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KANSAS FIELD RESEARCH 2020

K-STATE
Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

KANSAS FIELD RESEARCH 2020

Contents

4	Contributors
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Weather

6	Field Station Weather Reports
16	A Pilot Experiment to Replace Missing Rainfall Events Using Soil Moisture Information from the Kansas Mesonet

Corn

20	Tiller Contributions to Low-Density Corn Biomass and Yield
28	Dynamics of Post-Flowering Nitrogen Uptake and Nitrogen Recovery Efficiency Using ¹⁵ N Isotope Labeling in Corn
36	Corn Yield Response to Nitrogen in North-Central Kansas

Cropping and Tillage

40	Tillage Study for Corn and Soybeans: Comparing Vertical, Deep, and No-Tillage
44	Evaluation of Planting Technologies in Winter Canola

Grain Sorghum

50	Investigating the Use of Unmanned Aerial Vehicles and High-Resolution Multispectral Imagery to Characterize Grain Sorghum Senescence Patterns
55	Physiological Changes Across Historical Sorghum Hybrids Released During the Last Six Decades
61	Dryland Sorghum Nitrogen Management: Implications for Utilization as Ethanol Feedstock

Management Practices

- 66 Long-Term Cover Crop Management Effects on Soil Health in Semiarid Dryland Cropping Systems
- 71 Water Use and Productivity of Teff, a Dairy Quality Forage Crop
- 75 Water Use and Productivity of Corn and Grain Sorghum in Long-Term Crop Sequences
- 79 Dual Use of Cover Crops for Forage Production and Soil Health in Dryland Crop Production
- 87 Soil Microbial Seasonal Community Dynamics in Response to Cover Crop and Phosphorus Fertilizer Usage in a No-Till Corn-Soybean System in 2018

Soybean

- 93 Effect of Saltro Soybean Seed Treatment on Sudden Death Syndrome in Kansas in 2019
- 95 Effect of Late Season Management Practices on Soybean Seed Filling and Yield
- 100 Nitrogen and Sulfur Fertilization in Soybean: Impact on Seed Yield and Quality

Weeds

- 106 Weed Management and Soybean Yields as Influenced by Row Width and Post-Emergent Herbicide Application Timing
- 110 Efficacy of Late-Season Herbicide Programs for Controlling Palmer Amaranth in Postharvest Wheat Stubble
- 116 Response of Dicamba/Fluroxypyr/Glyphosate-Resistant Kochia to Atrazine and Alternative Postemergence Herbicides
- 122 Control of Multiple Herbicide-Resistant Palmer Amaranth in Enlist Corn
- 127 Response of Kansas Feral Rye Populations to Aggressor Herbicide and Management in CoAXium Wheat Production System

Wheat

- 134* Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2018–2019 Growing Season in Kansas
- 144* Wheat Variety-Specific Grain Yield Response to Plant Density Under Intensive Management Conditions in Western Kansas
- 157* Winter Wheat Variety-Specific Response to the Combination of Nitrogen and Foliar Fungicide in 2018–2019

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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, non-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.

2019 Weather Information

Precipitation during 2019 was almost double the average, however, five months were below average. Rainfall in May, June, and August was greater than the average by a factor of 2 times or more (Table 1). Overall, the 2019 growing season was close to average. The summer of 2019 had 30 days exceeding 90°F but none exceeding 100°F, which compared to 29 and 33 days exceeding 90°F, in 2017 and 2018, respectively. There were 11 days with low temperatures in the single digits, compared to 8 and 13 days in 2017 and 2018, respectively. The last freezing temperature in the spring was April 1 (average, April 18), and the first killing frost in the fall was October 11 (average, October 21). There were 176 frost-free days, fewer than the long-term average of 185.

The excessive rainfall made planting and field work challenging in the spring. However, the abundance of moisture was very favorable to corn, grain sorghum and soybean production. The full season corn hybrid trials averaged 155 bu/a and the short season 153, both very good for the year. The grain sorghum variety trial averaged 130 bu/a. The early maturing soybean variety trial averaged 73 bu/a and the later maturing trial 75, both outstanding.

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.

2019 Weather Information

The year was generally slightly cooler in the summer than last year, with above average rainfall during most of the growing season. The frost-free season was 182 and 181 days, respectively at Rossville and Paramore at the both units (average = 173 days), with 19 and 18 days in the single digits or lower at Rossville and Paramore, respectively. This was similar to 2018 but significantly more compared to 9 days in single digits at both units in 2017. The last spring freeze was April 13 (average = April 21), and the first fall freeze was October 11 (average = October 11). There were 30 and 31 days above 90°F at Paramore and Rossville, respectively, and none above 100°F. Precipitation was well above normal at both fields for the year (Table 2), with 7 months over average, especially May and August, which were 3 to 4 times greater than average. Irrigation requirements averaged 4.8 inches for the corn and 1.5 inches for the soybeans. The corn performance trials averaged 229 bu/a for the irrigated and 220 for the dryland. The soybean performance trials averaged 63 bu/a for the irrigated and 82 bu/a for the dryland. The sudden death syndrome foliar symptoms were not visible until mid-August in most fields in 2019, however, severity increased quickly, 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	2019	35-year avg.	Month	2019	35-year avg.
	----- in. -----			----- in. -----	
January	1.84	1.03	July	3.51	3.37
February	1.13	1.32	August	14.19	3.59
March	2.25	2.49	September	5.30	3.83
April	6.63	3.50	October	2.33	3.43
May	13.64	5.23	November	0.99	2.32
June	10.54	5.21	December	1.08	1.45
			Annual total	63.43	36.78

Table 2. Precipitation at the Kansas River Valley Experiment Field

Table 2. Precipitation at the Kansas River Valley Experiment Field				
Month	Rossville Unit		Paramore Unit	
	2019	30-year avg.	2019	30-year avg.
	----- in.-----		----- in.-----	
January	1.12	3.18	1.12	3.08
February	1.18	4.88	1.12	4.45
March	2.63	5.46	2.27	5.54
April	2.88	3.67	3.88	3.59
May	11.20	3.44	11.28	3.89
June	6.69	4.64	4.53	3.81
July	2.95	2.97	4.77	3.06
August	9.00	1.90	9.20	1.93
September	1.94	1.24	2.53	1.43
October	2.55	0.95	1.58	0.95
November	0.98	0.89	0.75	1.04
December	1.85	2.42	1.94	2.46
Total	44.97	35.64	44.97	35.23

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

Month	Ashland Bottoms		Belleville		Colby	
	2019	30-year average	2019	30-year average	2019	30-year average
	----- in. -----					
January	1.23	0.65	0.23	0.61	0.16	0.41
February	1.29	1.07	0.26	0.87	0.27	0.48
March	2.44	2.20	1.72	2.12	2.39	1.12
April	2.20	2.80	1.18	2.87	0.16	2.03
May	12.10	4.48	7.60	4.35	6.84	3.29
June	5.71	5.09	6.62	4.37	2.70	2.54
July	2.30	3.97	3.12	3.97	1.00	3.77
August	8.60	4.28	6.09	3.68	8.79	2.78
September	2.35	3.17	1.80	3.25	0.55	1.45
October	2.73	2.22	2.46	2.37	0.78	1.58
November	0.61	1.60	0.43	1.19	0.49	0.72
December	1.06	1.02	1.85	0.95	0.56	0.48
Annual	42.62	32.55	33.36	30.6	24.69	20.65
Last freeze	10/11/19		10/11/19		5/1/19	
First freeze	4/13/19		4/13/19		10/10/19	
Frost free days	181		181		162	
Days above 90°F	28		26		40	
Days above 100°F	0		0		5	
Days below 10°F	18		32		22	

Table 4. Precipitation at Great Bend, Hays, and Hutchinson

Month	Great Bend		Hays		Hutchinson	
	2019	30-year average	2019	30-year average	2019	30-year average
	----- in. -----					
January	0.16	0.61	0.53	0.50	0.70	0.50
February	0.27	0.83	0.33	0.71	0.87	0.71
March	2.39	1.94	0.69	1.81	1.74	1.81
April	0.16	2.36	0.90	2.14	2.06	2.14
May	6.84	4.38	7.76	3.26	12.23	3.26
June	2.70	3.97	1.59	2.83	4.49	2.83
July	1.00	3.41	0.96	3.92	0.42	3.92
August	8.79	3.33	12.51	3.04	6.02	3.04
September	0.55	1.96	1.57	2.05	0.29	2.05
October	0.78	2.05	1.51	1.58	0.93	1.58
November	0.49	0.97	0.38	0.89	0.45	0.89
December	0.56	0.85	2.34	0.72	1.29	0.72
Annual	24.69	26.66	31.07	23.45	31.49	23.45
Last freeze	4/19/19		4/28/19		4/14/19	
First freeze	10/11/19		10/10/19		10/11/19	
Frost free days	175		165		180	
Days above 90°F	58		65		60	
Days above 100°F	6		10		6	
Days below 10°F	17		16		9	

Table 5. Precipitation at Leoti, Manhattan, and Ottawa

Month	Leoti		Manhattan North Farm		Ottawa	
	2019	30-year average	2019	30-year average	2019	30-year average
	----- in. -----					
January	0.06	0.42	1.36	0.63	1.84	0.63
February	0.37	0.53	1.38	1.08	1.13	1.08
March	1.49	1.38	2.21	2.49	2.25	2.49
April	0.12	2.00	2.74	3.17	6.63	3.17
May	4.13	2.57	10.56	5.09	13.64	5.09
June	1.30	2.58	6.17	5.70	10.54	5.70
July	3.24	2.90	5.54	4.42	3.51	4.42
August	2.36	2.79	9.91	4.12	14.19	4.12
September	1.84	1.57	2.75	3.43	5.30	3.43
October	0.63	1.47	2.40	2.69	2.33	2.69
November	0.06	0.65	0.29	1.73	0.99	1.73
December	0.42	0.57	0.70	1.07	1.08	1.07
Annual	16.02	19.43	46.01	35.62	63.43	35.62
Last freeze	4/19/19		4/13/19		4/13/19	
First freeze	10/10/19		10/12/19		10/11/19	
Frost free days	174		182		181	
Days above 90°F	61		39		33	
Days above 100°F	7		1		0	
Days below 10°F	20		15		12	

Table 6. Precipitation at Silver Lake (Paramore), Rossville, and Scandia

Month	Silver Lake		Rossville		Scandia	
	2019	30-year average	2019	30-year average	2019	30-year average
	----- in. -----					
January	1.12	3.18	1.12	3.18	0.27	0.45
February	1.12	4.88	1.18	4.88	0.37	0.74
March	2.27	5.46	2.63	5.46	2.22	2.12
April	3.88	3.67	2.88	3.67	0.60	2.96
May	11.28	3.44	11.20	3.44	7.06	4.21
June	4.53	4.64	6.69	4.64	5.63	3.81
July	4.77	2.97	2.95	2.97	3.11	4.24
August	9.20	1.90	9.00	1.90	4.67	3.26
September	2.53	1.24	1.94	1.24	1.76	2.84
October	1.58	0.95	2.55	0.95	2.67	2.14
November	0.75	0.89	0.98	0.89	0.25	1.26
December	1.94	2.42	1.85	2.42	2.25	0.79
Annual	44.97	35.64	44.97	35.64	30.86	28.82
Last freeze	4/13/19		4/13/19		4/14/19	
First freeze	10/11/19		10/11/19		10/11/19	
Frost free days	181		181		180	
Days above 90°F	30		25		21	
Days above 100°F	0		0		0	
Days below 10°F	17		18		33	

Table 7. Precipitation at Brownell (HB Ranch), Caldwell (Wellington), and Harper

Month	Brownell (Ness City)		Caldwell (Wellington)		Harper	
	2019	30-year average	2019	30-year average	2019	30-year average
	----- in. -----					
January	0.37	0.53	1.14	1.00	1.21	1.00
February	0.30	0.67	0.84	1.36	0.53	1.19
March	0.68	1.74	2.32	2.93	1.81	2.99
April	0.89	1.94	3.46	2.96	3.79	3.18
May	7.43	3.08	21.8	4.74	12.05	4.71
June	2.97	3.06	2.52	5.53	8.40	5.20
July	0.59	3.52	0.78	3.56	1.05	3.27
August	3.21	2.80	8.85	3.72	3.40	2.95
September	0.38	1.84	5.86	2.58	2.71	2.79
October	1.61	1.46	5.35	3.16	4.75	2.74
November	0.29	0.88	0.71	1.92	0.75	1.88
December	1.94	0.74	1.89	1.24	0.99	1.25
Annual	20.66	22.26	55.52	34.70	41.44	33.15
Last freeze	4/19/19		4/13/19		4/14/19	
First freeze	10/10/19		10/29/19		10/11/19	
Frost free days	174		199		180	
Days above 90°F	60		58		65	
Days above 100°F	8		6		4	
Days below 10°F	18		17		5	

Table 8. Precipitation at Lakin, La Crosse, and Garden City

Month	Lakin		La Crosse		Garden City	
	2019	30-year average	2019	30-year average	2019	30-year average
----- in. -----						
January	0.36	0.34	0.38	0.58	0.34	0.47
February	0.59	0.44	0.24	0.84	0.75	0.52
March	1.89	0.98	0.25	1.85	2.08	1.23
April	0.04	1.55	1.39	2.33	0.09	1.74
May	5.48	2.54	9.43	4.08	5.87	3.00
June	2.30	3.19	2.24	3.90	1.11	3.10
July	1.11	2.88	2.05	3.69	2.07	2.80
August	2.58	2.65	7.19	3.00	1.54	2.51
September	0.13	1.57	0.09	2.17	0.14	1.42
October	0.20	1.44	0.30	1.57	0.37	1.22
November	0.10	0.60	0.00	0.99	0.23	0.54
December	0.90	0.60	0.00	0.86	1.23	0.60
Annual	15.68	18.78	23.56	25.86	15.82	19.15
Last freeze	5/22/19		4/14/19		4/19/19	
First freeze	10/8/19		10/10/19		10/10/19	
Frost free days	139		179		174	
Days above 90°F	68		55		70	
Days above 100°F	7		6		11	
Days below 10°F	21		18		20	

Table 9. Precipitation at Goodland, Concordia, and Beloit

Month	Goodland		Concordia		Beloit	
	2019	30-year average	2019	30-year average	2019	30-year average
January	0.33	0.38	1.11	0.38	1.03	0.62
February	0.40	0.49	1.61	0.49	1.35	0.76
March	1.17	1.07	2.31	1.07	1.89	1.91
April	0.38	1.59	1.44	1.59	1.07	2.47
May	5.10	2.95	9.55	2.95	8.41	4.16
June	2.26	3.25	5.08	3.25	3.98	3.81
July	1.71	3.47	2.38	3.47	1.94	4.36
August	9.47	2.70	6.46	2.70	8.65	3.09
September	0.65	1.22	1.80	1.22	1.17	2.64
October	0.26	1.37	1.74	1.37	2.32	1.99
November	0.75	0.71	0.41	0.71	0.27	1.21
December	0.30	0.46	1.77	0.46	2.31	0.90
Annual	22.78	19.66	35.66	19.66	34.39	27.92
Last freeze	5/2/19		4/15/19			
First freeze	10/10/19		10/11/19			
Frost free days	161		179			
Days above 90°F	44		21		36	
Days above 100°F	4		0		3	
Days below 10°F	23		25		23	

A Pilot Experiment to Replace Missing Rainfall Events Using Soil Moisture Information from the Kansas Mesonet

N. Parker and A. Patrignani

Summary

The Kansas Mesonet is a state-of-the-art environmental monitoring network that provides accurate rainfall measurements across Kansas. However, missing rainfall records are common problems in weather stations that rely on tipping bucket rain gauges. In this study, we conducted a pilot experiment to estimate missing rainfall records from root-zone soil moisture information recorded at Kansas Mesonet stations. Soil moisture is recorded at depths of 5, 10, 20, and 50 cm using the Campbell Scientific CS655 soil water reflectometer. Hourly rainfall and soil moisture data from mid-August 2017 to mid-May 2018 were taken from three stations (Lakin, Manhattan, and Hays) of the Kansas Mesonet. Rainfall was estimated as the difference in soil moisture storage between 1 hour before and 1 hour after a given rainfall event. Preliminary results show that soil moisture-derived rainfall can be more accurate than using rainfall data from nearby stations. Soil moisture could serve as very useful information in quality control procedures to flag missing rainfall events.

Introduction

Rainfall is the main water input in the soil water balance and serves as the major source of water supply to Kansas rainfed agricultural systems, surface water reservoirs, streams, and aquifers. Accurate rainfall information is therefore vital in monitoring drought, flood, and determining runoff and groundwater recharge rates. However, missing rainfall is a recurring problem in weather monitoring stations that rely on a tipping bucket rain gauge (the most commonly used rain gauge type for rainfall measurement) due to instrument malfunction, bucket collector clogging by spider webs and dust, and distortion by high winds and flooding (Sypka, 2019). The simplest and most popular existing method for missing rainfall estimation is using rainfall data from neighboring weather stations (i.e. same variable from a different station), which may not be representative of the missing record due to the spatial variability of rainfall.

In recent years, the growing number of in situ environmental monitoring networks measuring both atmospheric and soil moisture variables (Dorigo et al., 2011) provides new opportunities to fill precipitation gaps caused by malfunctioning of the tipping bucket rain gauges. Can we compute missing rainfall records using in situ soil moisture information (i.e. located at the same station) instead of using rainfall data from neighboring stations? The objective of this study was to estimate missing rainfall records using in situ soil moisture observations.

Procedures

Rainfall and soil moisture data used in this study were obtained from the Kansas Mesonet. The Kansas Mesonet is a network of weather stations established by K-State

Research and Extension in 1986 and currently consists of 40 out of the 60 total stations that monitor root zone soil moisture across the state of Kansas. The stations monitoring soil moisture have CS655 soil moisture sensors (Campbell Scientific Inc.) installed at 5, 10, 20, and 50 cm depths in the soil profile (Kansas Mesonet, accessed January 5, 2020).

Hourly rainfall and soil moisture data from mid-August 2017 to mid-May 2018 were taken from three stations of the Kansas Mesonet. The stations were: (1) Lakin located in Kearny County in western Kansas with a sandy loam-textured soil, (2) Manhattan in Riley County in northeastern Kansas with silty clay loam soil, and (3) Hays in Ellis County in central Kansas with silty loam.

Soil moisture-derived rainfall at a given location was estimated as the difference between the profile soil moisture storage 1 hour before the rainfall event and the storage at 1 hour after the rain. In addition, we took the rainfall data from the nearest neighboring station to each of the three locations to help assess the performance of soil moisture-estimated rainfall as against that of the neighboring station data in predicting missing rainfall events. The nearest neighbor stations to Lakin, Manhattan, and Hays Mesonet respectively, are Grant (15 miles from Lakin), Ashland Bottoms (5 miles from Manhattan), and La Crosse (19 miles from Hays).

Results and Discussion

There were 13 total hourly rainfall events in Lakin. The median amount was 6.3 mm and lasted for 4 hours while the maximum, 44.2 mm, and minimum, 1.3 mm lasted for 15 and 4 hours, respectively (Figure 1-A). The Manhattan station (Figure 1-C) recorded 42 hourly rainfall events in total with a median of 3 mm lasting for 4 hours while the maximum, 33.3 mm, and minimum, 1 mm, lasted for 7 and 5 hours, respectively. Hays (Figure 1-E) had 21 total number of events with the median, 3.6 mm lasting for 2 hours while the maximum, 28.7 mm and minimum, 1 mm, lasting for 10 hours, and 2 hours, respectively.

The estimated rainfall from in situ soil moisture was more highly correlated with the observed rainfall measurement from a rain gauge ($R = 0.92, 0.96, \text{ and } 0.94$, respectively) than estimation from the nearest station rainfall ($R = 0.8, 0.84, \text{ and } 0.49$, respectively) in Lakin, Manhattan, and Hays (Figure 1). Likewise, the rainfall estimation error from soil moisture was lower (root mean square error [RMSE] = 6, 3.3, and 6.5 mm, respectively) than that of the nearest station data (RMSE = 9 mm, 4.3 mm, and 10.5 mm, respectively) in Lakin, Manhattan, and Hays. Ashland Bottoms, located 5 miles from the Manhattan station, is much closer than the neighboring stations to Lakin and Hays and thus gave the best performance ($R = 0.84$, RMSE = 4.3 mm) for the nearest station method (Figure 1-D); however, it still performed poorer than the soil moisture approach. Occasionally, our proposed soil moisture method underestimated rainfall events totaling more than 30 mm due to the soil reaching saturation because of the high preceding soil moisture conditions. In some cases, it overestimated rainfall events exceeding 30 mm due to the infiltration of run-on water from the catchment.

Our preliminary results suggest that soil could serve as a natural rain gauge for the estimation of missing precipitation records. Soil moisture-derived rainfall resulted in a more accurate estimation of precipitation than using rainfall measurements from

nearby stations. Soil moisture information could be used in quality control procedures to flag missing rainfall events.

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Figure 1. Predicted rainfall from in situ soil moisture (subplots A, C, and E) and data from the nearest station (subplots B, D, and F) compared to the observed rainfall from a rain gauge. N is the number of hourly rainfall events analyzed and numbers in parenthesis represent the rainfall duration of the particular rainfall amount.

Tiller Contributions to Low-Density Corn Biomass and Yield

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Summary

Tillers (commonly termed “suckers”) have lower overall yield contributions in corn (*Zea mays* L.) than in other Poaceae species. Current research evaluating the value of tillers in corn is scarce, particularly under water-limited conditions. This study aims to quantify relationships between tiller, main plant, and full (considering both tiller and main plant fractions) plant aboveground biomass and yields of corn under low plant density scenarios. Experiments were conducted in the 2019 growing season at three sites across Kansas (Garden City, Goodland, and Manhattan) evaluating two tiller-prone corn hybrids common in this region (P0805AM and P0657AM) at two plant densities (10,000 and 17,000 plants/a) with tiller maintenance (YT) or tiller removal (NT) at the V10 growth stage (tenth leaf). Treatments were set in a split-split-plot under a randomized complete block design (RCBD) with three replications. Results showed that full shoot dry biomass at maturity was neutrally or positively influenced by both tiller presence and an increase in plant density. Although yield from ears on the main plant (herein termed as “main plant yields”) can be negatively impacted by tillers, full yield of all portions of the plant (herein “full plant yields”) were neutrally or positively influenced by tiller contributions. Tiller yield variation in this study was influenced by tiller reproductive development, specifically tassel and lateral ear types. Responsible mechanisms and environmental factors influencing these development processes remain largely unknown, and this will be the focus of continuing studies.

Introduction

Tillering is a genetically influenced environmental plasticity response that has historically been under great debate among corn producers, agronomists, and researchers. Tillers (commonly “suckers”) are induced by favorable environmental conditions in cereals, but due to relatively late development of tillers in corn, overall productivity contributions are less than in other Poaceae species. Current research evaluating the overall value of tillers to corn plant productivity is scarce, particularly under water-limited conditions. Because corn planted in water-limited or dryland environments, specifically in western Kansas, is commonly intended for final stands less than 20,000 plants/a, conditions are prime for tiller development given the use of conducive hybrids. Of particular interest in corn is the effect that tillers have on productivity of the main stalk (thus their nickname, “suckers”). Fact-based conclusions regarding tillering implications in modern corn hybrids are elusive. For this reason, the objective of this study was to quantify relationships between tiller, main plant, and full plant aboveground biomass and yields of corn under low plant density scenarios.

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Procedures

Data discussed here were gathered in the first year (2019) of a multi-year study conducted across the state of Kansas, at experimental field locations at the Ashland Bottoms Research Farm, Manhattan, KS (39.143°N, -96.639°W); Corteva Agriscience Research and Development Center, Garden City, KS (37.827°N, -100.857°W); and a Corteva Agriscience yield test AOI (Area of Interest), Goodland, KS (39.249°N, -101.782°W). Garden City and Goodland were maintained under limited irrigation, and Ashland Bottoms was a true dryland location. All plots were fertilized as necessary to avoid any deficiencies and maintained with appropriate pesticides. Eight-row plots were planted at 30-in. row spacing, with final dimensions of 20-ft wide × 30-ft long at Ashland Bottoms, and 20-ft wide × 17.4-ft long in Garden City and Goodland.

Plots were arranged in a split-split plot design, with three factors evaluated: planting density with two levels in the main plot, genotype with two levels in the sub-plot, and tiller treatment with two levels in the sub-sub-plot. For both levels of plant density [low (10,000 plants/a) and average (17,000 plants/a)], two Pioneer corn hybrids common in the selected region (P0805AM and P0657AM), and two tiller treatments [removal (NT) or maintenance (YT) of tillers present at phenological stage V10, as shown in Figure 1] were evaluated.

Measurements throughout the growing season included phenology; stand counts; tiller counts; partitioned dry shoot biomass at set phenological stages of fifth-leaf (V5), tenth-leaf (V10), pre-flowering (V16), reproductive milk stage (R3), and physiological maturity (R6); ear characterization counts; and partitioned grain yields. Partitioned shoot biomass was calculated by dividing aboveground dry biomass by component (tiller and main plant). Ear characterization counts were conducted at harvest, and accounted for the percentage of ears in a plot that belonged to each of three determined categories – main plant lateral ears (productive), tiller lateral ears (productive), and tiller apical ears (commonly “tassel ears,” unproductive), as shown in Figure 2. Final yields were also partitioned by ear type.

Our selected organization structure allowed for direct comparison and quantification of the effect of corn tillers on both the full plant and the main plant. Data were classified in all cases 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, each experimental location was analyzed separately. Analysis of variance (ANOVA) was performed to determine the significance of nested factors in the experimental design with regard to both final biomass measurements and harvest data. All statistical analysis was performed with R software.

Results

Mature Aboveground Biomass

While season-long biomass dynamics were measured, only R6 dry shoot biomass (measured at harvest) will be discussed in this report for the sake of simplicity. Mature biomass contributions by partition and location are shown in Figure 3.

Full plant dry biomass at Ashland Bottoms was similar when comparing the plots planted to the highest density with the plots containing intact tillers. Because main plant biomass was only affected by plant density, tillers had the same effect as a higher density on full plant biomass.

Main plant dry biomass values were significantly influenced by tiller presence in Garden City, which would be expected considering the added competition for resources. However, full plant and tiller biomass were not different considering any treatment in Garden City. That is, tillers had a completely neutral, balancing effect on full biomass in this location.

Biomass results in Goodland ultimately told the same story. Main biomass values were influenced by specific interactions of factors, resulting in significance only for one treatment with regard to hybrid (H), two treatments with regard to density (D), and two with regard to tiller (T) treatment. Although tiller biomass was stable across treatments, full biomass again experienced a balancing effect, resulting in no treatment difference when comparing D or T individually.

Final Grain Yield

Full grain yields partitioned by ear type are shown in Figure 4. Locations ordered by lowest to highest yield potential were as follows: Ashland Bottoms (100 bu/a), Garden City (150 bu/a), and Goodland (180 bu/a). Contributions from both tiller tassel ears and tiller lateral ears to full yields were different in all locations, with Garden City having the greatest yield from tiller tassel ears and Goodland having the greatest yield from tiller lateral ears. These contributions affected the significance of full yield differences between treatments.

Final yields at Ashland Bottoms were significantly lower in the 10,000 plants/a density for only one of the hybrids (P0805AM at 68 bu/a). The P0805AM hybrid yielded 94 bu/a at the 17,000 plants/a density, and the P0657AM hybrid yielded 92 bu/a and 86 bu/a for the 10,000 and 17,000 plants/a densities, respectively. In this regard, the presence of tillers had no effect on yields in this location.

Garden City full yields were not significantly different from each other considering any of the individual treatments applied. Plots without tillers (NT) yielded 144 bu/a and 160 bu/a for the 10,000 and 17,000 plants/a densities, respectively. Plots with tillers (YT) yielded 140 bu/a and 150 bu/a for the 10,000 and 17,000 plants/a densities, respectively. All treatment factors considered, tillers had a neutral effect on yields in this location also.

Considering full yields in Goodland, the only value significantly different from its counterparts was the lowest density without tillers, which yielded 152 bu/a. The 10,000 plants/a density with tillers (YT) yielded 173 bu/a, while the 17,000 plants/a density yielded 186 bu/a and 190 bu/a for plots without (NT) and with (YT) tillers, respectively. In this regard, plots with tillers (YT) were able to produce yields similar to those of plots with a 68% greater plant density (see Figure 5). Tillers in the higher plant density had no effect on final yield.

Ear Development Yield Impacts

To better understand tiller yield contributions, characterization of ear types was warranted. Results of ANOVA tests revealed that tiller ear counts were only significantly influenced by density ($P \leq 0.05$), and specifically in the Goodland location. Ear type characterization percentages for plots with maintained tillers (YT) are shown in Figure 6.

Of the total ears produced by plots at Ashland Bottoms, 25% and 4% were classified as tiller tassel (apical) ears in the low and average densities, respectively; 7% and 1% were classified as tiller lateral ears in the low and average densities, respectively.

Of the total ears produced in Garden City plots, 29% and 11% were classified as tiller tassel (apical ears) for the low and average densities, respectively; 13% and 6% were classified as tiller lateral ears for the low and average densities, respectively.

Of the total ears produced by plots in Goodland, less than 1% were classified as tiller tassel (apical) ears in both the low and average densities; 35% and 10% were classified as tiller lateral ears in the low and average densities, respectively.

Considering all locations and densities, Goodland plots planted at 10,000 plants/a produced the greatest percentage of tiller lateral ears (35% of total ears harvested), and Garden City plots planted at 10,000 plants/a produced the greatest percentage of tiller apical ears (29% of total ears harvested).

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Figure 1. Images demonstrating tiller biomass at time of removal (V10, tenth leaf). Right panel shows plot with tillers intact (YT). Left panel shows plot with tillers removed (NT).

Figure 2. Images illustrating difference in tiller ear development at low densities. Right panel shows a prolific main stalk with a productive, lateral ear-bearing tiller. Left panel shows multiple plants with tillers developing undesirable “tassel ears.”

Figure 3. Mean R6 dry shoot biomass and mean comparisons (Tukey) for each factor level deemed significant by ANOVA tests considering each partition and location separately. (Lowercase letters used to compare densities at a given factor level; uppercase letters used to compare tiller treatments at a given factor level; uppercase italic letters used to compare hybrids at a given factor level.)

Figure 4. Mean full grain yields (15% moisture) and mean comparisons (Tukey) for each factor level deemed significant by ANOVA tests considering each partition and location separately. (Lowercase letters used to compare densities at a given factor level; uppercase letters used to compare tiller treatments at a given factor level; uppercase italic letters used to compare hybrids at a given factor level.)

