kansas

G. Cruppe,[1] B.R. Jaenisch, B. Valent,[1] and R.P. Lollato

Summary
The objective of this project was to evaluate the yield response of different winter wheat varieties to different fungicide management treatments during the 2019–2020 growing season in Kansas. Fourteen varieties were evaluated under four fungicide treatments (no fungicide, application either at jointing, heading, or at both stages) in five 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 late in the season. Late-season diseases had a greater effect on grain yield when compared to early-season diseases. While varieties responded differently to fungicide management, there was an overall yield increase of 1.8 bushels per acre resulting from the jointing fungicide application; 3.3 bu/a from the heading fungicide; and 4.3 bu/a from the combination of both applications. Overall, susceptible varieties had a greater response to fungicide management compared to varieties with intermediate or high levels of genetic resistance. Late-season drought and heat stress affected three out of five locations (Belleville, Conway Springs, and Hutchinson planted late), resulting in less effect of fungicide management than in the other two locations (Ashland Bottoms and Hutchinson planted in the optimal timing). Although there were some similarities, the ranking of the highest yielding varieties was not uniform across locations. 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 and on the variety.

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; de Oliveira Silva et al., 2020; Munaro et al., 2020), although the response to fungicides depends on environmental conditions (Cruppe et al., 2017). 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, partially explaining the conservative behavior of Kansas wheat producers. Given the importance of fungicides in protecting the yield potential

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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

Five rainfed field experiments were established during the 2019–2020 winter wheat growing season in different Kansas locations: Ashland Bottoms, Belleville, Conway Springs, and Hutchinson. Two experiments, sown 18 days apart, were established in Hutchinson to create distinct yield and disease environments. Four experiments were sown using no-tillage practices and following a previous soybean crop, while one experiment was established under conventional tillage practices following a previous winter canola crop (Hutchinson sown at the optimum time). Experiments were sown using a commercial no-till drill (Great Plains 606-NT drill) at a seeding rate of 2.5 million seeds/a. 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 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) using the PDIFF statement for comparisons between least square means. The effect of environment, variety, fungicide management, and their interaction were treated as fixed effects, and the 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 average maximum temperature during the 2019–2020 wheat growing season ranged from 57.7°F in Belleville to 61.9°F in Conway Springs, while the average minimum temperature ranged from 33.7°F to 39.4°F for the same locations. Ashland Bottoms had the highest precipitation rate during the season (24.2 in.) and the experiment planted after soybeans in Hutchinson had the lowest precipitation amount (13.6 in.) (Table 1). Table 1 also shows the ratio between water supply (WS) and water demand (WD), which indicates how much of the reference water evapotranspiration was supplied by precipitation. This ratio ranged from 0.4 to 0.8, indicating either that the wheat crop received enough water during the season or experienced potential drought stress (i.e. ratio closer to 1 indicates good water supply).

We grouped the occurrence of the diseases into early (i.e., present 20 d after the jointing fungicide application) and late-season diseases (i.e., present 20 d after the heading fungicide application). Septoria blotch and tan spot were the most prevalent early-season diseases and negatively affected yield in one out of the five locations. Stripe rust, leaf rust, and tan spot were the most prevalent late-season diseases and reduced yields in three out of five locations.

Variety × Fungicide Management × Environment Interactions

There was a significant interaction between variety and fungicide management, environment and fungicide management, and variety and environment. While varieties responded differently to fungicide management and there was a wide yield range within and between environments, mean yield (across varieties and environments) ranged from 55.6 bu/a with no fungicide application to 59.7 bu/a with the dual fungicide application. With a few exceptions, varieties with intermediate to high levels of genetic resistance to the most prevalent diseases present at the studies' sites (e.g. LCS Chrome, WB4269, and DoubleStop CL Plus) had little or no yield benefit from the fungicide application. On the other hand, the fungicide application either at heading or at both stages (jointing and heading) had greater beneficial effects on the yield of susceptible varieties (e.g. WB-Grainfield, WB4458, and WB4303) (Table 2).

The response to fungicide management across genotypes was greater in Ashland Bottoms and Hutchinson planted in the optimum timing, which reflects the weather conditions experienced in these two locations. Specifically, there was a yield difference of 10.6 bu/a from the dual application, 9.1 bu/a from the heading application, and 2.7 bu/a from the jointing application (not statistically different) when compared to the control in Ashland Bottoms. The same pattern was observed in Hutchinson optimum, but the magnitude of the yield benefit was smaller. On the other hand, the combination of drought and heat stress late in the season in Belleville, Conway Springs, and Hutchinson planted late might have limited the benefits of the fungicide application (Table 3).

