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Kansas Field Research 2019

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Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

Kansas Field Research 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, no chemical, and combination methods; and (4) test fertilizer rates, timing, and application methods for agronomic proficiency and environmental stewardship.

Soil Description

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

2018 Weather Information

Precipitation during 2018 was almost average, however, eight months were below average and October was more than 3 times the average (Table 1). Overall, the 2018 growing season was warmer than average. The summer of 2018 had 29 days exceeding 90°F and 1 day exceeding 100°F, which compares to 37 and 29 days exceeding 90°F, respectively in 2016 and 2017, with one day exceeding 100°F in 2017. There were 13 days with low temperatures in the single digits, compared to 4 and 8 days in 2016 and 2017, respectively. The last freezing temperature in the spring was April 16 (average, April 18), and the first killing frost in the fall was October 21 (average, October 21). There were 188 frost-free days, similar to the long-term average of 185.

The growing conditions were very stressful in June and July, reducing the yield potential, especially with corn and wheat. The short and full season corn hybrid trials both averaged 111 bu/a. The soybean yields were hurt by the heat, especially in the early maturing trial. The early maturing soybean variety trial averaged 45 bu/a and the later maturing trial 56, compared to 72 in 2017, 79 in 2016, 59 in 2015, and 41 in 2014.

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.

2018 Weather Information

The year was colder in the winter and warmer in the summer than last year, with below average rainfall during most of the growing season. The frost-free season was 184 days at the both units (average = 173 days), with 18 and 17 days in the single digits or lower at Rossville and Paramore, respectively, compared to 9 days in single digits at both units in 2017. The last spring freeze was April 20 (average = April 21), and the first fall freeze was October 21 (average = October 11). There were 61 and 58 days above 90°F at Paramore and Rossville, respectively, and none above 100°F. Precipitation was just below normal at both fields for the year (Table 2), with a major exception being October rainfall, which was 6 to 7 times greater than average. Irrigation requirements were just over 11 inches for the corn and 4.8 inches for the soybeans. The corn performance trials averaged 237 bu/a for the irrigated and 114 for the dryland. The soybean performance trials averaged 58 bu/a for the irrigated and 56 bu/a for the dryland. The soil moisture in the dryland was a major yield-limiting factor, especially during July. The sudden death syndrome foliar symptoms were not visible until mid-August in most fields in 2018, reducing the yield loss due to the disease.

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

Month	2018	35-year avg.	Month	2018	35-year avg.
	---------- in. ----------			---------- in. ----------	
January	0.72	1.03	July	1.60	3.37
February	0.97	1.32	August	4.86	3.59
March	3.33	2.49	September	3.28	3.83
April	1.40	3.50	October	11.73	3.43
May	3.20	5.23	November	1.13	2.32
June	1.55	5.21	December	2.33	1.45
			Annual total	36.10	36.78

Table 2. Precipitation at the Kansas River Valley Experiment Field

	Rossville Unit		Paramore Unit	
Month	2018	30-year avg.	2018	30-year avg.
		----------in.----------		
January	0.49	3.18	0.56	3.08
February	0.38	4.88	0.42	4.45
March	0.75	5.46	0.63	5.54
April	1.39	3.67	0.99	3.59
May	4.55	3.44	3.57	3.89
June	5.94	4.64	3.56	3.81
July	2.18	2.97	1.38	3.06
August	3.99	1.90	3.67	1.93
September	2.62	1.24	1.87	1.43
October	6.63	0.95	7.03	0.95
November	0.81	0.89	0.81	1.04
December	3.48	2.42	3.29	2.46
Total	33.21	35.64	27.78	35.23

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

	Ashland Bottoms		Belleville		Colby	
Month	2018	30-year average	2018	30-year average	2018	30-year average
	in.					
January	0.4	0.65	0.26	0.61	1.41	0.41
February	0.4	1.07	0.66	0.87	0.37	0.48
March	0.69	2.20	1.08	2.12	0.6	1.12
April	1.71	2.80	1.23	2.87	1.01	2.03
May	3.28	4.48	2.55	4.35	4.44	3.29
June	2.15	5.09	4.29	4.37	3.29	2.54
July	2.86	3.97	6.85	3.97	2.54	3.77
August	6.65	4.28	4.2	3.68	2.81	2.78
September	5.02	3.17	5.09	3.25	0.59	1.45
October	5.88	2.22	5.72	2.37	3.37	1.58
November	0.75	1.60	1.37	1.19	0.42	0.72
December	2.48	1.02	3.41	0.95	0.97	0.48
Annual	32.27	32.55	36.71	30.6	21.82	20.65
Last freeze	4/19/18		4/20/18		4/27/18	
First freeze	10/14/18		10/11/18		10/11/18	
Frost free days	178		174		167	
Days above 90°F	64		53		51	
Days above 100°F	10		6		6	
Days below 10°F	15		30		24	

Table 4. Precipitation at Great Bend, Hays, Hutchinson

	Great Bend		Hays		Hutchinson	
Month	2018	30-year average	2018	30-year average	2018	30-year average
	in.					
January	0.15	0.61	0.65	0.50	0.30	0.50
February	0.24	0.83	0.40	0.71	0.26	0.71
March	1.41	1.94	0.70	1.81	2.14	1.81
April	1.36	2.36	1.24	2.14	1.18	2.14
May	6.23	4.38	3.73	3.26	3.83	3.26
June	5.17	3.97	4.24	2.83	5.05	2.83
July	2.69	3.41	8.85	3.92	6.84	3.92
August	5.15	3.33	5.48	3.04	3.14	3.04
September	5.43	1.96	3.64	2.05	4.43	2.05
October	6.45	2.05	6.75	1.58	9.18	1.58
November	0.62	0.97	0.78	0.89	0.81	0.89
December	2.25	0.85	1.35	0.72	2.62	0.72
Annual	37.15	26.66	37.81	23.45	39.78	23.45
Last freeze	4/26/18		4/26/18		4/19/18	
First freeze	10/15/18		10/11/18		10/15/18	
Frost free days	172		167		167	
Days above 90°F	60		61		67	
Days above 100°F	2		4		3	
Days below 10°F	20		20		14	

Table 5. Precipitation at Leoti, Manhattan, and Ottawa

	Leoti		Manhattan North Farm		Ottawa	
Month	2018	30-year average	2018	30-year average	2018	30-year average
	in.					
January	0.02	0.42	0.56	0.63	1.23	0.63
February	0.09	0.53	0.57	1.08	1.47	1.08
March	0.10	1.38	0.60	2.49	2.67	2.49
April	0.23	2.00	1.52	3.17	3.84	3.17
May	0.55	2.57	3.78	5.09	5.41	5.09
June	0.63	2.58	2.57	5.70	5.63	5.70
July	0.68	2.90	2.43	4.42	4.09	4.42
August	1.31	2.79	8.41	4.12	4.04	4.12
September	1.69	1.57	8.01	3.43	4.12	3.43
October	2.95	1.47	5.72	2.69	3.32	2.69
November	3.83	0.65	0.86	1.73	2.70	1.73
December	4.23	0.57	2.71	1.07	1.78	1.07
Annual	16.31	19.43	37.74	35.62	40.3	35.62
Last freeze	4/25/18		4/20/18		4/17/18	
First freeze	10/11/18		10/14/18		10/11/18	
Frost free days	168		177		181	
Days above 90°F	60		72		52	
Days above 100°F	9		6		1	
Days below 10°F	18		13		14	

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

	Silver Lake		Rossville		Scandia	
Month	2018	30-year average	2018	30-year average	2018	30-year average
	in.					
January	0.56	3.18	0.49	3.08	0.16	0.45
February	0.42	4.88	0.38	4.45	0.27	0.74
March	0.63	5.46	0.75	5.54	0.99	2.12
April	0.99	3.67	1.39	3.59	0.77	2.96
May	3.57	3.44	4.55	3.89	2.12	4.21
June	3.56	4.64	5.94	3.81	6.83	3.81
July	1.38	2.97	2.18	3.06	2.59	4.24
August	3.67	1.90	3.99	1.93	4.49	3.26
September	1.87	1.24	2.62	1.43	4.08	2.84
October	7.03	0.95	6.63	0.95	4.53	2.14
November	0.81	0.89	0.81	1.04	0.88	1.26
December	3.29	2.42	3.48	2.46	2.49	0.79
Annual	27.78	35.64	33.21	35.23	30.20	28.82
Last freeze	4/20/18		4/20/18		4/27/18	
First freeze	10/14/18		10/11/18		10/11/18	
Frost free days	177		177		167	
Days above 90°F	62		60		43	
Days above 100°F	0		0		0	
Days below 10°F	17		18		36	

Effect of Late Planting Dates on Corn Yield

E.A. Adee and K.L. Roozeboom

Summary

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

Procedures

Corn planting date studies were conducted at the Kansas River Valley (Topeka) and East Central Kansas (Ottawa) experiment fields in 2018. The experiment at the Topeka site was irrigated with irrigations totaling 9.5 inches applied June 8 through August 13 via an overhead sprinkler irrigation system that applied roughly 0.8 in. of water at each irrigation event. The experiment at Ottawa received no irrigation. A single hybrid was planted at each location at four or five planting dates. Corn was planted every two to three weeks from April 10 to June 11 at Topeka and from April 13 to June 29 at Ottawa. The U.S. Department of Agriculture's 2018 final planting date for corn at both locations was May 25. At Topeka, Pioneer 1197AM (111 CRM) was planted at 32,900 seeds per acre, and at Ottawa Pioneer 1138AM (111 RM) was planted at 26,500 seeds per acre. The experiment utilized a randomized complete block design with four replications. Individual plots had 12 rows and were 30-ft wide × 30-ft long. Yields were determined from the middle two rows of each plot to avoid influence from neighboring plots. Two harvest dates were required at each location to allow the later planted corn to mature and dry sufficiently for harvest. At Topeka, the first two plantings were harvested September 10 and the last two on September 19. The first three plantings at Ottawa were harvested September 25, and the last two plantings were harvested October 30. Yields were corrected to 15.5% grain moisture. Nitrogen and weed control were managed to have no known effects on yields.

Results

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

The lowest corn yield at Ottawa was the middle planting of May 18 (Table 1). The fourth planting date of June 8 yielded as well as the first two planting dates, and the fifth date on June 29 produced yields similar to the third date. All corn yields at Ottawa were reduced significantly due to the lack of rainfall, which was more than 8 inches below normal for the growing season, and extended periods of heat (Figure 1). The first two corn planting dates tasseled before the end of June, the third planting (May 18) around July 18, and the last two after August 1. Tasseling occurred in the May 18 planting date during the hottest and driest part of the growing season (Figure 1), likely limiting the effectiveness of pollination. These results demonstrate that later planted corn can yield as well as early planted corn in a year where water is a limiting factor depending on timing of rainfall events and temperature pattern.

At Topeka, the yield-limiting factor of moisture stress was greatly reduced by repeated irrigations (Figure 2), resulting in a more traditional yield response to planting date (Table 2). The highest yield was with the second planting date of April 23, with the first and third planting dates nearly equal, but more than 20 bu/a less than the second. The yield of the fourth planting date of 126 bu/a was slightly more than 50% of the yield from the second planting date. There was no difference between plant populations for the planting dates at Topeka (Table 2).

Grain test weights decreased at both locations after the second planting dates in the last week of April (Tables 1 and 2), however, they were greater than the 56 lb/bu standard at all but the last planting dates. This reduction in grain test weight is likely related to the shorter grain fill period for the later planting dates.

The preliminary results from this single year provide an example of how later planting date can be a viable option to avoid stressing the corn at critical stages when moisture is limiting. The results from the irrigated experiment at Topeka illustrate that if moisture is not limiting and planting is delayed, corn can still produce a substantial yield, though reduced from the potential of the optimum.

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

Planting date	Grain moisture	Grain test weight	Grain yield
	%	lb/bu	bu/a
April 13	15.3 d†	62.0 a	98 a
April 30	15.6 d	62.9 a	93 ab
May 18	18.8 b	60.7 b	60 bc
June 8	18.0 c	58.8 c	96 a
June 29	23.7 a	52.5 d	66 bc
Pr>F	<0.0001	<0.0001	0.05
LSD (0.05)	0.7	1.7	29

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

Table 2. Effect of planting date on corn under irrigation at the Kansas River Valley Experiment Field, Topeka, in 2018

Planting date	Plant population	Grain moisture	Grain test weight	Grain yield
	plants/a	%	lb/bu	bu/a
April 10	30750	17.1 b†	62.1 ab	215 a
April 23	30500	17.4 b	62.3 a	240 a
May 18	30375	17.0 b	61.3 b	219 a
June 11	27875	25.6 a	52.3 c	127 b
Pr>F	0.25	<0.0001	<0.0001	0.0050
LSD (0.05)	NS	1.3	0.9	48

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

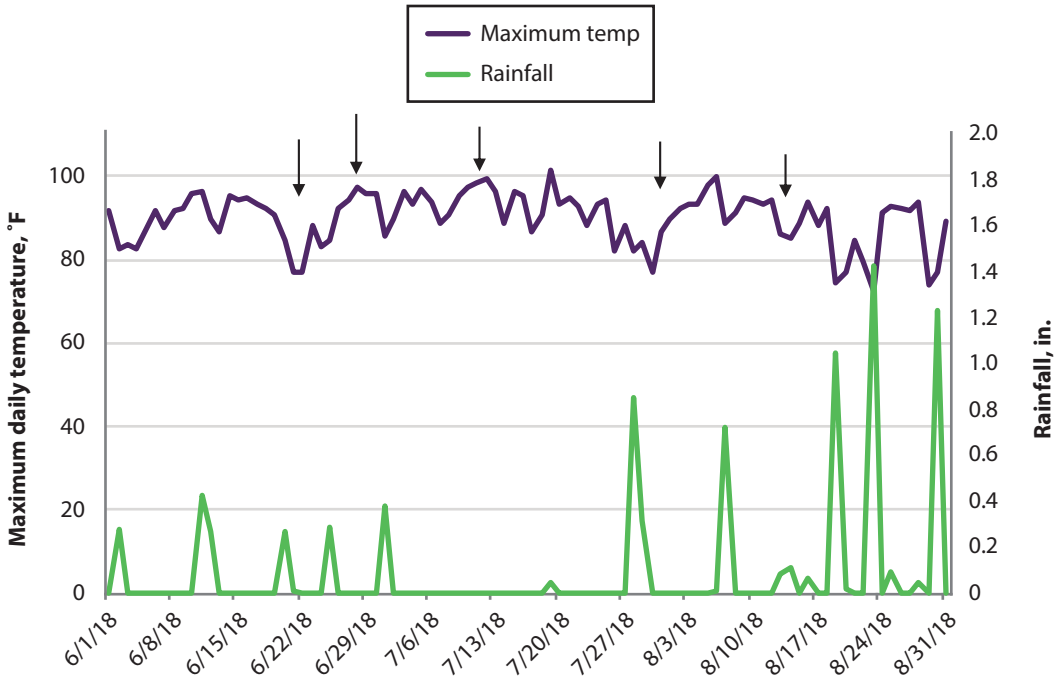

Figure 1. Daily maximum temperatures and daily rainfall at the East Central Kansas Experiment Field, Ottawa. Arrows indicate corn tasseling for successive planting dates.