Figure 5. Images demonstrating yield potential of corn tillers in different densities. Right panel shows prolific main stalk with two productive tillers in a 10,000 plants/a population. Left panel shows a main stalk with two productive tillers in a 17,000 plants/a population.

Figure 6. Characterization of ear types by density within location (only level deemed significant by ANOVA tests). Each ear type shown by percentage of total harvested ear count. Only YT plots (*maintained tillers*) were considered.

Dynamics of Post-Flowering Nitrogen Uptake and Nitrogen Recovery Efficiency Using ^{15}N Isotope Labeling in Corn

J.A. Fernandez, J.B. Nippert, and I.A. Ciampitti

Summary

In corn (*Zea mays* L.), breeding and selection for grain yield over time has been accompanied by a simultaneous increase in plant nitrogen (N) uptake. The understanding of plant N dynamics has attracted attention due to the environmental concerns related to N losses coming from fertilization. This research study was implemented to 1) describe N uptake and allocation dynamics, and 2) quantify fertilizer recovery efficiency across late-N strategies. Two field experiments (one under irrigation and one rainfed) were conducted at the Ashland Bottoms Research Farm, KS, during 2017. Three hybrids with different year of release and three N scenarios were tested. Isotope ^{15}N was utilized as tracer to determine ^{15}N recovery and N fate within plant organs when both timings of late-N were evaluated. As ^{15}N fertilizer was applied later in the season, lower recovery of the fertilizer was achieved and proportionally more N was allocated to the developing grains. These findings can motivate future investigations using ^{15}N labelling technique to evaluate fertilizer recovery efficiency in corn.

Introduction

Over time, breeding and selection for grain yield in corn has been accompanied by a simultaneous increase in N uptake (Ciampitti and Vyn, 2012; Haegele et al., 2013). The understanding of plant N dynamics has attracted attention due to the environmental concerns related to N losses coming from fertilization. Although late-season N-fertilization could be used as an alternative to synchronize N supply and demand, benefits of delayed N application strategies have not been consistently reported. A recent meta-analysis provided evidence for a lack of a repeatable effect of late N application on yield (Fernandez et al., 2020), but specifically quantified when late N might improve yield. Therefore, studies on post-flowering N uptake are necessary in order to warrant an efficient utilization of N. Integration of physiological indicators within the plant can help us identify productive opportunities to realize suitable fertilization strategies. The objectives of this study are to 1) describe N uptake and allocation dynamics, and 2) quantify fertilizer recovery efficiency across late-N strategies.

Procedures

Field Experiments

Two field experiments (one under irrigation and one rainfed) were conducted at the Ashland Bottoms Research Farm, Manhattan, KS, 2017 (39°08' N, 96°37' W). Soil analyses were conducted at pre-planting to characterize initial conditions. Overall, the area presented pH of 5.9, soil organic matter (SOM) 1.34%, 50 ppm of phosphorus (P) (Mehlich), and 158 ppm of potassium (K) at 6-inch soil depth. Table 1 presents climatic data for the growing season.

The experimental design consisted of a split plot design with two factors evaluated: genotype with three levels in the main plot, and fertilizer N rate with three levels in the sub-plot. Three hybrids with different year of release (3394, 1991; P1151, 2005; and P1197, 2014) and three N scenarios (zero N, N0; fertilized with N at R1 - flowering, NL1; and fertilized with N two weeks after R1, NL2) were tested in both studies. The studies were planted on May 5, 2017, in plots of 4 rows, 30 in. apart, and size of 10-ft wide × 70-ft long. For the two fertilized treatments, an initial 50 lb/a was added at planting, and a second application was added at V6 growth stage (50 lb/a and 100 lb/a for dryland and irrigated, respectively). Depending on the treatment, the last application (22 lb/a and 44 lb/a for dryland and irrigated, respectively) was performed at flowering (R1; Ritchie et al., 1997) or two weeks after R1. Total fertilizer N rate applied for the treatments receiving N was 122 lb/a for the rainfed and 194 lb/a for the irrigated condition. The experimental area was kept free of weeds, pests, and diseases during the growing season.

Isotopic Labeled Fertilizer Application and Calculation of ^{15}N Abundance

Isotope ^{15}N was utilized as tracer to determine ^{15}N recovery and N fate within plant organs when both timings of late-N were evaluated. For this evaluation, two 5-plant microplots, one for each ^{15}N -timing, were established within each experimental unit in order to trace the fate of N at R1 and two weeks after R1. Labeled fertilizer $\text{Ca}(\text{NO}_3)_2$ (10.15% ^{15}N) at 1 g per plant was applied with plastic syringes on both sides of the plants after diluting in 30 mL of water. Fertilizer was injected using the methodology employed in de Oliveira Silva et al. (2017), and the three center plants from each microplot were harvested five days after the ^{15}N application. Additionally, non-enriched plants were sampled to determine the background ^{15}N abundance in the fertilized and unfertilized soils, in order to account for possible small variations in the standard values of natural ^{15}N abundance (Cabrera and Kissel, 1989; Högborg, 1997). Plants were separated into leaves (leaf blades), stem (stems + leaf sheaths + tassels), ear (husks + cobs), and grain fractions; after that, samples were dried at 150°F until constant weight, and then ground through a 0.10 mm sieve for laboratory analyses. Nitrogen content and ^{15}N abundance were determined using an elemental analyzer (EA) coupled to an isotope ratio mass spectrometer (IRMS) at the Kansas State University Stable Isotope Mass Spectrometry Laboratory.

For each plant fraction, the atom percentage excess [At% (^{15}N)Excess] was calculated using the following equation:

$$\text{At\% } (^{15}\text{N})\text{Excess} = \text{At\% } (^{15}\text{N})_{\text{sample}} - \text{At\% } (^{15}\text{N})_{\text{control}}$$

, where $\text{At\% } (^{15}\text{N})_{\text{sample}}$ represents the percentage of ^{15}N abundance in the ^{15}N labeled samples, and $\text{At\% } (^{15}\text{N})_{\text{control}}$ corresponds to the percentage of ^{15}N abundance in non-labeled control plants.

Total ^{15}N uptake expressed in lb/a was estimated by the following equation:

$$^{15}\text{N uptake} = \text{N uptake} \times \left(\frac{\text{At\% } (^{15}\text{N}) \text{ Excess}}{100} \right)$$

, where N uptake per plant fraction is expressed in lb/a.

^{15}N uptake rate expressed in lb/a/ $^{\circ}\text{C}$ day was obtained as follows:

$$^{15}\text{N uptake rate} = \frac{^{15}\text{N uptake}}{\text{Thermal time between fertilizer application and sampling}}$$

Lastly, ^{15}N recovery lb/lb was calculated according to the following equation:

$$^{15}\text{N recovery} = \frac{^{15}\text{N uptake}}{^{15}\text{N applied}}$$

, where ^{15}N applied denotes the amount of N applied (lb/a) multiplied by At% (^{15}N) $\text{Excess}_{\text{fertilizer}}$

Statistical Analyses

Data were subjected to an analysis of variance (ANOVA) for each studied trait at the 2017 sites. Mixed effects models were fitted to the data using R program (version 3.6.1) in RStudio interface (RStudio Team, 2016). We combined the data from both studies (irrigated and dryland) and accounted for the study difference by including a site-level random effect. Adjustments on the distributional assumption of the residuals were taken into consideration for model fitting. Homogeneity of error variances was verified by plotting the residuals and fitted values. Significance of the factors were tested via ANOVA Type 3 tests using the *car* (Fox and Weisberg, 2019) package. Differences between the mean values of each treatment were determined by the LSD Fisher test ($\alpha = 0.05$) with *emmeans* (Lenth, 2019) package.

Results

Non-significant interactions between factors for yield and numerical components allowed for inferences at a marginal mean level. Figure 1 summarizes the average yield for N fertilization levels (N) and corn hybrids (H) evaluated in the 2017 experiment. Differences in yield were significant between N and H treatments ($P < 0.05$). Fertilized treatments differed from the zero N treatment. However, the two weeks delay of the last N application did not cause significant yield variations across these hybrids. Comparing genotypes, grain yield increased with year of introduction of each hybrid and, accordingly, the modern material (P1197, 206 bu/a) outyielded the older genotype (3394, 177 bu/a).

Figure 2 summarizes estimates for ^{15}N uptake rate (A) and (B), and for ^{15}N fertilizer recovery (C) and (D) across fertilizer N rate levels in the experiment at R1 and two weeks after R1. No evidence for interactions between sampling time, N, and genotypes were detected for ^{15}N uptake rate, allowing for inferences at a marginal mean level for each of the factors. In this way, differences in uptake rate were significant across sampling time ($P < 0.001$), but not for N treatments (Figure 2A and B).

Regarding ^{15}N recovery (at physiological maturity), a significant 2-way interaction between sampling time and N treatment was observed, so pairwise comparisons were performed across N levels within each sampling time. At R1, greater recovery efficiency was identified for both fertilized treatments when compared to the control without applied N (Figure 2C). In parallel, a significant increase over the zero N control was

observed at mid-grain filling only when N was delayed two weeks after R1 (Figure 2D). Respecting hybrids, no evidence for differences was detected in fertilizer recovery efficiency ($\alpha = 0.05$). However, it is important to consider that for this experiment reduced statistical power for H factor (whole plot) might be restraining inferences at this level.

Plant dynamics of N absorbed from R1 to maturity were quantified with ^{15}N fertilizer to investigate whether different N fertilization strategies have altered the fate and efficiency of N absorbed during the reproductive period. The proportion of ^{15}N uptake partitioned into leaves, stem, ear (cob + husk), and grains for each N treatment are represented in Figure 3. Nitrogen partitioning at physiological maturity allow us to conclude that plants differed in the allocation of post-flowering N depending on the supply of N. However, no changes were identified between late-season fertilization treatments. When N was applied, hybrids were proportionally more efficient in the allocation of post-flowering N towards the grains (Figure 3D). This difference was principally related to a reduced conservation of N in cob and husks (Figure 3C). In addition, a significant percentage of N from post-flowering uptake was present in stem tissue at maturity (from 0.12 to 0.13 lb/lb N absorbed, Figure 3B). Ning et al. (2017) concluded that this N retention in stems could constrain N utilization efficiency, especially under high N supply.

The current study proposes the utilization of isotope ^{15}N as tracer to describe N dynamics among hybrids under a late-N fertilization strategy. Results showed that as N fertilizer was applied in later reproductive stages, lower recovery of the fertilizer was achieved. These results acquire relevance considering that both yield and total N uptake were not affected. Under these conditions, we can expect a greater proportion of N demand to be covered by the soil N pool, instead of N coming from fertilizer. In addition, proportionally more N was allocated to the grain as fertilization was applied in the crop, in detriment to its distribution to cob and husk organs. Overall, these outcomes can motivate future investigations using isotope ^{15}N technique to span a wider range of historical hybrids and environmental conditions in order to improve the utilization of N in corn and the N environmental footprint in agricultural systems.

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Table 1. Monthly values for daily solar radiation, temperature, and total precipitation for the 2017 growing season

	May	June	July	August	September
Solar radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$)	25.2	27.3	26.5	23.0	18.5
Mean temperature ($^{\circ}\text{F}$)	65.8	75.4	80.4	72.1	72.0
Precipitation (inches)	3.74	2.82	1.33	6.09	0.81

CORN

Figure 1. Analysis of variance and means for yield (15.5% moisture) for three nitrogen (N) treatments (A) and three hybrids (B). Different letters indicate significant differences at $P \leq 0.05$.

Figure 2. Least-squares estimates for ^{15}N uptake rate (A and B), and for ^{15}N recovery (C and D) for three N treatments. Variables were equally measured at flowering (left section) and two weeks after flowering (right section). Isotope ^{15}N recovery was measured at physiological maturity (R6). Different letters indicate significant differences at $P \leq 0.05$.

Figure 3. Nitrogen allocation of ^{15}N absorbed at flowering stage (R1) across three N fertilization treatments in 2017. Relative proportion at maturity of ^{15}N applied at R1 stage to leaves (A), stem (B), cob + husks (C), and grains (D). Bars represent estimates averaged across genotypes, and whiskers the standard errors (SE) of the mean. Different letters indicate significant differences at $P < 0.05$.

Corn Yield Response to Nitrogen 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. During the 2019 cropping season, an N rate experiment in corn was established in Scandia, KS, evaluating five N fertilizer rates as UAN (28-0-0) under both dryland and irrigated conditions. Average yields ranged from 138 to 236 bu/a under rainfed and from 153 to 249 bu/a for irrigated conditions. Under both dryland and irrigated conditions, maximum yields were achieved with an N rate of about 161 lb/a. Total N supply was calculated as N at planting plus fertilizer, which was approximately 300 lb N/a.

Introduction

In spite of decades of research efforts to develop N recommendations, given the nature of the N cycle and its complexity, addressing the uncertainty in the relationship between corn yield and fertilizer N rate remains a predominant concern (Morris et al., 2018; Raun et al., 2019). Thus, the aim of this study was to evaluate the response of corn (*Zea mays* L.) grain yield to N fertilizer.

Procedures

A first year of a long-term study under a corn-soybean rotation was established in the 2019 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 planting time (May 3, 2019), six cores per soil sample were collected per plot at 0–6 inches soil depth in both rainfed and irrigated areas. A few soil features were tested such as pH, soil organic matter (SOM, %), soil texture (%), extractable (M-3) phosphorus (P, ppm), potassium (K, ppm), and N as nitrate (NO₃-N) and as ammonia (NH₄-N) (Table 1). Additionally, 3 cores per plot were collected at 0–24 inches to evaluate initial soil N availability.

The corn experiment consisted of a total of five fertilizer N rates in a randomized complete block design with five replications (Table 1) in plots 20-ft wide × 50-ft long. Soybeans served as a previous crop for corn plots. Plots were manually harvested on September 30, 2019, from the four central rows taking 4 subsamples of 1 m² each, then scaled to bu/a. Yields were corrected to 15.5% moisture content.

Data Analysis

The yield data analysis was executed by performing an analysis of variance (ANOVA) split by water condition. For each water condition, a mix 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 P -value adjustment. 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 acid pH, good SOM level, medium soil P, and high K. Initial soil N availability at 0–24 inches ($\text{NO}_3\text{-N}$ plus $\text{NH}_4\text{-N}$) was high in both cases ranging from 80–120 lb/a and from 97–130 lb/a for dryland and irrigated areas, respectively. In both cases, at least two thirds of the N was as $\text{NO}_3\text{-N}$ and the remaining one-third as $\text{NH}_4\text{-N}$.

Weather

The total precipitation during the planting-maturity period (May–September) was about 21 inches. The precipitation distribution pattern marked a humid period at the beginning of the season, with more than half of the seasonal rainfall (13 inches) during the first 60 days, and a relatively dry period during July with very good solar radiation and soil water levels around flowering (data not shown). The growing season ended with more regular and less intense precipitation events during the grain filling period. Thus, water stress risk was practically null until flowering (about July 20th) and low to very-low risk during the grain filling. Approximately 3 days before silking, four days in a row with more than 95°F were registered, with a negative impact on pollination that eventually reduced the attainable yield although levels remained high across all treatments.

Corn Grain Yield

In spite of the high initial soil N availability, the favorable weather conditions to the crop resulted in significant responses of grain yield to N fertilizer rate. Under both dryland and irrigated conditions, the lowest average yield resulted from the check plots (0 lb/a of N) (138 and 153 bu/a for dryland and irrigated, respectively) while the maximum yields were achieved with 161 and 214 lb/a of N, with no significant differences between these highest rates (233 bu/a and 236 bu/a for dryland; 242 bu/a and 249 bu/a for irrigated) (Figure 2A). Only slight differences between irrigated and rainfed in terms of N rate response curves were observed. When initial soil N availability was added to the N rate, the apparent N supply to achieve maximum yields was approximately 300 lb/a, and no significant differences between curves were observed (Figure 2B). Agronomic efficiencies were significantly affected by fertilizer N rate and results were quite similar between areas, ranging from 1.10 (214N) to 3.4 bu/lb of N (57N) at the dryland location, and from 1.2 (214 lb/a of N) to 3.5 bu/lb N (57 lb/a of N) at the irrigated area.

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Table 1. Soil fertility (0–6 inches) at planting of corn at irrigated and dryland areas in Scandia, KS, during the 2019 cropping season

0–6 inches	pH	SOM	Clay	Silt	Sand	P	K	NO ₃ -N	NH ₄ -N
		----- % -----				----- ppm -----			
Irrigated	6.0	2.8	20.5	57.5	22.0	10	490	14.7	3.6
Dryland	5.9	3.0	17.2	59.2	23.6	12	531	16.4	4.8

SOM = soil organic matter

P = phosphorus

N-NO₃ = nitrate nitrogen

N-NH₄ = ammonium nitrogen

K = potassium

Table 2. Crop management practices for corn and soybean at Scandia, KS, during the 2019 cropping season

Practices	Corn	
Irrigation	Dryland	Irrigated
Tillage	No-till	
Hybrid	P1197AM	
Planting date	05/03/2019	
Seeding rate	29,000 seeds/a	36,000 seeds/a
Row spacing	30 inches	
Nitrogen (N) fertilization	Rates: 0, 53, 107, 161, and 214 lb/a of N	
	Time: V5	
	Source: urea-ammonium-nitrate (UAN, 28-0-0)	
	Method: banded rows	
Phosphorus (P) fertilizer	Rate: 22 lb/a of P to all plots	
	Time: planting	
	Source: Triple Super-Phosphate (0-46-0)	
	Method: broadcast	

Weather data were gathered from the Kansas State University Mesonet system (Figure 1) from the North Central Kansas Research Station (Scandia, KS).

Figure 1. Daily and cumulative precipitation (PP) and reference evapotranspiration (ETo) on the left; and daily minimum and maximum air temperature, on the right for the 2019 cropping season at Scandia, KS.

Figure 2. Corn grain yield (bu/a) vs. nitrogen (N) rate treatments (left) and vs. N availability as soil NO₃-N and NH₄-N (0–24 inches, lb/a) + N fertilizer (applied at V5). Different lowercase letters indicate significant differences across fertilizer N rates for rainfed. Different capital letters indicate statistical differences in N rates for irrigated conditions (Tukey LSD 5%, $P < 0.001$).

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 seven 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% higher corn yields, and soybeans had up to a 3% 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 Excelsior 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 and 2016, 14-52-40-10 (N, P, K, and sulfur (S)) fertilizer was applied to the soybean stubble prior to fall tillage. Nitrogen (150 lb in 2012 and 2013;

180 lb in 2014, 2015, 2016, 2017, and 2018; 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, 2018, and 2019.

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, with 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. Combining data from 2013–2019 for analysis showed corn yields are favored by deep tillage, and soybean yields are a few bushels better with any kind of tillage in the system (Tables 3 and 4). Averages of stand counts taken at the V5 stage in the corn for 2014–2019 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. However, with these soils and environments we haven't seen a consistent yield advantage for any tillage system.

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

Year	2012	2013	2014	2015	2016	2017	2018	2019
Corn								
Planting date	12-Apr	30-Apr	21-Apr	14-Apr	11-Apr	24-Apr	23-Apr	22-Apr
Hybrid/variety	Pioneer P1395	Pioneer P1498 HR AQ	Pioneer P1105AM	Pioneer P1105AM	AgriGold 6538	Midland 534	Golden Harvest 11B63	Pioneer 1197
Seeding rate	30.6K	30K	32K	31.7K	31.7K	32K	32K	32.4K
Row spacing (in.)	30	30	30	30	30	30	30	30
Harvest date	31-Aug	27-Sep	11-Sep	10-Sep	19-Sep	20-Sep	31-Aug	17-Sep
Irrigation (in.)								
May	0.77	0	0	0	0	0	0	0
June	4.25	1.58	0	1.58	2.24	2.88	4.71	1.03
July	4.63	3.51	4.74	2.29	4.40	3.63	6.55	2.36
August	0.73	0.77	2.19	2.87	0.70	1.81	0.84	0
September	0	0	0	0	0	0	0	0
Soybean								
Planting date	14-May	15-May	21-May	1-Jun	31-May	26-May	7-May	June 6
Hybrid/variety	Pioneer P93Y92	Pioneer P94Y01	Asgrow 3833	Midland 3884NR2 + ILeVO	Stine 42RE02	Pioneer P39T67 + ILeVO	Midland 4373 RR2	Asgrow 36x6 + ILeVO
Seeding rate	155K	144K	140K	144K	140K	140K	140K	140K
Row spacing (in.)	30	30	30	30	30	15	15	15
Harvest date	5-Oct	8-Oct	9-Oct	13-Oct	17-Oct	17-Oct	17-Oct	17-Oct
Irrigation (in.)								
May	0.77	0	0	0	0	0	0	0
June	0.73	1.58	0	0.74	0.74	0	0	0
July	4.19	3.51	1.55	0.74	4.40	1.82	3.90	1.51
August	4.66	2.27	2.19	2.87	1.54	1.81	0.84	0
September	0	2.18	0	0	0	0	0	0

Table 2. Effects of tillage treatments on corn and soybean yields in 2012 at Kansas River Valley experiment fields

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

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

Table 3. Effects of tillage treatments on corn yields and plant stands in 2013–2019 at Kansas River Valley experiment fields

Tillage treatment	Corn yield							Average corn yield	Average stand
	2013	2014	2015	2016	2017	2018	2019	2013–2019	2014–2019
	----- bu/a -----								Plants/a
No-tillage	221	243	205	183 b*	226	206	218	215 b	32,344
Fall subsoil/spring field cultivate	217	259	213	202 a	233	214	231	223 a	32,156
Fall vertical tillage	196	259	207	189 b	226	210	219	215 b	31,958
Fall subsoil after sb/vertical tillage after corn	219	256	214	195 a	234	209	224	222 a	31,906
Pr>F [#]	0.48	0.27	0.1	0.005	0.59	0.7	0.11	0.005	0.63

*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 2013–2019 at Kansas River Valley experiment fields

Tillage treatment	Soybean yield							Average soybean yield
	2013	2014	2015	2016	2017	2018	2019	2013–2019
	----- bu/a -----							
No-tillage	62.4	52.8	69.7	80.2	67.4	69.3 ab*	78.1	68.5 b
Fall subsoil/spring field cultivate	64.3	54.6	73.1	76.1	72.8	74.9 a	79.2	70.7 a
Fall vertical tillage	64.4	55.5	72.8	78.6	68.1	75.0 a	80.5	70.7 a
Fall subsoil after sb/vertical tillage after corn	66.3	53.4	70.9	75.7	70.1	66.6 b	80.1	69.0 ab
Pr>F [#]	0.52	0.59	0.23	0.11	0.098	0.03	0.87	0.044

*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.

Evaluation of Planting Technologies in Winter Canola

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Summary

Winter canola (*Brassica napus* L.) stand establishment and winter survival are two of the most important limitations to canola production faced by farmers. We hypothesize that planting canola with a system that provides accurate in-row spacing will positively impact crop establishment, survivability, and reduce seed input costs. A planting system that provides a homogenous spatial and temporal distribution of canola plants will also positively affect yield. The objective of this study was to investigate the impact of three metering systems with different opener and seed delivery systems on stand establishment, spatial distribution, and yield at three seeding densities and under two potential yield levels within a field. To test this hypothesis, three on-farm research studies were evaluated in the south-central region of Kansas. Preliminary results indicate that in homogenous environments, new planting technologies have a positive impact on the spatial distribution of plants within a row.

Introduction

The introduction of winter canola into rotations with wheat (*Triticum aestivum* L.) could have both positive economic and agronomic impacts. The two main concerns for successful production are stand establishment and winter survival. Previous studies in Canada show canola stand uniformity had a significant impact on productivity (Chao et al., 2014). Non-uniform crop residue distribution and planting systems (planted versus drilled) are usually a cause of spatial variability (Liu et al., 2004). A different establishment can be explained from delayed germination due to seed quality problems (Egli, 2015), limited soil water availability (Nafziger et al., 1991), differences in planting depth within-row (Andrade and Abbate, 2005), and low soil temperature (Garcia-Huidobro et al., 1982). These factors can lead to temporal variability. Because of their indeterminate nature, canola plants have different compensatory mechanisms and possess the ability to compensate for poor spatial and temporal stand distribution; which could be the response that explains yield penalties or benefits.

Precision planting systems for canola are lacking, thus, improved technologies to reduce seed inputs and improve stand establishment and spatial patterns are needed. The objective of this study was to investigate the impact of three metering systems with different opener and seed delivery systems on 1) spatial distribution, and 2) yield at three seed densities and two potential yield levels within a field.

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Procedures

Three on-farm studies were carried out by canola growers in southern Kansas. The fields were located at 1) Hutchinson, KS (HUT); 2018-2019 growing season 2) Harper, KS (HAR); 2019-2020 growing season and 3) Caldwell, KS (CAL); 2019-2020 growing season. Nine treatments were established using combinations of the three metering systems and three seeding rates.

1. Air Volumetric Seeder - single disk opener, 1 lb/acre (SV-1).
2. Planter Singulated - double-disk opener, 1 lb/acre (PL-1).
3. Air Singulated Seeder - single disk opener, 1 lb/acre (SS-1).
4. Air Volumetric Seeder - single disk opener, 3 lb/acre (SV-3).
5. Planter Singulated - double-disk opener, 3 lb/acre (PL-3).
6. Air Singulated Seeder - single disk opener, 3 lb/acre (SS-3).
7. Air Volumetric Seeder - single disk opener, 5 lb/acre (SV-5).
8. Planter Singulated - double-disk opener, 5 lb/acre (PL-5).
9. Air Singulated Seeder - single disk opener, 5 lb/acre (SS-5).

The experimental design was a split-plot arranged in a randomized complete block with three replications. Historical yield information and/or satellite imagery were used to establish high and low-yield environmental zones. All experiments followed conventional tillage practices and were kept weed free before planting. Herbicide applications were performed by the producers using their preferred best management practices. For each location, the planting date, planting system, row spacing, environment, and variety information are presented in Table 1.

At the HUT site, only two planting systems were tested. The planter treatments were “double planted” to achieve a 7.5-in. row spacing. N-P-S fertilizer (nitrogen-phosphorus-sulfur) 120-46-6 lb/acre, respectively, was applied in a three-way split (before planting, winter, and early spring). Soil characterization was performed at the 6-in. depth for several parameters (Table 2). A desiccant was sprayed 7 days before harvest. Yield data were collected using the producer’s yield mapping system and calibrated with scale weights for each treatment. Weather data were extracted from Google Climate Engine (Huntington et al., 2017). All statistical analyses were performed using R software (R Core Team, 2018).

Measurements

In each plot, 10-ft² subplots were assigned to take the following measurements:

- Stand counts were performed at establishment and before harvest (counted as stems with fertile pods).
- Spatial distribution was measured as the distance between plants within a row. Coefficient of variation, (CV, %), was calculated as $(\text{std}(\sigma))/(\text{mean}(\mu))$ in three linear feet of three rows within each treatment and site.

Aerial imagery was taken at regular intervals in the spring after winter dormancy to evaluate the normalized difference vegetation index (NDVI).

Yields were adjusted to 10% moisture.

Results

Spatial Distribution

Lower coefficient of variation CV (%) values (Figure 1) indicate better spatial distribution. The analysis of variance (ANOVA) results for the main factors show significant differences in the planting systems only between locations. The means comparison was significantly different ($P > 0.05$) averaged across all seeding rates in HUT1 for the planter treatments and HAR2 for seeder singulated treatments (Table 3). There were no differences between the mean comparisons of the remaining treatments.

Yields HUT1 and HUT2 in 2018–2019

Only seeder volumetric and the planter treatments were evaluated in HUT1 and HUT2. In terms of yield in both environments, for each seeding rate the planting systems effect had the same behavior and did not differ. HUT2 yielded less than HUT1 (on average -18.4 bushels/acre), and 5 pounds/acre yielded more than 3 and 1 pounds/acre (on average + 4.4 and + 7.5 bushels/acre). We then compared the treatments by removing the environmental effect and treating the main two environments as individual trials. HUT1 presents significant differences in the interaction between planting systems and seeding rates (Table 4). HUT2 did not show differences. At 1 lb/acre, the seeder volumetric portrayed greater yield than the planter system. For 3 and 5 lb/acre rate levels, there were no statistical differences, but the planter showed greater yields more than the seeder volumetric treatments. Within each planting system, the yield was the same for all seeding rates for the seeder volumetric. For the planter, the 5 and 3 lb/acre seeding rates yielded more than the 1 lb/acre (Table 5).

Preliminary Conclusions

The HUT1 and HAR2 environments presented more homogenous field conditions, resulting in lower CV % for the planter (-17%) and the seeder singulated (-15%) treatments. For fields with more heterogeneity, treatment differences were not clearly identified. In HUT1, at lower seeding rates (1 lb/acre), the planter double pass negatively affected stand establishment and thus yields were penalized (-3.4 bushels/acre). At higher seeding rates (3 and 5 lb/acre), the planter technology presented a trend to show greater yields (+0.6 and +1.7 bushels/acre, respectively).

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Table 1. Planting dates, planting systems, row spacing, environments, and seed varieties information for every location

Location	Planting date	Seeding rates	Planting systems	Row spacing	Environments	Seed variety
Hutchinson (HUT)	10/1/2018	1, 3, 5 lb/acre	-(SV) MY15 John Deere 1990 CCS, 7.5-in. row spacing - air seeder. -(PL) MY14 John Deere 1790, 15-in. row spacing planter.	7.5 inches	2 HUT1 HUT2	Winfield Croplan CP2225W
Harper (HAR)	10/1/2019	1, 3, 5 lb/acre	-(SV) Horsch Anderson 500i, 7.5-in. row spacing air seeder. -(PL) MY15 John Deere 1745, 15-in. row spacing planter. -(SS) John Deere N540C, 7.5-in. row spacing with prototype singulation system.	15 inches	2 HAR1 HAR2	Winfield Croplan CP320WRR
Caldwell (CAL)	10/2/2019 10/10/2019 (SS)	1, 3, 5 lb/acre	-(SV) MY15 John Deere 1910, 7.5-in. row spacing - air seeder. -(PL) MY15 John Deere 1745, 15-in. row spacing- planter. -(SS) John Deere N540C, 7.5-in. row spacing with prototype singulation system.	15 inches	1 CAL	Torrington

Table 2. Chemical characteristics of soil in Hutchinson, KS, at 6-in. and 24-in. depth, collected right before the onset of the experiment

Location	CEC	OM	pH	Ca	Mg	Na	P-M	NO ₃ -N	NH ₄ -N	K
		LOI								
	meq/100 q	%					ppm			
Hutchinson 1	14	2.2	5.5	1178	191	82	23	7	11	102
Hutchinson 2	16	2.4	5.7	1574	201	33	25	14	11	129

CEC = cation exchange capacity. OM LOI = organic matter loss on ignition. Ca = calcium. Mg = magnesium. Na = sodium. P = phosphorus, Mehlich-3. N-NO₃ = nitrates. N-NH₄ = ammonium. K = potassium.