The ranking of the highest yielding varieties was not uniform across locations. In three out of five locations, a single variety outyielded the others (LCS Chrome in Ashland Bottoms, WB-Grainfield in Belleville, and WB4269 in Hutchinson optimum). Both in Ashland Bottoms and Hutchinson optimum, the top yielding varieties also had the lowest disease ratings. Seven varieties encompassed the highest yielding group in Conway Springs (e.g. Tatanka, Bob Dole, WB-Grainfield, SY Monument, WB4303, Larry, and DoubleStop CL Plus) and three varieties were part of the top group in Hutchinson planted late (WB4269, Bentley, and Tatanka) (Table 4).

Preliminary Conclusions

The effect of foliar fungicide was neither uniform across environments nor across varieties. However, our data suggest that the application of fungicide usually out-yielded the non-fungicide control, but the degree of this benefit was dependent upon the environment (high vs. low yielding environment) and on the varieties evaluated (resistant vs. susceptible varieties). Additionally, late-season diseases had a greater impact on wheat grain yield compared to early-season diseases, which reflects the greater variety response to treatments that include the late fungicide application (i.e. at heading or the dual application).

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Table 1. Average maximum (Tmax) and minimum (Tmin) temperatures, precipitation, grass evapotranspiration (ETo), and ratio between water supply (WS) and water demand (WD) during the 2019–2020 wheat growing season for the five studied sites in Kansas

Location	Tmax	Tmin	Precip.	ETo	WS:WD
	--------------- °F	---------------	------------- inches	-------------	
Ashland Bottoms	59.3	37.0	24.2	30.3	0.80
Belleville	57.7	33.7	12.5	31.0	0.40
Conway Springs	61.9	39.4	16.4	35.9	0.46
Hutchinson (opt.)	61.7	37.2	16.8	34.5	0.49
Hutchinson (late)	59.4	34.6	13.6	30.8	0.44
Average	60.0	36.4	16.7	32.5	0.52
Max	61.9	39.4	24.2	35.9	0.80
Min	57.7	33.7	12.5	30.3	0.40

Table 2. Wheat grain yield as affected by fungicide management and variety across the five different environments in Kansas during the winter wheat season of 2019–2020. Numbers highlighted in bold indicate the highest yield within each fungicide treatment (*P* < 0.05).

	Fungicide management			
Variety	Control	Jointing application	Heading application	Dual application
	------------------------------- Grain yield (bu/a)	-------------------------------		
Bentley	56.0	57.3	**62.7**	62.9
Bob Dole	57.4	55.6	59.2	57.7
DoubleStop	57.6	59.1	59.4	58.1
Everest	52.0	55.5	53.5	56.8
Green Hammer	56.3	54.0	54.8	53.9
Larry	56.0	59.4	60.2	**63.0**
LCS Chrome	**59.1**	**60.4**	57.9	60.5
SY Monument	55.5	56.7	60.3	61.4
Tatanka	57.0	58.8	58.1	60.0
WB-Grainfield	55.9	59.1	**62.1**	**65.3**
WB4269	**60.7**	**62.0**	**62.4**	**63.7**
WB4303	52.6	54.9	57.1	58.6
WB4458	48.5	50.9	54.4	57.1
Zenda	54.0	56.7	57.0	56.5

Table 3. Wheat grain yield as affected by fungicide management and the different environments during the winter wheat season of 2019–2020. Numbers highlighted in bold indicate the highest yield within each environment ($P < 0.05$).

	Environment				
Fungicide	Ashland Bottoms	Belleville	Conway Springs	Hutchinson opt.	Hutchinson late
	Grain yield (bu/a)				
Control	57.1	51.2	**55.0**	64.3	50.6
Jointing application	59.8	51.1	**54.8**	**68.8**	51.4
Heading application	**66.2**	50.1	52.3	**69.9**	**54.1**
Dual application	**67.7**	52.6	**54.0**	**71.1**	**53.0**

Table 4. Wheat grain yield as affected by variety and the different environments during the winter wheat season of 2019–2020. Numbers highlighted in bold indicate the highest yield within each environment ($P < 0.05$).

	Environment				
Variety	Ashland Bottoms	Belleville	Conway Springs	Hutchison opt.	Hutchinson late
	Grain yield (bu/a)				
Bentley	63.4	51.8	55.0	71.3	**57.1**
Bob Dole	64.2	50.0	**57.0**	61.5	54.7
DoubleStop	65.5	49.6	**55.5**	71.4	50.6
Everest	57.7	46.6	48.8	67.4	51.7
Green Hammer	64.1	46.2	52.2	64.4	46.9
Larry	63.3	52.3	**57.1**	71.7	53.7
LCS Chrome	**71.1**	53.9	53.9	68.4	50.2
SY Monument	58.2	54.9	**55.7**	70.7	52.9
Tatanka	59.2	51.7	**58.0**	68.3	**55.2**
WB-Grainfield	65.8	**60.8**	**55.9**	67.7	53.0
WB4269	64.5	54.2	55.2	**79.8**	**57.3**
WB4303	58.2	50.0	**55.7**	64.2	50.9
WB4458	58.3	50.3	45.2	63.3	46.7
Zenda	64.1	45.1	50.6	69.1	51.2

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