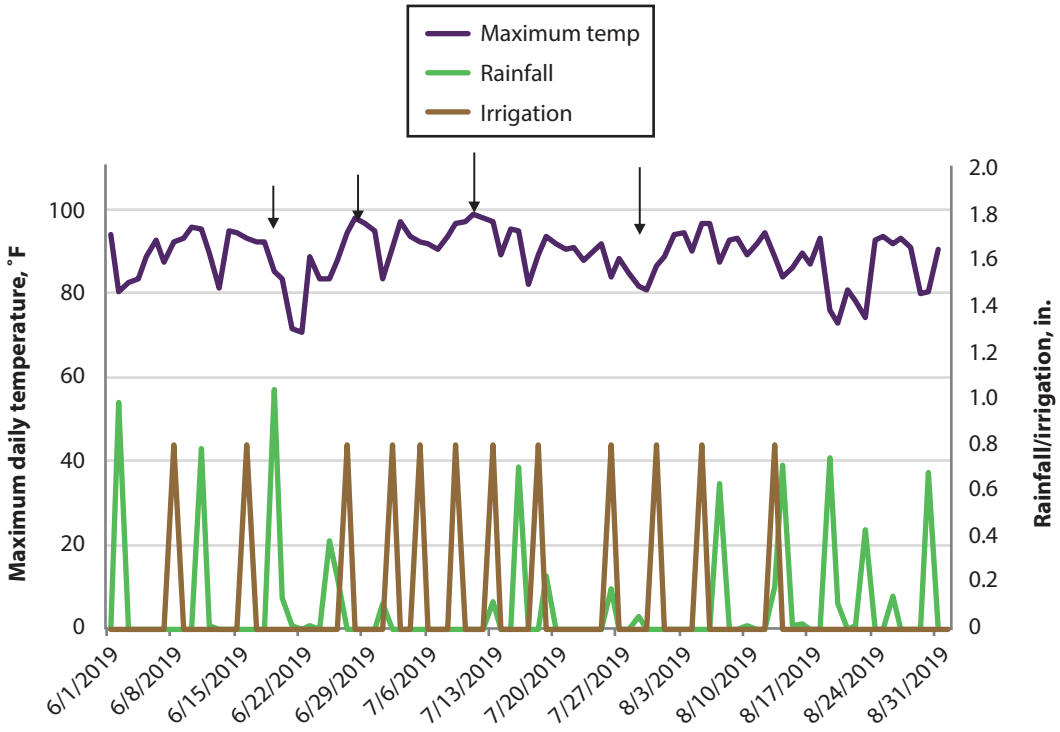

Figure 2. Daily maximum temperatures, daily rainfall and irrigation at the Kansas River Valley Experiment Field, Topeka. Arrows indicate corn tasseling for successive planting dates.

Use of Satellite Imagery to Predict Corn Phenology at a Regional Scale

L. Nieto, R. Schwalbert, and I.A. Ciampitti

Summary

Existing methods to report phenology are expensive, labor-intensive, time-consuming, and often not very accurate, especially at some specific crop growth stages. The objective of this study was to develop large-scale phenology models via utilization of satellite imagery data and machine learning techniques for the southwest (SW) agricultural crop reporting district of Kansas. Different satellite images collected from Landsat were utilized as the main input to obtain different vegetation indices (normalized difference vegetation index, NDVI; enhanced vegetation index, EVI; green chlorophyll vegetation index, GCVI; normalized difference water index, NDWI; and global vegetation moisture index, CVMI). Vapor Pressure Deficit (VPD), temperature, precipitation, and growing degree units (GDU) were evaluated for improving phenology prediction models. A large set of ground truth data with information about day of the year, crop phenology, and field location was provided by Crop Quest Inc. (Dodge City, KS) from 2014–2018 and utilized to train two different statistical models (Random Forest and Support Vector Machine) to catalog corn fields, and build a phenology evolution model for this crop.

Introduction

During the crop-growing season, the U.S. Department of Agriculture (USDA) via its agency, National Agricultural Statistics Service (NASS), releases a weekly report concerning the Crop Progress and Report Conditions (CPRC), providing an estimate of the crop phenology and overall condition of selected crops in major producing states. Phenology crop progress estimates are based on survey data collected each week from an extensive network of regional agricultural agents based on their field observations. Although this is a useful source of information, this task is labor-intensive, time-consuming, and biased on the data collection process. In addition, in some regions of the United States the CPRC are released after the crop is planted, decreasing the prediction power of estimating planting and emergence progress of the crop. Therefore, in an effort to improve the overall prediction of crop phenology and to resolve potential issues related to data bias and missing information, utilization of satellite imagery can play a key role in this work (Figure 1).

The objective of this research study was to explore and test the utilization of different classifiers to find the most accurate approach to predict crop phenology by integrating data, such as field survey (ground-truthing), remote sensing, and weather, via utilization of machine learning techniques.

The project is focused on the Southwest Agricultural Statistics District (SW), KS. The ground-truth consist in a large dataset owned by CropQuest, focusing on crop phenology for corn fields during the 2014–2018 growing seasons. This dataset was comprised of the following features: 1) geolocation of each field; 2) date of visit; 3) crop phenol-

ogy; and 4) crop (e.g., corn in this study). Approximately 60,000 observations were made (Figure 2a) in Kansas, and approximately 25,000 observations just in the SW region of Kansas (Figure 2b).

Procedures

Briefly, the data preparation presented the following steps: 1) corn fields from the SW region in Kansas were selected from the dataset; 2) the different phenology stages from the original dataset (more than 20 categories) were combined into nine classes, these classes follow the most critical moments for field management practices (Table 2); 3) the geolocation of each field was utilized to locate the farms and the CONUS layer by Yan and Roy (2015) was used to recreate the boundaries of the fields presented in the dataset and transform these points into a shapefile; 4) satellite imagery (Landsat mission) from each farmer field was selected due to its spatial resolution, using one image per month, masking clouds, and selecting the best pixels to calculate the different vegetation indices; and 5) weather information (Table 1).

The different vegetation indices were selected according to the purpose of this research and to enhance some variables in the canopy. As an example, Cai (2018) stated that NDVI is based on the fact that healthy plants usually have a greater reflectance in the near infrared (NIR) than visible bands. The problem with the NDVI is that it tends to saturate at high biomass levels. The EVI was designed to reduce the influence of some atmospheric effects, including the blue band, into the calculation. The GCVI has been found to have most linear relationship with leaf area index (LAI) for corn and soybeans than other indices. The NDWI was developed to approximate canopy water thickness, based on the rationale that the shortwave infrared (SWIR) band is sensitive to leaf water and soil moisture. Finally the GVMI index is more suitable when looking at the global water content.

In terms of weather information, the Gridded Surface Meteorological dataset merges the high-resolution spatial data from PRISM with high temporal resolution data from NLDAS. From this data layer, we extracted metrics related to precipitation, minimum and maximum temperature, and VPD. Using these data, a GDU model was applied as:

$$GDU = [(Max.\ temp.\ (°F) - Min.\ temp.\ (°F))/2] - 50°F\ (base\ temp.).$$

All data layers were merged with the ground truth data, providing a final output of a table with the spectral bands, vegetation indices, weather data, and phenological growth stages in each georeferenced point, per month during the growing season. All computations mentioned were performed into a Google Earth Engine Environment (GEE) platform. The GEE is a cloud-based platform optimized for parallel processing of geospatial data for environmental data analysis, supporting work with large datasets. The GEE code editor allows us to rapid visualize the spatial analyses using JavaScript. The final table with all the information obtained in the GEE platform was then moved to the R environment to train the classifiers.

The two models selected to test in this study were:

1. Random Forest (RF).
2. Support Vector Machine (SVM).

The first classifier (RF) was selected due its performance with a large amount of data. In this classifier, each tree is a representation where the leaves are the class labels and the branches are the mergers of features that lead to those class labels. Then is trained by a random subset of the original dataset and the final classification is computed by aggregating results of all tree predictors. The second classifier (SVM) can solve problems in classification by looking for the global optimum and taking advantages from all the dimensions existing in the data to solve problems that a simpler model cannot achieve.

Results

The accuracy (number of all correct predictions divided by the total number of predictions) was selected as a parameter to compare the behavior of the models. The values for this specific parameter range between 0 and 1, 1 being the best scenario, where the model is able to predict one class 100% of the times.

The results considering accuracy for yearly analysis not using weather and using weather information are shown in Tables 3 and 4 respectively.

A second analysis was executed for each month during the growing season, from May to September, again not using weather and using this variable in the analysis. (Tables 5 and 6).

Conclusions

Several conclusions can be drawn from this preliminary analysis. First, the weather dataset is critical when training models. The use of this parameter helps to increase the accuracy of both models (Random Forest and Support Vector Machine), especially during the critical period of the crop (June-August), but with a positive impact throughout the entire growing season.

Second, a special treatment was necessary for the 2018 data. The phenology prediction model was built with crop data that presented a dissimilar weather condition relative to 2018, an anomalous year (e.g., high temperatures early in June). Thus, the phenology prediction model could improve as the data evaluated and added to the model could include broader weather variation.

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Table 1. Datasets used to study corn phenology indicators

Vegetation indices	Weather information
Normalized difference vegetation index (NDVI) (Tucker, 1979)	Precipitation (Pr)
Enhanced vegetation index (EVI) (Huete, 2002)	Maximum temperature (Tmx)
Green chlorophyll vegetation index (GCVI) (Gitelson, 2003)	Minimum temperature (Tmin)
Normalized difference water index (NDWI) (Gao, 1996)	Vapor pressure deficit (VPD)
Global vegetation moisture index (CVMI) (Ceccato, 2002)	Growing degree units (GDU)

Table 2. Class division for corn growth and phenology stages

Class number	Phenology stages*	Observations
1	V0-V1	Planted
2	V2-V4	Vegetative
3	V5-V8	
4	V9-V16	
5	R1-R3	Reproductive
6	R4	
7	R5	
8	R6	
9	H	Harvested

*Ciampitti *et al.* 2016.

Table 3. Yearly accuracy for Random Forest and Support Vector Machine considering all the variables except weather

Year	Random Forest	Support Vector Machine
2018	**0.79**	0.77
2017	**0.88**	0.68
2016	**0.90**	0.79
2015	**0.89**	0.71
2014	**0.87**	0.67

Table 4. Yearly accuracy for Random Forest and Support Vector Machine including weather parameters

Year	Random Forest	Support Vector Machine
2018	0.85	0.63
2017	0.89	0.92
2016	0.92	0.73
2015	0.91	0.93
2014	0.86	0.87

Table 5. Monthly accuracy for Random Forest (RF) and Support Vector Machine (SVM) considering vegetation indices and no weather

Year	Model	May	June	July	Aug	Sep	
2014	RF	0.75	0.6726	0.807	0.9198	0.6512	
	SVM	0.8571	0.7083	0.814	0.9321	0.6366	
		May	June	July	Aug	Sep	
2015	RF	0.93	0.8571	0.4545	0.6094	0.8864	
	SVM	0.97	0.8571	0.4909	0.6011	0.9038	
		May	June	July	Aug	Sep	
2016	RF	0.9727	0.57	0.7233	0.4697	0.8281	
	SVM	0.9727	0.5222	0.7547	0.5251	0.8281	
		J 1	J 2	July	A 1	A 2	Sep
2017	RF	0.7514	0.6042	0.733	0.5597	0.4583	0.7995
	SVM	0.7715	0.599	0.7961	0.5767	0.473	0.7226
		May	June	July	Aug	Sep	
2018	RF	0.8927	0.5183	0.3729	0.4731	0.936	
	SVM	0.8927	0.4878	0.4746	0.5484	0.8722	

Table 6. Monthly accuracy for Random Forest and Support Vector Machine considering all the variables (vegetation indices and weather information)

Year	Model	May	June	July	Aug	Sep	
2014	RF	0.86	0.84	0.84	0.9	0.77	
	SVM	0.61	0.95	0.98	0.95	0.94	
		May	June	July	Aug	Sep	
2015	RF	0.97	0.77	0.67	0.84	0.89	
	SVM	0.99	0.97	0.8	0.95	0.98	
		May	June	July	Aug	Sep	
2016	RF	0.89	0.87	0.81	0.82	0.77	
	SVM	0.79	0.81	0.71	0.55	0.76	
		J 1	J 2	July	A 1	A 2	Sep
2017	RF	0.89	0.75	0.79	0.76	0.75	0.77
	SVM	0.98	1	0.9	0.97	0.94	0.9
		May	June	July	Aug	Sep	
2018	RF	0.91	0.68	0.45	0.58	0.93	
	SVM	0.9	0.62	0.4	0.55	0.92	