Table 3. Mean comparison of CV(%) between planting systems in different locations

Location	Planting system	Mean (%)	Group
Hutchinson 1	Seeder volumetric	101	a
	Planter	83	b
Harper 2	Seeder volumetric	120	a
	Planter	108	ab
	Seeder singulated	105	b

Different group letters represent differences across planting systems at ($P < 0.05$) using Tukey comparison.

Table 4. ANOVA table for main factors in yields using F-test in HUT1

Factor test	<i>P</i> -value
Seeding rate	0.077
Planting system	0.600
Seeding rate: planting system	0.038*

Significance level: 0.01(*) and 0.05(.).

Table 5. Mean comparison between seeding rates and planting systems

Seeding rate	Planting systems	Mean (bushels/acre)	Group
1	Seeder volumetric	40.5	a
	Planter	37.1	b
3	Seeder volumetric	42.5	a
	Planter	43.1	a
5	Seeder volumetric	43.3	a
	Planter	45.0	a

Planting systems	Seeding rate	Mean (bushels/acre)	Group
Seeder volumetric	5	43.3	a
	3	42.5	a
	1	40.5	a
Planter	5	45.0	a
	3	43.1	a
	1	37.1	b

Different letters represent differences at ($P < 0.05$).

Figure 1. Violin charts of the coefficient of variation (CV, %) of each treatment for every location and environment. Dots represent means. Red dots show planter (PL) treatments, green dots show seeder singulated (SS) treatments, and blue dots show seeder volumetric (SV) treatments. Number 1 represents a seeding rate of 1 lb/acre; number 3, 3 lb/acre; and number 5, 5 lb/acre.

Investigating the Use of Unmanned Aerial Vehicles and High-Resolution Multispectral Imagery to Characterize Grain Sorghum Senescence Patterns

I.H. Barnhart, L. Mayor,¹ and I.A. Ciampitti

Summary

Grain sorghum is important to producers around the world. In precipitation-limited environments, sorghum is the grain of choice because it is able to produce grain yields with limited precipitation. Plant breeders place a priority on breeding for a characterized form of post-flowering drought-tolerance, known as stay-green (SG). Assessing thousands of plots for this trait can be labor intensive and time consuming, so the goal of this study was to use unmanned aircraft vehicles (UAVs) equipped with high-resolution cameras to characterize and quantify senescence patterns in grain sorghum. A field experiment with 20 hybrids was planted in Manhattan, KS. The UAV used was a Matrice 200 equipped with a MicaSense RedEdge-MX camera, and data was collected at four different sorghum growth stages. Vegetative indices (VIs) were computed from the multispectral data, including the normalized difference vegetative index (NDVI), normalized difference red edge (NDRE) index, the simple ratio (SR), green chlorophyll index (GCI), and the red edge chlorophyll index (RECI). Correlation and regression analyses were conducted to determine both the relationship of ground-measured senescence scores and the depth of senescence detection into the canopy. Results showed weak to no VI correlation with ground-truth senescence scores. Significant R^2 coefficients were shown between VIs and ground-truth senescence ratings at physiological maturity with the first 7 leaves of the canopy. We therefore conclude that the MicaSense RedEdge-MX may not be the most effective camera to determine grain sorghum senescence patterns.

Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is an important crop grown worldwide (Stefoska-Needham et al., 2015). It is used as a food source for humans and animals, as well as in biofuel production systems. It is especially important to the world's dryland cropping systems, being well-adapted to precipitation-limited environments (Jordan et al., 2012). When compared to field corn, sorghum has an economic and yield advantage in dry environments (Mullet et al., 2001). Many grain sorghum genetic lines have the ability to resist post-flowering drought stress that can severely limit grain yields (Sanchez et al., 2002). This ability is in part because of the "stay-green" (SG) trait, which has been defined as a trait giving plants the ability to stay green under post-flowering drought conditions. This trait is considered very important by several agronomic breeders, as breeding this trait to other lines could help to increase worldwide sorghum yields (Duvick et al., 2004). In large-scale breeding trials, the SG trait has been measured primarily visually, but doing so can be very labor-intensive. With the increased use of

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unmanned aerial vehicles (UAVs) and high-resolution imaging in agriculture, new opportunities arise to quantify this trait with said sensors. As UAV data has been used to evaluate and quantify plant health in the past, using UAVs would potentially allow breeders to evaluate many plots with ease and efficiency. Therefore, the goal of this experiment was to assess the ability of UAVs and multispectral imagery to detect grain sorghum senescence patterns.

Procedures

This experiment was conducted in collaboration with Corteva Agriscience in Manhattan, KS. In 2019, 20 Pioneer grain sorghum hybrids released from 1963 to 2017 years were planted in a randomized complete block design, with three replications per hybrid. Experiment plots were planted in 8 rows on 30-inch row centers. Plots were arranged in dimensions of 17.5 ft × 20 ft. Planting was done on June 8, 2019, with a planting population of 70,000 seeds/a. Soil fertility was maintained based on results of soil samples, and pests were controlled as needed with chemical control products.

Flights were conducted with a DJI Matrice 200 (DJI, Shenzhen, China) equipped with a MicaSense RedEdge-MX multispectral camera (MicaSense, Seattle, Washington, USA). The camera was a 5-lens camera capable of capturing 5 simultaneous bands on the electromagnetic spectrum (blue, green, red, red edge, and near infrared). Flights were conducted based on sorghum growth stage, and took place at flowering (F), soft dough (SD), hard dough (HD), and physiological maturity (M). Flights were flown under clear, sunny conditions within 2.5 hours of solar noon. This was done to keep lighting conditions the same for all measurement periods. Flights were controlled with the DJI Pilot application and were flown with GPS waypoint mapping missions. Flight altitude was set at 100 feet (30 meters), and the UAVs were flown with a front and side overlap of 80%. The camera was set to take an image every 2 seconds to ensure sufficient numbers of images for later processing. Images captured in-flight were stored to an on-board SD card. Calibration images were taken before and after each flight to ensure image quality. In addition, 4 ground targets were placed around the experiment and real-time kinematic points were taken on these targets to aid in the accuracy of image processing.

Within 2 days of each flight, ground-truth senescence measurements were taken on each plot. Due to time constraints, 5 consecutive plants were set aside for visual scoring in the 7th row of each plot. Visual senescence ratings were taken of each plant from flag leaf to the first consecutive leaf that was completely senescent. This scale ranged from 100 (no visible senescence) to 0 (complete leaf mortality). In order to identify these plants from aerial imagery, elevated ground targets were placed between the 5th and 6th row (Figure 1A). This was done to avoid shading the plants on which measurements were taken, and the length of the target corresponded to the length of the 5 plants in row 7.

Image processing was done in Agisoft Metashape (Agisoft, St. Petersburg, Russia). Images were processed into an orthomosaic photo using a procedure of aligning photos, generating a sparse point cloud, a dense point cloud, and digital elevation model. The resulting orthomosaic photo was then exported to ArcGIS Pro (ESRI, Redlands, California, USA) for data extraction. Locations of the measured plants were found, and

polygons were drawn in each plot to create a boundary where data from plants could be extracted (Figure 1B). Each orthomosaic photo was classified with a pixel-based support vector machine to remove background noise. Images were classified into four categories: sorghum leaves, shadows, soil, and grain heads. Classification accuracies for sorghum leaves were checked and were found to be between 88–94% for each measurement day. After this, vegetative indices (VIs) were computed, based on spectral information gathered from the multispectral camera. These were the normalized difference vegetation index (NDVI), normalized difference red edge index (NDRE), simple ratio (SR), green chlorophyll index (GCI), and red edge chlorophyll index (RECI). A conditional statement was then built using the “Con” tool to extract information from the sorghum leaves class, thus masking features on which measurements were not taken. The average VI value was then extracted and exported for statistical analysis in R (R Core Team, Vienna, Austria).

Statistical analysis involved comparing the average senescence scores with the average VI values from each plot. To observe changes in visual senescence, only leaves rated as 100 at flowering were used, as sorghum plants are expected to have 100% of their leaf area at this stage. Visual senescence measurements were averaged for each leaf to form a “plant” score, and these plant scores were averaged to form a “plot” score. The average plot score was correlated with the average VI using Pearson’s correlation coefficients. To determine if VI data were related to certain leaves within the canopy, the first 8 leaves of each plant were averaged to form an average leaf score for each plot. Regression analysis was then performed to determine this relationship.

Results

Pearson’s correlation coefficients revealed little to no correlations between VI data and the average plot measurements (Table 1). Regression analysis indicated that the majority of significant relationships were found between the NDRE and SR indices and the first 7 leaves at the physiological maturity stage (Table 2). Significant R^2 values ranged from 0.08–0.17 for the NDRE, and between 0.08–0.13 for the SR. No significance patterns were observed with SD and HD measurements.

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Table 1. Correlations between average plot senescence scores and average vegetative indices values extracted

Stage	NDVI	NDRE	SR	GCI	RECI
SD	0.114 ^a	0.124	-0.002	-0.139	-0.063
HD	0.028	0.11	0.004	-0.144	-0.095
M	0.118	0.308	0.205	-0.165	-0.025

^aPearson’s correlation coefficients.

NDVI = normalized difference vegetation index. NDRE = normalized difference red edge index. SR = simple ratio. GCI = green chlorophyll index. RECI = red edge chlorophyll index.

Table 2. Regression R² values for determining depth of canopy senescence detection

Leaf	Soft dough					Hard dough					Maturity				
	NDVI	NDRE	SR	GCI	RECI	NDVI	NDRE	SR	GCI	RECI	NDVI	NDRE	SR	GCI	RECI
1	0.00	0.05	0.01	0.00	0.01	0.02	0.01	0.01	0.00	0.01	0.06 *	0.10 **	0.10 **	0.00	0.01
2	0.00	0.08 **	0.01	0.01	0.02	0.01	0.06 *	0.01	0.01	0.00	0.05 *	0.17 ****	0.13 ***	0.00	0.00
3	0.00	0.03	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.14 ***	0.10 **	0.01	0.00
4	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.02	0.10 **	0.08 **	0.02	0.00
5	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.08 **	0.08 **	0.01	0.00
6	0.01	0.02 *	0.02	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.04	0.16 ***	0.09 **	0.01	0.00
7	0.01	0.04	0.00	0.04	0.02	0.01	0.02	0.01	0.01	0.00	0.04	0.09 **	0.09 **	0.00	0.01
8	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.01	0.03	0.00

Significant R² values were seen between NDRE and SR values computed for the maturity stage when regressed against average ground-measured senescence scores for each leaf.

NDVI = normalized difference vegetation index. NDRE = normalized difference red edge index. SR = simple ratio. GCI = green chlorophyll index. RECI = red edge chlorophyll index. *, $P \leq 0.1$; **, $P \leq 0.05$; ***, $P \leq 0.01$; ****, $P \leq 0.001$.

Figure 1. Ground targets (A) were set up in each plot to identify plants that were measured; shape file polygons (B) were then created around these plants for data extraction.

Physiological Changes Across Historical Sorghum Hybrids Released During the Last Six Decades

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Summary

For the last decades, sorghum (*Sorghum bicolor* L. Moench) improvement in the United States (US) has been related to targeted modifications in genotype, environment, and management ($G \times E \times M$) combinations. Retrospective studies are relevant to document changes in the phenotype associated to breeding process and to explore alternatives to improve yield and its physiological associated traits. This study aims to characterize yield changes over time for hybrids with different years of release. Field trials were conducted during 2018 and 2019 growing seasons in eight environments/site-years across the states of Kansas and Texas including 20 grain sorghum hybrids released between 1963 and 2017. Grain yield was measured across all hybrids and environments. Detailed physiological descriptors were measured in one of the environments including grain filling, grain set efficiency (grains g⁻¹) at flowering, panicle length, and dynamics of water-soluble carbohydrates (WSC) during the reproductive period. Overall sorghum grain yield improvement was 0.4 bu/a/year ($P < 0.005$). Grain set per unit of reproductive biomass at flowering was positively associated with the hybrid's year of release, explaining the increases in grain number. Panicle size increased in newer hybrids, thus, supporting the reported changes in grain number per unit area. Modern sorghum hybrids displayed greater WSC remobilization during the reproductive period ($P < 0.05$). However, further research on sorghum's WSC dynamics is needed for understanding its contribution to yield improvement.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is an important cereal crop ranking in production among the top five cereal crops of the US, its major producer (Maunder, 2002). During the last decades, improvement of grain sorghum yield in the US has been mainly related to changes in $G \times E \times M$ combinations (Assefa and Staggenborg, 2010; Pfeiffer et al., 2018). However, physiological changes related to sorghum hybrids released since 1960s until the present decade remains to be determined.

Yield gains and related traits have been studied in detail on other cereal crops such as wheat and maize. Donmez et al. (2001) and Xiao et al. (2012) suggested that the understanding of the physiological traits associated with yield formation plays a key role in the identification of limiting factors, and the development of new strategies for yield improvement in winter wheat. Similarly, plant traits associated with yield genetic gain over time in maize have been thoroughly studied in US hybrids (Duvick, 2005), accounting for approximately 50% of the yield gain during the past seven decades.

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Comparatively, yield improvement in grain sorghum can be assumed to be around 40% due to hybrid improvement and around 60% due to management (Duvick, 1999).

Highlighting the importance of identifying traits associated with yield improvement, this study proposes to characterize the yield and physiological trait changes over time for sorghum hybrids with different years of release. The lack of information on US sorghum yield changes over time motivated us to pursue the implementation of this research study. Our hypothesis is that there has been genetic gain for yield in Pioneer sorghum over the last 60 years due to changes in a few key traits related to resource capture and resource use efficiency.

Procedures

A total of eight field experiments were conducted across the states of Kansas and Texas during the 2018 and 2019 growing seasons (four trials each season). During 2018, experiments were planted in the following counties: Cloud (KS), Finney (KS), Riley (KS), and Moore (TX). For the 2019 planting season, experiments were conducted in the following counties: Riley (KS), Moore (TX), Hale (TX), and Dallam (TX). Table 1 presents a summary of climatic conditions during 2018 and 2019 growing seasons.

The experimental design for all locations was a randomized complete block design (RCBD), with 20 genotypes and three replications. Sorghum genotypes were Pioneer hybrids spanning six decades of genetic selection (from 1963 until 2017). Plots were 17.5-ft long per two rows (30-in. row spacing across all sites) for all the locations except Riley, KS (2019) with 8 rows and 17.5-ft long. All locations were utilized to obtain data on sorghum yield, and one location (Riley, KS, 2019 season) was used to obtain detailed physiological descriptors of yield formation.

Measurements

Total aboveground plant biomass was measured at flowering and maturity. Plant fractions were separated in leaves and stem during vegetative stages; and leaves, stem, and panicle (plus grain) during the reproductive stages. Dry weight was obtained after drying plant fractions in a forced-air oven at 150°F until constant weight.

Grain dry matter and moisture content were collected during the grain filling period and at maturity.

Grain set efficiency was calculated with the relationship between the number of grains per panicle and the panicle dry weight at flowering,

$$\text{Grain set efficiency} = \frac{\text{Grain number}}{\text{Panicle biomass}}$$

where grain number is the final grain number in grains per ft² and panicle biomass is the panicle dry weight at flowering in grams per ft².

Pictures of ten consecutive panicles per plot with metric reference were taken at physiological maturity to determine panicle length, compiling a total of 30 panicle measure-

ments per hybrid. Panicle length is defined as the length in inches of the panicle from the first branch to the top of the panicle.

Water soluble carbohydrates (WSC) were analyzed in the stem fraction using the anthrone reagent method (Yemm and Willis, 1954).

Results

Yield Across Years of Release and Yield Components

A significant increase in yield across decades has been found for the evaluated sorghum hybrids released from 1963 until 2017 across the eight environments evaluated. The yield trend across years was represented in Figure 1A using the best linear unbiased estimators (BLUEs) for grain yield on each genotype. Yield gain was primarily associated with a greater number of grains per unit area across time (Figure 1B) rather than improvements in grain weight (Figure 1C), although this component remained relatively stable over time. Similar responses on yield and its components were previously documented by Assefa and Staggenborg (2010) and Pfeiffer et al. (2018) for sorghum hybrids in the US.

Grain Set Efficiency and Panicle Size Over Years of Release

A positive relationship was found between grain set efficiency and the period of years of introduction of the selected hybrids (Figure 2). Hybrids with greater yield are able to set more grains per unit of reproductive biomass at flowering (Gizzi and Gambin, 2016). In parallel, an increase of the size of the panicle was documented across years (Figure 3) contributing to the explanation of an increase in the number of grains per panicle. These results are consistent with findings documented by Pfeiffer et al. (2018), reporting an increase in panicle size for US sorghum hybrids.

Grain Number as a Function of WSC Concentration and Remobilization

The concentration of carbohydrates (WSC) at flowering was not significantly associated with the number of grains (Figure 4A). However, a positive relationship was found between the number of grains and the remobilization of WSC from stems during the reproductive period (Figure 4B). Modern sorghum hybrids were able to fill a greater number of grains per unit of area by increasing the remobilization of WSC from the stems during the reproductive period. Likewise, Pfeiffer et al. (2018) found in new hybrids less sucrose (%) in the biomass at maturity as an indicator of more use efficiency of the assimilates accumulated during the vegetative period.

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Table 1. Weather information for 2018 and 2019 growing season for Cloud (KS), Dallam (TX), Finney (KS), Hale (TX), Moore (TX), and Riley (KS) locations

Location	2018				2019			
	Cloud, KS	Finney, KS	Moore, TX	Riley, KS	Cloud, KS	Dallam, TX	Hale, TX	Riley, KS
Max. Temp. (°F)	76.3	83.6	78.4	79.2	76.8	88.9	88.5	80.2
Min. Temp. (°F)	53.8	57.0	52.1	57.2	54.5	55.6	66.1	58.8
Precipitation (in.)	22.1	19.5	4.45	26.4	12.2	5.46	11.4	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; TexMesonet, 2017).

Figure 1. Relationship between best linear unbiased estimators (BLUEs) for grain yield (A), grain number (B), and grain weight (C) all relative to the year of release (from 1960s to 2010s) for 2018 and 2019 experiments.

Figure 2. Relationship between grain set efficiency (grain number/panicle dry weight) and years of release of the hybrids (from 1960s to 2010s) for the 2018 and 2019 experiments.

Figure 3. Correlation between means of panicle length (expressed in inches) and years of release of the hybrids (from 1960s to 2010s) for the 2019 experiment.

Figure 4. Grain number per unit area as a function of water-soluble carbohydrates (WSC) at flowering (A) and WSC remobilization (WSC at flowering - WSC at maturity) (B) for the 2018 experiment.

Dryland Sorghum Nitrogen Management: Implications for Utilization as Ethanol Feedstock

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Summary

A study was initiated in 2018 to collect preliminary data to quantify nitrous oxide (N_2O) emissions from dryland grain sorghum in western Kansas. Results indicate that the greatest flux of N_2O occurred within the first 14 days after fertilization when plant uptake was minimal and soil moisture was elevated. During this time period, the timing and amount of rainfall was critical with respect to N_2O flux. Nitrous oxide flux during the fallow phase was negligible. The cumulative emissions factor for fertilizer-derived N_2O estimated for Colby ($\sim 0.3\%$) is well below the Intergovernmental Panel on Climate Change (IPCC) default estimate of 1.0%. These preliminary factors are very promising for documenting the sustainability of dryland grain sorghum as biofuel feedstock.

Introduction

A common dryland cropping system in western Kansas is a wheat-grain sorghum-fallow rotation. Sorghum is better adapted to dryland production than other row crops, particularly corn. This drought-tolerant crop offers farmers in western Kansas a viable choice to preserve regional resources. Approximately 1/3 of US grain sorghum is used for ethanol production. Grain sorghum produces an equivalent amount of ethanol compared to corn while using 1/3 less water during its life cycle (Wang et al., 2008). Recent changes in the life cycle assessment of corn has resulted in grain sorghum appearing less favorable as a biofuel crop. Nitrous oxide emissions (N_2O) have recently been identified as a critical research gap that is limiting the life cycle assessment for sorghum. Cumulative cropping system N_2O emissions from grain sorghum production are generated from two main inputs: 1) the conversion of applied inorganic fertilizer, and 2) decomposition of crop residue following harvest (fallow period). Based on the default emissions factor of 1% each from fertilizer and residue from the Intergovernmental Panel on Climate Change (IPCC), the cumulative cropping system emissions factor for grain sorghum is approximately 2.0% (amount of N_2O -N derived from fertilizer and residue). This has important implications for the competitiveness of grain sorghum for biofuel production. This research will provide data needed to understand the magnitude of potential N_2O emissions from dryland systems in the Southern Great Plains.

Procedures

This field study was conducted at the Kansas State University State Northwest Research and Extension Center in Colby. Plots were established on a Keith silt loam under a standard rotation of wheat-fallow-grain sorghum-fallow such that the grain sorghum was no-till planted into wheat stubble from the 2017 wheat harvest. Treatments were designed based on a yield goal of 115 bu/a and included: 1) control (zero N applied); 2)

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1.12 lb N (soil+applied)/bu, applied as 32-0-0 UAN solution at planting; 3) same rate as treatment 2 with the addition of a urease inhibitor (Agrotain) using 32-0-0 liquid fertilizer; and 4) 1.6 lb N (soil+applied)/bu, applied as 32-0-0 UAN solution at planting. All three fertilizer treatments were adjusted for profile nitrogen (N). In addition, treatment 4 was representative of a standard K-State recommendation and was adjusted for soil organic matter ($\text{lb N/a} - \% \text{ SOM} \times 20$) (Leikam et al., 2003). The applied N rate for treatments 2 and 3 was 95 lb N/a and 110 lb N/a for treatment 4. Treatment 3 represented an N application method utilizing a common best management practice for nitrogen use. Plots were 20 × 40 ft with the treatments arranged in a complete randomized block design replicated four times. Precipitation was measured by a Kansas Mesonet weather station adjacent to the plots.

Emissions of N_2O were measured using a vented static chamber method described in the U.S. Department of Agriculture GRACEnet Project Protocols (Parkin and Venterea, 2010). Chambers were installed centered over the row, directly after planting and fertilization. Stainless steel chambers consisted of two components: an anchor that remained in the plot for the entire growing season and a lid that sealed to the anchor at time of sampling. The lid was equipped with a sampling port for manual gas extraction using a syringe. Each sampling event consisted of four gas measurements taken over a 45-minute time series (0, 15, 30, and 45 minutes). Gas samples were stored in the vials and shipped overnight to Oklahoma State University for analysis by gas chromatography to determine N_2O .

Emissions were measured every two days following fertilization for a period of seven days, followed by weekly measurements during the growing season. Additional gas measurements were taken within 24–48 hours following precipitation events at the research site. Chambers were left in place following harvest, and gas samples were taken during the fallow period when the plots were accessible.

Grain sorghum was planted on June 18 using the sorghum hybrid SP34A15 at a seeding rate of 55,250 seeds/a with a 30-inch row spacing, resulting in eight rows per plots. On November 13, two rows from the center of each plot were hand-harvested by removing the aboveground biomass (stalk and head) from 8 row-feet for grain yield and yield component analysis.

Using the cumulative flux values, grain yield, and applied fertilizer rates, three different emissions values were calculated (Table 1). Yield-scaled N_2O emissions ($\text{lb N}_2\text{O-N/bu}$) were estimated by dividing the cumulative N_2O flux by grain yield. Fertilizer-induced N_2O emissions ($\text{lb N}_2\text{O-N/a}$) were calculated as the difference between the cumulative flux of each fertilizer treatment and the cumulative flux for the 0 N control treatment. The emissions factor (%) for each fertilizer treatment was calculated as the % of applied fertilizer converted to N_2O during the year.

Results and Discussion

The highest daily N_2O flux values occurred during the first 14 days after planting and fertilization, when plant uptake of N was minimal and water-filled pore space (WFPS) averaged >70%. Elevated emissions of N_2O have been documented to begin upon reaching 60% WFPS (Sehy et al., 2003). During that 14-day period, several rain-

fall events were recorded, totaling 26% of the entire growing season rainfall amount (Figure 1). The flush of N_2O during that time period made up approximately 80–90% of the cumulative N_2O emissions for all treatments. A large precipitation event (2.4 inches) occurred on October 8 and 9, 2018, but a resulting flush of N_2O was not recorded at the next sampling date on October 16. Emissions were undetectable for all treatments. Resulting WFPS values were >80% following this rainfall event and remained above 80% for the remainder of October. The predominant gas released from denitrification processes at WFPS >80% is nitrogen gas (N_2), not N_2O . Also, at this point in the growing season, nutrient uptake by the crop has ceased and the inorganic pool of N in the upper profile was likely depleted.

Overall, cumulative flux was low for all treatments, ranging from 0.3 lb N_2O -N/a for the control (0 N) to 0.67 lb N_2O -N for treatment 2 (95 lb N/a) (Table 1). Statistical analysis of the cumulative flux values indicated there were no significant differences between treatments (Table 1). Daily N_2O flux values were low throughout the growing season.

Low daily and cumulative flux values could be explained by the timing of peak nutrient uptake by the crop. As described by Vanderlip (1993), sorghum enters a rapid growth phase approximately 20–25 days after it emerges. Plant nutrient demand increases, and nitrogen uptake is rapid as the sorghum enter growth stage 3 (30–40 days post-emergence). Nitrogen uptake remains high until stage 6 (half-bloom) when around 70% of the total N has been assimilated. Nutrient uptake essentially stops when the crop reaches stage 8 (hard dough).

Nitrous oxide flux activity during the fallow phase (after sorghum harvest and until wheat planting in the fall) was very low for all treatments. Cumulative flux values during the fallow phase were below 0.2 lb N_2O -N/a for all treatments. The only gas sampling event that recorded measurable N_2O emissions was May 16, 2019. During the winter and early spring months, gas flux was undetectable. Several factors could contribute to almost negligible flux values during the winter fallow period, including N removal by the crop and environmental conditions. Nitrogen removal by the sorghum grain ranged from 89 lb N/a for the control to approximately 130 lb N/a for the three applied N treatments. Nitrogen uptake by the stover ranged from 75 lb N/a for the control to 83 lb N/a for the other three treatments.

The control treatment had significantly lower yields than the treatments receiving a N application without a N stabilizer; however, there were no statistical differences between the applied N treatments (Table 1). No statistical differences were observed between the yield-scaled N_2O emissions or the fertilizer-induced N_2O emissions.

While no significant differences were observed, the emissions factor (N_2O -N derived from fertilizer) was less than 0.3% for all treatments, indicating that the IPCC emissions value of 1.0% is potentially overestimating N_2O flux from dryland sorghum production in western Kansas. Preliminary estimates of N_2O -N derived from crop residue were also substantially lower than 1.0% (data not shown). Given that the IPCC cumulative cropping system emissions factor for grain sorghum is approximately 2.0%, these results are very promising for documenting the sustainability of ethanol produced using grain sorghum grown in the Southern Great Plains.

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Table 1. Effects of nitrogen (N) application rates on grain sorghum yield, cumulative nitrous oxide (N₂O) flux, and different N₂O emission factors during the 2018 growing season at the Kansas State University Northwest Area Research Station in Colby, KS

Treatment	Yield	Cumulative N ₂ O flux	Yield-scaled N ₂ O emissions	Fertilizer- induced N ₂ O emissions	N ₂ O emissions factor
	bu/a	lb N ₂ O-N/a	lb N ₂ O-N/bu	lb N ₂ O-N/a	
0 N applied	124 b	0.30 a	0.002 a		
95 lb N/a	146 a	0.67 a	0.005 a	0.36 a	0.38a
95 lb N/a + stabilizer	139 ab	0.51 a	0.004 a	0.21 a	0.22a
110 lb N/a (KSU N recommendation)	149 a	0.49 a	0.003 a	0.19 a	0.18a

Letters within a column represent a significant difference at LSD (0.05).

GRAIN SORGHUM

Figure 1. Daily rainfall (inches) during the 2018 growing season at the Kansas State University Northwest Area Research Station in Colby, KS. Rainfall was measured by a Kansas Mesonet weather station adjacent to the plots.

Figure 2. Cumulative nitrous oxide (N_2O) flux during the 2018 growing season as affected by nitrogen (N) fertilizer treatment at the Northwest Area Research Station in Colby, KS.

Long-Term Cover Crop Management Effects on Soil Health in Semiarid Dryland Cropping Systems

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

Summary

Growing cover crops (CC) in semiarid drylands may provide benefits to soil health. This study examined long-term CC management effects in a no-till winter wheat-grain sorghum-fallow cropping system in southwest Kansas. Objectives were to assess the impacts of CCs on 1) soil organic carbon (SOC) and nitrogen (N) stocks, 2) soil susceptibility to erosion, as well as to 3) quantify the effects of haying cover crops as annual forages. Treatments were spring-planted and included peas for grain as well as one-, three-, and six-species CC mixtures of oats, triticale, peas, buckwheat, turnips, and radishes compared with conventional chemical-fallow. Half of each CC treatment was harvested for forage. All phases of each rotation were present every year. Soil samples were collected from the 0- to 6-inch depth in 2018 and 2019 corresponding with wheat planting and harvest in the three-year rotation. Results indicate no significant difference in SOC with CCs compared to fallow in either 2018 or 2019, though SOC stocks were greater than in 2012. This was possibly due to periods of drought reducing total carbon (C) inputs compared to earlier periods of relatively greater precipitation. Haying of CCs had no effect on soil health indicators compared to when CCs were left standing. Soil N was not increased with CCs compared to fallow or peas. Mean weight diameter of wet aggregates in 2018 was not different between CCs hayed (0.042 in.) and CCs left standing (0.044 in.) but was greater than fallow (0.033 in.) or peas (0.030 in.). Growing a CC significantly increased the proportion of larger (0.30- to 0.08-in.) aggregates (37%) compared to peas (21%) but not compared to fallow (24%). These differences were not significant after wheat harvest in 2019. Our findings suggest that CCs may improve soil physical properties compared to conventional chem-fallow in semiarid dryland cropping systems.