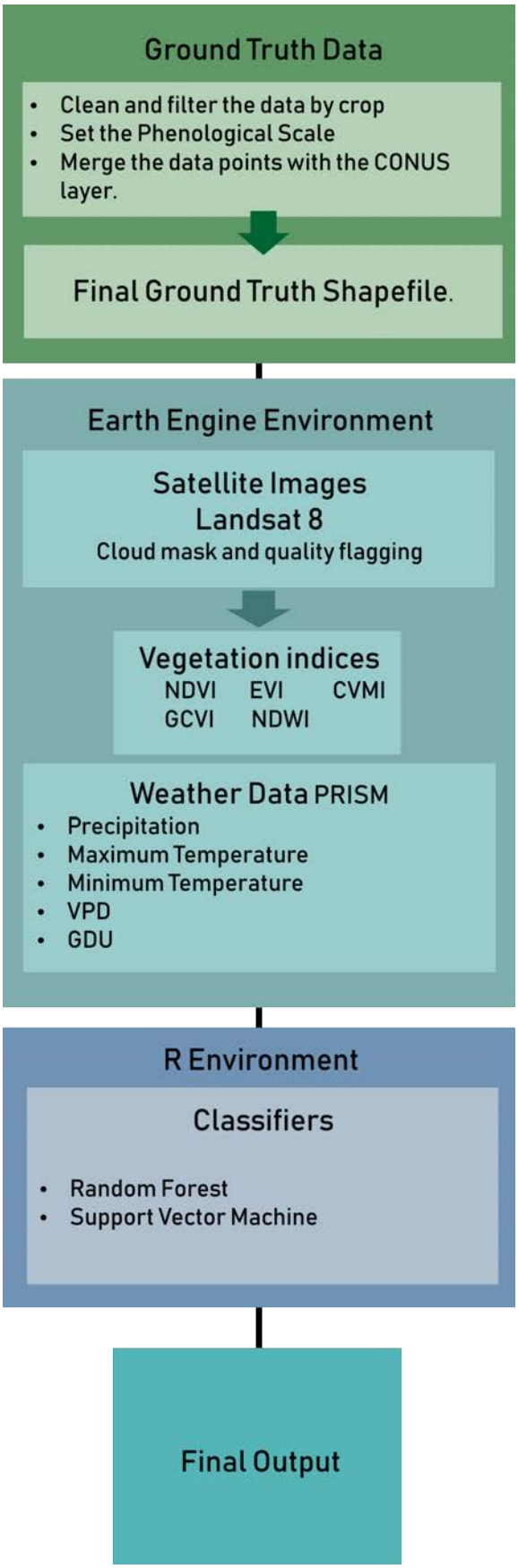

Figure 1. Workflow.

A

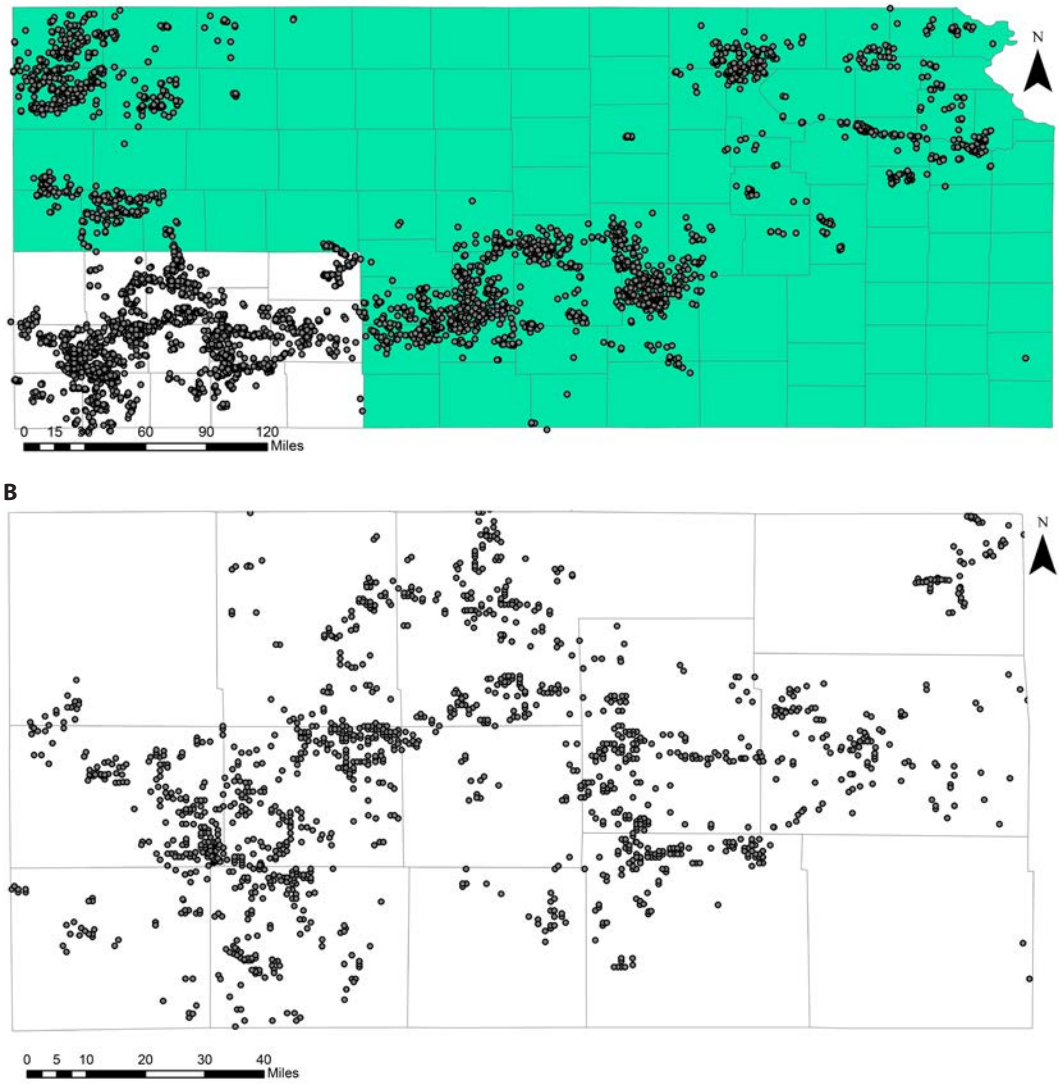

Figure 2. A) Data point distributions in Kansas in 2014. B) Data point distributions in the Southwest Agricultural District in 2014.

Effect of Late Nitrogen Fertilization on Grain Yield and Grain Filling in Corn

J.A. Fernandez and I.A. Ciampitti

Summary

For decades, yield improvement in corn has been accompanied by an increase in plant nitrogen (N) uptake. Modern hybrids are absorbing more N during reproductive stages, while delaying N remobilization to the grain for later in the growing season. To evaluate the effect of late-season N applications in distinct corn genotypes, grain yield and grain filling parameters were evaluated in field experiments under early and late N regimes during 2017 and 2018 growing seasons. Hybrids with different release years (3394, 1990s; P1151, 2000s; and P1197, 2016) and contrasting N application scenarios (including a zero-N control) were evaluated at the Kansas State University Ashland Bottoms Research Farm, Manhattan, KS. Results showed that under N stress conditions, the absence of N fertilization in corn significantly reduced yields, by affecting both grain number (GN) and grain weight (GW). Regarding genotypes, a positive trend was found between the year of release of the hybrid and yields, with greater yields for the modern hybrid (i.e., 206 bu/a for P1197). No significant effects were found between N applied at silking or 2 weeks after R1 for the 2017 field study; comparably, no impact of including an additional application at V12 was detected during 2018. In respect to the grain filling process, N fertilization significantly increased the grain filling duration (GFD) and grain filling rate (GFR). Still, evaluations across altered source-sink ratios are needed in order to investigate whether differential responses to late-season N are determined by variations in the availability of assimilate.

Introduction

In corn, a strong connection was documented between plant N demand and final grain yield (Ciampitti and Vyn, 2013). Studies have shown that yield improvement across decades was accompanied by an increase in plant N uptake, as modern hybrids absorb more N during reproductive stages (Ciampitti and Vyn, 2012; Haegele et al., 2013)—while delaying N remobilization to the grain until later in the growing season. Current hybrids accumulate approximately 35–40% total N after silking (Ning, 2017). Still, evaluation on a range of N management practices is necessary to understand the optimal approach to improve yields and fertilizer use efficiency in corn.

Current N fertilization strategies in corn are still characterized by a weak synchrony with plant N uptake during the growing season. In the United States, it is estimated that producers apply only 25% of total N after planting (Cassman et al., 2002), generally expected to be placed at early growth stages. Additionally, environmental concerns due to the risk of pollutant N losses from denitrification, leaching, volatilization, and surface run-off have recently placed N management under scrutiny (Raun and Johnson, 1999; Cassman et al., 2003). As a result, using late N fertilization is a method to synchronize the N supply and demand in the system, and potentially increase fertilizer recovery efficiency. However, studies are required to assess the effects of late season N

on grain yield and its numerical components. This research study was implemented to evaluate yield and grain filling N responses to different late-N fertilization strategies among hybrids released during different decades.

Procedures

A two-year field study was conducted at the Kansas State University Ashland Bottoms Research Farm, Manhattan, KS, during 2017 and 2018 (39°08' N, 96°37' W). At 6-in. soil depth, the soil pH was 5.9, soil organic matter was 1.34%, there was 50 ppm of phosphorus (Mehlich), and there was 158 ppm of potassium. Table 1 presents climatic data for the 2017 and 2018 growing seasons.

In 2017, two field experiments (one under irrigation and one rainfed) were arranged in 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. For genotype, three Pioneer hybrids with different release years (3394, 1990s; P1151, 2000s; and P1197, 2016) and three contrasting N scenarios (zero N, N at flowering, and N at two weeks after flowering) were tested. The study was planted on May 5, 2017, in plots of four rows, 30 in. apart and were 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 rainfed and irrigated, respectively). Depending on the treatment, the last application (22 lb/a and 44 lb/a for rainfed and irrigated, respectively) was performed at silking (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.

In 2018, one irrigated location was managed as a split-plot with factorial subplot, where hybrids were assigned to whole plots. Subplots were combinations of levels of N and source-sink treatment factors + a zero-N negative control. The study was planted on April 25, 2018, with similar plot sizes and layout as 2017. For genotypes, two Pioneer hybrids were evaluated (3394 and P1197). For N, two fertilization approaches were tested with the same final N rate of 194 lb/a: 1) early N, split in two applications (50% planting and 50% V6); and 2) late N, split in three applications (50% planting, 20% V6, and 30% V12). Four levels of source-sink ratio were included with: 1) control with normal pollination; 2) reduced sink, with partially restricted pollination; 3) reduced source, with partial defoliation; and 4) reduced both sink and source, combination of treatment 2 and 3. Reduced sink treatments were achieved using a bag to cover the entire ear when the silks were 1-in. long (Rajcan and Tollenaar, 1999). Partial defoliation was accomplished by removing, between two or three weeks after silking, the four topmost leaves. Lastly, a zero N (no N applied) treatment with normal pollination was added as a negative control. Experimental areas were kept free of weeds, pests, and diseases during the growing season.

The measurements for both years included soil N levels (nitrate + ammonium), plant stand counts, leaf area index ((LAI) Plant Canopy Analyzer LAI 2200), shoot biomass at silking and physiological maturity, yield determination by combine harvest equipment, and yield components (grain number, seed weight, and harvest index). Grain filling was measured since R2 growth stage, collecting one ear per plot every three to four

days (2017) or per week (2018) from each treatment combination, until harvest. Ten kernels from the central portion of the ear were sampled to track changes in kernel dry weight and water volume during the entire period.

Results

Grain Yield and Numerical Components

For 2017 and all treatment combinations, GN and GW were both positively correlated with final grain yield ($R^2 = 0.58$ and $R^2 = 0.43$, respectively) in agreement with other previous studies (Andrade et al., 1996) (Figure 1A and B). For 2018, grain number was mostly related to final yield. No overall relationship was found for GW in the 2018 study, where the artificial modification of both grain number and weight, by impeding pollination or reducing foliage, was reflected in a notorious variability of the results.

In order to confirm the relationship between crop condition at the beginning of grain filling (silking) and final grain weight, its correlation with total biomass at R1 and leaf area index (LAI) at R1 was tested for 2017 and 2018 (Figure 2A and B, respectively). In addition, these parameters were also tested at R3 with the aim of detecting any differences between the two fertilized treatments; however, no differences were found between them (data not shown).

2017 Experiment

Table 2 summarizes average yields and yield components for fertilizer N rate levels (N) and corn hybrids (H) evaluated during 2017. There was a significant interaction between N and water condition (WC) for final grain yields. A single level effect of H was observed in yields ($P \leq 0.05$). A positive trend was found between the year of release of the hybrid and yields, from 177 bu/a for 3394 (early 1990s) to 206 bu/a for P1197 (modern). As expected, fertilized treatments differed from the zero N treatment (with a more prominent effect under irrigated conditions – explaining the WC × N interaction), while there were no significant differences in average yields between late-N treatments.

Regarding yield components, significant differences between N levels and genotypes were found for grain number (GN) ($P \leq 0.001$ and $P \leq 0.05$, respectively), and between N treatments for grain weight (GW) ($P \leq 0.001$). Overall, final GW did not differ between genotypes, reflecting that yield variations among H were primarily driven by the number of grains per ear defined around silking. However, GN and GW were both affected by the absence of N fertilization, suggesting that GW reductions could have a considerable effect on yields, particularly in N stressed environments.

2018 Experiment

For 2018, yield components were consistently affected by source-sink (S) treatments (Table 3). As for the focus of this report on H and N effects, no significant differences were observed among treatments for yields and grain number. Only a minor interaction was apparent between N and H for final grain weight. Interestingly, final grain yields did not differ between early and late N treatments, signifying that an additional application of N was not beneficial for increasing yields under the 2018 conditions. Further evaluations and comparisons on source-sink treatments still need to be performed.

Grain Filling Rate and Duration

Grain filling dynamics were evaluated in terms of duration of the grain filling period (GFD) and rate of dry matter accumulation (GFR) using a bi-linear model. Additionally, grain filling period was considered as divided by two phases, a lag phase and a linear grain filling phase. The lag phase represents a period of active cell division (Borras and Westgate, 2006) when potential kernel size is defined. Lag phase duration (LPD) was calculated in the applied bi-linear model as the period from silking to the intersection of the curve with the x-axis, representing initial linear grain fill. There were no differences in duration of lag phase across N treatments or hybrids across experiments (data not shown). This indicates that variations in GFD (especially during 2017 experiment, Table 2) were primary driven by changes in linear grain filling or effective grain fill, which is considered as the period between end of lag and final GW (black layer formation).

Moreover, all N conditions evaluated in this study, reached final GW (black layer formation) at a similar moisture content [estimated means = 35.7% (2017) and 35.2% (2018)], indicating that the model of grain filling on a water-concentration basis (WC, %) was not affected by changes in the rate or timing of N. Another aspect that requires further investigation is the grain maximum water content (MWC) that was achieved across N management strategies, considering that MWC is an indicator of potential grain volume and, therefore, grain size.

2017 Experiment

Increments in GW were both related to changes in GFD and in the GFR for N treatments in 2017 (Table 2). The effect of N supply in GFR was dissimilar between genotypes, reflecting a significant genotype and environment interaction response N × H (Table 2, $P < 0.05$). The three genotypes displayed a positive response with N fertilization, while no significant effect was observed as triggered by late N applied.

2018 Experiment

For 2018, and averaged over the levels of source-sink, no differences between early and late N supply were identified for grain filling parameters (Table 3). Differential responses can be expected from late-season N, determined by variations in N uptake partitioning during reproductive stages.

Conclusions

In N stressed conditions, the absence of fertilization in corn significantly reduced grain yields, by affecting both GN and GW. Regarding genotypes, a positive trend was found between the year of release of the hybrid and yields, with higher yields for the modern hybrid (i.e., 206 bu/a for P1197). Regarding the grain filling process, N fertilization significantly increased GFD and GFR; however, no differences in grain filling parameters were observed between early and late N applications.

Even though split applications until early reproductive stages differed from the zero N control treatment, no significant effects were found between N applied at silking or 2 weeks after R1 for any of the analyzed parameters in the 2017 field study. Similarly, in the 2018 study no significant effect of including an additional application at V12 was

observed, when compared against a more typical approach of split N at planting + at V6. Further studies are needed in order to unravel reproductive N uptake dynamics and partitions to better understand N impact during the grain filling process in corn.

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Table 1. Monthly values for daily solar radiation, temperature, and total precipitation for the 2017 and 2018 growing seasons. Source: Kansas Mesonet, 2019

	2017					2018				
	May	Jun	Jul	Aug	Sep	May	Jun	Jul	Aug	Sep
Solar radiation (MJ m^{-2} day^{-1})	25.2	27.3	26.5	23.0	18.5	23.7	26.4	24.5	21.8	16.5
Mean temperature (°F)	65.8	75.4	80.4	72.1	72.0	72.1	79.7	78.6	76.6	69.6
Precipitation (inches)	3.74	2.82	1.33	6.09	0.81	3.28	2.15	2.86	6.65	5.02

Table 2. Analysis of variance and means for yield (15.5% moisture), grain number, grain weight, grain filling rate, and duration for three nitrogen (N) levels and three hybrids (H) under two water conditions (WC, irrigated and rainfed) for the 2017 experiment

Factor	Yields	GN	GW	GFR	GFD
	bu/a	grains/m^2	mg/grain	mg/GDUs grain	GDUs
0 (zero) N	119 b	2927 b	217 b	0.31 b	1146 b
N at flowering	234 a	4017 a	273 a	0.33 a	1219 a
N 2 weeks after flowering	223 a	4195 a	279 a	0.34 a	1207 ab
3394	177 b	3285 b	254 a	0.34 a	1158 b
P1151	194 ab	4021 a	251 a	0.32 a	1181 ab
P1197	206 a	3833 ab	263 a	0.32 a	1232 a
Sources of variation					
Hybrid	*	*	Ns	+	*
Nitrogen	***	***	***	**	*
WC × H	Ns	Ns	Ns	Ns	Ns
WC × N	*	+	Ns	Ns	+
H × N	Ns	Ns	*	*	Ns
WC × H × N	Ns	Ns	Ns	Ns	Ns

Different letters indicate significant differences at $P \leq 0.05$.
+ Significant at $P \leq 0.1$; * significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; *** significant at $P \leq 0.001$.
Ns = non-significant.
GN = grain number. GW = grain weight. GFR = grain filling rate. GFD = grain filling duration. GDUs = growing degree units.

Table 3. Analysis of variance and means for yield (15.5% moisture), grain number, grain weight, grain filling rate, and duration for two nitrogen (N) levels†, two hybrids (H), and four source-sink (S) treatments for 2018 experiment

Factor	Yields	GN	GW	GFR	GFD
	bu/a	grains/m^2	mg/grain	mg/GDUs grain	GDUs
Early N	169 a	2652 a	274 a	0.35 a	1126 a
Late N	169 a	2572 a	283 a	0.36 a	1142 a
3394	161 a	2328 a	283 a	0.35 a	1140 a
P1197	177 a	2896 a	274 a	0.36 a	1129 a
Sources of variation					
Source-sink	Ns	***	***	**	*
Hybrid	Ns	Ns	Ns	Ns	Ns
Nitrogen	Ns	Ns	Ns	Ns	Ns
S × H	Ns	+	+	Ns	Ns
S × N	Ns	Ns	Ns	Ns	Ns
H × N	Ns	Ns	+	Ns	Ns
S × H × N	Ns	+	Ns	Ns	Ns

Different letters indicate significant differences at $P \leq 0.05$.
+ Significant at $P \leq 0.1$; * significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; *** significant at $P \leq 0.001$.
Ns = non-significant.
GN = grain number. GW = grain weight. GFR = grain filling rate. GFD = grain filling duration. GDUs = growing degree units.
†For interpretation of the results, negative control (zero N + control source-sink) was excluded from the analysis.

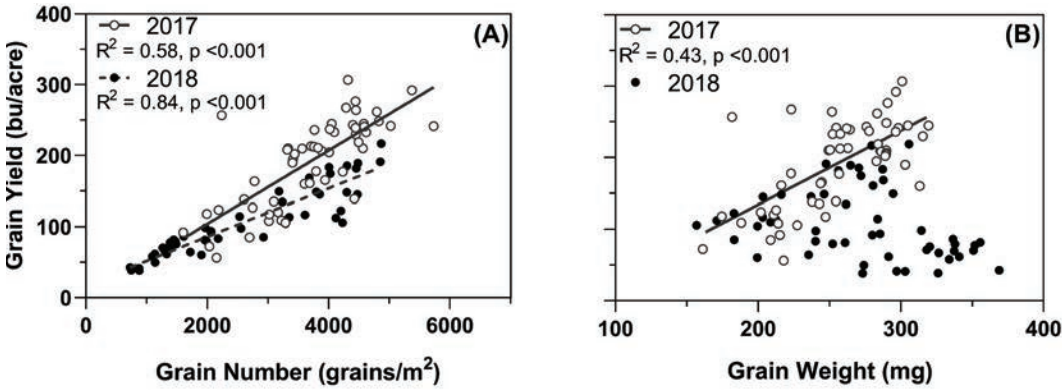

Figure 1. Relationship between final grain yield and grain number (A) and grain weight (B), for data from 2017 (open symbols) and 2018 (closed symbols) field experiments.

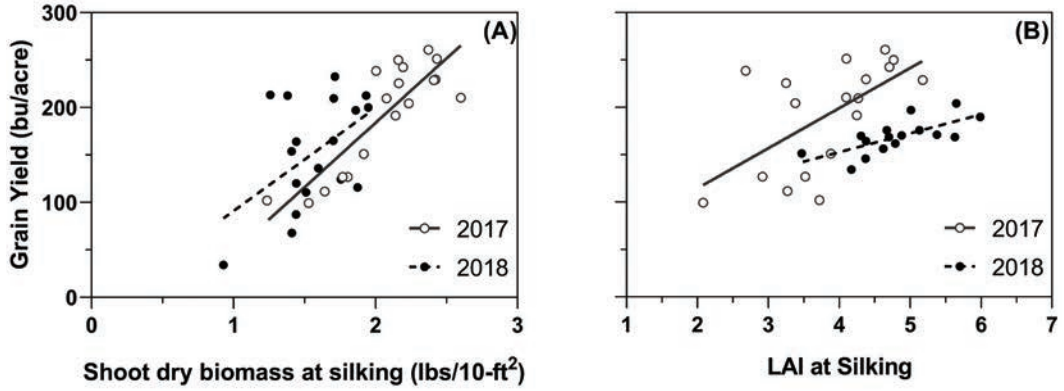

Figure 2. Relationship between final grain yield and shoot dry biomass (A) and leaf area index (B) at silking, for data from 2017 (open symbols) and 2018 (closed symbols) field experiments.

Influence of Soybean Planting Date on Sudden Death Syndrome and Soybean Yield

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

Summary

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

Soybean planting dates have been moving increasingly earlier in much of the soybean growing region, including Kansas. Yield loss of up to 0.5 bushel per day is not uncommon when soybeans are planted after May 10 in many soybean growing regions. However, in the Kansas River Valley, many of the soybeans have been planted after mid-May because of the perennial problem with SDS on soybeans. Later planting has been prescribed as a management practice to help avoid the cooler/wetter soils that can create greater probability of infection by the fungus. These data show that the severity of SDS is greater with the earlier planting date, but the yield is greater as well. The earlier planting date has a higher yield potential that can be reduced by SDS, but with SDS tolerant varieties there is still a significant yield benefit.

Procedures

Planting Date Study

Two soybean planting date studies evaluating the severity of SDS and soybean yield were conducted at the Kansas River Valley experiment fields in Topeka from 2015–2018. One study was specifically looking at SDS by promoting infection (early and greater irrigation volume), and the other was targeting best management practices to minimize SDS. In the study promoting SDS, two soybean varieties of MG 3.5, one SDS susceptible and one SDS tolerant, were planted into fields with a history of SDS in 2015, 2016, 2017, and 2018, on average planting dates of May 3 and 20, and June 8 and 22. The soil was Eudora silt loam and the previous crop was corn. Both studies had foliar symptoms of SDS develop during the growing season. Foliar symptoms of SDS were rated weekly starting July 29, 2015, at R3 (beginning pods); August 8, 2016, at R4 (full-length pods); August 25, 2017, at R5 (beginning seed); and August 13, 2018, at R5; until R6 (full seed) for all planting dates. Ratings were based on incidence and severity of symptoms resulting in percent defoliation. Harvest was completed by mid-October for all four study years.

Best Management Practice Study

Management practices to reduce or avoid SDS were implemented in this study. These include treating the seed with ILeVO (Bayer) at 35 mL/unit of seed to protect against SDS, and withholding irrigation until the crop was getting close to moisture stress

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(September 1, 2015; August 10, 2016; July 16, 2017; and June 5, 2018) with less than 3 inches the first three years, and 6.7 inches in 2018. Three soybean varieties of differing maturity group (MG) were planted on three different dates. Soil type, rainfall, and herbicide programs were the same as in the SDS Planting Date Study. Also, SDS ratings and harvest were the same dates as the SDS Planting Date Study.

Results

The severity of SDS was greatest with the early planting dates in both studies (Figures 1 and 3), decreasing to very little SDS for the June planting dates with the varieties having average or below-average tolerance to SDS. Overall, SDS foliar symptoms developed later in 2016, 2017, and 2018 than in 2015, resulting in a lower severity of SDS. However, the effect of planting date on SDS was consistent with all studies, confirming that earlier planting dates can result in more severe symptoms of SDS.

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

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

Summary

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

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

Acknowledgment

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

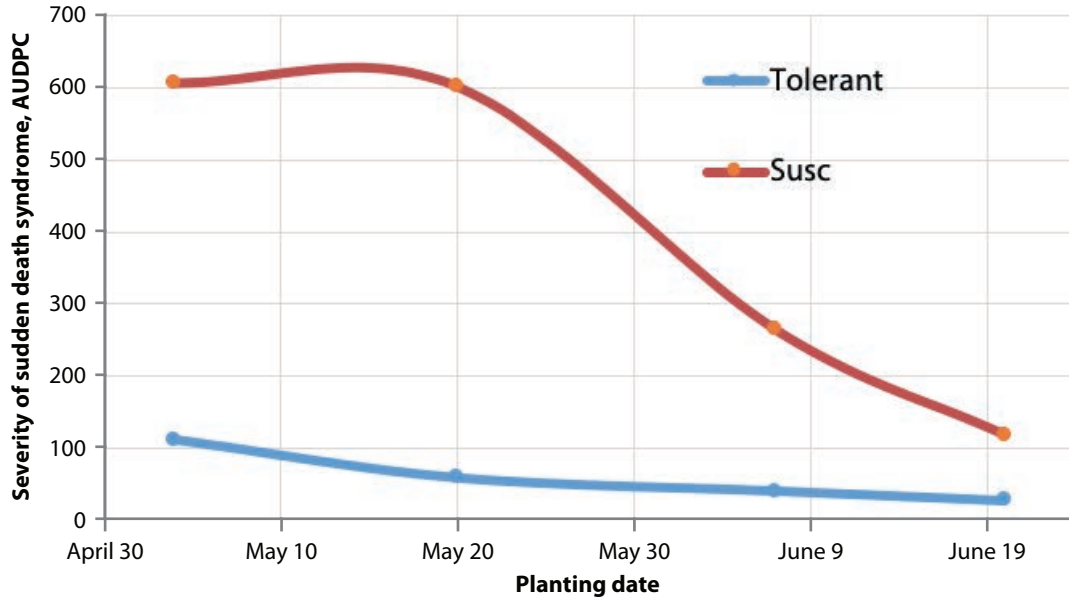

Figure 1. Effect of planting date for two soybean varieties on severity of sudden death syndrome (SDS) measured as area under disease progress curve (AUDPC), Kansas River Valley experiment fields, 2015, 2016, 2017, and 2018 averages.