Introduction

Growing cover crops (CCs) in semiarid dryland cropping systems in the central Great Plains (CGP) has potential to provide several benefits to soil health in the region. These include reduced susceptibility to soil erosion as well as improved nutrient cycling. However, even with these potential benefits and an increasing interest among CGP crop producers, CC adoption has been slow in the region. This is mostly due to the fact that CCs may deplete vital soil water, which results in reduced yields of subsequent cash crops compared to chemically-controlled summer-fallow, where herbicides are used to manage weed growth to store soil moisture for the next crop. Past research efforts in southwest Kansas have shown that replacement of fallow with CCs or forage crops resulted in increased soil organic matter (SOM) content and stability of wet soil aggregates, as well as reduced soil wind-erodible fraction and runoff. These results suggest that CCs in semiarid regions have the potential to improve soil health similarly to those reported in more humid regions, at least in the short term (<10 years), despite limited

rainfall and high evaporative demand. However, information is lacking regarding the long-term (>10 years) soil health effects of integrating cover crops in dryland cropping systems.

Increased adoption of CCs by dryland producers in the semiarid CGP can enhance residue cover to reduce the susceptibility of the soil to erosion. Reducing erosion is particularly important in semiarid dryland crop production systems where residue levels are often low, and fallow fields are left exposed. Grazing and/or haying of CCs for forage can provide an economic benefit to offset potential lost revenue associated with decreased crop yields when CCs are grown ahead of a cash crop in dry years. However, there is concern that harvesting CCs as forages and the resulting reduction in residue left on the soil surface may negate the beneficial effects of CCs for soil conservation. Our objectives were to assess the long-term impacts of CCs on 1) soil organic carbon (SOC) and nitrogen (N) stocks, 2) soil susceptibility to erosion, as well as to 3) quantify the effects of haying CCs as annual forages upon soil health.

Procedures

This study was conducted in a long-term experiment of fallow replacement (cover crops, forage crops, and grain crops) established in 2007 at the Kansas State University Southwest Research-Extension Center near Garden City, KS. The soil is a Ulysses silt loam with 1 to 3% slope. The study design was a split-split-plot randomized complete block with four replications. Crop phase was the main plot, crop species or mixture was the split plot, and termination method (cover, forage, or grain) was the split-split plot. Cover crops included a triticale monoculture, a three-species mixture of oats/triticale/pea, and a six-species cocktail mixture of oats/triticale/pea/buckwheat/turnip/radish. Cover crop plots were split with half of each plot harvested for forage. Additionally, peas were grown and harvested for grain. Treatments with spring-planted crops grown in place of fallow were compared with the conventional winter wheat-grain sorghum-fallow cropping system for a total of 8 treatments. All phases of each crop rotation were present every year.

Soil sampling occurred before wheat planting in fall 2018 and after wheat harvest in summer 2019. Soil cores were taken from the 0- to 2-, 2- to 6-, and 6- to 12-inch depths for determination of bulk density as well as SOC and inorganic nitrogen (NO_3 and NH_4) stocks. Briefly, the samples taken at each depth were dried at 220°F for 48 hours, and bulk density was determined by mass of oven-dry soil divided by the volume of the core. Subsamples from each depth were air-dried and ground to pass through a 0.08-in. sieve. Soil nitrate-N ($\text{NO}_3\text{-N}$) and ammonium-N ($\text{NH}_4\text{-N}$) concentrations in samples were determined colorimetrically after the soil samples were extracted with 2 M KCl. A portion of the samples were ground with a mortar and pestle to pass through a 0.01 in. sieve, and SOC concentration was determined by dry combustion using a CN analyzer after pretreating samples with 10% (v/v) HCl to remove carbonates. Additional samples collected from the 0- to 2-in. soil depth with a flat shovel were air-dried and passed through sieves with 0.185- to 0.30-in. mesh to obtain air-dry aggregates of 0.185- to 0.30-in. diameter. These samples were used to estimate water-stable aggregates by the wet-sieving method. A sand correction was done for each aggregate size fraction, and the data were used to compute the aggregate size distribution and mean weight diameter (MWD) of water-stable aggregates. Monthly precipitation data (Table 1) over

the study period were obtained from the Mesonet station located about 500 ft from the experiment. Statistical analysis was completed in SAS using PROC GLIMMIX in SAS v. 9.4 (SAS Inst. Inc., Cary, NC) to assess differences among management scenarios.

Results

Soil Organic Carbon and Nitrogen Stocks

Treatments of differing CC species diversity were not significantly different for any observed soil health parameter. Soil organic carbon stocks (Table 2) in 2018 and 2019 showed no significant differences compared to fallow but were greater than SOC values determined in 2012 (Blanco-Canqui et al., 2013). This suggests SOC gains made with CCs in semiarid environments may not persist during sustained periods of drought (Table 1) that reduce total carbon inputs from lower CC biomass as well as wheat and grain sorghum yields that result under very dry conditions. Cover crops did not increase soil N (Table 3) compared to peas or fallow. However, recommended rates of N were applied to both wheat and sorghum crops and may have masked any potential differences. Soil N stocks were lower in 2019 following winter wheat harvest.

Bulk Density and Water-Stable Aggregates

Soil bulk density (BD), a common measurement of soil compaction, was decreased with CCs (1.42 g/cm³) compared to fallow (1.48 g/cm³) (Table 2) but was similar to grain pea (1.39 g/cm³) in fall 2018. No difference in soil bulk density was determined across treatments following winter wheat harvest in 2019. Water-stable aggregates are measured as an indicator of soil susceptibility to erosion. Larger aggregates are less susceptible to erosive forces. In 2018, the proportion of larger (0.08–0.30 in.) aggregate size fractions was increased with CCs (37%) compared to peas (21%) but was similar to fallow (24%) (Table 5). The proportion of smaller (0.01–0.04 in.) aggregates was decreased with CCs (32%) compared to fallow (45%) but was similar to peas (41%). Results were not significant in 2019 following winter wheat harvest. Mean weight diameter of wet aggregates in 2018 (Table 4) was not different when CCs were left standing (0.044 in.) versus when they were hayed as an annual forage (0.042 in.), but both were greater than fallow (0.033 in.) or peas (0.030 in.). Differences were not significant in 2019. Results suggest that intensification of cropping systems with CCs in place of fallow under no-till management may be a means of improving soil physical properties in semiarid drylands.

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Table 1. Monthly precipitation from 2007 to 2019 at Garden City, KS

Month	Precipitation													30-yr avg.†
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
	Inches													
Jan.	0.6	0.3	0.1	0.7	0.2	0.0	0.3	0.0	0.5	0.0	1.5	0.0	0.3	0.5
Feb.	0.6	0.6	0.1	0.4	0.4	0.8	0.2	0.0	0.3	0.3	0.0	0.0	0.8	0.6
Mar.	1.8	0.3	1.1	1.8	0.7	1.9	0.1	0.1	0.3	0.0	2.8	0.4	2.1	1.3
Apr.	2.9	1.7	4.4	2.2	1.8	1.6	0.3	0.5	0.4	4.7	4.4	0.8	0.1	1.7
May	1.2	1.9	1.9	3.9	1.1	0.3	1.0	0.6	6.3	1.1	1.1	2.2	5.9	3.0
Jun.	2.5	3.1	3.7	1.4	1.7	1.2	1.6	9.4	1.4	4.0	1.1	3.9	1.1	3.1
Jul.	1.7	1.2	3.1	1.3	0.55	1.9	3.0	3.0	4.9	5.8	2.1	8.6	1.9	2.8
Aug.	2.6	2.5	2.2	2.7	2.4	1.0	3.4	1.8	2.9	1.8	2.3	1.8	1.4	2.5
Sept.	2.1	0.7	1.6	0.3	0.35	1.1	1.5	2.5	0.0	0.1	3.2	1.9	0.1	1.4
Oct.	0.2	4.7	3.0	0.7	0.4	0.9	0.8	1.6	2.5	0.0	1.9	3.6	0.4	1.2
Nov.	0.1	0.4	0.4	0.1	0.4	0.0	0.7	0.0	0.9	0.1	0.0	0.3	0.2	0.6
Dec.	1.3	0.0	0.2	0.1	2.0	0.5	0.1	0.2	1.1	0.2	0.0	1.6	1.2	0.6
Annual	17.6	17.3	21.7	15.7	12.1	10.9	12.9	19.6	21.5	18.1	20.3	25.0	15.5	19.24

†30-year averages are for the period 1981-2010.

Table 2. Cover crop management effect on bulk density (BD) and soil organic carbon (SOC) stocks in the 0- to 6-inch soil depth in spring 2012, fall 2018, and summer 2019

Treatment	Spring 2012		Fall 2018		Summer 2019	
	BD	SOC	BD	SOC	BD	SOC
	g/cm ³	tons/acre	g/cm ³	tons/acre	g/cm ³	tons/acre
Fallow	1.49 a†	8.33 a	1.48 a	9.36 a	1.39 a	8.71 a
Pea (grain)	1.40 a	9.20 ab	1.39 b	9.61 a	1.39 a	9.19 a
Cover crops (standing)	1.47 a	9.29 b	1.41 b	9.80 a	1.39 a	8.73 a
Cover crops (hayed)	1.45 a	8.85 ab	1.43 ab	9.79 a	1.40 a	9.10 a

†Means with the same lower-case letter within the same column are not significantly different among management scenarios.

Table 3. Effect of cover crop management on soil nitrogen (NO₃-N and NH₄-N) stocks in the 0- to 6-inch soil depth in fall 2018 and summer 2019

Treatment	Fall 2018		Summer 2019	
	NO ₃ -N	NH ₄ -N	NO ₃ -N	NH ₄ -N
	----- lb/a -----			
Fallow	31.82 a†	3.73 a	7.89 a	0.15 a
Pea (grain)	39.42 a	4.90 a	9.41 a	1.71 a
Cover crops (standing)	38.04 a	4.47 a	9.22 a	1.86 a
Cover crops (hayed)	34.44 a	4.56 a	9.43 a	1.77 a

†Means with the same lower-case letter within the same column are not significantly different among management scenarios.

Table 4. Effect of cover crop management on mean weight diameter (MWD) of wet aggregates from the 0- to 2-inch soil depth in fall 2018 and summer 2019

Treatment	Fall 2018	Summer 2019
	MWD	
	----- Inches -----	
Fallow	0.033 ab†	0.082 a
Pea (grain)	0.030 b	0.070 a
Cover crops (standing)	0.044 a	0.090 a
Cover crops (hayed)	0.042 ab	0.080 a

†Means with the same lower-case letter within the same column are not significantly different among management scenarios.

Table 5. Cover crop management effect on wet aggregate size distribution for the 0- to 2-inch soil depth in fall 2018 and summer 2019

Sample period	Treatment	< 0.01-in.	0.01- to 0.04-in.	0.04- to 0.08-in.	0.08- to 0.30-in.
		----- Percent of each size fraction -----			
Fall 2018	Fallow	23 a†	45 a	8 a	24 ab
	Pea (grain)	30 a	41 ab	8 a	21 b
	Cover crops (standing)	26 a	32 b	6 a	37 a
	Cover crops (hayed)	23 a	33 ab	7 a	37 a
Summer 2019	Fallow	20 a	35 a	12 a	33 a
	Pea (grain)	21 a	39 a	13 a	26 a
	Cover crops (standing)	24 a	30 a	8 ab	39 a
	Cover crops (hayed)	23 a	38 a	4 a	34 a

†Means with the same lower-case letter within the same column and sample period are not significantly different among management scenarios.

Water Use and Productivity of Teff, a Dairy Quality Forage Crop

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

Summary

Teff grass can be a competitive summer annual forage in Kansas. Teff grass is a rapidly growing, high quality forage that could be a good option for producers in water-limited areas with a short growing season. The cultivar ‘Excalibur’ exhibited superior biomass (4280 lb/a) and crop water productivity (610 lb/a-in.), among teff cultivars. This study also indicated that biomass productivity and crop water productivity of sorghum sudangrass (696 lb/a-in.) tended to be greater than that of forage pearl millet (528 lb/a-in.). Further research into teff grass should focus on integration of teff into irrigation management systems with restricted water supply.

Introduction

Water-efficient forage crops can contribute to limited irrigation management systems. Teff grass (*Eragrostis tef* [Zucc.] Trotter) is a dairy-quality forage crop (Saylor, 2018) with limited water requirements during a short mid-summer growing season. The water use of teff grass has not been determined in the U.S. Our objective was to determine forage yield, crop water use, and crop water productivity of teff grass, under field conditions and in comparison with sorghum sudangrass (*S. × drummondii* [(Nees ex. Steud.) Millsp. & Chase]) and forage pearl millet (*P. glaucum* [L.] R.Br.).

Procedures

Field sites were established at the Kansas State University Northwest Research-Extension Center in Colby, KS, (39°23’36.3”N 101°03’47.7”W) in 2016 and 2017. The plots were established on a Keith silt loam (fine-silty, mixed, superactive, mesic Aridic Argiustolls) in 2016 and on a Richfield silt loam (fine, smectic, mesic Aridic Argiustolls) in 2017. In both years, tillage included passes with a field cultivator and a cultipacker to prepare a firm seedbed. Four commonly available teff varieties, along with sorghum sudangrass and pearl millet, were planted on June 8, 2016, and May 31, 2017, in 20- × 30-ft plots at rates of 10 lb/a for teff, and 20 lb/a for sorghum sudangrass and forage pearl millet. Areas of poor emergence were reseeded by hand to ensure adequate crop stands. Teff grass was sown no deeper than 15 mm, while sorghum sudangrass and forage pearl millet were sown no deeper than 30 mm. Fertilizer applications included 61 lb N/a as 32-0-0 and 30 lb P/a as 10-34-0 in both years. Weed management in 2016 included one application of dicamba and 2,4-D-LV6 (post-emerge) and another application of 2,4-D-LV6. In 2017, one application of 2,4-D-LV6 (post-emerge) was made. In both years, hand hoeing was required to maintain weed-free plots. Plots were irrigated (2.0 in. in 2016, 1.2 in. in 2017) after planting, to aid emergence in both years. Apart from that, no irrigation was applied during the 2016 and 2017 growing seasons.

Aboveground biomass (AGB) was measured by harvesting plants within a 30- × 30-in. quadrat. In 2016, harvest began on all plots once the majority of teff grass plots had reached late boot stage. All plots were harvested on the same day every 4–5 days from

40–58 days after planting (DAP). In 2017, each plot was harvested once it reached late boot stage. Teff grass varieties were harvested from 41–63 DAP, whereas sorghum sudangrass and forage pearl millet were harvested from 63–82 DAP. Above-ground biomass was determined after samples were dried to a constant weight. Stage of development was recorded at each biomass sampling.

Stored soil water (SSW) was measured using neutron thermalization and calculated, in 12-in. increments for the 9 ft soil profile. Soil water depletion (SWD) was calculated from the difference in the equivalent depths of successive SSW determinations for sampling periods beginning with crop emergence (15 DAP) and thereafter corresponding to biomass sampling. Cumulative water use (CWU) was calculated using the soil water balance ($CWU = SWD + \text{precipitation} + \text{irrigation}$), with no corrections for drainage or evaporation. Berms were installed around each plot to control for runoff using a “ditcher”; a type of row cultivator in 2016 but not in 2017. Crop water productivity (CWP, lb/a-in.) was determined each sampling period by dividing AGB by CWU.

Experimental design was randomized complete block design with 4 blocks as replicates, conducted in two environments (years). Treatment design was split-in-time, analyzed as repeated measure (Littell et al., 2006). The whole plot effect was annual forage cultivar (four varieties of teff grass, sorghum sudangrass, and pearl millet), the split-in-time effect was the sampling period. Analysis of variance was performed using the MIXED procedure (SAS Institute, Cary, NC, version 9.4, 2012) for AGB, CWU, and CWP. Entry and sampling period were treated as fixed effects. Non-trivial random effects included combinations of year, replication (year), year $\times$ cultivar, year $\times$ sampling period and year $\times$ cultivar $\times$ sampling period. As sampling intervals were not uniform, the covariance structure of residual error effects was evaluated with the spatial autocorrelation models ‘Power,’ ‘Gaussian,’ and ‘Spherical.’ Criteria included successful model convergence and minimized Bayesian information criterion and corrected Akaike’s information criterion.

Results

Environmental Conditions

The growing seasons extended from planting to 58 and 82 DAP in 2016 and 2017, respectively. Total precipitation for each growing season was 4.29 in. during 2016, and 7.40 in. during 2017. Average maximum/minimum air temperatures for each growing season were 104/51°F in 2016 and 93/64°F in 2017. No disease or pest was observed in either year.

Crop Development

Crops emerged six DAP in 2016 and nine DAP in 2017. In 2017, one pearl millet plot was terminated due to poor establishment and growth. All teff varieties reached the late boot stage within 41–48 DAP in 2016, and 41–43 DAP in 2017. Sorghum sudangrass and pearl millet reached the late boot stage at 72 and 58 DAP in 2016, respectively, and at 63 DAP in 2017. Accordingly, comparisons among the three species were limited to a narrow sampling interval corresponding to late panicle emergence for teff, early boot for forage pearl millet and whorl stage for sorghum sudangrass.

Biomass, Water Use, and Crop Water Productivity

No differences were detected in biomass productivity, water use, crop water productivity nor canopy formation among the three species, when evaluated at similar sampling periods (Table 1), despite substantial numerical differences. In contrast, teff cultivars differed in biomass, when analysis was restricted to the four teff varieties. Excalibur had greater biomass productivity than the other cultivars; water use of Moxie tended to be greater than that of Haymore. Biomass productivity and water use increased during the sampling intervals for teff cultivars (Table 2).

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Table 1. Productivity and water use of teff, sorghum sudangrass, and forage pearl millet, Colby, Kansas, 2016 and 2017

Species	Biomass	CWU	CWP
	lb/a	inch	lb/a-in.
Teff	4450	9.17	485
Sorghum sudangrass	6850	11.18	696
Forage pearl millet	5370	11.57	528

CWU = crop water use.

CWP = crop water productivity.

Table 2. Productivity and water use of teff cultivars, Colby, KS, 2016 and 2017

Cultivar	Biomass	CWU	CWP
	lb/a	inch	lb/a-in.
Corvallis	3220	7.05	492
Haymore	3470	6.89	528
Moxie	3590	7.68	503
Excalibur	4280	7.48	610
Sampling period			
1	2160	4.49	512
2	2940	5.51	578
3	3660	6.93	560
5	4290	8.90	490
6	4610	9.80	560

CWU = crop water use.

CWP = crop water productivity.

Water Use and Productivity of Corn and Grain Sorghum in Long-Term Crop Sequences

R.M. Aiken

Summary

Dryland corn and grain sorghum showed similar water productivity of grain and above-ground biomass, relative to respective growing periods, at the apparent yield frontier. The yield frontier indicates the maximum productivity for a given amount of water use. This similarity in productive response to water supply provides a foundation for improved precipitation use. Yield gaps relative to the yield frontier appear substantial. Water supply during the grain filling period was the primary driver of feed grain crop productivity, and was affected more by available soil water at pollen shed than by precipitation during grain-fill or available water at maturity. Grain sorghum and corn differed in responses to annual conditions, offering potential for risk management.

Introduction

Crop water productivity (ratio of above-ground biomass or grain to growing season water use) is an important component of precipitation use. Warm-season grass crops maintain water productivity with large intrinsic transpiration efficiency and enhanced tolerance of warmer temperatures. The timing and quantity of water supply frequently constrains grain productivity in semi-arid cropping systems. Cropping intensity (relative frequency of expected harvests during a multi-year crop sequence) can also influence precipitation use. The central U.S. High Plains constitutes a distinct region with regard to historic seasonal water supply, which may relate to global atmospheric circulation patterns. The objective of this long-term cropping system study was to evaluate effects of cropping intensity and crop selection on precipitation use in a temperate semi-arid region. The focus of this analysis is crop water productivity of feed grain crops.

Procedures

Three-year crop sequences, established in 2002, consisted of a winter wheat phase (WW); a feed grain phase (corn or grain sorghum) and a broadleaf phase (spring canola, field pea, soybean or sunflower; or a non-cropped fallow period). Each phase was present each year with three replicates. Crop water use was calculated from cumulative precipitation and soil water depletion during vegetative and reproductive (grain filling) development. Canopy formation at pollen shed was assessed using a canopy light transmission method. Above-ground biomass and grain fraction were determined by hand-harvest after physiological maturity. Experimental and structural effects were analyzed by analysis of variance and analysis of covariance (PROC GLM in SAS v. 9.4 (SAS Inst. Inc., Cary, NC)).

Results

All response variates differed among years, with differential responses for corn and grain sorghum. Cropping intensity (0.67 or 1.0) reduced all response variates except water

use during vegetative growth. Water use during grain filling was the greatest source of variation observed in both above-ground biomass and grain productivity, followed by inter-annual effects and cropping intensity. The apparent yield frontier (fit by eye) indicated similar productivity increases of 1270 lb/a-in. (above-ground biomass, relative to season water use, Figure 1) and 1340 lb/a-in. (grain, relative to water use during grain filling, Figure 2). Grain yield exhibited a consistent relationship with above-ground biomass, similar for both crops (Figure 3).

Figure 1. Above-ground biomass shown in relation to seasonal crop water use for corn and grain sorghum, grown in three-year continuous-crop or fallow crop sequences; apparent yield frontier fit by eye.

Figure 2. Grain yield shown in relation to crop water use (pollen shed through maturity) for corn and grain sorghum, grown in three-year continuous-crop or fallow crop sequences; apparent yield frontier fit by eye.

Figure 3. Grain yield shown in relation to above-ground biomass for corn and grain sorghum, grown in three-year continuous-crop or fallow crop sequences.

Dual Use of Cover Crops for Forage Production and Soil Health in Dryland Crop Production

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

Summary

Integrating a cover crop (CC) into dryland crop production in the semiarid central Great Plains (CGP) can provide several ecosystem benefits. However, CC adoption is slow and not widely popular in the CGP because CCs utilize water that otherwise would be available for the subsequent cash crop. Grazing or haying CCs can provide economic benefits to offset revenue loss associated with decreased crop yields when CCs are grown ahead of a cash crop. Objectives of the current research were to 1) determine forage production of CC mixtures, and 2) evaluate the impacts of removing CCs for forage on subsequent crop yields and soil health. Cover crop treatments evaluated were a mixture of oat and triticale that were either grazed, hayed or left standing compared to chem-fallow. The study was conducted from 2015 to 2019 in a wheat-sorghum-fallow cropping system with all crop phases present in each block and year of the study. Results showed forage mass varied from year-to-year, ranging from 3145 lb/a in 2015 to 1655 lb/a in 2019, and was highly dependent on growing season precipitation and temperature. Forage crude protein, digestibility, and mineral concentrations were greatest in years when CCs were sampled earlier in maturity. Average CC residue left post-grazing was 79% of forage mass available pre-grazing, and ranged from 60% in 2016 (no regrowth) to 123% in 2019 (more regrowth). Growing CCs ahead of wheat reduced winter wheat yield in 2 out of the 4 years compared to chem-fallow. Across years, winter wheat yield with chem-fallow was 51.9 bu/a compared to an average of 41.8 bu/a for the CC treatments. Cover crop treatments had no effect on grain sorghum yield. Sorghum grain yield ranged from 70.7 bu/a with CC hayed to 77.0 bu/a for the CC grazing treatment. Winter wheat or sorghum yields with haying or grazing a CC were similar to yields when CCs were left standing. Grazing CCs increased bulk density near the soil surface in 1 of the 4 years when bulk density was measured. Compared to fallow, growing a CC increased soil organic carbon (SOC) concentration measured within the top 2- to 6-inch soil depth, but not near the soil surface (0 to 2 inches).

Introduction

Cropping system diversification with CCs can provide several benefits. These include improving soil quality, nutrient cycling, weed and pest suppression, as well as reduced wind erosion. Cover crop adoption is not widely popular in water-limited environments because CCs utilize water that otherwise would be available to the subsequent cash crop. Grazing or haying CCs as forage can provide economic benefits and help offset loss in revenue associated with decreases in wheat yields when cover crops are grown in place of fallow. This approach could provide an opportunity for dryland producers to build soil health and produce harvestable forage for the region's livestock.

The few growers that have adopted CCs in dryland systems are using them for soil health improvement and as a supplemental forage resource. Information is limited on

best management options for CCs in dryland systems and producers are asking questions on best CC mixtures, and planting times for integrating CCs into cropping systems in dryland environments. Developing climate-specific CC management options for dryland farmers will improve adoption and CC use in the CGP. Our research effort includes investigating a flex-cover cropping option where CCs are grown only in years when there is adequate soil moisture. Flex-fallow is the concept of only planting CC when soil moisture levels are adequate and the precipitation outlook is favorable. Under drought conditions, implementing flex-fallow should help minimize negative impacts in dry years. Research objectives were to 1) determine forage production of CC mixtures, and 2) evaluate the impacts of removing CCs for forage on soil water content, subsequent crop yields, and soil health.

Procedures

This study is a component of a large CC field experiment initiated in spring 2015 at the Kansas State University experiment fields at HB Ranch near Brownell, KS. The overall goal of the CC trials was to develop climate-specific CC management options for integrating CCs into dryland crop production in western Kansas. Field experiments compared summer fallow to grazing or haying CC, and growing CC solely for cover in the fallow phase of a wheat-sorghum-fallow crop rotation system. Study design was a split-plot with four replications in randomized complete blocks. Main plots were three crop phases of wheat-sorghum-fallow, and sub-plots were ten CC treatments of single, two-, three-, and six-species mixtures of oat, triticale, peas, radish, turnips, and buckwheat compared to chemical-fallow. The CCs were planted in the spring of the fallow phase of the rotation. Each phase of the crop rotation was present within each block in each year of the study. In addition, a flex-cover crop treatment was included and planted to CC only when soil moisture levels were adequate and the precipitation outlook was favorable. This treatment remained as fallow when available soil water content at CC planting was < 12 in., and summer and fall precipitation outlook was not favorable. This treatment was implemented only in 2018 when conditions were met (less soil water content and precipitation outlook was unfavorable). The CC treatments were either grazed, hayed, or left as cover. Generally, grazing and haying of CCs occurred at heading. The CCs were all terminated by the third week in June with glyphosate and 2,4-D in 2015. Paraquat and Aim EC were used to terminate CCs in 2016 through 2019.

Prior to grazing, available forage mass from the grazing treatment was sampled by taking two clippings of 3 ft × 2 ft from each plot. Fresh weights of samples were recorded, and oven dried at 50°C for at least 48 hours in a forced-air oven for dry matter (DM) determination. The plots were then mob-grazed using a stocking density that utilized approximately 30 to 40% of the available forage mass at the time of grazing. Residue left post-grazing was determined as described above. Hayed treatments were harvested at heading to determine forage DM production and nutritive value. Forage harvests were performed during the last week in May 2015, the first week in June 2016 and 2017, and in the third week of June in 2018 and 2019. During each harvest, a 3-ft × 100-ft forage strip was harvested from each plot using a Carter plot forage harvester (Carter Manufacturing Company, Inc.) to a 6-inch stubble height. Whole plots sample weights were recorded, sub-samples were weighed, and oven dried for DM. Oven-dried samples from both grazing and hayed treatments were ground to pass through a 1-mm mesh screen

in a Wiley Mill (Thomas Scientific, Swedesboro, NJ). The ground samples were then analyzed for forage nutritive value [crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in vitro* dry matter digestibility (IVDMD)], and tissue nutrient concentrations (Ward Laboratories, Inc., Kearney, NE) using Foss 6500 near infrared spectroscopy (NIRS).

Soil samples were taken to determine bulk density and soil water content at winter wheat planting, and were measured at 3 ft in 2015, and at 5 ft in subsequent years of the study (2016 through 2019). Two soil cores were collected from each plot and data averaged for a single soil bulk density or water content measurement. In 2019, soil samples were taken at 0 to 2 inches and 2 to 6 inches after CC termination to determine SOC concentration. Winter wheat and sorghum grain yields were determined by harvesting a 5-ft × 100-ft area from the center of each plot using a small plot combine. Statistical analysis was conducted with the PROC MIXED procedure of SAS (version 9.4, SAS Inst., Cary, NC) to examine forage production, soil bulk density, SOC, and winter wheat and grain sorghum yields as a function of cover crop management options. This report will summarize results of the oat/triticale CC grazing or haying component of this study.

Results

Forage Mass, Nutritive Value and Cover Crop Residue Post-Grazing

Results over five growing seasons showed relatively high forage production but available forage mass varied year-to-year. As expected, the forage mass produced varied over the five years because of variations in soil water availability and air temperature in the spring. Across CC treatments, forage mass was greatest in 2015 (3145 lb/a) and least in 2019 (1655 lb/a, Figure 1a). The lower ($P < 0.05$) CC forage mass production in 2019 was due to wetter than normal spring conditions that delayed cover crop planting until late April. Similarly, a cold and dry spring in 2016 resulted in less CC productivity. In years with limited regrowth (2016, 2017, and 2018), CC forage mass at the time of grazing was similar to ungrazed (cover) CC treatment. However, in 2015 when grazing was initiated early, the ungrazed CC treatment had more biomass than was measured pre-grazing. The hay treatment was harvested at a greater height (6 inches) and therefore had relatively lower yields than cover treatments (clipped at 2 inches). In 2015 and 2019 when there was time for regrowth before CC termination, biomass left after grazing was similar to that measured pre-grazing (Figure 1b). Excluding 2019, which had more post-grazed biomass than pre-grazing, residue left post-grazing across the four remaining years (2015 through 2018) averaged 68% of that at pre-grazing. This result suggests careful grazing of CCs can leave an adequate amount of residue to protect the soil to achieve soil health goals while providing a forage resource for livestock.

Forage CP, IVDMD, and mineral concentrations were greater in years when CCs were harvested just at heading (2015, 2017, and 2019) than when CCs were more mature (2016 and 2018) with seed heads (Table 1). In general, grazed CC treatments had more CP, nutrients (Ca, P, K) and IVDMD concentrations than CC hayed treatments. Similarly, the hayed treatment had significantly greater ADF and NDF concentrations compared to the grazed treatments (Table 1). This was expected because grazed treatments were usually sampled 7 to 10 days earlier than the hayed treatments. Delaying harvest resulted in more mature plants, reducing forage digestibility and nutritive value.

Nonetheless, in a production setting, grazing of forage would likely begin at a more immature stage of forage growth and the quality would match the needs of stocker cattle.

Soil Bulk Density and Soil Organic Carbon

In general, except in 2015, growing a CC had no effect on soil bulk density measured at 0 to 2 inches at winter wheat planting. Grazing a CC in 2015 resulted in a significant increase in soil bulk density at 0 to 2 inches (Figure 2a). This was because of a significant precipitation event (> 3 inches of rainfall) that occurred during grazing, which prompted removing of cattle from the plots to prevent further soil compaction. No difference in bulk density was observed beyond the top 2 inches over the study period. The SOC concentration measured in 2019 was not different due to treatments at the surface 0- to 2-inch soil depth. However, the CC treatments did increase SOC concentration within 2- to 6-inch depth (Figure 2b) compared to fallow. The SOC concentration with haying or grazing CCs was similar to that of the true cover treatment, suggesting belowground biomass from CC roots contributes to SOC storage. This short-term study showed CCs could be utilized for forage with minimal impacts on SOC.