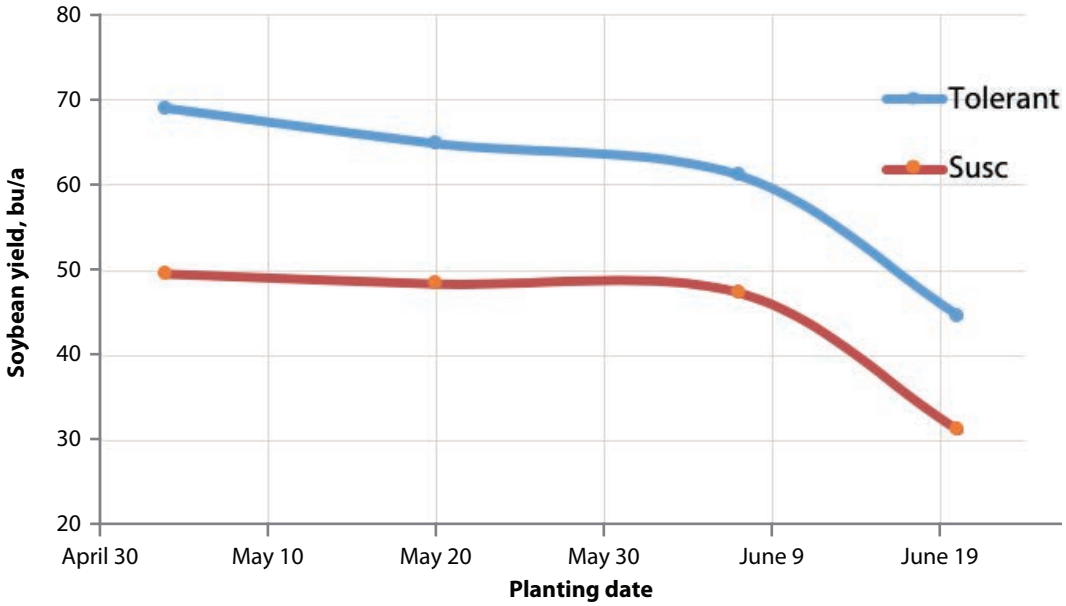

Figure 2. Effect of planting date on yield for two soybean varieties with different levels of susceptibility to sudden death syndrome (SDS), Kansas River Valley experiment fields, 2015, 2016, 2017, and 2018 averages.

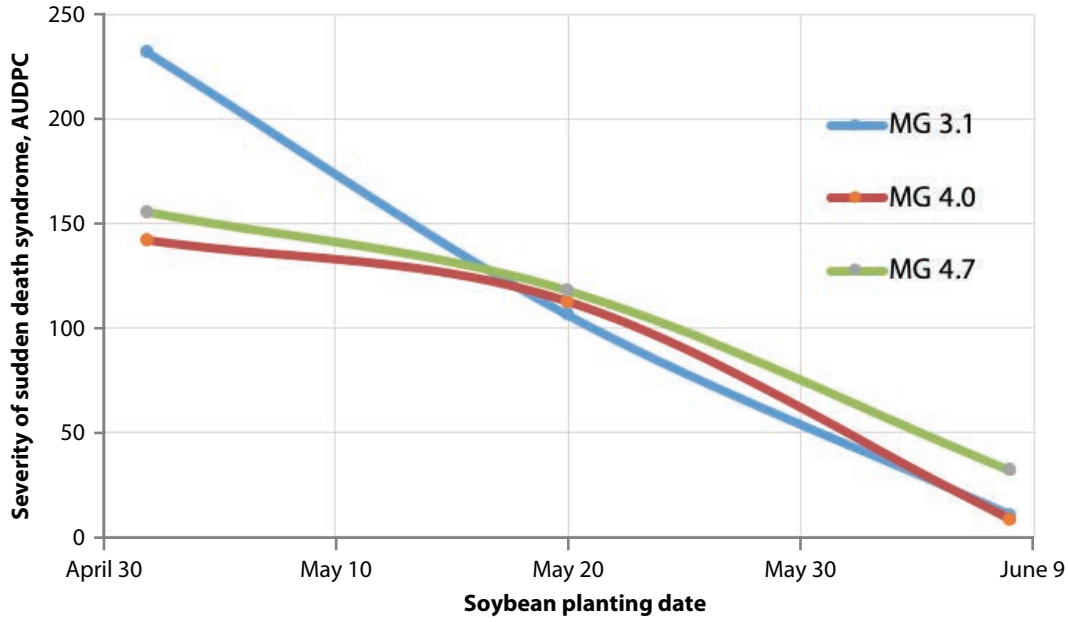

Figure 3. Effect of planting date on severity of sudden death syndrome (SDS) measured as area under disease progress curve (AUDPC) in soybean varieties of different maturity groups (MG) treated with ILeVO, Kansas River Valley experiment fields, 2015, 2016, 2017, and 2018 averages.

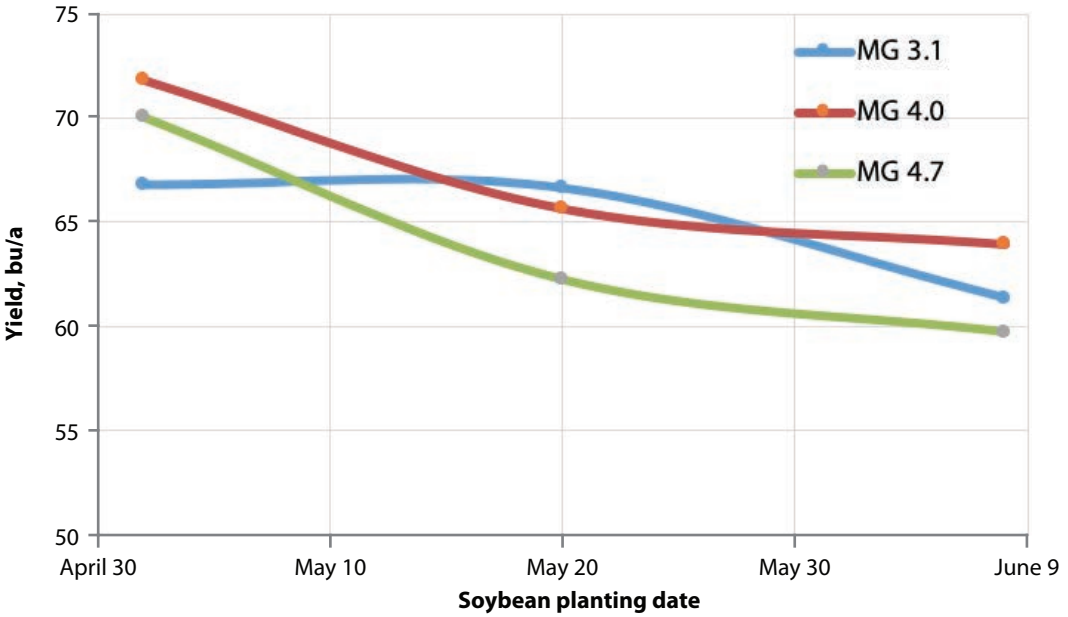

Figure 4. Effect of planting date on yield of soybean varieties of different maturity groups (MG), Kansas River Valley experiment fields, 2015, 2016, 2017, and 2018 averages.

Agronomic Optimal Plant Density by Yield Environment in Soybean

W.D. Carciochi and I.A. Ciampitti

Summary

This research report presents a summary of a peer-reviewed publication: Carciochi W.D.; Schwalbert R.; Andrade F.H.; Corassa G.M.; Carter P.; Gaspar A.P.; Schmidt J.; Ciampitti I.A. 2019. Soybean seed yield response to plant density by yield environment in North America. Agronomy Journal.

Recent economic and productive circumstances have caused interest in within-field variation of the agronomic optimal plant density (AOPD) for soybean [*Glycine max* (L.) Merr.]. Thus, the objective of this study was to determine the AOPD by yield environment (YE) for soybean. During 2013 and 2014, nine site-years with a total of 78 yield-to-plant density responses were evaluated in different regions of the United States and Canada. A soybean database evaluating seeding rates ranging from 69,000–271,000 seeds/a was utilized, including the final number of plants and seed yield. The data were classified in YEs: low (LYE, <59.6 bu/a), medium (MYE, 59.6-64.1 bu/a), and high (HYE, >64.1 bu/a). The main outcomes for this study were: 1) AOPD decreased by 24% from LYE (127,000 plants/a) to HYE (97,000 plants/a); 2) greater AOPD in a LYE was not related to a low plant survival rate; and 3) cumulative precipitation during soybean reproductive growth period was 39% lower in LYE compared with MYE and HYE, possibly reducing its reproductive ability. This study presents the first attempt to investigate the seed yield-to-plant density relationship via understanding final plant establishment and by exploring the influence of weather defining soybean YEs in North America.

Introduction

Soybean [*Glycine max* (L.) Merr] production costs in the United States increased approximately 50% over the past decade, with seed cost representing roughly 37% of the total production costs. In addition, seed price increased approximately 46% due to biotechnology advancements. Therefore, defining the agronomic optimal plant density (AOPD) for soybean is a critical decision for producers to optimize return on investment. The AOPD is defined as the minimum number of plants (in a per-unit-area basis) required to maximize yield. On the other hand, soybean plant density levels above the AOPD increase the risk of lodging and disease development without adding a yield benefit, reinforcing the need for defining the AOPD for this crop.

Soybean seed yield response to plant density has not shown consistent results. Recent studies proposed classifying each study in a yield environment (YE) based on its average productivity. Therefore, a broad database comprised of studies evaluating soybean seed yield response to plant density in varying YEs could assist in providing an unbiased analysis focused at both local and regional levels. Thus, the objective of this study was to determine the AOPD by yield environment (YE) for soybean.

Procedures

Data Description

The data evaluated in the current analysis were obtained from trials performed during nine site-years in different regions of US (Illinois, Indiana, and Iowa) and Canada (Ontario) by DuPont Pioneer researchers during the 2013 and 2014 growing seasons. In each site-year, four different seeding rates were tested in 78 soybean studies and the data were evaluated looking at different yield levels (1,344 data points, Figure 1A and B). The experimental design used was a randomized complete block design (RCBD) with four to six replications (plot size 15 × 10 ft). Seeding rates ranged from 69,000–271,000 seeds/a, reaching final plant densities from 24,000 to 263,000 plants/a. All field studies were planted with 15- and/or 30-in. row spacing, managed with conventional till (chisel plowed or disked), in rainfed environments, and using relative maturities ranging from 2.8 to 4.2.

At physiological maturity seed yield was determined for each plot and adjusted to 130 g/kg moisture content. The final plant density was also determined and later used to calculate the ratio between achieved and target plant density (Figure 1C).

Weather data (precipitation, daily mean temperature, and solar radiation) were obtained for each site-year from the Climate Engine for the US and from the Government of Canada web page (http://climate.weather.gc.ca) for Canadian data. Weather data from each site-year were divided into approximate vegetative (involving from May to July) and reproductive (from August to October) periods. This analysis permitted a characterization of potential scenarios for early- versus late-season weather conditions for soybeans in each site-year in relation to the yield classification developed (YEs) (Figure 1B, D-F).

Statistical Analysis

The average yield of each study was used to classify the dataset in different YEs. This method acknowledges that variations within a study are only due to the treatment (plant density). The kernel density distribution of yield data (average yield for each study) was divided into terciles (<33%, 33–66%, and >66%) (Figure 1B), obtaining 26 studies in each YE. Thus, low (LYE, <59.6 bu/a), medium (MYE, 59.6-64.1 bu/a), and high (HYE, >64.1 bu/a) YEs were defined.

Linear regression with plateau was implemented to quantify the soybean yield response to plant density. We used hierarchical Bayesian models, allowing us to calculate the most probable AOPD at each YE. Cumulative probability of AOPD and AOPD range to achieve the plateau for the seed yield-to-plant density relationship were calculated in each YE. In addition, the relationship between the achieved and the target plant density (seeding rate) was compared among YEs using Bayes inference. Lastly, weather data (precipitation, daily mean temperatures, and solar radiation) were compared among YEs for vegetative and reproductive periods using Bayes inference.

Results

For the pooled data, a seed yield response to plant density was not observed (Figure 1A). However, when the studies were classified by YE, significant yield responses to plant density occurred in the different YEs (Figure 2). For the LYE the most probable AOPD

was 127,000 plants/a (Figure 2A), decreasing to 96,000 and 97,000 plants/a in the MYE (Figure 2B) and HYE (Figure 2C), respectively. This is a 24% decrease in AOPD from LYE to MYE and HYE.

Low plant densities in the LYE highly penalized seed yield. For example, at a plant density of 80 thousand plants/a in the LYE, seed yield decreased by 12% relative to the maximum yield (plateau) obtained for this YE (64.1 bu/a). Meanwhile, at the same abovementioned plant density level, seed yield only decreased by 5% for the MYE and by 4% for the HYE relative to their respective plateau yield levels for these YEs (plateau at 67 and 70 bu/a, respectively).

It was hypothesized that low plant establishment and survival in the LYE could be one of the potential factors affecting the differential yield response to seeding rate between YEs. However, the current work portrayed greater plant establishment (relative to the target seeding rate) for the LYE, with the plant density-to-target seeding rate ratio following the order from high to low: LYE>MYE>HYE (Figure 1C). Therefore, this study refutes the hypothesis that a greater seeding rate in the LYE is related to a lower plant survival rate relative to the HYE.

The exceedance probability of the AOPD at each YE (Figure 3A) showed a greater difference for the LYE compared with both MYE and HYE. For example, the maximum probability for reaching the AOPD with less than 100 thousand plants/a was 58% for both the MYE and HYE but was reduced to 17% for the LYE. Additionally, the probability analysis showed that the 50% interquartile range (between 25 and 75 quartiles) for the AOPD ranged between 109,000 and 144,000 plants/a for the LYE, 77,000 and 114,000 plants/a for the MYE, and 76,000 and 117,000 plants/a for the HYE (Figure 3B).

A simple analysis of the average weather conditions for the three YEs (Figure 1D-F) showed that the cumulative precipitation during the late-season soybean growth period (reproductive) was 39% lower in LYE compared with MYE and HYE (Figure 1D). Previous studies reported that drought stress during early reproductive growth stages reduced per-plant leaf area and number and length of branches, and consequently seed yield was also reduced. Moreover, average daily mean temperature for the reproductive period was 8% higher in LYE compared to MYE and HYE (Figure 1E), which could exacerbate the effect generated by the lower precipitation in the LYE.

In summary, environmental conditions (e.g., water availability, temperature, and radiation), as well as other factors such as fertility or pests, could affect soybean leaf area and branching, thus reducing crop growth rate and negatively affecting soybean′s reproductive ability. Therefore, variation in environmental conditions producing different yield potential (and YEs) affects the final AOPD for soybeans.

Conclusions

Results of our study showed that AOPD depends on the YE so plant density could be reduced by 24% in both MYE and HYE relative to the LYE. This is valuable information for site-specific management strategies, such as variable seeding rate. Thus, within a field, yield variation could be better related to the adjustment of seeding rate for soybeans, improving both the productivity and net return for farmers. Adjusting

seeding rates reduces risks of yield losses due to suboptimal densities in the LYE, while limiting higher seed costs due to supra-optimal densities, especially for MYE and HYE.

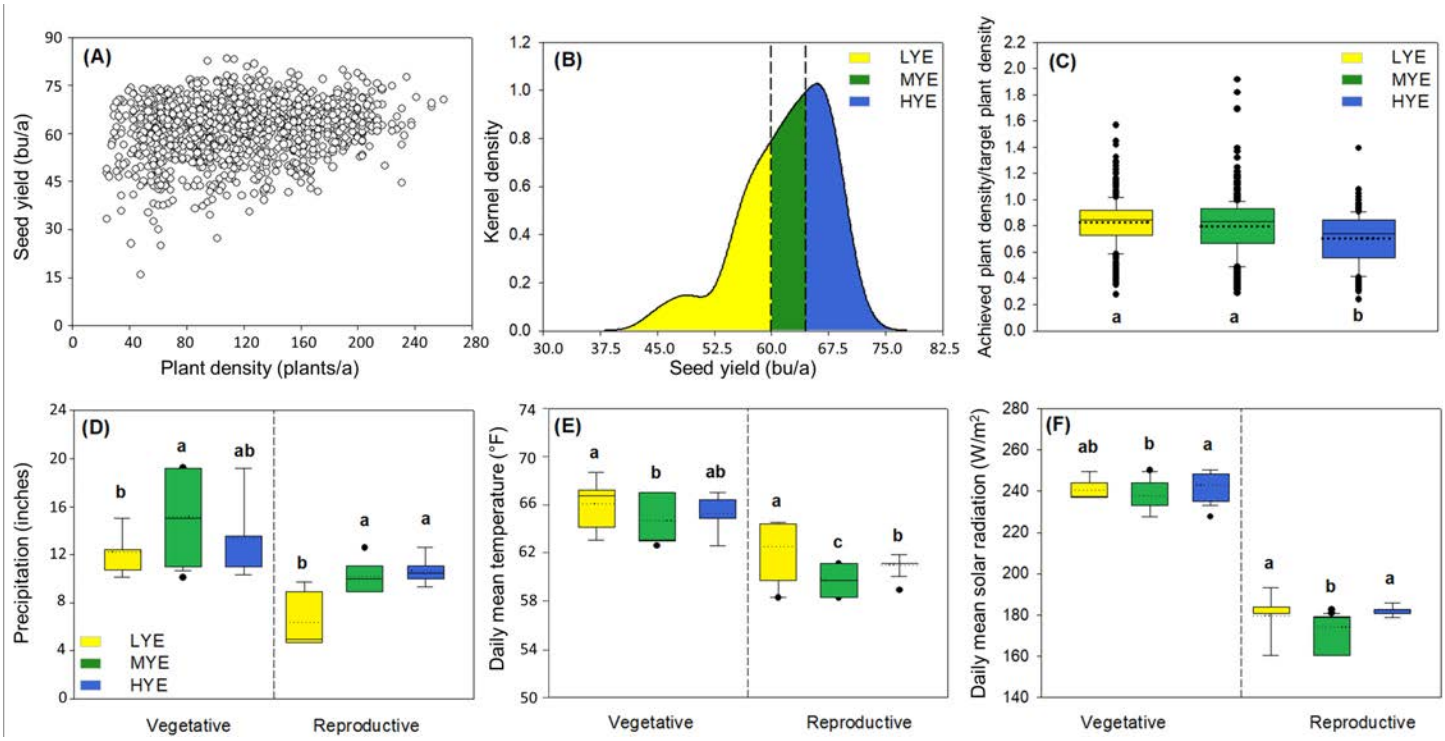

Figure 1. Relationship between seed yield and plant density (A); density distribution of average seed yield for each study and yield environments classified by terciles (low yield environment, LYE, <59.6 bu/a; medium yield environment, MYE, 59.6-64.1 bu/a; and high yield environment, HYE, >64.1 bu/a) (B); box plots portraying the ratio between the achieved plant density and the target plant density (C); average accumulated precipitation (D); daily mean temperature (E); and daily mean solar radiation (F) for vegetative (May to July) and reproductive (August to October) periods for LYE, MYE, and HYE. The box plots portray the 5th (lower whisker), 25th (bottom edge of the box), 75th (top edge of the box), and 95th (upper whisker) percentiles. The solid line within the box represents the median, the dotted line represents the mean, and the circles referred to outliers. Different letters in the same growing period and panel indicate differences between YEs using Bayes inference.

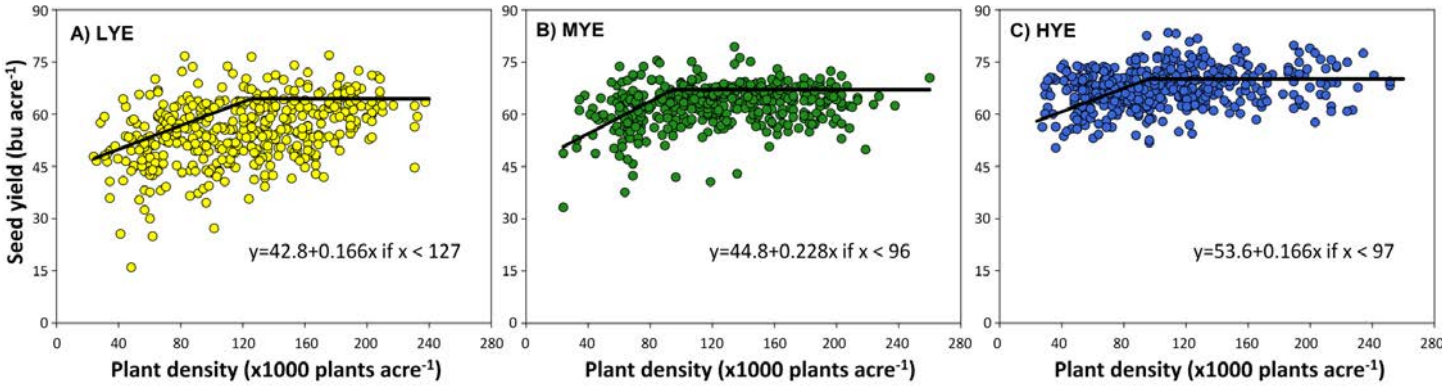

Figure 2. Relationship between seed yield and plant density for low (LYE, <59.6 bu/a; (A), medium (MYE, 59.6-64.1 bu/a; (B), and high yield environments (HYE, >64.1 bu/a; (C). Models were fitted using hierarchical Bayesian models.

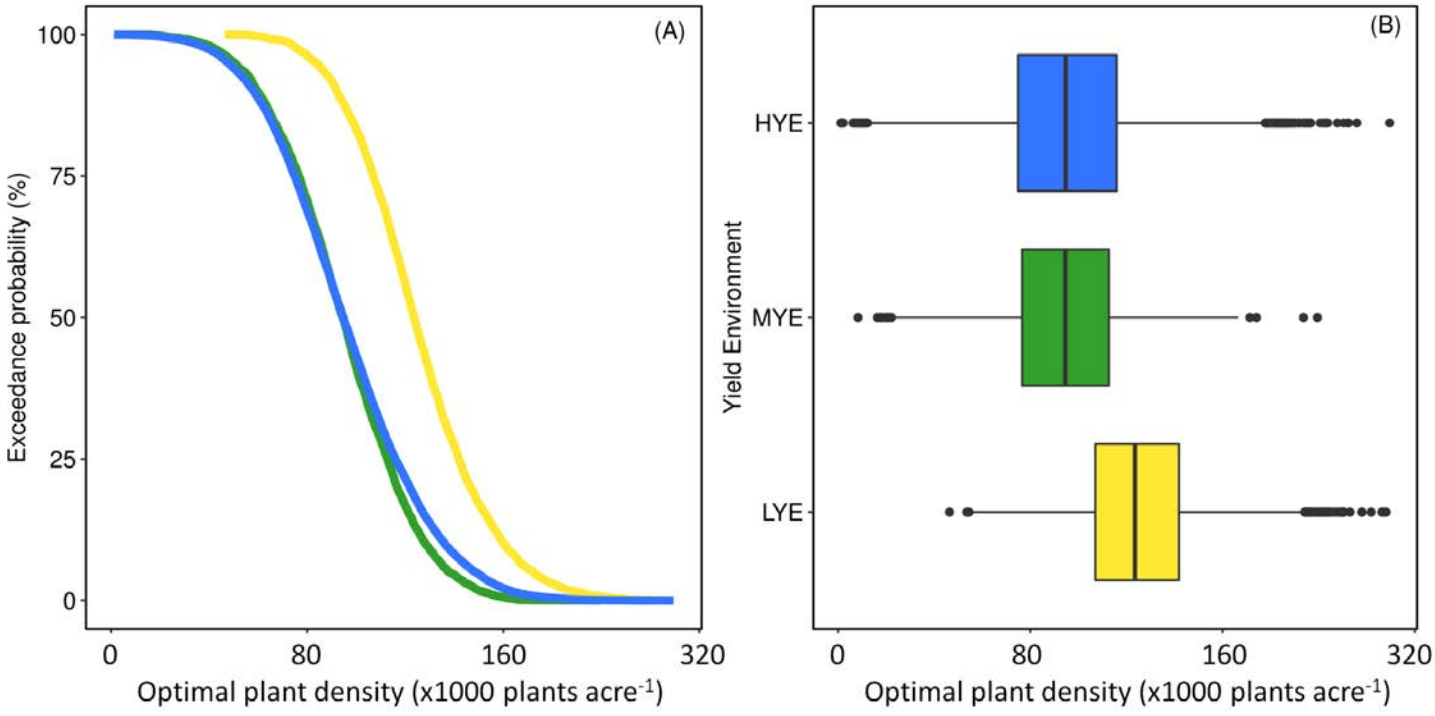

Figure 3. Exceedance probabilities (%) of agronomic optimal plant density (AOPD, plants/a) (A); and AOPD range to achieve the plateau-level for the seed yield-to-plant density relationship for the low (LYE, in yellow), medium (MYE, in green), and high yield environment (HYE, in blue) (B). For panel B, box plots portray the 25th (bottom edge of the box) and the 75th (top edge of the box). The solid line within the box represents the median and the circles referred to outliers.

Management Strategies for Double-Crop Soybean Planted After Wheat

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

Summary

Double-crop (DC) soybeans (*Glycine max* L.) are gaining popularity as an alternative system to intensify productivity without expanding the farming area and can potentially increase net return. However, the DC soybean system faces many challenges such as late planting, which decreases yield potential. A study was conducted in four site-years in Ashland Bottoms, KS, during the 2016 and 2017 growing seasons. In both years, the soybean variety planted was Asgrow 4232 (MG 4.2). The soybean was planted right after two different wheat harvest timings (Study 1, early-wheat harvest 18–20% moisture; and Study 2, conventional-harvest 13–14% moisture). Seven treatments were evaluated in each of the soybean planting dates: 1) common practice; 2) no seed treatment (without seed fungicide + insecticide treatment); 3) non-stay green (without foliar fungicide + insecticide application); 4) high seeding rate (180,000 seeds/a); 5) wide rows (30-inch row-spacing); 6) nitrogen (N) fixation (without late-fertilizer N application); and 7) kitchen sink (includes all management practices). There was adequate precipitation distribution in 2016, which helped to nurture the soybean plants even when planting later in the season. In 2017, precipitation was not well distributed, and the early planting date was affected by low precipitation during early season. Overall, the high plant population and the kitchen sink treatments presented maximum yields, while the common practice scenario showed the lowest yields.