Winter Wheat and Grain Sorghum Yield

Winter wheat yields after CCs were not significantly affected in 2016 and 2018 (Figure 3a). However, a significant decrease in winter wheat yield was observed in 2017 and 2019 when CCs were grown ahead of wheat (Figure 3a). In 2019, however, the CC hayed treatment had similar wheat yield compared to chem-fallow. Cover crops were terminated in late June in 2018, at that point triticale had matured seeds that resulted in volunteer triticale reducing winter wheat yields in the cover and grazed CC treatments. Averaged across the 5 years, growing a CC ahead of wheat reduced winter wheat yields compared to chem-fallow. Wheat yields averaged 41.8 bu/a with CC treatments and 51.9 bu/a with fallow (Figure 3a), representing a 10 bu/a decrease in wheat yields when a CC was planted ahead of wheat. In general, CC management had no effect on sorghum grain yield in this study. Across years, sorghum grain yield ranged from 70.1 bu/a with the hayed treatment to 77.0 bu/a when a CC was grazed.

Over this 5-year study, haying or grazing a CC had no significant effect on wheat or sorghum yields compared to yields when CC was left as cover (Figures 3a and 3b). This finding suggests CC could be utilized for forage with similar impact on subsequent crop yields compared to when grown as a true CC. This is significant because utilizing CC for forage (grazing or haying) will generate income to offset revenue loss associated with decreased crop yields when CCs are grown ahead of a cash crop. Another benefit is potential savings in herbicide application costs from growing CCs. In this study, three to four herbicide applications were done to control weeds in chem-fallow treatment compared to two herbicide applications in the CC treatments (termination of CCs and another burndown prior to wheat planting).

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Table 1. Cover crop forage mass and nutritive content¹ at heading, before grain fill over 5 years at the Kansas State University experiment fields at HB Ranch near Brownell, KS

Year	CP	ADF	NDF	IVDMD	Ca ¹	P	K
----- % -----							
2015	19.1 a ²	33.7 c	53.8 c	84.9 a	0.77 a	0.41 a	3.13 a
2016	8.6 d	39.9 a	66.5 a	66.0 b	0.31 c	0.25 d	2.07 c
2017	11.7 b	34.5 bc	62.7 ab	73.0 b	0.46 b	0.29 bc	2.13 bc
2018	9.9 cd	36.4 b	58.1 bc	68.2 b	0.35 c	0.27 cd	2.32 bc
2019	10.3 c	35.8 b	57.1 bc	80.1 a	0.37 c	0.30 b	2.33 b
Cover crop	%						
Grazed	12.9 a	34.2 b	56.2 b	76.6 a	0.51 a	0.31 a	2.43 a
Hayed	11.0 b	37.9 a	63.0 a	72.4 b	0.39 b	0.29 b	2.37 a

CP = crude protein. ADF = acid detergent fiber (higher values reflect lower digestibility). NDF = neutral detergent fiber (higher values reflect lower animal intake). IVDMD = *in vitro* dry matter digestibility (reflects relative energy differences).

¹Only planted when there was adequate moisture. Ca = calcium. P = phosphorus. K = potassium.

²Values within a column followed by the same letter(s) are not significantly different ($P < 0.05$).

Figure 1. Forage mass as influenced by (a) year and (b) cover crop management at the Kansas State University experiment fields at HB Ranch near Brownell, KS. Bars followed by the same letter(s) are not significantly different ($P < 0.05$).

Figure 2. Cover crop management effect on soil bulk density (a) measured from fall 2015 to 2018 and soil organic carbon (b) measured in 2019 at the Kansas State University experiment fields at HB Ranch near Brownell, KS. Bars followed by the same letter(s) are not significantly different ($P < 0.05$).

Figure 3. Cover crop management effect on winter wheat grain yield (a) and grain sorghum yield (b) over the study period at the Kansas State University experiment fields at HB Ranch near Brownell, KS. Bars followed by the same letter(s) are not significantly different ($P < 0.05$).

Soil Microbial Seasonal Community Dynamics in Response to Cover Crop and Phosphorus Fertilizer Usage in a No-Till Corn-Soybean System in 2018

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Summary

This study examined microorganism community composition in plots managed with and without cover crops and three contrasting phosphorus (P) fertilizer management techniques in a no-till corn-soybean system. This work was performed in the spring and fall of 2018 at the Kansas Agricultural Watershed Field Laboratory (KAW), Manhattan, KS. The study design was a 2×3 complete block factorial design with three replications, with cover crop presence or absence and three levels of P fertilizer management (control, fall broadcast, and spring injected). To examine microorganism community composition, phospholipid fatty acid (PLFA) analysis was used. Only the main effect of cover crop was found to have a significant impact. Results show greater microbial biomass within plots that had a cover crop as compared to those that did not. The community structure between cover crop plots and non-cover crop plots was similar; however, their abundance was less in non-cover crop plots than in those that had a cover crop.

Introduction

There are numerous indicators for soil health, soil microorganisms are one component of soil health. A deeper understanding of how soil microbial dynamics respond to management practices can aid in providing more efficient and effective indicators of soil health to benefit producers. A PLFA analysis quantifies phospholipid fatty acids present in a soil sample. Phospholipid fatty acids are found in all cellular membranes and vary in different organisms. For this reason, quantifying phospholipid fatty acids in a soil from contrasting management scenarios can detect differences in the microbial community. Microorganisms tested for in this PLFA analysis include bacteria (prokaryotes) and eukaryotes (Thies, 2008).

Bacteria are prolific within agricultural soils; it is predicted there could be 300,000 different kinds of bacteria within one gram of soil (Gans et al., 2005). There is still much that remains unknown about soil microorganisms; however, some soil bacteria are known to have agriculturally beneficial roles. Many bacteria contribute to agriculture in making nutrients accessible to crops. Some specific kinds of bacteria are known to be helpful to plants. Actinomycetes are fibrous bacteria that look similar to fine roots. Actinomycetes can form associations with crops to allow crops to have greater access to water and nutrients (Bhatti et al., 2017). A PLFA analysis separates gram positive and gram-negative bacteria, which refers to structural characteristics of the bacterial cell wall. The PLFA analysis performed in this study separates bacteria into the follow-

ing categories: actinomycetes, gram-negative, gram-positive, and anaerobic. All bacteria are either gram-negative or gram-positive, and this classification relates to the structural characteristics of the bacterial cell wall. Anaerobic bacteria thrive in low oxygen conditions such as wet soils. Bacteria that fall into multiple categories within the PLFA are not counted in multiple categories, for example actinomycetes are a kind of gram-negative bacteria, however, they are quantified only in the actinomycetes category.

Every living organism that is not a prokaryote is a eukaryote. Organisms are classified as eukaryotes based on their cell structure. An PLFA analysis provides the following eukaryotic categories for soil microorganisms: arbuscular mycorrhizal fungi (AMF), fungi, and eukaryotes. Arbuscular mycorrhizal fungi form beneficial associations with crops similar to actinomycetes. Arbuscular mycorrhizal fungi allow crops to have greater access to water and nutrients and are also known to aid in soil structure by producing glomalin. Glomalin can protect plant roots and also binds soil particles together aiding in soil aggregate stability (Chen et al., 2018). Fungi can break down complex organic material that allows greater nutrient availability for crops. There are many different kinds of soil eukaryotes that are not AMF nor another type of fungi, one kind of eukaryote common in agricultural soils are protists. Protists largely consume bacteria and also increase nutrient availability (Bonkowski and Clarholm, 2012). Arbuscular mycorrhizal fungi are a kind of fungi, and all fungi are eukaryotes. However, the PLFA analysis does not list members in more than one group.

This study aims to better understand the dynamics of soil microorganisms in relation to cover cropping and fertilizer treatments. The KAW is managed as a corn, soybean rotation with cover crops planted after harvest each year. Results discussed in this report were from samples taken in the spring and fall of 2018 before termination of a cover crop of triticale and rapeseed (spring) and after harvesting of soybean (fall).

Procedures

The KAW is located at Kansas State University Ashland Bottoms Research Farm, Manhattan, KS. There are 18 plots at this site that range in size from 1.2 to 1.6 acres. The predominant soil at the site is on Smolan silty clay loam with an average slope of 6 to 8%. Three fertilizer systems were tested: fall broadcast (FB) application of -us, spring injected (SI) application of phosphorus, and no fertilizer application (CN). Each of these fertilizer applications were performed with a cover crop (CC) and with no cover crop (NC). This study utilized a 2×3 factorial design with three replicates laid out in a randomized complete block design.

Cover crops were first planted in 2015 and have been planted every year since. Cover crops have included: winter wheat before soybean in 2016, triticale and rapeseed before corn in 2017, and before soybean in 2018. Every year, the same amount of P fertilizer was applied as either a fall broadcast or spring injected applications. The form of P applied in the fall broadcast treatment was diammonium phosphate (DAP) at 120 lb/a (55 lb P_2O_5 /a), and the form of P applied in the spring injected treatment was ammonium polyphosphate at 14 gal/a (55 lb P_2O_5 /a). Nitrogen (N) fertilizer, 28% urea ammonium nitrate, was injected below the surface at a uniform rate of 130 lb N/a for all plots in corn years. In spring and fall of 2018, just before the CC was terminated (spring) and after the cash crop was harvested (fall), soil samples were collected from the 0- to 2-inch depth.

These samples were passed through a 2 mm sieve, frozen, and freeze dried prior to being sent to the Soil Health Assessment Center at the University of Missouri for phospholipid fatty acid (PLFA) analysis. The University of Missouri soil testing lab extracts the samples with an organic solvent and then uses gas chromatography to analyze the samples (Buyer and Sasser, 2012).

Results

There were no main fertilizer treatment effect and no interaction treatment effects in spring 2018 ($P > 0.05$ in all categories) (Table 1) nor fall 2018 ($P > 0.05$ in all categories) (Table 2). The cover crops' main effect was significant in all categories of the PLFA analysis for both spring 2018 ($P \leq 0.01$ for all categories) (Table 1) and fall 2018 ($P < 0.05$) (Table 2). Total microbial biomass was significantly greater in the cover crop treatment in both spring 2018 ($P \leq 0.01$) (Table 1) and fall 2018 ($P \leq 0.01$) (Table 2) (Figure 1). The microbial community composition as a percentage of the total community in the treatments were managed with cover crops and without cover crops in both the spring and fall 2018 samplings (Table 3).

Discussion

The findings from the PLFA analysis show a higher abundance of microorganisms present in plots that had a cover crop as compared to plots that did not have a cover crop. This finding was not surprising given that cover crops are known to support microbial populations, which is likely due to their ability to provide nutrients to microbes when cash crops are not present in fields, specifically increasing organic carbon in soil (Finney et al., 2017; Lehman et al., 2015; McDaniel et al., 2014; Nair et al., 2012; Spedding et al., 2004). The community makeup of microorganisms was found to be similar between both the cover crop and the no cover crop plots; however, this is in contrast to other research that demonstrates cover crops impacting the community makeup of microorganisms (Finney et al., 2017). This difference could be due to the sampling depth, as other work (Finney et al., 2017) examined depths deeper than 2 in., and it is possible that at depths beyond 2 in. there may be a different microbial community makeup than what was found in this study. The results discussed here are from a single time point, and as such it will be interesting to see whether findings presented here remain consistent over multiple growing seasons, or if the differences between cover crop and no cover crop plots develop with time.

These results show an increase in the abundance of soil microorganisms with the use of cover crops. Soil microorganisms aid in nutrient cycling processes, allowing nutrients to become available to crops; they also aid in soil structure. Cover crops may offer benefits to soil health in respect to the soil microorganism community, however, their relation to direct yield benefits remains to be determined.

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Table 1. Spring 2018 *P*-values and least significant differences (LSD) of treatments in (pmol/g)

Spring 2018	Treatment groups	Total biomass	AM fungi	Gram negative	Gram positive	Fungi	Anaerobe	Actinomycetes	Eukaryotes
<i>P</i> -value	Fertilizer × CC	0.42	0.75	0.48	0.44	0.69	0.24	0.37	0.07
	Fertilizer	0.43	0.52	0.40	0.36	0.46	0.36	0.69	0.13
	CC	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*
LSD	CC	11260.69	563.20	3627.8	2704.02	868.17	156.62	1342.78	173.72

* Indicates statistically significant *P*-values. *P* < 0.05.

CC = cover crop. AM = arbuscular mycorrhizal.

Table 2. Fall 2018 *P*-values and least significant differences (LSD) of treatments in pmol/g

Fall 2018	Treatment groups	Total biomass	AM fungi	Gram negative	Gram positive	Fungi	Anaerobe	Actinomycetes	Eukaryotes
<i>P</i> -value	Fertilizer × CC	0.20	0.25	0.31	0.20	0.24	0.33	0.35	0.47
	Fertilizer	0.70	0.73	0.76	0.54	0.76	0.77	0.80	0.23
	CC	<0.01*	<0.01	0.02*	<0.01*	0.04*	<0.01*	<0.01*	0.04*
LSD	CC	6145.54	287.22	2248.92	1564.38	439.14	114.56	883.27	222.25

* Indicates statistically significant *P*-values. *P* < 0.05.

CC = cover crop. AM = arbuscular mycorrhizal.

Table 3. Phospholipid fatty acid analysis microorganism community category breakdown by percent in spring and fall 2018

Microorganism category	Spring 2018		Fall 2018	
	Cover crop	No cover crop	Cover crop	No cover crop
	----- % -----			
Fungi	3.8	3.1	3.7	3.5
Arbuscular mycorrhizal fungi	4.6	4.3	5.2	5.1
Actinomycetes	16.3	17.5	15.7	15.8
Anaerobic bacteria	1.8	1.8	1.9	1.9
Eukaryotes	2.0	1.6	2.3	2.3
Gram negative bacteria	39.8	39.0	39.8	40.9
Gram positive bacteria	31.7	32.7	31.3	30.5

MANAGEMENT PRACTICES

Figure 1. Total microbial biomass measured by phospholipid fatty acid analysis for spring and fall 2018 in plots with cover crop and plots without cover crop (no cover).

Effect of Saltro Soybean Seed Treatment on Sudden Death Syndrome in Kansas in 2019

E.A. Adee

Summary

Sudden death syndrome (SDS) is a disease caused by the soilborne fungus *Fusarium virguliforme*. This fungus prefers wet conditions and thus is usually most severe in irrigated fields. SDS tends to be most severe on well-managed soybeans with a high yield potential. It also tends to be more prevalent on fields that are infested with soybean cyst nematode (SCN) or planted early when soils are wet and cool. Historical yield losses from this disease are generally in the range of 1–25%. While there are differences in susceptibility between varieties, there are no varieties that are resistant to SDS. Fortunately, for the past several years, ILeVO (Bayer CropScience) seed treatment has shown to be effective at reducing the severity and yield loss to SDS, especially when used in combination with more tolerant varieties. A new seed treatment for SDS, Saltro (Syngenta Crop Protection), will be available to farmers for the first time in 2020.

Procedures

The objective of this study was to determine the effectiveness of seed treatments on sudden death syndrome (SDS) of soybeans. Irrigated soybeans were grown at the Kansas State University Kansas River Valley Experiment Field near Topeka, KS. The field was Eudora silt loam with pH at 6.4 and organic matter at 1.6%, and the previous crop was corn that was vertical tilled prior to planting. The field had a history of SDS. Varieties NK S39-R9X (four replications) and NK S35-K9X (two replications) were planted at 160,000 seeds/acre on May 16, 2019. Seed in all the treatments was treated with CruiserMaxx Vibrance seed treatment at 3.22 fl oz/cwt. Saltro alone, Saltro with Avicta, Saltro with Clariva, and ILeVO were included in the study. The study was a randomized complete block design with six replications, and plots were 10-ft wide × 30-ft long. Soybean cyst nematode (SCN) population at planting was very low at 43 eggs/100 cc of soil. Rainfall was supplemented with two irrigation events consisting of 0.61 inches each in the last week of July. Plant populations were counted at V1-2 and V2-3, and severity of SDS foliar symptoms were rated every five to six days after onset of symptoms from August 16 through September 3. Area under disease progress curves (AUDPC) were calculated from the four ratings. Grain was mechanically harvested to estimate the yield from the center two rows with a John Deere 3300 plot combine (October 6), and yield adjusted to 13% moisture. Analysis of the data was conducted using PROC GLIMMIX in SAS v. 9.4 (SAS Inst. Inc., Cary, NC), with significance declared at $P < 0.05$.

Results

Rainfall was above average every month of the growing season, with May (11.28 in.) and August (9.2 in.) precipitation almost three and five times the average, respectively. July (88°F) was the warmest month, especially during the last half, while August (85°F) was four degrees below average. There were no differences between the varieties for

data collected, so they were combined for analysis. Foliar symptoms appeared relatively late (August 16) with soybeans at R4. The progression of symptoms increased rapidly, however, with individual plots at 40% by August 22. The plant population at V1 to V2 was slightly lower with the ILeVO treatment (Table 1), but there were no differences in population at V3 (data not shown). A strong negative correlation between AUDPC for SDS ratings and yield was observed (-0.7 Pearson coefficient, $P < 0.0001$). Saltro (1.52 fl oz/cwt) and ILeVO (2.17 fl oz/cwt) seed treatments greatly reduced the severity of SDS and increased soybean yield compared to the control. The addition of the Avicta and Clariva Elite Beans to Saltro did not alter the performance of Saltro on SDS and soybean yield.

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Table 1. Effect of soybean seed treatments on severity of Sudden Death Syndrome and soybean yield at Kansas River Valley Experiment Field, Topeka, 2019

Treatments	Plant population V1 to V2 (Plants/a)	Sudden death severity ^y (%)	AUDPC ^x	Yield (bu/a)
Control	139,973 a ^w	46.2 a	395 a	59.5 c
Saltro 1.52 fl oz/cwt	141,167 a	12.6 b	66 b	71.8 ab
Saltro 1.52 fl oz/cwt + Avicta 6.2 fl oz/ cwt	144,329 a	5.9 b	44 b	70.8 ab
Saltro 1.52 fl oz/cwt + Clariva Elite Beans 5.6 fl oz/cwt	141,425 a	9.0 b	48 b	71.1 ab
ILeVO 2.17 fl oz/cwt	122,259 b	12.2 b	70 b	66.2 b
<i>P</i> -value	0.039	<0.0001	<0.0001	<0.0001
CV (%)	8.8	57	77	8.2

^y Disease severity was estimated on September 3 at R6.

^x AUDPC = area under disease progress curve from August 16 - September 3.

^w Data followed by the same letter or without letters within a column were not significantly different at $P < 0.05$.

CV = coefficient value.

Effect of Late Season Management Practices on Soybean Seed Filling and Yield

F.E. Baronio and I.A. Ciampitti

Introduction

For soybean (*Glycine max* [L.] Merr.), final seed yield is primarily explained by modifications in the seed number per unit area. However, changes in individual seed weight can contribute to variations in seed yield. Final seed weight is defined by the amount of biomass accumulated in seeds per day (i.e., rate of seed growth) and the duration of this phase (i.e., number of days for seed filling). During the seed filling period, the seed growth rate and the duration are sensitive to growing conditions. Thus, any limitation on resources availability (e.g., water, radiation, and nutrients) during this period can be translated into reductions in seed weight that ultimately will affect final seed yield. The objective of this study was to identify late-season management practices potentially contributing to increased final seed weight and seed yield in soybeans.

Procedures

A field study was conducted at the Ashland Bottoms Research Farm, Ashland Bottoms, KS (39.14° North, 96.64° West). The type of soil was quartic Argiduolls (18% clay, 54% silt, and 28% sand). Soil samples were collected before planting at 6-inch soil depth. The pH was 7.6, soil phosphorus (Mehlich) was above the critical threshold (90 ppm), and soil organic matter was 2.1%. The soybean variety utilized for this study was P38T20X (a maturity group 3.8; DuPont Pioneer), planted June 26, 2019, under rainfed conditions and a target plant density of 145,650 plants per acre. Maximum average temperature during the season was 83.1°F and 62.0°F the minimum. Total seasonal precipitation was 15.95 inches from planting to harvest.

Plots were arranged in a complete randomized block design with four replications. Plots were 45 feet long with four rows spaced at 30 inches. Treatments were applied at full pod formation (R4 growth stage) and consisted of different management practices:

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

When needed, plots were sprayed to control weeds, pests, and diseases with a handheld backpack sprayer.

In each soybean plant within all treatments, seed samples were collected 15 days after the onset of seed filling and every 7 or 10 days until physiological maturity (R7 growth

stage). Final seed weight, rate, and duration were determined fitting a bi-linear model to the data collected.

$$\text{Seed weight (mg/seed)} = a + b \times d \text{ (for } d < c) \quad [1]$$

$$\text{Seed weight (mg/seed)} = a + b \times c \text{ (for } d > c) \quad [2]$$

where b is the linear seed growth rate (mg/day), and c is the duration of the seed filling period in days.

At physiological maturity, an area of 18.75 ft² in the two central rows of each plot was manually harvested to determine final seed yield.

Results

Seed Yield and Seed Weight

Seed yield ranged between 34.2 and 52.3 bu/a and seed weight ranged from 132 to 166 mg/seed, respectively. However, statistical differences among treatments were not detected for yield or seed weight (Figures 1, 2, 3, and 4).

Duration and Rate

Rate and duration of seed filling were not affected by any of the evaluated treatments (Figures 2 and 3). Thus, variation observed in all the investigated variables can be mainly attributed to the spatial variability of the experimental conditions.

Conclusions

Treatments applied did not affect final seed weight or seed yield. Furthermore, across all treatments similar trends were observed for the seed growth rate and seed filling duration. Future research should consider evaluating the effect of these treatments tested at different crop growth stages.

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SOYBEAN

Figure 1. Seed yield (bu/a) for each treatment. The top vertical bars are the 95% confidence interval. Fun + Ins = fungicide and insecticide. N = nitrogen. PN = plant nutrition.

Figure 2. Seed filling rate for each treatment. The top vertical bars are the 95% confidence interval. Fun + Ins = fungicide and insecticide. N = nitrogen. PN = plant nutrition.

SOYBEAN

Figure 3. Seed filling duration for each treatment. The top vertical bars are the 95% confidence interval. Fun + Ins = fungicide and insecticide. N = nitrogen. PN = plant nutrition.

Figure 4. Final seed weight rate for each treatment. The top vertical bars are the 95% confidence interval. Fun + Ins = fungicide and insecticide. N = nitrogen. PN = plant nutrition.

Figure 5. Changes in seed dry weight accumulation from the onset of the seed filling (R5 growth stage) until physiological maturity, end of the season. Each point represents the average of four replications. Fun + Ins = fungicide and insecticide. N = nitrogen. PN = plant nutrition.

Nitrogen and Sulfur Fertilization in Soybean: Impact on Seed Yield and Quality

L.H. Moro Rosso, W.D. Carciochi, S.L. Naeve,¹ P. Kovács,² S.N. Casteel,³ and I.A. Ciampitti

Summary

Over time, plant breeding efforts for improving soybean [*Glycine max* (L.) Merr.] yield were prioritized and effects on seed nutritional quality were overlooked, decreasing protein concentration. This research aims to explore the effect of nitrogen (N) and sulfur (S) fertilization on soybean seed yield, seed protein and sulfur amino acids concentration. In 2018, ten field trials were conducted across the main US soybean producing region. The treatments were fertilization at 1) planting (NSP); during 2) vegetative growth (NSV); and 3) reproductive growth (NSR) and 4) unfertilized (Control). Nitrogen fertilization was applied at the rate of 40 lb/a utilizing urea ammonium nitrate (UAN), and S at 9 lb/a via ammonium sulfate (AMS). A meta-analysis was performed to consider small variations among experimental designs. A summary of the effect sizes did not show effects for seed yield. However, fertilization at planting (NSP) increased seed protein by 1% more than the control across all sites. Overall, sulfur amino acid concentration increased by 1.5% relative to the control, but the most consistent benefit came from fertilization during the reproductive growth (NSR), increasing sulfur amino acids by 1.9%. Although N and S fertilization did not affect seed yields, applying N and S in different stages of the crop growth can increase protein concentration and improve protein composition, providing the opportunity to open new US soybean markets.

Introduction

Soybean [*Glycine max* (L.) Merr.] demands a great amount of nitrogen (N) during the seed filling period compared to other legumes and cereals. The plant N assimilation from the soil supply and biological nitrogen fixation (BNF) frequently does not match the requirements for a high yielding crop. This gap between assimilation and requirement forces the plant to prematurely remobilize N from other organs and consequently establish a “self-destruction” status, hampering the synthesis of highly energetic compounds in the seed, such as proteins and amino acids (Sinclair and de Wit, 1975). Over the last decades, plant breeding efforts overlooked changes in seed quality (defined here as nutritional composition) and concentrated on increasing soybean yields. The latter was achieved, increasing production and profitability, but the former was diminished, creating a concern for the global industry and producers. This study aims to explore the effect of N and S fertilization on seed yield, seed protein, and concentration of sulfur amino acids—such as cysteine and methionine. We hypothesized that N and S fertilization as a management practice can help offset the reduction in protein levels and protein quality (amino acids concentration), especially when adopted during the seed filling period.

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Procedures

Sites and Measurements

This research project was conducted across seven states of the main soybean producing region in the United States (KS, MN, AR, IL, IA, SD, and IN), investigating management practices with potential effects on soybean nutritional quality. However, experimental designs and treatments are slightly different across locations, requiring a preliminary selection of studies to perform the analysis in this report. Selection of trials, from the 2018 season, was done considering the presence of the following treatments in at least one variety $\times$ planting date combination (defined as the study): 1) fertilization at planting (NSP); during 2) vegetative growth (NSV); 3) reproductive growth (NSR); and 4) an unfertilized (Control). A description of the 10 selected studies and their soil properties before planting is presented in Table 1. Regarding fertilizers and nutrient rates, ammonium sulfate (AMS) was applied to provide 9 lb/a of S-SO₄, and urea ammonium nitrate (UAN) to provide 40 lb/a of N. At harvest, seed yield was recorded and seed samples were analyzed in terms of protein and sulfur amino acids concentration with the near infrared (NIR) method (Pazdernik et al., 1997).

Statistical Analysis

A meta-analysis was adopted considering the different experimental procedures and designs across locations. The response ratio effect sizes, in logarithmic scale, of each treatment relative to the control, were estimated according to Borenstein et al. (2009). First, the effect sizes were calculated per study and associated to the within-study variability. The between-study variability was also estimated in order to assign specific weights to each study (random effect model). Finally, the summary of the effect sizes was calculated for each of the treatments and variables. The I^2 parameter, percentage of between-study variance over the total variance, was calculated for each model and could be associated with specific conditions of each study (e.g. weather and soil), beside the random error. The R software (R Core Team, 2019) was used to perform calculations, analysis, and figures.

Results

Responses on Seed Yield and Quality

The summary of effect sizes shows no yield response from N and S fertilization applied at any time of the soybean season (Figure 1). Seed protein concentration across sites was increased by 1% more than the control only by the fertilization at planting (Figure 2). The sulfur amino acids were always enhanced after N and S application, increasing 1.7%, 1.5% and 1.9% when applied at NSP, NSV, and NSR, respectively—all relative to the control. In addition, for sulfur amino acids, the summary of effect sizes for the late fertilization (NSR) was the most precisely estimated, with smaller 95% confidence intervals (CI). Overall, the magnitude of changes in protein and amino acids was relatively small, around 1–2% over the control, which represents less than 1% of changes on the basis of concentration by dry weight.

Final Considerations and Next Steps

Much of the between-study variance is not explained by the current meta-analysis model. A future step for fine-tuning this model could be to consider the input of weather and soil variables to improve the estimation of the summary effect size. In addition, more studies from the literature or from different field locations should be

explored, minimizing the weight of specific sites on the final results, and even allowing statistical comparison of fertilization timings during the season.

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Table 1. Description of the ten studies relative to planting date, maturity group (MG), and soil properties (pH, clay, and soil organic matter)

State	Study	Planting date (2018)	MG [†]	pH	Clay (%)	SOM [‡] (%)
IN	IN1	05-11	3.4	6.4	25	3.4
	IN2	06-05	3.4	6.4	25	3.4
	IN3	05-24	2.4	6.2	20	3.7
	IN4	05-24	3.4	6.2	20	3.7
SD	SD1	05-15	1.1	6.1	30	4.7
	SD2	05-15	2.4	6.1	30	4.7
	SD3	06-04	1.1	6.1	30	4.7
	SD4	06-04	2.4	6.1	30	4.7
	SD5	05-17	1.1	6.6	35	3.4
	SD6	05-17	2.4	6.6	35	3.4

[†] Relative maturity group. [‡] Soil organic matter (loss-on-ignition).

Studies were located in Indiana (IN) and South Dakota (SD), with study codes representing single combinations of planting dates and MG.

Figure 1. Treatment effect sizes for soybean seed yield across studies. Squares are located on the log of the response ratios (RR), or effect sizes. Size of the squares represent the weight of the study on the final summary, and horizontal bars represent the 95% confidence intervals (CI). The width of the gray bar on the effects summary determines whether the treatment had a positive, negative, or no effect (ns) on seed yield (95% CI). Percentages (left of the summary) indicate the final RR, and the I^2 represents the between-study variability. Nitrogen (N) and sulfur (S) application at planting is presented in the left panel (NSP), during the vegetative growth in the center (NSV), and during the reproductive growth in the right panel (NSR).

Figure 2. Treatment effect sizes for seed protein concentration across studies. Squares are located on the log of the response ratios (RR), or effect sizes. Size of the squares represent the weight of the study on the final summary, and horizontal bars represent the 95% confidence intervals (CI). The width of the gray bar on the effects summary determines whether the treatment had a positive, negative, or no effect (ns) on protein (95% CI). Percentages (left of the summary) indicate the RR, and the I^2 represents the between-study variability. Nitrogen (N) and sulfur (S) application at planting is shown in the left panel (NSP), during the vegetative growth in the center (NSV), and reproductive growth in the right (NSR).

Figure 3. Treatment effect sizes for sulfur amino acids concentration across studies. Squares are located on the log of the response ratios (RR), or effect sizes. Size of the squares represent the weight of the study on the final summary, and horizontal bars represent the 95% confidence intervals (CI). The width of the gray bar on the effects summary determines whether the treatment had a positive, negative, or no effect (ns) on sulfur amino acids (95% CI). Percentages (left of the summary) indicate the summary RR, and the I^2 represents the between-study variability. Nitrogen (N) and sulfur (S) application at planting is presented in the left panel (NSP), during the vegetative growth in the center (NSV), and N and S applied during the reproductive growth is presented in the right panel (NSR).

Weed Management and Soybean Yields as Influenced by Row Width and Post-Emergent Herbicide Application Timing

S.R. Duncan and E.A. Adee

Summary

Irrigated soybeans were grown in 2018 and 2019 at the Kansas River Valley Experiment Field near Rossville, KS. Soybeans were planted in 30-inch or 15-inch rows and a standard pre-emergent herbicide was applied. Planting dates were May 11 and June 4 in 2018 and 2019, respectively. The post-emergent herbicide was applied at approximately 21 or 35 days following soybean planting (DAP). Weed control and crop injury were visually evaluated approximately every seven days following herbicide application. Yields, moisture, and test weights were calculated from the center two rows in 30-inch plots and four rows in 15-inch plots after combine harvest. Predominant weeds present were Palmer amaranth, giant foxtail, ivyleaf morningglory, and honeyvine milkweed. Soybean yields from plots without post-emergent herbicide applied were reduced 6–17% vs. those that were treated. In the 27-day longer growing season of 2018, yield of soybeans planted in 15-inch rows trended slightly, though not significantly, higher than those planted in 30-inch rows.

Introduction

Increasing incidences of herbicide resistant weeds in soybean production have led to more integrated weed management programs. The incorporation of pre-emergence herbicides and narrowing soybean row width are two fairly simple and effective practices to help boost soybean yields and improve weed suppression. Palmer amaranth has become an extremely important, and difficult, weed to control with herbicides alone. In Kansas, resistance of Palmer amaranth to five different herbicide groups has been documented and is suspected in two more. Our goal was to reduce weed competition to soybeans with an integrated management plan resulting in less competition, greater yields and greater profits for growers.

Procedures

The studies were established in 2018 and 2019 at the Kansas River Valley Experiment Field Rossville Unit just east of Rossville, KS, on a Eudora sandy/silt loam soil. All plots were planted with a Kinze 7000 split-row planter. For 30-inch rows, every other planter unit was disabled. The treatments were arranged in a randomized complete block design with four replications. Individual plots were 10 feet by 35 feet. Cultural practices are listed in Table 1. The soybean cultivar was changed for the 2019 experiment to one with dicamba tolerance due to anticipated herbicide drift issues from other studies and neighboring fields. Post-emergent herbicide treatments were applied as described in Table 2. Weed control and crop injury were recorded both years. Weed control was excellent and very little, if any, crop phytotoxicity from the post-emergent treatments was noted (data not shown). At harvest the center two rows from the 30-inch plots and the center four 15-inch rows were machine harvested with a John Deere 3300 combine

with a 5-foot header. Plot weight, moisture and test weight for each plot was taken at harvest. Soybean yields were adjusted to row width and 13% moisture.

Results

2018

The yields in 2018 were excellent (Table 3) as the result of a full 160-day growing season and excellent precipitation nearly all season long to supplement the irrigation. The pre-emergence herbicide program was applied to all plots, including the untreated checks, since this study was focused on a post-emergent program. The pre-emergence received adequate rainfall to be activated and did a good job early. The area of the study was in a prime Palmer amaranth and giant foxtail area of the field. Emergence was a little slowed by limited rainfall after planting, but the crop did emerge and establish fairly uniformly. The first post-emergent application (Table 2) was made June 5 (26 DAP) when soybeans had reached V3, just as Palmer amaranth (2-leaf), ivyleaf morningglory (cotyledons), and giant foxtail (1-2 leaf) were breaking through the pre-emergence herbicides. Excellent control of the broadleaves was obtained in all treatments, but giant foxtail was not affected in treatments that did not contain Roundup PowerMAX in the mix. The 35 DAP post-emergent treatments were applied June 18. Soybeans were at five to six leaf and moving to R1. At that point, some of the Palmer amaranth was past the labeled maximum height of 4–6 inches for adequate control and morningglory was spreading out up to eight inches. Control was still fairly good, but some weeds did escape and were a challenge the rest of the growing season. Adequate rainfall and supplemental irrigation carried the crop successfully to harvest. Soybeans were harvested October 18. Yield results (Table 3) for even the very weedy Untreated Check treatments were still 63.5 bu/a, but the weed seedbank increased tremendously in those areas. Fifteen-inch row soybeans with good weed control tended to be top yielders, but the top 30-inch row yields were not significantly less. Another, not statistically significant trend, was that the straight Cobra treatments on 26 DAP soybeans at either row spacing and led us to consider adjustments for the next year.

2019

The spring planting season was entirely different in 2019. Soybeans were not planted until June 4 because of frequent and excessive rainfall the entire month of May. In addition, the cultivar used was changed to one with dicamba tolerance for insurance against ambient drift into the plots, and the pre-emergence treatment was adjusted to more closely fit practices of local growers (Table 1). Again, the pre-emergence herbicide mixture was applied to all plots. Soybeans germinated and emerged rapidly and uniformly. Palmer amaranth pressure was heavy, but not as intense as in 2018, but the giant foxtail was off to a strong start as the result of plenty of moisture and warm soil. The first post-emergent treatments were early (only 17 DAP) because of the rapid growth of the weeds and the soybeans, which were V3-V4. Weed kill from this application was good, but there were already Palmer amaranth weeds that were burned back but survived. Soybeans in 15-inch rows did out-compete the stunted weeds and suppressed them fairly well the rest of the season. The soybeans in 15-inch rows had closed the canopy less than 30 days after that first application. More weeds survived the first post-emergent in 30-inch row soybeans and were able to compete and produce more seed than desired (personal observation). The application at 35 DAP did an adequate job of controlling weeds, but the soybean canopy was closing rapidly

and sheltering many of the larger weeds in the canopy from getting complete coverage. Soybeans were harvested October 15. The entire 2019 growing season from planting to harvest was 133 days, fully 27 days shorter than the 2018 growing season. Yields were still good (Table 3), and once again the numerically highest yields were in the 15-inch rows. However, in 2019, it was the two latest treatments that trended to the top. Interestingly, neither was statistically significantly greater than the untreated checks of either row spacing.

Future Research

This study will continue in 2020 with two planting dates vs. one. In addition, canopy closure will also be monitored to aid in developing a sound dataset that growers, advisors, and industry can use to make sound decisions.

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Table 1. Practice summary for a soybean weed management study

	2018	2019
Cultivar	Bayer LL CZ3481LL	Asgrow 39X7 with ILcVO
Seeding rate per acre		
15-inch rows	155,000	160,000
30-inch rows	140,000	140,000
Pre-emergence herbicide	1 quart/a Durango + 3.4 oz Fierce	6 oz Authority Maxx + 1.5 pt Dual II Magnum + 24 oz Roundup WeatherMAX
Planting date	May 11	June 4
21 DAP treatment	June 5	June 21
35 DAP treatment	June 18	July 8
Harvested	October 18	October 15

DAP = days after planting.

Table 2. Treatments for post-emergent weed management study in soybeans in 2018–2019

Row width	Herbicide(s)	Rate(s)	Timing
Inches		Product/a	Days after planting
15	Untreated (UTC)	---	---
15	Cobra	11 oz.	21
15	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	21
15	Cobra	11 oz.	35
15	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	35
30	Untreated (UTC)	---	---
30	Cobra	11 oz.	21
30	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	21
30	Cobra	11 oz.	35
30	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	35

Table 3. Soybean yields as affected by a post-emergent weed management program 2018–2019

Row width	Herbicide	Rate	Days after planting	Yield	
				2018	2019
Inches		Product/a		----- bu/a -----	
15	Untreated (UTC)	---	---	62 d†	68 ab
15	Cobra	11 oz.	21	76 bc	60 b
15	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	21	81 ab	67 ab
15	Cobra	11 oz.	35	84 ab	75 a
15	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	35	89 a	75 a
30	Untreated (UTC)	---	---	66 cd	65 ab
30	Cobra	11 oz.	21	73 bcd	68 ab
30	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	21	77 abc	68 ab
30	Cobra	11 oz.	35	87 abc	64 b
30	Cobra + Roundup PowerMAX	11 oz. + 39 oz.	35	80 ab	70 ab

† Means within a year followed by the same letter are not significantly different at $\alpha = 0.10$.

Efficacy of Late-Season Herbicide Programs for Controlling Palmer Amaranth in Postharvest Wheat Stubble

R. Liu, V. Kumar, N. Aquilina, and T. Lambert

Summary

Late-season control of Palmer amaranth in postharvest wheat stubble is a challenge for Kansas producers. The objective of this study was to determine the effectiveness of POST herbicide programs (with multiple modes of actions) for late-season control of Palmer amaranth in postharvest wheat stubble. The study was conducted at the Kansas State University Agricultural Research Center in Hays, KS, in 2019. The study site had a natural seedbank of Palmer amaranth that emerged immediately after wheat harvest. All selected herbicide programs were tested 3 weeks after wheat harvest, when Palmer amaranth plants had attained a height of 2 to 2.5 feet with inflorescence initiation. Twenty-four herbicide programs comprising Roundup PowerMax, Clarity, 2,4-D, Aatrex, Gramoxone, Sencor, Valor SX, Spartan, Sharpen, Authority Supreme, Kochiavore, Panther MTZ, and Huskie applied alone or in tank-mixtures were tested at recommended-use rates. All herbicide treatments were arranged in a randomized complete block design with four replications. Visual Palmer amaranth control was assessed at 2, 4, and 8 weeks after treatment (WAT) by using a rating scale of 0–100% (where 0 = no control and 100% = complete plant death). The aboveground Palmer amaranth biomass and seed production were determined by harvesting plants from a 10.7-ft² quadrat placed at the center of each plot 8 WAT. All tested herbicide programs, except Kochiavore and a tank-mixture of Huskie + Aatrex provided > 88% control of Palmer amaranth 8 WAT. In contrast, late-season control of Palmer amaranth did not exceed 71% at 8 WAT with Kochiavore or a tank-mixture of Huskie plus Aatrex treatments. Consistent with visual control (%), a majority of those tested programs significantly reduced shoot dry weights (>77% reduction) and seed production (>93% reduction) of Palmer amaranth compared to nontreated weedy check. Overall, these results suggest that several POST herbicide programs exist that growers can utilize for effective late-season control of Palmer amaranth in postharvest wheat stubble.

Introduction

Palmer amaranth (*Amaranthus palmeri* S. Wats.) has become the most problematic weed species in agronomic crops across western and central parts of Kansas (Thompson et al., 2018). It is a dioecious (male and female flowers on separate plants) summer annual broadleaf weed that belongs to the pigweed family (Ward et al., 2013). Palmer amaranth manifests several unique biological traits such as extended period of emergence, aggressive growth (1 to 2 inch per day), and prolific seed production (a single female plant can produce up to 0.6 million seeds) (Keeley et al., 1987; Steckel et al., 2004; Ward et al., 2013). In addition, Palmer amaranth is also highly prone to develop herbicide resistance (Heap, 2020).

Glyphosate-resistant (GR) Palmer amaranth is fairly common in Kansas fields. Recent Palmer amaranth surveys from south central Kansas have also revealed the prevalence

of reduced sensitivity (potential resistance) to glyphosate (EPSPS inhibitor), chlorsulfuron (ALS inhibitors), atrazine (PS II inhibitor), and mesotrione (HPPD inhibitor) among field populations (Kumar et al., 2020). The multiple herbicide-resistant (MHR) Palmer amaranth is now a serious management concern to Kansas growers. Currently, Palmer amaranth populations are reported with resistance to one or more of the following herbicide site(s) of action, including sulfonylureas (ALS inhibitors), atrazine (PS II inhibitor), mesotrione (HPPD inhibitor), glyphosate (EPSPS inhibitor), and recently to 2,4-D (synthetic auxins) in Kansas (Heap, 2020; Kumar et al., 2019).

Palmer amaranth after wheat harvest can grow and produce significant numbers of seeds (Bagavathiannan et al., 2012). The seedbank allows Palmer amaranth to establish and reproduce, making management more challenging in the subsequent growing seasons. In order to prevent the further spread of GR Palmer amaranth, it is critical to develop postharvest Palmer control strategies in wheat stubble. Therefore, the objective of this study was to determine the effectiveness of late-season POST herbicide programs on control and seed production of Palmer amaranth in postharvest wheat stubble.

Procedures

The field study was conducted at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS, in 2019. Winter wheat (variety 'Joe') was planted at the experimental site in fall of 2018 and harvested on July 11, 2019. The study site had a natural Palmer amaranth seedbank. Palmer amaranth seedlings emerged immediately after wheat harvest. Twenty-four selected herbicide programs were tested when Palmer amaranth plants reached to the height of 2 to 2.5 ft and were showing signs of inflorescence initiation. Treatments were arranged in a randomized complete block design, with 4 replications. All herbicide programs were tested at recommended-use rates (Table 1). All herbicide treatments were applied on August 2, 2019, with a CO₂-pressurized backpack sprayer equipped with TeeJet AIXR 110015 flat spray nozzle tips (Spraying Systems Co., Wheaton, IL) calibrated to deliver 15 gallons per acre spray solution. Data on visual Palmer amaranth control on a scale of 0 to 100% (0 = no control and 100 = complete control) were collected at 2, 4, and 8 weeks after treatment (WAT). Aboveground shoot biomass was determined by hand-harvesting Palmer amaranth plants from a square yard quadrat at the center of each plot at 8 WAT. Palmer amaranth plants collected for biomass were threshed and cleaned to determine the seed production in each treatment. Data on Palmer amaranth control (%), biomass, and seed production 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

Efficacy of Late-Season Herbicide Programs

All tested herbicide programs provided >88% control of Palmer amaranth at 8 WAT, except Kochiavore and a tank-mixture of Huskie + Aatrex (Figures 1 and 2). A majority of the tested programs significantly reduced Palmer amaranth shoot biomass (>77% reduction) and seed production (>93% reduction) compared to nontreated weedy check (Figures 3 and 4). Among all tested programs, the least reduction in Palmer amaranth shoot biomass (9% reduction) and seed production (72% reduction) was

observed with a tank mixture of Huskie + Aatrex in comparison to nontreated weedy check (Figures 3 and 4).

Conclusions and Implications

These preliminary results indicated that several alternatives (other than glyphosate) POST burndown herbicides—including Clarity, 2,4-D, Gramoxone, Sharpen, and Liberty—exist which can be utilized in combination with Aatrex, Authority Supreme, Panther MTZ, Sencor, Spartan, and Valor for effective late-season control of Palmer amaranth in postharvest wheat stubble.

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Table 1. List of herbicide programs tested for controlling Palmer amaranth in postharvest wheat stubble at the Kansas State University Agricultural Research Center in 2019

Treatment #	Herbicide programs ^{a,b}	Rate (oz/a)	Herbicide groups
1	Nontreated	---	---
2	Roundup PowerMax	32	9
3	Clarity	16	4
4	2,4-D amine	32	4
5	Roundup PowerMax + Clarity	32+16	9 & 4
6	Roundup PowerMax + 2,4-D amine	32+32	9 & 4
7	Clarity + Aatrex	16+16	4 & 5
8	Clarity + 2,4-D amine	16+32	4
9	Gramoxone	48	22
10	Gramoxone + Aatrex	48+16	22 & 5
11	Gramoxone + Sencor	48+5	22 & 5
12	Gramoxone+ Valor	48+2	22 & 14
13	Gramoxone + 2,4-D amine	48+32	22 & 4
14	Gramoxone + Spartan	48+4	22 & 14
15	Gramoxone + Authority Supreme	48+10	22 & 14, 15
16	Gramoxone + Panther MTZ	48+15	22 & 5, 14
17	Sharpen	2	14
18	Sharpen + Aatrex	2+16	14 & 5
19	Sharpen + Sencor	2+5	14 & 5
20	Sharpen + 2,4-D amine	2+32	14 & 4
21	Kochiavore	16	4 & 6
22	Huskie + Aatrex	15+16	6, 27 & 5
23	Liberty	36	10
24	Liberty + 2,4-D amine + Roundup PowerMax	36+32+32	10, 4, 9
25	Liberty + Clarity + Roundup PowerMax	36+16+32	10, 4, 9

^a Herbicide treatments were applied on 2- to 2.5-ft tall Palmer amaranth plants showing inflorescence initiation in postharvest wheat stubble.

^b All treatments were applied with appropriate adjuvants as dictated by each herbicide label.

Figure 1. Effect of late-season herbicide programs on Palmer amaranth control at 2, 4, and 8 weeks after treatment (WAT) in postharvest wheat stubble.

Figure 2. Palmer amaranth control in postharvest wheat stubble at 8 WAT: A) Nontreated; B) Gramoxone alone; C) Kochiavore; and D) Liberty + Clarity + Roundup PowerMax.

Figure 3. Effect of late-season herbicide programs on Palmer amaranth shoot biomass at 8 weeks after treatment in postharvest wheat stubble.

Figure 4. Effect of late-season herbicide programs on Palmer amaranth seed production in postharvest wheat stubble.

Response of Dicamba/Fluroxypyr/ Glyphosate-Resistant Kochia to Atrazine and Alternative Postemergence Herbicides

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

Summary

Two kochia accessions (KS-4A and KS-4H) were previously identified from a corn field near Garden City, KS, with multiple resistance to glyphosate (Roundup PowerMax), dicamba (Clarity), and fluroxypyr (Starane Ultra). The objectives of this research were to (1) determine the response of these kochia accessions to preemergence (PRE) and postemergence (POST) applied atrazine (Aatrex) in dose-response assays, and (2) determine the effectiveness of alternative POST herbicides. Seeds of a known susceptible kochia accession (SUS) collected from research fields in Hays, KS, were used for comparison. Greenhouse experiments were conducted at the Kansas State University Agricultural Research Center near Hays, KS, in a randomized complete block design with 4 to 12 replications. For Aatrex PRE dose-response assay, germination trays (each 10- × 10-inch) containing field soil were used. Fifty seeds from each accession were separately sown on the soil surface in each tray. PRE applied Aatrex doses, including 0, 1/4X, 1/2X, 1X, 2X, and 4X (1X of Aatrex = 32 oz/a) were tested. Emerged kochia seedlings from each tray were counted 28 days after treatment (DAT). For Aatrex POST dose-response assay, kochia plants from SUS and KS-4H accessions were grown in 4- × 4-inch pots containing commercial potting mixture. The same doses of Aatrex (as for PRE dose-response) were tested on 3- to 4-inch tall kochia plants. In a separate greenhouse study, the SUS and KS-4H accessions were also tested with alternative POST herbicides. Data on percent visual control and shoot biomass were collected at 21 DAT in both Aatrex POST and alternative POST herbicide studies. Results indicated that the effective dose (ED₅₀ values) of PRE applied Aatrex required for 50% reduction in seedling emergence of KS-4A, KS-4H, and SUS was 129, 7, and 1 oz/a, respectively, indicating 129- and 7- fold resistance in KS-4A and KS-4H accessions. Furthermore, the KS-4H accession showed 248-fold resistance to POST applied Aatrex, as compared to SUS accession. Among alternative POST herbicide programs, Gramoxone, Huskie, Talinor, and Sharpen alone or with 2,4-D provided excellent control (96-100%) of SUS and KS-4H accession at 21 DAT. In conclusion, these results indicate that dicamba/fluroxypyr/glyphosate-resistant kochia plants from Garden City, KS, are also highly resistant to PRE and POST applied atrazine. However, alternative POST herbicides such as Huskie, Talinor, Gramoxone, Sharpen alone, or with 2,4-D were effective control options for these multiple resistant kochia accessions.

Introduction

Kochia (*Bassia scoparia* L.) is a highly invasive and troublesome weed species across the United States Great Plains, including Kansas (Kumar et al., 2018a). It has an extended emergence period from early spring through late summer (Dille et al.,

2017; Kumar et al., 2018b). Kochia has an aggressive growth habit and it can tolerate various abiotic stresses such as cold, heat, drought, and salinity (Friesen et al., 2009; Kumar et al., 2018a). Kochia has high outcrossing potential and can exchange genes between and among field populations (Beckie et al. 2016). Kochia plants produce a lot of seeds (a single plant can produce >100,000 seeds) and spread those seeds through wind-mediated tumbling of matured plants in late fall (Kumar et al., 2018a). Season-long competition from kochia in soybean, corn, and sorghum can reduce grain yields by 30 to 40% (Kumar et al., 2018a).

Kochia also has a high tendency to evolve herbicide resistance (Heap 2020). In 2017, kochia accessions were identified from corn fields near Garden City, KS, with multiple resistance to glyphosate, dicamba, and fluroxypyr (Kumar et al., 2019). About 3.1- to 9.4-fold resistance to dicamba, 3.0- to 8.6-fold resistance to fluroxypyr, and 3- to 13-fold increase in EPSPS gene copies (target site of glyphosate) were found in these kochia accessions (Kumar et al., 2019). However, the response of these multiple resistant kochia accessions to atrazine (Aatrex) and other alternative POST herbicides is unknown. The main purpose of this study was to (1) determine the response of these kochia accessions to preemergence (PRE) and postemergence (POST) applied atrazine (Aatrex) in dose-response assays, and (2) determine the effectiveness of alternative POST herbicides.

Procedures

Fully matured seeds of kochia plants surviving two applications of Starane Ultra (fluroxypyr) at field-use rate (6.4 fl oz/a) were originally collected from two different corn fields near Garden City, KS, in fall 2017. The progeny seeds of two different accessions (KS-4A and KS-4H) collected from one of these corn fields were used. In addition, seeds of a known susceptible kochia accession (SUS) collected from research fields in Hays, KS, were also used for comparison. Greenhouse experiments were conducted at Kansas State University Agricultural Research Center near Hays, KS. For Aatrex PRE dose-response assays, germination trays (each 10 × 10 inch) containing sterilized field soil were utilized. Experiments were performed in a completely randomized design with four replications (one tray = one replication). Fifty randomly selected seeds from each accession were uniformly spread on the soil surface in each tray. Doses of PRE applied Aatrex, including 0, 1/4X, 1/2X, 1X, 2X, and 4X (1X of Aatrex = 32 fl oz/a) were tested. Emerged kochia seedlings for all three accessions from each tray were counted at 28 days after treatment (DAT). For Aatrex POST dose-response and alternative POST herbicides, separate experiments were conducted using 4- × 4-inch plastic pots containing commercial potting mixture. Kochia plants from SUS and KS-4H accessions were grown and separately treated with POST Aatrex doses (same as mentioned for PRE dose-response assay) along with 1% v/v crop oil adjuvants and alternative POST herbicides. Alternative POST herbicide programs, including Gramoxone, Huskie, Kochiavore, Liberty, Scorch, Sharpen alone or with 2,4-D, Starane NXT, and Talinor were tested at field-use rates (Table 1). Experiments were conducted in a randomized complete block design with 12 replications. Data on percent visual control (on a scale of 0 to 100; 0 being no control and 100 being dead plant) were recorded at 21 DAT, and individual plants were harvested to determine the shoot biomass at 21 DAT. Data from PRE and

POST Aatrex dose-response assays were analyzed using a three parameter log-logistic model in *R* software using following equation (Ritz et al., 2015):

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

where *y* refers to the number of seedlings per tray or shoot biomass (% of untreated), *d* is the upper limit, *b* is the slope of each curve, *e* (also known as ED₅₀ or GR₅₀ value) is the Aatrex dose required to cause 50% reductions in seedlings emergence (for PRE dose-response) or shoot biomass reduction (for POST dose-response), and *x* is the Aatrex dose. Resistance factor (referred as R/S ratio) to Aatrex was estimated by dividing the ED₅₀ or GR₅₀ value of each multiple resistant accession (KS-4A and KS-4H) by the GR₅₀ value of SUS accession. Data on percent visual control with alternative POST herbicides 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

PRE dose-response experiments indicated that the effective dose (ED₅₀ values) of PRE applied Aatrex required for 50% reduction in seedling emergence of KS-4A, KS-4H, and SUS was 129, 7, and 1 oz/a, respectively, indicating 129- and 7- fold resistance in KS-4A and KS-4H accessions (Figure 1). In POST dose-response assay, the KS-4H accession exhibited high level (248-fold) resistance to Aatrex, as compared to SUS accession (Figure 2). Among all alternative POST herbicides tested, Gramoxone, Huskie, Talinor, and Sharpen alone or with 2,4-D provided excellent control (94 to 100%) of both SUS and KS-4H accessions. (Table 1). Scorch and Starane NXT treatments provided moderate control (87%) of both accessions at 21 DAT. In contrast, Kochiavore and Liberty treatments provided differential control of SUS (94 to 99% control) and KS-4H (84 to 85%) accessions at 21 DAT (Table 1).

Conclusions

Results indicate that dicamba/fluroxypyr/glyphosate-resistant kochia from Garden City, KS, is also resistant to PRE and POST applied atrazine. Growers can utilize POST herbicides such as Huskie, Talinor, Gramoxone, and Sharpen alone or with 2,4-D to manage this multiple-resistant kochia on their production fields.

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Table 1. Effect of alternative POST herbicides on dicamba/fluroxypyr/glyphosate-resistant and -susceptible kochia in a greenhouse study conducted at the Kansas State University Agricultural Research Center, Hays, KS

Herbicide (s)	Rate	SUS	KS-4H
	fl oz/a	----- % control ⁴ -----	
Huskie ¹	15	96 aA	98 aA
Kochiavore	16	94 bA	84 bB
Scorch ¹	32	83 cA	79 bcA
Starane NXT ¹	14	85 cA	87 bA
Liberty ²	36	99 aA	85 bB
Talinor ²	18	100 aA	99 aA
Sharpen ³	2	100 aA	100 aA
Sharpen + 2,4-D ³	2 + 18	99 aA	100 aA
Gramoxone ¹	48	100 aA	100 aA

¹Nonionic surfactant (NIS) at 0.25% v/v was included.

²Crop oil concentrate (COC) at 1% v/v was included.

³Methylated seed oil (MSO) at 1% v/v and ammonium sulfate (AMS) at 2% v/v was included.

⁴Means for each kochia accession within a column followed by similar lowercase letters are not significantly different based on Fisher's protected LSD test at $P < 0.05$; means for an herbicide within a row followed by similar uppercase letters are not significantly different based on Fisher's protected LSD test at $P < 0.05$ for % control.

Figure 1. Seedlings emergence of susceptible (SUS) and two dicamba/fluroxypyr/glyphosate-resistant kochia accessions (KS-4A, KS-4H) treated with various doses of Aatrex applied PRE 28 days after treatment (DAT). R/S = resistance factor. ED₅₀ is the estimated amount of Aatrex PRE herbicide (oz/a) required to achieve 50% reduction in seedlings emergence of SUS, KS-4A, and KS-4H accessions.

Figure 2. Shoot dry weight (% of untreated) response of SUS and KS-4H kochia accessions treated with POST Aatrex at various doses 21 days after treatment (DAT). R/S = resistance factor. GR₅₀ is the estimated amount of POST Aatrex (oz/a) needed for 50% reduction in shoot biomass of SUS and KS-4H kochia accessions.

Control of Multiple Herbicide-Resistant Palmer Amaranth in Enlist Corn

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

Summary

Recent evolution of multiple herbicide resistant (MHR) Palmer amaranth [resistant to 2,4-D, glyphosate (Roundup), chlorsulfuron (Glean), atrazine (Aatrex), and mesotrione (Callisto)] is a serious threat to newly developed stacked trait technologies, including Enlist crops (tolerant to 2,4-D, glyphosate, and glufosinate). Field experiments were conducted in 2019 at the Kansas State University Agricultural Research Center near Hays, KS, to determine the effectiveness of various preemergence (PRE) followed by (*fb*) postemergence (POST) herbicides (multiple modes of action) for controlling this MHR Palmer amaranth in Enlist corn. The study was established in no-till dryland wheat stubble where MHR Palmer amaranth seeds were uniformly infested. All PRE treatments included Roundup at 32 oz/a to control volunteer wheat seedlings at the time of corn planting. Treatments were arranged in a randomized complete block design, with four replications. Herbicides were applied using a handheld boom sprayer calibrated to deliver 15 GPA. Data on percent visual control of MHR Palmer amaranth were recorded biweekly throughout the season, and corn grain yield was recorded at harvest. All PRE *fb* POST herbicide programs—except PRE applied Armezon Pro plus Aatrex *fb* a POST treatment of Roundup + Enlist One + Liberty, and a sequential PRE *fb* POST treatment of Roundup + Enlist One + Liberty—provided excellent, season-long control (92-96%) of MHR Palmer amaranth. In contrast, end-season control of MHR Palmer amaranth did not exceed 85% with PRE applied Armezon Pro plus Aatrex *fb* a POST treatment of Roundup + Enlist One + Liberty, and a sequential PRE *fb* POST treatment of Roundup + Enlist One + Liberty. Corn grain yields were significantly improved among all the tested herbicide programs compared to the nontreated weedy check plots. These results indicate that the effective PRE *fb* POST (two pass) programs evaluated in this study can be utilized for effective management of MHR Palmer amaranth in Enlist corn.

Introduction

Palmer amaranth (*Amaranthus palmeri* S. Wats.) is a dioecious (male and female flowers on separate plants) summer annual broadleaf weed that belongs to the pigweed family (Ward et al., 2013). It has several unique biological traits, including extended period of emergence, aggressive growth, and prolific seed production (Keeley et al., 1987; Steckel et al., 2004; Ward et al., 2013). It is also highly prone to develop herbicide resistance (Heap, 2020). Palmer amaranth has become the most problematic weed species in agronomic crops across western and central parts of Kansas (Thompson et al., 2018).

A Palmer amaranth biotype (MHR) from central Kansas has recently been confirmed with multiple resistance to 2,4-D (3.2-fold), glyphosate (11.8-fold), chlorsulfuron (5.0-fold), atrazine (14.4-fold), mesotrione (13.4-fold), and reduced sensitivity to fomesafen (Kumar et al., 2019). Evolution of multiple resistant Palmer amaranth biotypes

poses a serious threat to newly developed stacked-trait technologies, including Enlist crops, which are tolerant to 2,4-D, glyphosate, and glufosinate. An increasing use of glyphosate, 2,4-D, and/or glufosinate with the recent commercialization of these Enlist crops may need greater attention.

Herbicides with multiple sites of action (premixes/tank-mixtures) are needed to manage MHR Palmer amaranth in Enlist crops. The main objective of this study was to evaluate the effectiveness of various PRE *fb* POST herbicide premixes and/or tank-mixtures for controlling MHR population in Enlist corn.