Introduction

Sustainable intensification of agricultural systems should be better studied and practiced, with the objective of increasing food production to meet the global population's needs. Although challenging, the goal of increasing soybean yields is possible with new and innovative technologies and cropping systems, improved production methods, and effective educational/technology transfer programs. Double-cropping (DC) soybean after small grains addresses world food demand by growing two crops in one year, and simultaneously addresses environmental concerns by growing a harvestable "cover crop" and minimizing the cost of summer weed control where there is no direct return on investment. Also, with declining commodity prices of wheat, producers are seeking other avenues to increase the productivity of their land and increase net return from their farms. Soybean can be managed in no-till (NT) systems, reducing costs due to less machinery, fuel, and labor expenses after the wheat harvest. Furthermore, NT maintains wheat residue on the soil surface, which prevents excessive runoff of nutrients and other chemicals and enhances good soil properties. Double-crop soybean area increased by 28% from 1988 to 2012 in the United States (Seifert and Lobell, 2015). The total DC area was projected to be 4.5 million acres representing 5% of the soybean planted area in the US (USDA – NASS, 2018). However, the yield gap between full-season and double-crop soybeans is large, with the risk of crop failure due to heat and drought during the late summer. To improve yields for DC soybean some management practices should be further investigated:

- Fertilizer application, promoting stronger plant growth and earlier canopy closure to overcome stresses due to a late planting season;
- Ideal row spacing and seeding rate, allowing more plants in the same unit area, potentially suppressing weed establishment and increasing yield;
- Integrated pest management, the risk of late summer soil and foliar disease and insects could decrease yield; and
- Earlier planting time to lengthen growing season and allow more time for soybean plants to set pods and seed before the first killing frost.

The objective of this study was to improve yields and profitability of soybeans grown in double crop systems without sacrificing wheat yield or profitability, and identify the main yield-limiting factors affecting crop productivity.

Procedures

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

The studies were arranged in a randomized complete block design with four replications. Plot size was 10-ft wide × 60-ft long. The soybean variety utilized was Asgrow 4232, maturity group 4.2. Soybean was planted immediately after wheat harvest of the cultivar WB Cedar. In each year, there were two experiments with two different planting dates (based on early and late wheat harvest). Early planting dates were June 10, 2016, and June 13, 2017; and late planting dates were June 23, 2016, and June 22, 2017. Seven treatments were evaluated: 1) common practice; 2) no seed treatment; 3) non-stay green; 4) high plant population (180,000 seeds/a); 5) wide rows (30 in.); 6) N fixation (without late-season fertilizer N); and 7) kitchen sink. The specific management practice included for each treatment is listed in Table 2.

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

Results

Yield and Biomass

The year of 2016 presented adequate precipitation distribution and quantity. Therefore, there were no significant effects when comparing yield responses to management treatments (Figure 1). In 2017, precipitation distribution was not ideal for early planting. There was no rain between early and late planting, and for that reason, the experiment that was planted later presented an advantage in relation to uniform emergence.

For all the experiments, except for the early planting in 2017, the high plant population and kitchen sink treatments showed a trend of greater yields relative to the other treatments evaluated in this study.

Biomass accumulation was greater in 2016 for both planting dates when compared to 2017 (Figure 2). However, there were no significant effects for difference among planting dates or treatments for biomass accumulation.

Conclusions

Despite early planting being beneficial when planting DC soybeans, in a year with not very well distributed rain events, it is critical to observe previous soil moisture and precipitation forecast to guarantee good plant emergence and establishment of seedlings.

When planting DC soybean, it is strongly recommended to increase seed quantity. In adverse conditions, greater seed number will help to maintain plant population at a recommended level.

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Seifert, C. A., & Lobell, D. B. (2015). Response of double cropping suitability to climate change in the United States. *Environmental Research Letters*, *10*(2), 024002.

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

Soil parameters	2016	2017
pH	5.9	6.1
Mehlich P (ppm)	57.7	62.5
CEC (meq/100 g)	7	9.4
Organic matter (%)	1.1	1.5
Potassium (ppm)	223.0	206.3
Calcium (ppm)	1028.8	1061.1
Magnesium (ppm)	105.8	118.3

CEC = cation exchange capacity.

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

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

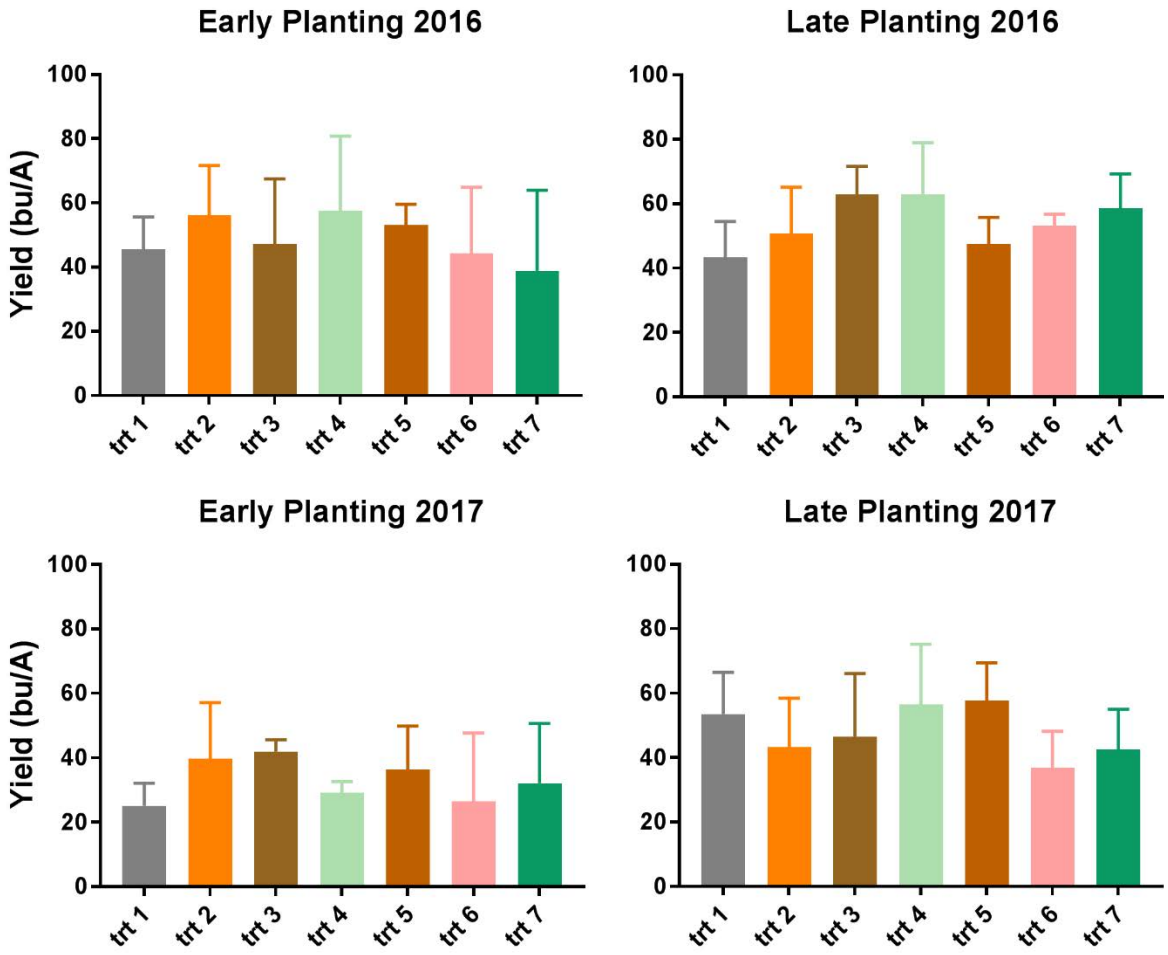

Figure 1. Grain yield for double-crop soybean, when planted early and late at Ashland Bottoms, KS, for 2016 and 2017. See Table 1 for list of treatments.

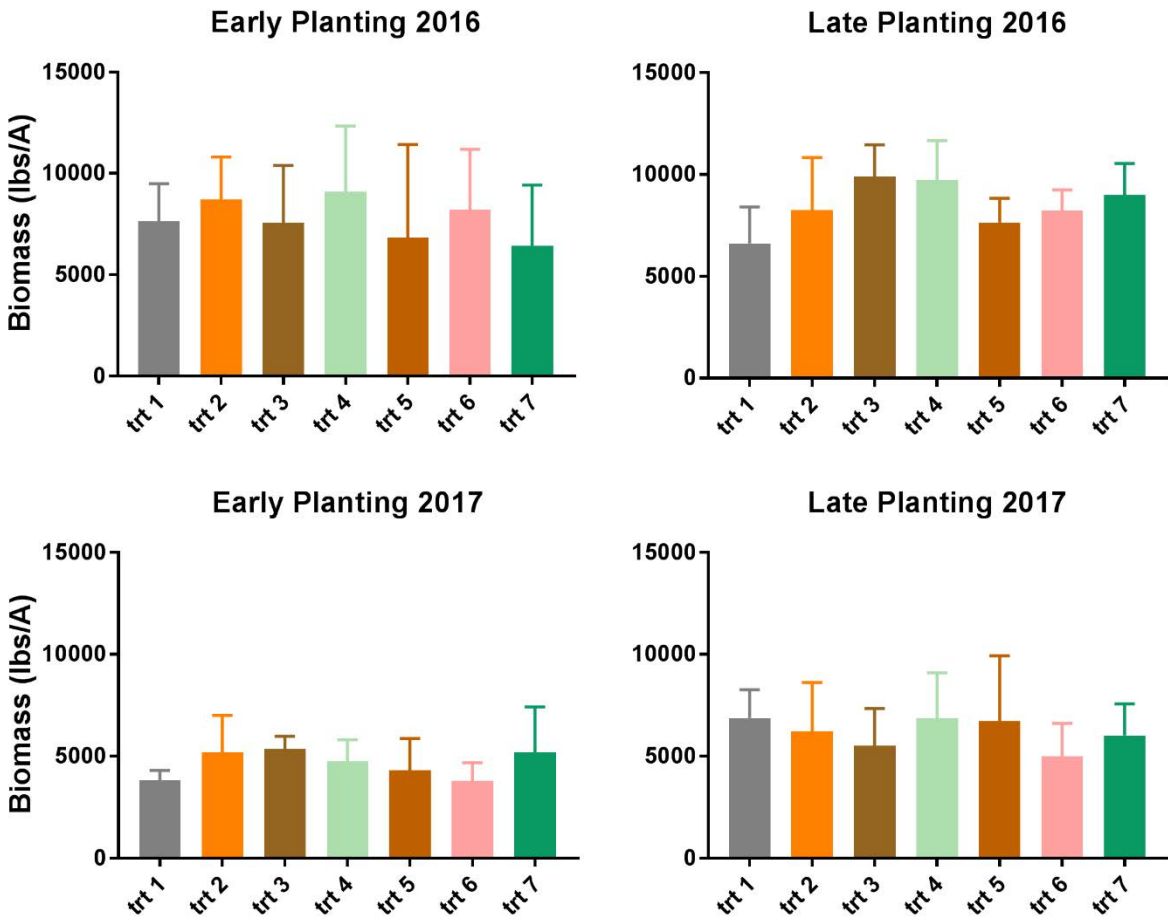

Figure 2. Dry biomass at growth stage R7 (maturity) for double-crop soybean, when planted early and late at Ashland Bottoms, KS, for 2016 and 2017. See Table 1 for list of treatments.

Historical Soybean Study: Grain Filling × Nitrogen Fixation

S. Tamagno and I.A. Ciampitti

Summary

Genetic gain is characterized by comparing the performance of genotypes from a different year of release. Historic studies are useful to understand changes in yield-related traits that also contribute to yield potential. This study aims to quantify yield improvement for soybean through a set of seven genotypes with different years of release, and their respective numerical components, with a focus on final seed weight generation under two different nitrogen (N) conditions. Changes in biological N fixation (BNF) were quantified during the seed-filling period (SFP). Non-linear models were fit to the data to characterize seed weight and BNF changes throughout the SFP. Genetic gain led to an overall yield increase of 0.49 bu/a/year mainly explained by increases in the seed number rather than seed weight. Nitrogen application increased yield equally across genotypes ($P < 0.01$), and final seed weight in all genotypes tested. Biological nitrogen fixation activity was reduced by 44% at the onset of the SFP, however, no N deficiencies were observed.

Introduction

Final seed yield is defined by the number of seeds and their individual weights. Historically, increases in yield have been explained by increases in the seed number for many crops, including maize (Duvick et al., 2004), wheat (Loss and Siddique, 1994), and soybean (de Felipe et al., 2016). However, less attention has been paid to responses under differential nitrogen (N) conditions when historical genotypes are compared. Seed production in soybean requires larger amounts of N compared to cereal crops because of its chemical composition, however, soybean response to N fertilization has not always increased seed yield (Mourtzinis et al., 2018). Moreover, N fertilization reduces the biological N fixation (BNF) activity by inhibiting the process. This study aimed to quantify yield improvement for soybean through a set of seven genotypes with different years of release and their respective numerical components, with a focus on final seed weight generation under two different nitrogen (N) conditions. We also quantified the effect of N fertilization on the BNF activity during the seed filling period.

Procedures

A field study was conducted at the Kansas River Valley research station (Rossville, KS) during the 2016 and 2017 growing season. Plots were arranged in complete randomized blocks with three replicates in a split-plot design with seven genotypes (subplots) and two fertilizer N rates (main plots). Seven soybean varieties with different years of release were tested: P3981 (1980), 9391 (1987), 9392 (1991), 93B82 (1997), 93B67 (2001), 93M90 (2003), and P35T58R (2013).

An unfertilized condition without N applied was used as a control, and a high N condition was used with 600 lb/a equally split at planting, beginning of flowering (R1),

and R3 growth stages. The high N condition provided a non-limiting N scenario, and induced variability in the BNF by partially inhibiting the process. Nitrogen treatments were side-dressed using liquid urea ammonium nitrate (UAN; N-P-K, 28-0-0), all applied via a hand-held backpack sprayer.