Procedures

A field study was conducted at the Kansas State University Agricultural Research Center near Hays, KS, in 2019. Enlist corn hybrid 'DKC62-53' was planted in no-till dryland wheat stubble on May 16 using 17,425 seeds per acre. Seeds of an MHR Palmer amaranth were uniformly infested at the site. Ten herbicide programs (Table 1), including PRE and POST were arranged in randomized complete block design with 4 replications. Herbicides were applied with a CO₂-pressurized backpack sprayer using Teejet AIXR110015 nozzles at 15 GPA. Plot size was 10 × 30 feet. PRE herbicides were applied on May 17, immediately after corn planting. POST herbicides were applied on June 13, at V6 to V8 corn growth stage. Data on percent corn injury and percent visual control of MHR Palmer amaranth were recorded at biweekly intervals, and corn yield was estimated by harvesting the middle two rows of each plot at maturity. All data were subjected to ANOVA using PROC MIXED in SAS v. 9.4 (SAS Inst. Inc., Cary, NC). Means were separated by Fisher's protected LSD test at $P < 0.05$.

Results

All PRE herbicide treatments were activated with enough moisture through rainfall events prior to and soon after corn planting. No corn injury was observed with any of the PRE and/or POST herbicide programs tested in this study (data not shown). PRE *fb* POST programs, including Roundup + SureStart II + Aatrex *fb* Roundup + Enlist One + Liberty + RealmQ; Roundup + Resicore + Aatrex *fb* Roundup + Enlist One + Liberty + Dual II Magnum; Roundup + FulTime NXT *fb* Roundup + Enlist One + Liberty + Corvus; Roundup + Anthem Maxx + Aatrex *fb* Roundup + Enlist One + Liberty plus Warrant; Roundup + Acuron *fb* Roundup + Enlist One + Liberty; Roundup + Harness Max *fb* Roundup + Enlist One + Liberty; Roundup + Keystone NXT *fb* Roundup + Enlist One + Liberty had an excellent season-long control (92 to 96%) of MHR Palmer amaranth (Table 1). End-of-season control of MHR population was 85% with PRE applied Roundup + Armezon Pro + Aatrex *fb* a POST treatment of Roundup + Enlist One + Liberty, and a sequential PRE *fb* POST treatment of Roundup + Enlist One + Liberty (Figure 1). There were no significant differences in corn grain yields among all PRE *fb* POST herbicide programs and yields ranged between 2.7 to 2.9 tons/a (Figure 2).

Conclusions

Results from this study indicate that two-pass herbicide programs (PRE *fb* POST) containing multiple herbicide sites of action are needed for season-long control of five-way resistant Palmer amaranth population. Effective PRE *fb* POST programs evaluated

in this study can serve as important component of integrated strategies for managing MHR Palmer amaranth in Enlist corn.

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Table 1. List of herbicide programs and rates evaluated in Enlist corn at the Kansas State University Agricultural Research Center near Hays, KS

Treatment number	Herbicide Programs ^{a,b}	Rate (fl oz/a)	Timing
T1	Nontreated weedy check	---	---
T2	SureStart II + Aatrex <i>fb</i> Enlist One + RealmQ + Liberty	40 + 32 <i>fb</i> 32 + 16 + 32	PRE <i>fb</i> POST
T3	Resicore + Aatrex <i>fb</i> Enlist One + Dual II Magnum + Liberty	40 + 32 <i>fb</i> 32 + 16 + 32	PRE <i>fb</i> POST
T4	FulTime NXT <i>fb</i> Enlist One + Corvus + Liberty	80 <i>fb</i> 32 + 5.6 + 32	PRE <i>fb</i> POST
T5	Anthem Maxx + Aatrex <i>fb</i> Enlist One + Warrant + Liberty	4 + 32 <i>fb</i> 32 + 64 + 32	PRE <i>fb</i> POST
T6	Acuron <i>fb</i> Enlist One + Liberty	80 <i>fb</i> 32 + 32	PRE <i>fb</i> POST
T7	Harness Max <i>fb</i> Enlist One + Liberty	40 <i>fb</i> 32 + 32	PRE <i>fb</i> POST
T8	Keystone NXT <i>fb</i> Enlist One + Liberty	56 <i>fb</i> 32 + 32	PRE <i>fb</i> POST
T9	Armezon Pro + Aatrex <i>fb</i> Enlist One + Liberty	20 + 32 <i>fb</i> 32 + 32	PRE <i>fb</i> POST
T10	Enlist One + Liberty <i>fb</i> Enlist One + Liberty	32 + 32 <i>fb</i> 32 + 32	PRE <i>fb</i> POST

^a All PRE and POST programs were applied with Roundup PowerMax at 32 fl oz/a.

^b PRE programs included ammonium sulfate (AMS) at 2% v/v and POST included Class Act Ridion at 2% v/v.

PRE = preemergence. POST = postemergence. *fb* = followed by.

Figure 1. Percent control of five-way resistant Palmer amaranth with PRE *fb* POST herbicide programs in Enlist corn. The top bars represent the standard error of means. Palmer amaranth control in treatment 1 (nontreated weedy check) was 0% throughout the season; therefore, not shown in this figure.

Figure 2. Effect of PRE *fb* POST herbicide programs on Enlist corn grain yield. Vertical bars represent the standard error of means.

Response of Kansas Feral Rye Populations to Aggressor Herbicide and Management in CoAXium Wheat Production System

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

Summary

Feral rye (*Secale cereale* L.), also commonly known as cereal or volunteer rye, is a troublesome winter annual grass weed species in wheat producing regions of the United States, including Kansas. Lack of effective herbicide options complicates the selective control of feral rye in winter wheat. The main objectives of this research were (1) to determine the response of 10 feral rye populations collected from central Kansas wheat fields to Aggressor herbicide in dose-response assays, and (2) to evaluate the effectiveness of Aggressor herbicide for feral rye control in CoAXium winter wheat in Kansas. Dose-response assays indicated that all tested feral rye populations from Kansas wheat fields were highly sensitive to Aggressor herbicide with GR₉₀ values (doses of Aggressor herbicide needed for 90% reductions in shoot biomass at 3 weeks after treatment) ranging from 4.2 to 9.3 fl oz/a. A field study conducted near Great Bend, KS, indicated that Aggressor herbicide applied at ≥ 10 fl oz/a in fall or spring timings provided an excellent end-season control ($\geq 94\%$) of feral rye in CoAXium winter wheat. Overall, these results suggest that effective feral rye control could be achieved with Aggressor herbicide in a CoAXium wheat production system in Kansas.

Introduction

Feral rye (*Secale cereale* L.) is a troublesome winter annual grass weed species in wheat producing regions of the United States, including Kansas. Feral rye seeds can germinate in fall or early spring with optimum soil temperatures ranging from 55 to 60°F. A single feral rye plant can produce up to 600 seeds of which only a small percentage can remain dormant and viable in soil seedbank for > 5 years. Season-long interference of feral rye has been reported to reduce wheat grain yield by $> 50\%$ in Colorado, Kansas, Montana, Nebraska, and Wyoming (Cobel and Fay, 1985; Westra and D'Amato, 1989). The contamination of feral rye seeds can cause wheat dockage, losses in wheat quality, and grade reduction. Due to its winter annual life cycle, selective control of feral rye is difficult in winter wheat (Young et al., 1984).

The CoAXium wheat production system is a new non-GMO herbicide-resistant wheat technology that combines the use of Aggressor (quizalofop-p-ethyl, Group 1) herbicide with wheat varieties containing genes that confer tolerance to this herbicide – AXigen trait. Three CoAXium hard red winter wheat varieties (LCS Fusion AX, Crescent AX, and Incline AX) that contain the AXigen trait (resistance to the ACCase class of herbicides) are now commercially available for use. The Aggressor herbicide has good foliar activity on grass weed species, so the CoAXium wheat production system may provide an opportunity for postemergence (POST) control of feral rye in wheat. However, to our knowledge, there is currently no published information on the effectiveness of Aggressor for feral rye control in CoAXium winter wheat in Kansas. In addition, the

response of feral rye populations infesting Kansas wheat fields to Aggressor herbicide is also unknown.

The main objectives of this research were to (1) determine the response of feral rye populations collected from winter wheat fields in central Kansas to Aggressor, and (2) evaluate the effectiveness of Aggressor herbicide for feral rye control in CoAXium winter wheat in Kansas.

Procedures

Feral Rye Populations Collection

Fully matured seeds of 10 feral rye populations (one population per field site) were collected from winter wheat fields in central Kansas in 2018 (Table 1). The sampling field sites were randomly chosen depending upon feral rye infestation prior to wheat harvest. For each population, fifty to sixty seed heads were collected from each field site and composited together in a paper bag. The collected feral rye seed heads were air dried and then manually threshed and cleaned.

Dose Response Study

Seeds of each feral rye population were separately sown in square plastic pots (4 by 4 inch) containing a commercial potting mixture (Miracle-Gro Moisture Control Potting Mix, Miracle-Gro Lawn Products, Inc., Marysville, OH) in a greenhouse at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS. Growth conditions in the greenhouse were set at $77/73 \pm 4^\circ\text{F}$ day/night temperatures and 16/8 h day/night photoperiods. At 3- to 4-leaf stage, feral rye seedlings were separately treated with Aggressor at 0, 1, 2, 4, 8, and 16 fl oz/a using a stationary cabinet spray chamber. All Aggressor treatments included 1% (v/v) methylated seed oil (MSO). Greenhouse experiments were conducted in a randomized complete block (blocked by population) design with 12 replications (one plant/pot comprised a replication) per Aggressor dose, and repeated. All feral rye plants from each population were cut at the soil surface and the aboveground shoot biomass samples were determined at 3 weeks after treatment (WAT). Shoot biomass reduction (% of nontreated) of each feral rye population was regressed against Aggressor doses by using a three-parameter log-logistic model (Equation 1) (Ritz et al., 2015):

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

where y refers to shoot biomass (% of nontreated), d is the upper limit, b is the slope of each curve, e is the Aggressor dose needed for 50% reduction in shoot biomass referred as GR_{50} , and x is the Aggressor dose. All nonlinear regression parameter estimates and their standard errors and GR_{90} value (Aggressor dose needed for 90% reduction in shoot biomass) for each population were estimated using the *drc* package in *R* software (Ritz et al. 2015).

Field Study

An on-farm field study near Great Bend, KS, was conducted to evaluate Aggressor herbicide for feral rye control in winter wheat during the 2018/2019 growing season. The study utilized a CoAXium winter wheat variety “LCS Fusion AX” planted on November 19, 2018 using seeding rate of 60 lb/a. The field site had a natural infes-

tation of feral rye population. The three POST treatments of Aggressor herbicide in fall (10 fl oz/a), spring (10 and 12 fl oz/a), and fall followed by (fb) spring (8 fb 8 fl oz/a) were arranged in a randomized complete block design with 4 replications. All treatments were applied with a CO₂-pressurized backpack sprayer using Teejet AIXR110015 nozzles, at 15 GPA. Fall applications were made on December 19, 2018, (3- to 4-leaf stage of wheat), and spring applications were made on April 4, 2019 (3- to 4-tillers stage of wheat). Percent feral rye control was visually assessed at biweekly intervals after spring applications. Data were subjected to ANOVA using PROC MIXED in SAS (SAS Inst. Inc., Cary, NC). Means were separated by Fisher's protected LSD test at $P < 0.05$.

Results

Dose-Response Study

Based on a fitted model, the estimated GR₉₀ values (Aggressor doses needed for 90% shoot biomass reduction at 3 WAT) indicated a variable response to Aggressor herbicide among all tested feral rye populations. The estimated GR₉₀ values of FR01, FR04, FR05, FR06, FR09, and FR10 feral rye populations were significantly lower (ranged from 4.2 to 6.2 fl oz/a) compared to FR02, FR03, FR07, and FR08 populations (ranged from 7.1 to 9.3 fl oz/a) according to approximate t-test (Table 2 and Figure 1). Nevertheless, the GR₉₀ values of all 10 feral rye populations were lower than the Aggressor field-recommended rate (10 to 12 fl oz/a) for feral rye control in CoAXium winter wheat (Anonymous, 2017).

Field Study

No visual injury on winter wheat was observed with any Aggressor treatment tested (data not shown). Results indicated that all Aggressor treatments at ≥ 10 fl oz/a provided excellent end-of-season feral rye control ($\geq 94\%$) compared to non-treated weedy check, irrespective of application timing (Table 3 and Figure 2).

Conclusions

Results from greenhouse study indicated that feral rye populations collected from Kansas winter wheat fields were highly sensitive to Aggressor herbicide. The field study also showed an excellent feral rye control with Aggressor herbicide irrespective of rate or application timing. Altogether, these results suggest that CoAXium winter wheat technology can provide an alternative option for effective feral rye control in Kansas wheat production systems.

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Table 1. Winter wheat field sites in central Kansas from where the seeds of feral rye were randomly collected in 2018

Population	County	GPS coordinates	
		Longitude	Latitude
FR01	Stafford	-98.75	38.24
FR02	Stafford	-98.73	38.23
FR03	Stafford	-98.74	38.17
FR04	Russell	-98.53	38.95
FR05	Russell	-98.53	38.95
FR06	Reno	-98.20	38.15
FR07	Rice	-98.33	38.34
FR08	Barton	-98.73	38.33
FR09	Pratt	-98.61	37.81
FR10	Pratt	-98.53	37.76

Table 2. Regression parameter estimates from the whole plant dose response study based on shoot biomass (% of nontreated) at 3 weeks after treatment (WAT) of 10 feral rye populations treated with increasing doses of Aggressor herbicide in a greenhouse at Kansas State University Agricultural Research Center in Hays, KS

Population	Regression parameters estimates ^{1,2,3}			
	d ($\pm$ SE)	b ($\pm$ SE)	GR ₅₀ values	GR ₉₀ values
FR01	99 (2.5)	0.6 (0.1)	0.13	4.9
FR02	100 (2.6)	1.0 (0.1)	0.52	7.4*
FR03	100 (2.6)	0.8 (0.1)	1.04	9.3*
FR04	100 (2.4)	1.1 (0.4)	0.26	5.4
FR05	99 (2.5)	0.5 (0.1)	0.26	6.2
FR06	100 (2.6)	0.4 (0.1)	0.13	4.5
FR07	99 (2.4)	0.9 (0.1)	0.65	8.3*
FR08	99 (2.1)	1.1 (0.1)	1.04	9.2*
FR09	99 (2.7)	0.7 (0.1)	0.13	5.2
FR10	99 (2.5)	0.6 (0.2)	0.13	4.2

¹Abbreviations: FR01 through FR10 were feral rye populations collected from winter wheat fields in central Kansas. SE = standard error of mean.

² d is the upper limit, b is the slope of each curve, and GR₅₀ and GR₉₀ are the effective doses (fl oz/a) of Aggressor herbicide needed for 50% and 90% shoot biomass reduction (% of nontreated) for each feral rye population.

³An asterisk (*) denotes a significant difference of the GR₉₀ values between FR02, FR03, FR07, FR08 and FR01, FR04, FR05, FR06, FR09, FR10 feral rye populations according to approximate t -test (Ritz et al., 2015).

Table 3. Feral rye control with fall/spring-applied Aggressor herbicide in LCS Fusion AX winter wheat at a grower's field near Great Bend, KS, in 2019

Herbicide	Rate	Timing ^c	Feral rye ^d		
			4/18/2019	5/2/2019	6/6/2019
	fl oz/a		----- % control -----		
Aggressor + NIS ^a	10	FP	89 ab	94 ab	96 a
Aggressor + MSO ^b	10	FP	89 ab	94 ab	96 a
Aggressor + MSO ^b	10	SP	75 c	94 ab	96 a
Aggressor + MSO ^b	12	SP	80 bc	93 ab	94 a
Aggressor + NIS ^a / Aggressor + MSO ^b	8 (Fall)/ 8 (Spring)	FP/SP	93 a	96 a	98 a

^a Nonionic surfactant (NIS) at 0.25% v/v was included.

^b Methylated seed oil (MSO) at 1% v/v was included.

^c Fall POST (FP) was applied on December 19, 2018, Spring POST (SP) was applied on April 4, 2019.

^d Means within each column followed by same alphabet letters are not different based on Fisher's protected LSD test at $P < 0.05$.

Figure 1. Shoot biomass reduction (% of nontreated) response of 10 feral rye populations from Kansas wheat fields treated with Aggressor at 3 weeks after treatment (WAT) in dose-response studies conducted at the Kansas State University Agricultural Research Center near Hays, KS.

Figure 2. Visual control of feral rye in CoAXium wheat plots treated with Aggressor herbicide in fall (A), spring (B), fall followed by spring (C), and non-treated weedy check (D). Pictures taken on May 2, 2019.

Wheat Grain Yield Response to Seed Cleaning and Seed Treatment as Affected by Seeding Rate During the 2018–2019 Growing Season in Kansas

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Summary

The objective of this project was to evaluate winter wheat stand count and grain yield responses to the interactions among seeding rate, seed cleaning, and seed treatment in the state of Kansas during the 2018–2019 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 at seven Kansas locations. In-season measurements included stand count, grain yield, grain test weight, and grain protein concentration, though this report only shows stand count and grain yield. Stand count increased with increases in seeding rate at all locations, with improvements in seed cleaning in five locations, and by seed treatment in one location. Grain yield increased with increases in seeding rate in five locations, with improvements in seed cleaning in four locations, and with seed treatment in one location. Significant interactions on grain yield occurred between seeding rate and seed cleaning (one location) and seeding rate and seed treatment (two locations), usually suggesting an advantage for seed cleaning or seed treatment at low seeding rates. The combined analysis across locations suggested that seeding rate and seed cleaning improved stand count (~140,000 and ~35,000 more plants established for each level of seeding rate and seed cleaning improvement) and grain yield (about 5 and 2 more bushels per acre for each improvement in seeding rate and seed cleaning, respectively). This research is an initial step in evaluating the value of the seed certification process; it does not compare certified seed versus bin-run seed. The seed used in this study was derived from commercial seed production fields (i.e., high quality seed) and not from commercial grain production fields, which usually provide 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 (Evans and Fischer, 1999). This study used data from well-managed field experiments where the crop achieved levels close to its potential (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. To ensure potential conditions can be attained, the first step after variety selection is to ensure a good population establishment through quality seed, appropriate seeding rate, and seed treatment (though these practices might not always be economical).

Seeding rate is important within the context of attaining potential yields because it defines the first yield component: plant population. A recent review of winter wheat response to seeding rate suggested that the optimum seeding rate depended on yield environment (Bastos et al., 2020). Grain yield was independent of population in high-yielding environments (e.g., high fertility sown at the appropriate time, where tillering is abundant); and higher seeding rates were required in lower-yielding environments (e.g., where the crop does not have as much time to tiller) to improve grain yield (Bastos et al., 2020). Similar results were reported by Fischer et al. (2019) and Lollato et al. (2019) suggesting an insensitivity of wheat to seeding rate in high-yielding environments; and by Jaenisch et al. (2019) suggesting that higher seeding rates were required in lower-yielding environments.

Not all seeded seeds become an emerged plant. In fact, Bastos et al. (2020) suggested that the ratio of achieved over target plant density ranged from 60 to 100% in nine Kansas experiments. Factors that might impact this ratio include seed quality and seed treatment (Pinto et al., 2019). While seed cleaning (e.g., air screening followed by gravity table) can affect seed size (Peske et al., 2012); and seed treatment can reduce the risk of disease transmission (Khanzada et al., 2002) —thus both improving seed quality—the effects of seed cleaning and treatment on wheat grain yield have been inconsistent (Edwards and Krenzer, 2006; Kashyap et al., 1994; 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 to start developing a more probabilistic response of yield gain and breakeven.

Procedures

Field experiments were conducted during the 2018–2019 winter wheat growing season in seven locations across Kansas: Ashland Bottoms, Belleville, Beloit, Colby, Hutchinson, Leoti, and Manhattan (Table 1). In Colby and Beloit, 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 per acre), 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 time 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. Seed treatment consisted of 5 oz/a of Cruiser Maxx and 0.75 oz/a Cruiser 5FS. The same wheat variety (‘SY Monument’) was evaluated at all locations. Harvest occurred using a Massey Ferguson XP8 small-plot, self-propelled combine. Plot ends were trimmed at harvest time to avoid border effect.

Measurements and Statistical Analyses

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. Nitrogen (N) rates were adjusted for a 75 bushel per acre yield goal using a 2.4 conversion factor and accounting for soil profile N, organic matter,

and other N credits. In-season measurements included stand count (measured about 20–30 days after sowing, except for one location that did not emerge in the fall, Table 1) 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 included those to account for the statistical design of the experiment (i.e., replication, replication $\times$ seeding rate, and replication $\times$ seeding rate $\times$ seed cleaning).

Results

Weather Conditions

The weather data for the studied locations during the 2018–2019 winter wheat growing season are shown in Table 2. Overall, the weather was characterized by below average temperatures and above average precipitation. The fall had anywhere from 5.0 to 17.3 inches of precipitation, which coupled with cool temperatures, slowed down crop development. In many cases, such as in Beloit, the wheat only emerged in the spring. The studied locations received anywhere from 7.7 to 24.9 inches of precipitation during the spring.

Overall Treatment Significance on the Measured Variables

Table 3 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 and test weight at all locations, and grain yield in five locations. Seed cleaning affected stand count in five locations, and grain yield in four locations. Seed treatment affected stand count in one location and grain yield in one location.

Stand Count

Across all treatments and locations, stand count ranged from 357,154 to 895,900 plants per acre (Table 4). At all locations, the achieved population was considerably lower than the target, ranging from 51 to 85%. The locations with the lowest stand count were Beloit and Belleville (360,000–630,000 plants per acre) and the location with the highest stand count was Hutchinson (504,000–896,000 plants per acre). In Colby, the total number of tillers was counted instead of actual population, resulting in much greater values (Table 4). At all locations, established population increased consistently with increases in seeding rate and with improvements in seed cleaning (the latter, except for Belleville and Manhattan). In Beloit, the only location in which seed treatment was a significant effect, application of seed treatment increased stand establishment from 477,754 to 507,406 plants per acre (data not shown).

Grain Yield

Treatment effects on grain yield depended on location. The grain yield data are shown in Table 5, for the analysis in which only the main effects were significant (Belleville, Mitchel, Colby, and in the combined analysis). At these locations and in the combined analysis, a target seeding rate of 1,200,000 seeds per acre always out-yielded a target seeding rate of 600,000 seeds per acre (77.6–89.6 bushels per

acre versus 70.1–79.9 bushels per acre); whereas seeding at 900,000 seeds per acre resulted in intermediate yields (72.9–84.8 bushels per acre). Regarding seed cleaning, gravity table always out-yielded no seed cleaning (75.6–86.5 bushels per acre versus 71.3–83.0 bushels per acre), whereas air screen was intermediate (73.7–84.9 bushels per acre).

There were also some significant interactions between treatments on wheat grain yield. Specifically, there were significant seed treatment by seeding rate interactions in Colby and in Hutchinson, and a significant seeding rate by seed cleaning interaction in Manhattan (Table 3). In Colby, the presence of seed treatment increased grain yield at seeding rates of 600,000 and 900,000 but not at 1,200,000 (Figure 1). In Hutchinson, there was a similar trend at the 600,000 seeds per acre seeding rate (a trend for a yield benefit of seed treatment), but an opposite trend at the 900,000 seeds per acre (Figure 1). In Manhattan (where the significant interaction was between seeding rate and seed cleaning), grain yield increased linearly in response to increases in seeding rate when the seed was air screened or received no cleaning. These relationships showed a crossover interaction where air screen tended to yield more at 600,000 seeds per acre and ‘None’ tended to yield more at 1,200,000 seeds per acre (Figure 2). Meanwhile, gravity table yielded similarly to both treatments at the low seeding rate and out-yielded them at the 900,000 seeds per acre rate, following a quadratic shape with diminishing yield increases beyond this point.

Preliminary Conclusions

Winter wheat population establishment and grain yield responses to seeding rate, seed cleaning, seed treatment, and their interactions are dependent on environmental conditions. Usually, increasing seeding rate and improving seed cleaning resulted in more plants emerged per unit area, but only translated into increased grain yield in about half of the times. The other times, grain yield was affected by the interaction among these factors, which suggested a greater benefit of seed cleaning or of seed treatment at lower seeding rates. 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 first year of this research, which will continue for two more years to establish probabilities of yield gain and breakeven on seeding rate, seed cleaning and seed treatment.

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Table 1. Dates of major field activities at the seven locations where the seed rate by seed cleaning by seed treatment trial was established during the 2018–2019 growing season

Location	Sowing date	Stand count	N fertilization	Fungicide	Harvest
Ashland Bottoms	11/1/2018	1/9/2019	3/22/2019	5/31/2019	7/1/2019
Belleville	10/3/2018	11/7/2019	4/2/2019	5/16/2019	7/15/2019
Beloit	11/4/2018	3/10/2019	4/1/2019	---	7/8/2019
Colby	10/3/2018	11/7/2019	4/2/2019	---	7/23/2019
Hutchinson	10/22/2018	11/14/2019	3/18/2019	5/15/2019	6/26/2019
Leoti	9/27/2018	11/5/2019	3/21/2019	5/16/2019	7/2/2019
Manhattan	10/23/2018	12/10/2019	3/22/2019	5/20/2019	7/1/2019

Table 2. Average maximum (Tmax) and minimum (Tmin) temperatures, and cumulative precipitation and evapotranspiration (ETo) during the fall (September 1- December 31), winter (January 1-March 31), and spring (April 1-July 15) at the study locations during the 2018–2019 growing season

Location	Season	Tmax	Tmin	Precipitation	ETo
Ashland Bottoms	Fall	59.2	37.9	14.1	9.2
	Winter	41.1	23.1	5.0	5.0
	Spring	77.2	55.0	22.3	20.4
Belleville	Fall	56.7	35.7	13.6	9.6
	Winter	37.6	21.2	2.2	4.5
	Spring	75.0	51.7	17.9	18.8
Beloit	Fall	58.8	36.2	14.0	10.2
	Winter	40.1	21.1	2.9	5.2
	Spring	77.7	52.5	14.2	21.0
Colby	Fall	58.3	33.5	5.4	12.6
	Winter	40.7	20.0	2.8	5.4
	Spring	74.4	47.4	10.4	21.3
Hutchinson	Fall	59.7	34.4	5.2	14.6
	Winter	41.7	21.3	1.9	6.3
	Spring	76.0	48.2	7.7	21.5
Leoti	Fall	58.8	37.9	17.2	10.6
	Winter	44.5	24.5	3.3	6.0
	Spring	78.0	54.4	19.0	19.5
Manhattan	Fall	60.0	39.0	17.3	9.4
	Winter	42.0	23.9	5.0	4.9
	Spring	77.8	55.6	24.9	19.0

Table 3. Significance of seeding rate, seed cleaning, seed treatment and their interactions on stand count and grain yield at seven Kansas locations where the trial was conducted, as well as the analysis combined across sites, during the 2018–2019 growing season

Factor	Ashland Bottoms	Belleville	Beloit	Colby	Hutchinson	Leoti	Manhattan	Combined
Stand count								
Rate (R)	0.0003	0.0003	<.0001	0.03	<.0001	0.002	0.001	<.0001
Cleaning (C)	0.05	0.17	0.005	0.04	0.0094	0.001	0.45	0.0002
Treatment (T)	0.76	0.61	0.05	0.89	0.2342	0.29	0.82	0.88
R × C	0.23	0.39	0.44	0.52	0.9861	0.07	0.96	0.12
R × T	0.48	0.49	0.97	0.83	0.6475	0.79	0.26	0.62
C × T	0.59	0.83	0.44	0.24	0.4926	0.11	1.00	0.66
R × C × T	1.00	0.36	0.10	0.56	0.9309	0.12	0.57	1.00
Yield								
Rate (R)	0.19	0.01	0.01	0.0009	0.06	0.68	0.0001	0.0002
Cleaning (C)	0.29	0.03	0.03	0.02	0.45	0.89	0.005	0.01
Treatment (T)	0.58	0.25	0.91	0.04	0.16	0.51	0.56	0.58
R × C	0.44	0.73	0.22	0.13	0.47	0.80	0.05	0.25
R × T	0.37	0.55	0.80	0.03	0.03	0.62	0.75	0.52
C × T	0.52	0.36	0.11	0.31	0.72	0.49	0.11	0.99
R × C × T	0.17	0.79	0.37	0.72	0.54	0.97	0.72	0.30

Table 4. Wheat population (stand establishment) as affected by seeding rate and seed cleaning at seven experiments conducted in Kansas during the winter wheat season of 2018–2019, as well as the combined analysis across experiments

Location	Seeding rate			Seed cleaning		
	600000	900000	1200000	None	Air screen	Gravity table
	----- Plants per acre -----					
Ashland	425985 c	560881 b	742368 a	524938 b	593717 a	610579 a
Bottoms						
Belleville	363419 c	476127 b	614129 a	457490	485446	510739
Beloit	357154 c	484614 b	635973 a	466026 b	479303 b	532412 a
Colby	1710093 b	1992870 ab	2166021 a	1814637 b	2000493 a	2053854 a
Hutchinson	504526 c	716188 b	895900 a	673589 b	686901 b	756124 a
Leoti	418886 b	533369 a	578186 a	460153 b	517838 a	552450 a
Manhattan	456603 c	565318 b	689120 a	575524	547569	587948
Combined	433884 c	570377 b	703941 a	538339 c	566294 b	603568 a

The effect of seed treatment was only significant at one location so data are shown in text. Means within the same location and variable (either seeding rate or seed cleaning) followed by the same letter indicate no statistical difference at the 0.05 probability level.

Table 5. Wheat grain yield as affected by seeding rate and seed cleaning (significant main effects) at two experiments conducted in Kansas during the winter wheat season of 2018–2019, as well as the combined analysis across experiments

Location	Seeding rate			Seed cleaning		
	600,000	900,000	1,200,000	None	Air screen	Gravity table
	----- Bushels per acre -----					
Belleville	74.7 b	82.9 a	89.4 a	79.2 b	82.3 ab	85.4 a
Beloit	70.1 b	72.9 ab	77.6 a	71.3 b	73.7 ab	75.6 a
Colby	---	---	---	79.6 b	81.7 a	83.2 a
Combined	79.9 c	84.8 b	89.6 a	83.0 b	84.9 ab	86.5 a

Means within the same location and variable (either seeding rate or seed cleaning) followed by the same letter indicate no statistical difference at the 0.05 probability level.

WHEAT

Figure 1. Winter wheat grain yield as affected by the interaction between seeding rate and seed treatment at (A) Colby and (B) Hutchinson in experiments conducted during the 2018–2019 growing season. The least significant difference (LSD) is shown.

WHEAT

Figure 2. Winter wheat grain yield as affected by the interaction between seeding rate and seed cleaning at Manhattan in experiments conducted during the 2018–2019 growing season. The least significant difference (LSD) is shown. Linear and polynomial (Poly.) trends are shown.

Wheat Variety-Specific Grain Yield Response to Plant Density Under Intensive Management Conditions in Western Kansas

R.P. Lollato, K. Mark, and B.R. Jaenisch

Summary

Seeding rate determines the first yield component of field crops, which is the plant population. However, wheat is less responsive to plant populations than other crops due to the high plasticity in tillering potential, and this responsiveness depends on resource availability. The objective of this project was to evaluate winter wheat population, grain yield, and grain test weight responses to seeding rate and its interaction with variety in a highly managed production system where manageable stresses were limited. Experiments evaluating the response of the wheat varieties 'Joe,' 'WB-Grainfield,' 'Langin,' and 'LCS Revere' to seeding rates ranging from 200,000–1,000,000 seeds per acre were established in a field managed by growers who consistently win state and national wheat yield contests near Leoti, KS. Trials were established at a relatively late date in 2017–2018 (delayed by pre-sowing rainfall), and at the optimal timing during 2018–2019. Growing seasons contrasted in that 2017–2018 was dry (approximately 6 inches in-season precipitation) and had warm grain filling conditions, and 2018–2019 was cool and moist (appx. 13 inches in-season precipitation). Stand count increased with increases in seeding rate both years but final population was closer to the target population during 2017–2018. Grain yield response to seeding rate and to variety depended on year, but all varieties responded similarly to seeding rate. In 2017–2018, grain yield increased linearly from appx. 40–60 bushels per acre with increases in seeding rate from 200,000–400,000 seeds per acre. During 2018–2019, the lowest yield was recorded across varieties in the plots with 200,000 seeds per acre, with the treatments ranging from 400,000–1,000,000 seeds per acre all resulting in the same yield level. Grain yield as affected by emerged plant population (instead of seeding rate) showed similar trends, though quadratic relationships indicated a maximum yield at about 500,000–580,000 plants per acre in 2018–2019. Grain test weight was impacted by the interaction of variety, seeding rate, and year. Greatest test weight values resulted in 2017–2018, when the test weight of all varieties responded in a quadratic way to seeding rates. In 2018–2019, there was no clear trend in varieties' test weight responses to population. These results suggest that wheat grain yield responses to seeding rate (and to plant population) are more dependent on sowing date and weather conditions than on variety, with optimum sowing times and a warm fall allowing for seeding rate as low as 400,000 seeds per acre without yield penalty. Meanwhile, later sowing dates and cooler fall conditions required seeding rates of up to 1,000,000 seeds per acre to maximize grain yield.

Introduction

The literature reports inconsistent wheat responses to seeding rate. While the most reported relationship between wheat grain yield and seeding rate is quadratic (Holliday, 1960), some authors suggested that this response might be positive linear, quadratic-plateau, plateau-negative linear, and even inexistent (Whaley et al., 2000; Lloveras et

al., 2004; 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 the number of plants and thus, by its yield components (Whaley et al., 2000); and above which other factors such as disease pressure, insects, lodging, or insufficient resources might limit yield (Lloveras et al., 2004). Recently, a comprehensive analysis of winter wheat yield response to plant density suggested that it depends on the level of resource availability of the environment (Bastos et al., 2020). In high-yielding environments (greater than 90 bushels per acre) where the crop is not limited by resources (including fertility levels, 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 bushels per acre average) and low- (45 bushels per acre average) yielding environments, wheat responded to increases in plant population up until the increase of approximately 25–31 plants per square feet (approximately 1.1–1.35 million plants per acre), leveling out at greater populations (Bastos et al., 2020).

Another important conclusion from the Bastos et al. (2020) study was that the optimum plant population also depended on the variety's tillering potential. Varieties with greater tillering potential usually required less population to maximize yields when compared to varieties with lower tillering potential. Wheat has a very high compensation capacity among its yield components compared to other crops, but this evidence suggests that varieties with high tillering potential have even greater compensation capacity than those with low tillering potential and might offer an opportunity to fine-tune seeding rate recommendations.

With few exceptions, the majority of the studies of wheat yield response to seeding rates 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). Nonetheless, to increase food production to feed an increasing global population without expanding agriculture into current native lands, the large yield gap in Kansas and in the region (Lollato et al., 2017) must be reduced. Thus, more information is needed about wheat yield response to plant population under intensive management systems that have the objective to maximize yield (e.g., Lollato and Edwards, 2015; Jaenisch et al., 2019). 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 2017–2018 and the 2018–2019 winter wheat growing seasons in a commercial wheat field near Leoti, KS. The research plots were 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 high-yielding 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 per acre). The experiments were planted on October 13, 2017, and

September 27, 2018. The crop was planted after a long summer fallow in sorghum (2017–2018) and corn (2018–2019) residue, and in both years it was the second crop after manure application (5 tons per acre, providing approximately 150 pounds of nitrogen (N) and phosphorus (P)). During 2017–2018, management of the field consisted of 80 pounds of N per acre in December; 3.5 ounces per acre of Rave herbicide on February; 6 ounces per acre Azoxystrobin plus 2 ounces per acre Xcite (cytokine) at double ridge stage; and finally 6 ounces per acre generic Azoxystrobin, 4 ounces per acre generic Tebuconazole, 2 ounces per acre Xcite, and 1 pound per acre Harvest More Urea Mate once the flag leaf was fully emerged. During 2018–2019, crop management consisted of 40 pounds of N per acre in September plus 65 pounds of N per acre and 8 lb sulfur (S) in December, 3.5 ounces per acre Rave herbicide in February plus 6 ounces per acre generic Azoxystrobin and 2 ounces per acre Xcite (cytokine) in early March, and finally 8 ounces per acre Approach Prima (Picoxystrobin plus Cyproconazole) plus 2 ounces per acre Xcite and 1 pound per acre Harvest More Urea Mate once the flag leaf was fully emerged. Very likely, all the manageable stresses were reduced. Harvest occurred using a Massey Ferguson XP8 small-plot, self-propelled combine. Plot ends were trimmed at harvest time to avoid border effect.

A total of 15 individual soil cores (0- to 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 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 as 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 for individual locations.

Results

Weather Conditions

The two growing seasons included in this study were very contrasting, as shown in Figure 1. The most contrasting aspect was in-season precipitation, which was approximately 6 inches in 2017–2018 versus appx. 13 inches in 2018–2019. Another important difference between seasons was in total temperature accumulated during the fall. Due to precipitation in late September, the trial was not established until October 13 in the 2017–2018 season, which is considerably later than the optimum sowing date for the region (near September 25). Meanwhile, sowing date was much closer to the optimum during 2018–2019. This difference in sowing date allowed for more temperature accumulation during the fall in the second season (982 vs. 884°F), leading to greater fall tillering and canopy development.

Overall Treatment Significance on the Measured Variables

Table 2 shows the results from the analysis of variance for stand establishment, grain yield, and grain test weight as affected by seeding rate, variety, year, and their interaction. For stand establishment, there was a significant year by seeding rate interaction. For grain yield, there were significant year by variety and year by seeding rate interactions. For grain test weight, there was a significant year by variety by seeding rate inter-

action. Significant interactions with year indicate the response to that specific management practice depended on year.

Stand Establishment

Stand establishment (or emerged plant population) increased with increases in seeding rate in both years; however, the final plant population was closer to the target at lower seeding rates and further away from the target at higher seeding rates, and the number of plants emerged per increase in seeding rate depended on year (Figure 2). In 2017–2018, final plant population was closer to the target at all populations, and each increase in 100,000 seeds per acre increased final population establishment to about 85,190 plants. Meanwhile, the attained population was further from the target in 2018–2019 (except for the lowest seeding rate of 200,000 seeds per acre) and increases in 100,000 seeds per acre only resulted in 56,930 additional plants per acre. These differences were likely led by greater pre-sowing precipitation in 2017–2018 as compared to seeding in a dryer topsoil in 2018–2019.

Grain Yield

Grain yield response to seeding rate and variety depended on year, but there was no variety by seeding rate interaction, suggesting that all varieties responded similarly to seeding rates. In the hot and dry season of 2017–2018, when the trial was sown late and grain yield ranged from 40 to 60 bushels per acre, grain yield responded linearly to increases in seeding rate, with the lowest yields achieved at the 200,000 seeds per acre treatment and the highest yields at the 1,000,000 seeds per acre seeding rate (Figure 3). Meanwhile, there was a more quadratic or linear-plateau response to seeding rate in 2018–2019 when the crop was planted earlier and allowed for greater fall tillering and grain yields ranging from 85–110 bushels per acre. In this case, yields were lowest at the 200,000 seeds per acre rate and increased with seeding rate increases until the 400,000 seeds per acre rate, with no increases in grain yield with further increases in seeding rate. These results agree with the report by Bastos et al. (2020) in that grain yield is less responsive to plant population at higher yielding environments. The variety effect also depended on year, as Langin and Joe were the highest yielding varieties in 2018–2019 (53–56 bushels per acre, versus 49–50 bushels per acre for WB-Grainfield and LCS Revere); and Langin and WB-Grainfield were the highest yielding varieties in 2018–2019 (103–104 bushels per acre versus 98–99 bushels per acre for Joe and Langin).

Grain yield as a function of actual plant population (rather than seeding rate) is shown by variety in Figure 4. The trends were similar to those of the seeding rate, in which yields increased linearly with increases in plant population during 2017–2018, and in a quadratic way in 2018–2019. Due to the limited fall tiller potential and dry and hot grain filling period conditions experienced in 2017–2018, we hypothesized that the primary tillers were the main drivers of yield, as the secondary tillers would not have been produced. If produced, the secondary tillers would likely not have survived the harsh environmental conditions. Thus, increasing population increased the number of primary tillers available and therefore increased grain yield. In the quadratic responses experienced during 2018–2019, the peak (maximum grain yield) occurred at plant populations of approximately 500,000 plants per acre for Langin and Joe, and at about 580,000 plants per acre for LCS Revere and WB Grainfield.

Grain Test Weight

The three-way interaction between year, seeding rate, and variety suggested that test weight response of the different varieties depended on seeding rate and on year simultaneously. Overall, test weight was greater during 2017–2018 (59–66 pounds per bushel) as compared to 2018–2019 (57–60 pounds per bushel), likely due to the much more favorable grain filling weather in 2018–2019 which allowed for grains to be produced from secondary and even tertiary heads, which are later in development and usually have low test weight (Figure 5). In 2017–2018, LCS Revere had the greatest test weight across all seeding rates except the highest one, and its advantage over the other varieties was greater at lowest seeding rates. Test weight increased with increases in seeding rate from 200,000 to appx. 600,000 seeds per acre for WB-Grainfield, Langin, and LCS Revere; while for Joe, which had the lowest test weight at the lowest seeding rate, test weight increased until 1,000,000 seeds per acre. In 2018–2019, test weight increased linearly with increases in seeding rate for LCS Revere and Langin in the entire range of 200,000–1,000,000 seeding rate; it followed a quadratic trend for WB-Grainfield, increasing in the 200,000–600,000 range and stabilizing afterwards; and it was irrespective of seeding rate for Joe. Similar trends were observed when grain test weight was plotted as function of emerged plants per acre, with quadratic trends in 2017–2018 and linear (Langin and LCS Revere), quadratic (WB-Grainfield), and absent (Joe) responses of grain test weight to plant population in 2018–2019 (Figure 6).

Preliminary Conclusions

These trials provided information on variety-specific grain yield and grain test weight response to seeding rate under intensive management practices, where resource availability (i.e., nutrients, foliar diseases control, etc.) was not limiting. Findings suggested that yield response to seeding rate was more dependent on growing season conditions than on varieties. When the crop had limited tillering potential in the fall due to a later sowing date, and a lower yield potential due to a drier season, yield responded linearly to increases in seeding rate and plant population. Meanwhile, when the crop had plenty of time to tiller during the fall, seeding rates as low as 400,000 seeds per acre were sufficient to maximize yields under these highly managed conditions.

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Table 1. Initial soil fertility measured at wheat sowing during the 2017–2018 and 2018–2019 growing seasons for the trial conducted near Leoti, KS

Depth	Unit	2017–2018		2018–2019	
		0–6 in.	6–24 in.	0–6 in.	6–24 in.
Calcium	ppm	2401	4876	2131	5064
Cation exchange capacity	meq/100 g	21	31	23	32
Chlorine	ppm	12	8	5	4
Copper	ppm	3	2	1	1
Iron	ppm	45	13	46	13
Potassium	ppm	826	604	649	577
Magnesium	ppm	399	558	386	629
Manganese	ppm	27	5	30	6
Sodium	ppm	28	24	13	11
NH ₄ -N	ppm	4	3	4	2
NO ₃ -N	ppm	36	3	13	13
Organic matter	%	2.4	1.6	2.3	1.7
pH	---	6.2	7.9	6.2	7.6
Phosphorus	ppm	92	18	70	15
Sulfur	ppm	5	4	4	3
Zinc	ppm	2	1	1	1
Clay	%	26	30	26	32
Sand	%	34	24	18	16
Silt	%	40	46	56	52

Table 2. Significance of seeding rate, variety, year, and their interactions on population establishment, grain yield, and grain test weight for the trial conducted near Leoti, KS, during the 2017–2018 and 2018–2019 growing seasons

Effect	Degrees of freedom	Pr < F		
		Population	Yield	Test weight
Seeding rate (R)	4	<.0001	<.0001	<.0001
Variety (V)	3	0.7364	0.0003	<.0001
R × V	12	0.7735	0.4573	0.1949
Year (Y)	1	0.0528	0.0014	0.0007
Y × R	4	<.0001	0.0021	<.0001
Y × V	3	0.1757	0.034	<.0001
Y × R × V	12	0.7239	0.388	0.0013

WHEAT

Figure 1. Growing degree-days accumulation (upper panel) and in-season rainfall accumulation (lower panel) during the 2017–2018 and 2018–2019 growing seasons for the trials conducted near Leoti, KS.

WHEAT

Figure 2. Emerged plant population as affected by seeding rate during the 2017–2018 and 2018–2019 growing seasons for the trials conducted near Leoti, KS.

WHEAT

Figure 3. Wheat grain yield response to seeding rate (upper panel) and variety (lower panel) during the 2017–2018 and 2018–2019 growing seasons for the trials conducted near Leoti, KS. Linear and polynomial (Poly.) trends are shown.

WHEAT

Figure 4. Wheat variety-specific grain yield response to emerged plant population during the 2017–2018 and 2018–2019 growing seasons for the trials conducted near Leoti, KS. Linear and polynomial (Poly.) trends are shown.

WHEAT

Figure 5. Wheat grain test weight response to the interaction of seeding rate and variety during the 2017–2018 (upper panel) and 2018–2019 (lower panel) growing seasons for the trials conducted near Leoti, KS. Linear and polynomial (Poly.) trends are shown.

WHEAT

Figure 6. Wheat variety-specific grain test weight response to emerged plant population during the 2017–2018 and 2018–2019 growing seasons for the trials conducted near Leoti, KS. Linear and polynomial (Poly.) trends are shown.

Winter Wheat Variety-Specific Response to the Combination of Nitrogen and Foliar Fungicide in 2018–2019

R.P. Lollato, K. Mark, and B.R. Jaenisch

Summary

Yield improvements to wheat can result both from variety selection and adoption of improved management practices. However, the yield response to improved management practices can be variety-specific and can result in decreases in protein concentration. Our objectives were to evaluate the yield and protein responses of different commercial winter wheat varieties to increased nitrogen (N) rates and application of foliar fungicides. We conducted a trial combining 20 winter wheat varieties and two management level intensities. The standard management consisted of N applied for a 75 bushel per acre yield goal and no fungicide; and intensive management consisted of an additional 40 pounds of N per acre and two fungicide applications—the first at jointing and the second at flag leaf emergence. The study was conducted at two Kansas locations (Great Bend, following a terminated cover crop; and Ashland Bottoms, following a previous soybean crop) during the 2018–2019 growing season. Grain yield ranged from 18–103 bushels per acre, with greatest yields recorded in the intensive management treatment in Great Bend and the lowest yields recorded in the standard management treatment in Ashland Bottoms. While there were no statistical differences in the varieties' responses to intensive management, both the ranking of varieties and the yield increase from intensive management depended on location. Grain protein concentration ranged from 10.5–17.7% across all treatments, and the intensive management increased grain protein concentration from 12.7–13.9% in Ashland Bottoms and from 14.1–14.5% in Great Bend. The intensive management concomitantly increased grain yield and grain protein concentration at Ashland Bottoms, and increased grain yield while sustaining grain protein concentration at Great Bend, suggesting that total N removal in the grain increased with intensive management. While we did not investigate the net profits from the intensive management, these results suggest that intensifying management on wheat could add income from additional yield produced and protein premiums, as long as these are available.

Introduction

Wheat yield at the state level in Kansas has rarely surpassed 50 bushels per acre. Nonetheless, recent evidence suggests that the long-term dryland potential yield is about 77 bushels per acre (Lollato and Edwards, 2015; Lollato et al., 2017). While it would not be economical to manage the crop for potential yields every year, Lobell et al. (2009) suggested that attaining about 75–80% of the potential yield is usually the economic optimum for dryland systems. Thus, there is currently a yield gap of 8–13 bushels per acre in Kansas that could be fulfilled through improved management while maintaining profitability.

Recent analyses of factors contributing to yield gaps in Kansas suggested that both nitrogen management and foliar fungicides are among the most important factors

contributing to the regional yield gaps (de Oliveira Silva et al., 2020a; Jaenisch et al., 2019; Lollato et al., 2019a). Specifically, Lollato et al. (2019a) evaluated several years of data from fields entered in the Kansas Wheat Yield Contest and suggested that foliar fungicides were the most important management factor associated with wheat yields. The authors also highlighted differences in nitrogen management between high- and low-yielding growers. Furthermore, Jaenisch et al. (2019) showed that foliar fungicides could contribute as much as 15–20 bushels per acre yield to differences for a variety with high susceptibility to stripe rust in a season when stripe rust is prevalent. De Oliveira Silva et al. (2020a) later suggested that, while the 15 bushels per acre yield difference between fungicide versus non-fungicide was possible, it depended on the variety's susceptibility to major diseases such as leaf rust and stripe rust.

Beyond the variety-specific response to fungicide, de Oliveira Silva et al. (2020a) also suggested that a variety's straw strength can contribute to a variety's response to nitrogen. Nitrogen is the macronutrient needed in greatest amounts by the wheat crop (de Oliveira Silva et al., 2020b), and the crop's yield response to N seems to depend on yield environment (Cruppe et al., 2017; Lollato et al., 2019b). In other words, the agronomic optimum nitrogen rate is greater at higher yield environments as compared to lower yield environments. Thus, maximizing wheat yields in intensively managed, high-yielding crops might require greater amounts of N, though this would depend on the initial N available in the soil profile.

Given the importance of foliar fungicide and nitrogen management to maximize wheat yields, and the dependence of their responses on variety, the objective of this research was to evaluate how different wheat varieties responded in grain yield and grain protein concentration to additional nitrogen and two foliar fungicide applications in Kansas.

Procedures

Field experiments were conducted in two Kansas locations (Ashland Bottoms and Great Bend) during the 2018–2019 winter wheat growing season. The experiment was sown using no-tillage practices after soybeans in Ashland Bottoms, and using conventional tillage practices after a terminated cover crop in Great Bend. A complete two-way factorial treatment structure was arranged in a split-plot design where two levels of management intensities were the main plot (standard versus intensive management), and 20 commercial winter wheat varieties were the sub-plot. Standard management included enough nitrogen fertilizer for a 75 bushel per acre yield goal (considering nitrogen in the soil profile at sowing plus credits from organic matter and one fertilization event with urea during early spring at Feekes 3-4) and no fungicide application. Intensive management included the same N management adopted in the standard management plus an additional 40 pounds of N per acre applied at Feekes 6, and two fungicide applications: 4 ounces per acre of Aproach fungicide at jointing (Feekes 6-7) followed by 6.8 ounces per acre of Aproach Prima fungicide at heading. Dates of field activities are listed in Table 1. The winter wheat varieties included in this study were: AM Eastwood, Gallagher, Joe, LCS Chrome, LCS Mint, Langin, Larry, Lonerider, Paradise, SY Grit, SY Monument, SY Rugged, Smith's Gold, Spirit Rider, T158, Tatanka, WB4303, WB Grainfield, Whistler, and Zenda. Harvest occurred using a Massey Ferguson XP8 small-plot, self-propelled combine. Plot ends were trimmed at

harvest time to avoid border effect. Measurements included grain yield (corrected for 13% moisture content) and grain protein concentration at harvest maturity (dry basis).

Statistical analysis was performed using a three-way ANOVA in PROC GLIMMIX in SAS v. 9.4 (SAS Inst. Inc., Cary, NC) where variety, management, year, and their interactions were considered fixed effects. Replication, replication nested within year, and management nested within replication and year were treated as random effects in the analysis of variance.

Results

Weather Conditions

Overall, the weather conditions during the 2018–2019 growing season tended towards excessive amounts of precipitation. For instance, at the two studied locations, growing season total rainfall was 34.1 inches in Ashland Bottoms and 29.5 inches in Great Bend (Table 2): both values correspond to greater amounts than the normal annual rainfall at these locations. The majority of the precipitation was accumulated during the spring (16.1 to 20 inches), but the fall was also considerably moist. Temperatures overall were cool, which allowed for the development of stripe rust at both locations (visual observations only) and for a prolonged grain filling period which improved grain yields.

Grain Yield

Across the all locations, varieties, and management intensities, grain yield ranged from 18 to 103 bushels per acre. The highest grain yields were recorded in the intensive management treatment in Great Bend while the lowest grain yields were recorded in the standard management treatment in Ashland Bottoms. The analysis of variance suggested a significant location by management interaction, as well as a significant location by variety interaction, but not variety by management or variety by management by location interaction (Table 3). These results suggest that the ranking of varieties depended on location, and the ranking of management also depended on location; but that there were no statistical differences in how varieties responded to management. Across all varieties, the intensive management increased grain yield from 32 to 41 bushels per acre in Ashland Bottoms, and from 68 to 85 bushels per acre in Great Bend (Table 4). In Ashland Bottoms, the lowest yielding variety was Lonerider (29 bushels per acre) while the highest yielding was LCS Chrome (44 bushels per acre). In Great Bend, the lowest yielding variety was Larry (57 bushels per acre) and the highest yielding variety was Zenda (90 bushels per acre). While there was no variety by management interaction, the magnitude of variety-specific response to management ranged from a yield gain of 0.6 bushels per acre (Paradise) to 19 bushels per acre (AM Eastwood) in Ashland Bottoms, and from 6.6 bushels per acre (Smith's Gold) to 27.6 bushels per acre (Larry) in Great Bend. We suspect that we did not have sufficient observations to detect differences among varieties and their interaction with management.

Grain Protein Concentration

Grain protein concentration on a dry basis ranged from 10.5 to 17.7% across all locations, varieties, and management intensities. Similar to grain yield, grain protein concentration was affected by the interaction of location and management, and by the interaction of location and variety (Table 3). The intensive management increased grain protein concentration from 12.7 to 13.9% in Ashland Bottoms, and from 14.1

to 14.5% in Great Bend (not significant) (Table 5). In Ashland Bottoms, the lowest protein concentration variety was Whistler (11.2%) and the highest were Lonerider and Paradise (14.8%). In Great Bend, the lowest protein concentration variety was Tatanka (13.4%) and the highest testing were Lonerider and Larry (14.8%). Despite no statistical significance in variety by management interaction, the difference in protein concentration between management practices ranged from 0.6% (LCS Chrome) to 1.9% (Larry) in Ashland Bottoms, and from -0.7% (Paradise) to 1.4% (Langin) in Great Bend.

Grain Yield × Grain Protein Relationship

At the same nitrogen levels, there is usually a negative relationship between grain protein concentration and grain yield due to a greater amount of starch accumulated in the grain at greater yield levels (Lollato and Edwards, 2015; Lollato et al., 2019b). In this study, there were weak negative relationships between protein and yield ($r^2 < 0.08$) except for the intensive management in Ashland Bottoms ($r^2 = 0.41$) (Figure 1). Interestingly, the intensive management concomitantly increased both grain yield and grain protein concentration in Ashland Bottoms, and increased grain yield while sustaining grain protein concentration in Great Bend. These results suggest that the amount of N exported in the grain would have been much greater under intensive management as opposed to standard management.

Preliminary Conclusions

These results suggest that both the effects of management and of variety depended on environment, but varieties responded similarly to management. Similar results were reported in previous years of this study (de Oliveira Silva et al., 2019b), though in both cases there were large numerical differences in variety-specific response to management. Thus, we hypothesize that there were not enough observations to build statistical power and detect these differences. During 2018–2019, intensive management increased grain yield at both locations, and grain protein concentration in one location, sustaining protein at similar levels at the second location. While we did not investigate the net profits from the intensive management in this publication, these results suggest that intensifying management on wheat could add income from both additional bushels produced, as well as from protein premiums when these are available.

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Table 1. Date when different field operations were performed in the variety by management intensity trial conducted in Ashland Bottoms and Great Bend during the 2018–2019 winter wheat growing season

Location	Operation	Stage	Date
Ashland Bottoms	Sowing	---	11/1/2018
	Nitrogen	Feekes 4	3/22/2019
	Feekes 6 nitrogen	Feekes 6	4/17/2019
	Fungicide	Feekes 7	5/2/2019
	Fungicide	Feekes 10.5	5/31/2019
Great Bend	Sowing	---	10/2/2018
	Nitrogen	Feekes 4	3/27/2019
	Fungicide	Feekes 6	4/15/2019
	Feekes 6 nitrogen	Feekes 6	4/19/2019
	Fungicide	Feekes 10.5	5/16/2019

Table 2. Average maximum (Tmax) and minimum (Tmin) temperatures, 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 locations during the 2018–2019 growing season

Location	Season	Tmax °F	Tmin °F	Precip. inches	ETo inches
Ashland Bottoms	Fall	52.6	30.8	9.1	5.2
	Winter	41.5	23.4	5.0	5.3
	Spring	75.6	53.1	20.0	17.3
Great Bend	Fall	52.3	31.0	10.4	6.6
	Winter	42.2	23.4	3.1	6.0
	Spring	75.4	51.1	16.1	18.4

Table 3. F-test probabilities resulting from the three-way analysis of variance of variety, management, location, and their interaction for the trials conducted in Ashland Bottoms and Great Bend, KS, during the 2018–2019 winter wheat growing season

Effect	Num DF	Yield	Protein	Test wt.
----- P > F -----				
Variety (V)	19	<.0001	<.0001	<.0001
Management (M)	1	<.0001	0.0001	0.0083
V × M	19	0.6301	0.8115	0.0083
Location (L)	1	0.0007	0.0085	0.0159
L × M	1	0.0117	0.0027	0.105
L × V	19	<.0001	<.0001	<.0001
L × M × V	19	0.9542	0.3791	0.0117

Values less than 0.05 indicate statistical significance.

Table 4. Winter wheat grain yield as affected by variety, management, location, and their interaction for the trials conducted in Ashland Bottoms and Great Bend during the 2018–2019 growing season

Variety	Ashland Bottoms				Great Bend			
	IM	SM	Mean	Diff.	IM	SM	Mean	Diff.
	----- bu/a -----							
AM Eastwood	46	27	37	20	87	65	76	22
Gallagher	45	39	42	6	84	70	77	14
Joe	43	39	41	5	83	73	78	10
Langin	41	34	37	7	85	70	78	15
Larry	36	27	31	9	71	44	58	28
LCS Chrome	48	40	44	8	84	73	78	11
LCS Mint	40	30	35	10	79	54	66	25
Lonerider	33	25	29	9	86	67	76	19
Paradise	33	32	32	1	86	74	80	12
Smith's Gold	42	33	38	9	87	81	84	7
Spirit Rider	37	28	33	8	96	79	88	17
SY Grit	39	29	34	10	92	68	80	24
SY Monument	45	30	38	15	82	71	77	11
SY Rugged	42	36	39	6	79	71	75	8
T158	41	28	34	13	93	70	81	23
Tatanka	45	30	37	15	71	54	63	17
WB Grainfield	42	35	38	7	82	55	69	27
WB4303	39	33	36	6	98	81	90	17
Whistler	39	31	35	8	71	46	59	25
Zenda	39	31	35	8	97	84	91	12
Mean	41	32			85	68		
LSD	14							

IM = intensive management, SM = standard management.

Table 5. Winter wheat grain protein concentration as affected by variety, management, location, and their interaction for the trials conducted in Ashland Bottoms and Great Bend during the 2018–2019 growing season

Variety	Ashland Bottoms				Great Bend			
	IM	SM	Mean	Diff.	IM	SM	Mean	Diff.
	----- % -----				-----			
AM Eastwood	13.9	12.9	13.4	0.9	14.6	14.3	14.5	0.3
Gallagher	14.9	13.1	14.0	1.8	14.9	14.0	14.5	0.9
Joe	13.5	12.7	13.1	0.8	15.0	14.4	14.7	0.6
LCS Chrome	13.2	12.7	12.9	0.6	14.9	14.5	14.7	0.4
LCS Mint	12.8	11.4	12.1	1.4	14.5	13.5	14.0	1.0
Langin	13.6	12.3	12.9	1.3	14.8	13.4	14.1	1.4
Larry	14.8	12.9	13.9	1.9	14.8	14.8	14.8	-0.1
Lonerider	15.6	13.9	14.8	1.7	15.0	14.7	14.8	0.3
Paradise	15.7	13.9	14.8	1.8	14.0	14.7	14.4	-0.7
SY Grit	14.7	13.0	13.8	1.6	14.5	14.2	14.4	0.3
SY Monument	13.4	12.5	12.9	0.9	14.8	14.2	14.5	0.7
SY Rugged	14.1	12.9	13.5	1.3	14.1	13.6	13.9	0.5
Smith's Gold	13.8	12.7	13.2	1.2	14.3	13.6	14.0	0.7
Spirit Rider	14.6	13.6	14.1	1.0	14.4	14.3	14.3	0.1
T158	13.8	12.7	13.2	1.1	14.3	13.8	14.1	0.5
Tatanka	12.5	11.5	12.0	1.0	13.6	13.2	13.4	0.4
WB4303	14.4	13.5	13.9	0.9	14.7	14.2	14.4	0.5
WB Grainfield	13.2	11.8	12.5	1.4	14.2	14.8	14.5	-0.6
Whistler	11.5	10.8	11.2	0.7	14.1	14.0	14.1	0.1
Zenda	14.4	13.3	13.9	1.2	14.3	13.6	14.0	0.7
Mean	13.9	12.7	13.3		14.5	14.1	14.3	
LSD	0.9							

IM = intensive management, SM = standard management.

WHEAT

Figure 1. Grain protein concentration as affected by grain yield and management intensity in Ashland Bottoms and Great Bend during the 2018–2019 growing season. IM = intensive management. SM = standard management.

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