The study was planted on May 12 and May 18 for the 2016 and 2017 growing seasons, respectively. Both years were planted in corn-soybean rotations. The plot size was 10-ft wide × 50-ft long with rows spaced at 30 in. For all treatments, seeds were inoculated and plots were maintained weed- and pest-free during the growing season.

At harvest, the two center rows in each plot were harvested with a plot combine and 2.2 lb of seed sample was collected in each plot. Individual seed weight was measured from a 1000 seed subsample. Then, seed number was estimated from the seed weight and seed yield information. Seed yield is expressed as dry matter basis.

Seeds were sampled in all plots at R5 weekly until harvest maturity in order to characterize the seed-filling curve and estimate final seed weight. Samples were taken from nodes in the upper third of canopy height and nodes in the lower third to adjust for differences in seed development. After sampling, pods were immediately placed in plastic hermetic bags for transport to the lab. Seeds were excised from pods in a humid box to avoid water loss. Seed dry weight (mg/seed) was measured after drying the samples at 149°F until constant weight was reached. Maximum and minimum temperatures were used to calculate the thermal units as TT = ((Max + Min)/2) – 8, using 8°C as the base temperature.

Final seed weight was estimated adjusting a logistic growth curve nonlinear model:

$$SW(mg/seed) = Asym - Drop \times exp[-exp(lrc) \times TT^{pwr}] \qquad \text{Equation 1}$$

where the parameters describe the maximum weight (*Asym*), the difference between the minimum and maximum weights (*Drop*), the natural log of a rate constant (*lrc*), and the power to which thermal time (TT) during the SFP is raised (*pwr*).

In each sampling time, plants were removed to use the stem fraction to measure ureides and nitrates concentration using a hot water extraction method, (Hungria and Araujo, 1994). Both concentrations were used to calculate the relative abundance of ureides (%RAU) as a parameter to estimate BNF throughout the SFP. The percentage of BNF was quantified using established calibrations from Unkovich et al. (2008). A quadratic function was fitted to characterize the dynamics during the SFP:

$$BNF(\%) = a + b \times TT + c \times TT^2 \qquad \text{Equation 2}$$

where the parameter represents the BNF percentage in the beginning of the SFP and *b* and *c* are parameters of the function.

The effect of genotype, N condition, and their interaction on the seed yield and seed number was tested with a mixed model. Genotype and N condition were considered fixed effects, while blocks and years were considered random. Nitrogen condition factor

was nested in blocks, and blocks were nested in the year factor. To test if there was a genetic gain over seed yield and seed number, release year was used as a quantitative variable in the model.

A non-linear mixed model was adjusted to fit the data for seed weight and BNF. Different models were compared including different fixed factors and their interactions. Thus, data were fitted first to a full model including all fixed effects and their interactions, a model for main effects, a model considering only the variety effect, and a model with the N condition effect. The best model was selected using the Akaike information criterion (AIC). All statistical analyses were performed using R software (R Core Team, 2017). Nonlinear mixed models were fitted using the "nlme" function from the nlme package, while linear mixed models were fitted using the "lme" function from the lme4 package.

Results

Genetic Gain in Seed Yield and Seed Number Across Different Nitrogen Conditions

The analysis for seed yield showed no significant ($P > 0.05$) interaction of the N conditions with the varieties tested in this experiment (Table 1). However, the effect of N application showed a positive increase in seed yield in all genotypes showing constant difference ($P < 0.01$) among genotypes with a different year of release (Figure 1A). Genetic gain in seed yield showed an improvement of 0.49 bu/a/year of seed yield increase for both N conditions.

For the seed number trait, the interaction factor was not significant, nor was the N condition (Table 1). However, seed number increased across years of release and can potentially explain yield increases as depicted in Figure 1B. Moreover, when the overall data set for seed yield and seed number is regressed (Figure 1C) a significant relationship can be observed. However, graphical distribution of the data depicts, in many cases, a similar number of seeds for different treatments that reach different final seed yield. This dispersion in the data can be partially explained by changes in the other numerical component of the final seed yield, such as the seed weight.

Final Seed Weight Responses to Nitrogen Conditions

Grain filling dynamics were found significantly different between genotypes and N conditions. The best model to report the accumulation of biomass in the developing seeds was the one including only the main effects (i.e. variety and treatment). Thus, the interaction was not significant, meaning that changes in seed weight were constant among varieties. For all genotypes in this study, the high N condition resulted in a higher seed weight compared to the control condition with large genotypic variability for this trait (Table 2).

Even though large variability was observed for the dynamics in the SFP (Figure 1), the final seed weight did not show any relationship with the year of release ($P > 0.05$). Hence, for the set of genotypes used in this study, yield increases can be fully attributed to increases in seed set per area. While seed weight showed differences among genotypes and treatment, its contribution to the overall yield was lower compared with the seed number.

Genetic Variability and Nitrogen Responses to BNF Dynamics during the SFP
Comparisons between models for BNF dynamics during the SFP showed the best fit for the model included only the N condition factor. There were no interactions or differences between genotypes for BNF dynamics.

Percentage of BNF at the beginning of the SFP was significantly higher in the control compared with the high N condition (Figure 3). The magnitude of this response can be attributed to the effect of the nitrates in the soil that originated from fertilizer applications, which inhibited the activity in the nodules.

Given the parameters from Equation 2, the magnitude of the reduction was significant ($P < 0.05$) and represented a 44% reduction in the percentage of BNF at the beginning of the SFP from the control condition (Table 1). Even though BNF activity is the main source of N during the SFP, the amount of the nutrient provided by the fertilizer application was enough to maintain photosynthesis levels to still supply photoassimilates to the seeds and increase their respective seed weights.

Conclusions

In this study, genetic gain represented an overall yield increase of 0.49 bu/a/year and it was mainly explained by increases in the seed number rather than seed weight. The effect of N application did not show a differential response for the release year, moreover, N application increased yield equally across genotypes.

Seed weight was the main yield component affected by N treatments. Dynamics in seed biomass accumulation were different across genotypes and treatments. However, increases in seed weight remained constant given the lack of significant interaction effect.

Biological nitrogen fixation activity was affected by the fertilizer N application, showing an overall reduction close to 44% at the onset of the SFP. Despite the significant inhibition of the process, N sourcing from the fertilizer application was still enough to increase seed yield and seed weight.

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Table 1. Analysis of variance and mean values of seed yield and seed number for each genotype and nitrogen (N) condition

	Seed yield	Seed number
	bu/a	seed/ft^2
9391	42.7 *bc*	187 *bc*
9392	41.0 *bc*	180 *bc*
93B67	42.6 *bc*	182 *bc*
93B82	46.6 *b*	202 *ab*
93M90	45.8 *b*	197 *b*
P35T58R	55.8 *a*	241 *a*
P3981	36.3 *c*	151 *c*
Control	40.9 *B*	179
High N	47.8 *A*	202
Variety	***	***
Treatment	**	ns
Variety × Treatment	ns	ns

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability level, respectively.
NS = not significant.
Means followed by the same letter are not significantly different based on Tukey's HSD test ($P < 0.05$).

Table 2. Final seed weight and their standard error for each combination of variety and nitrogen (N) condition

Treatment	Variety	Seed weight
		mg/seed
Control	9391	126 ± 3.26 *hi*
	9392	122 ± 3.15 *i*
	93B67	135 ± 3.52 *fgh*
	93B82	143 ± 3.22 *cdef*
	93M90	139 ± 3.38 *defg*
	P35T58R	129 ± 3.48 *ghi*
	P3981	132 ± 3.36 *gh*
High N	9391	146 ± 3.35 *cdef*
	9392	143 ± 3.21 *efg*
	93B67	155 ± 3.64 *abc*
	93B82	164 ± 3.28 *a*
	93M90	160 ± 3.47 *ab*
	P35T58R	150 ± 3.60 *bcde*
	P3981	152 ± 3.46 *bcd*

Means followed by the same letter are not significantly different based on Tukey's HSD test ($P < 0.05$).

Table 3. Values for parameters (Equation 2) and their standard errors from the curves in Figure 3

Parameter	Treatment	Value
a	High nitrogen	52.2 ± 5.75*a*
	Control	92.6 ± 5.74*b*
b	High nitrogen	0.03986 ± 0.0157*a*
	Control	-0.00696 ± 0.0156*b*
c	High nitrogen	-0.0000267 ± 0.000011
	Control	-0.0000423 ± 0.000011

Means followed by the same letter are not significantly different based on Tukey's HSD test ($P < 0.05$).

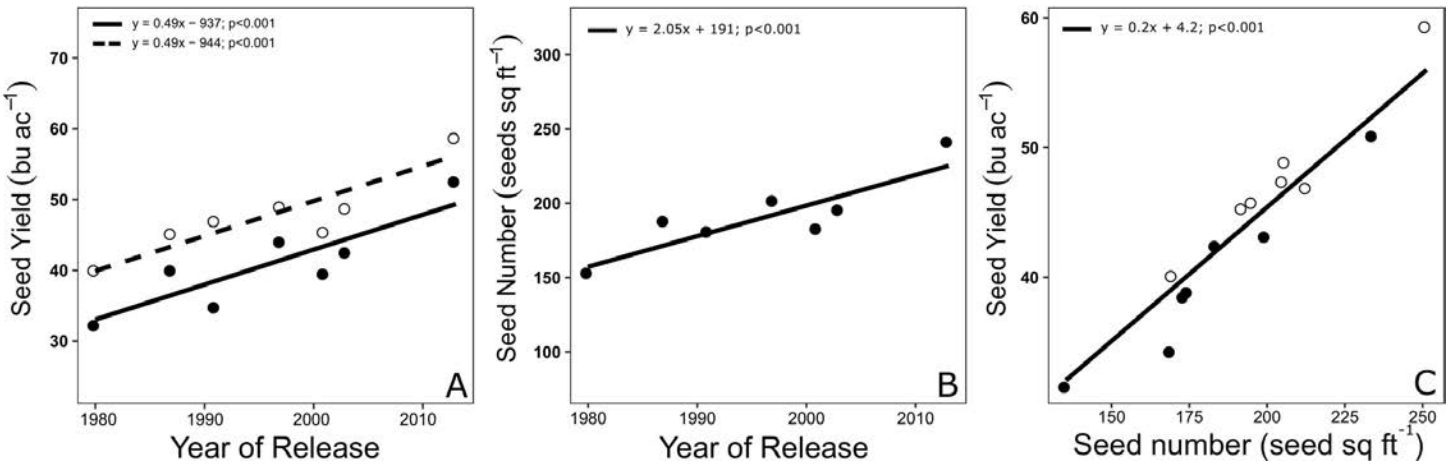

Figure 1. Relationship of the year of release with seed yield (A) and seed number (B) and the relationship between seed number and seed yield (C). Dashed curve and open circles represent the high nitrogen condition and full curves and circles represent the control condition. Each data point is the average of two years of experiment.

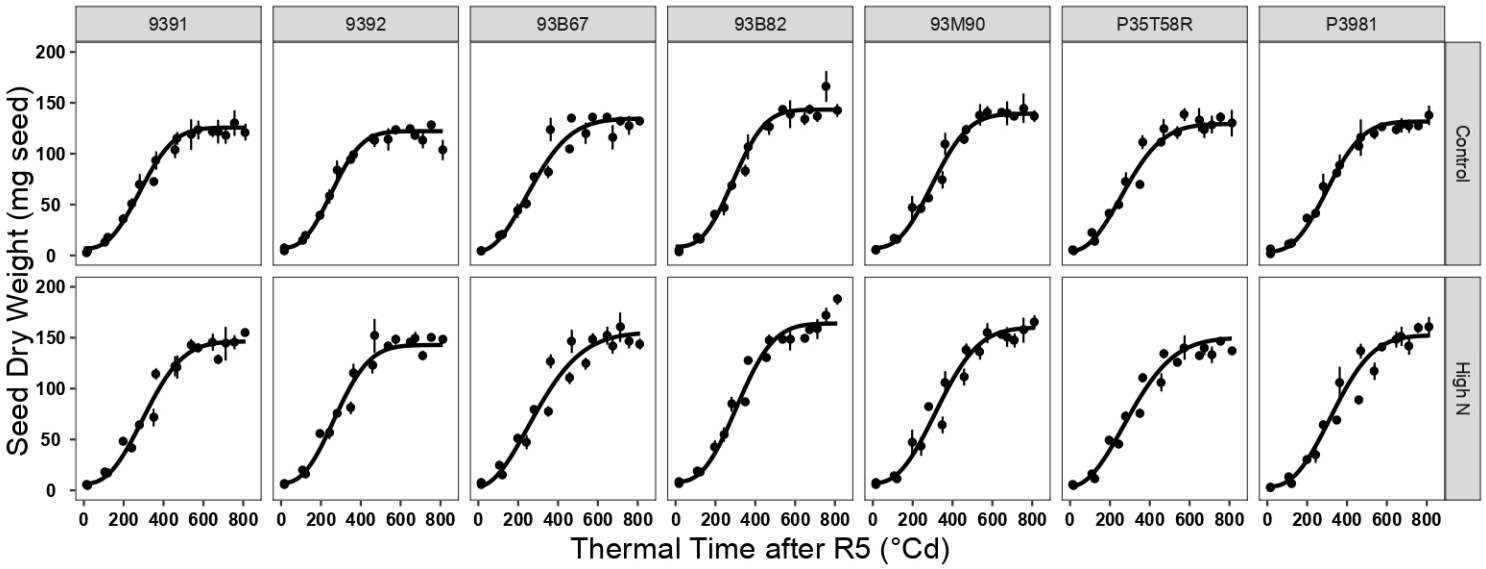

Figure 2. Changes in seed weight after R5 stage for all genotypes in the control condition and the high nitrogen condition. Vertical bars represent standard error for each data point.

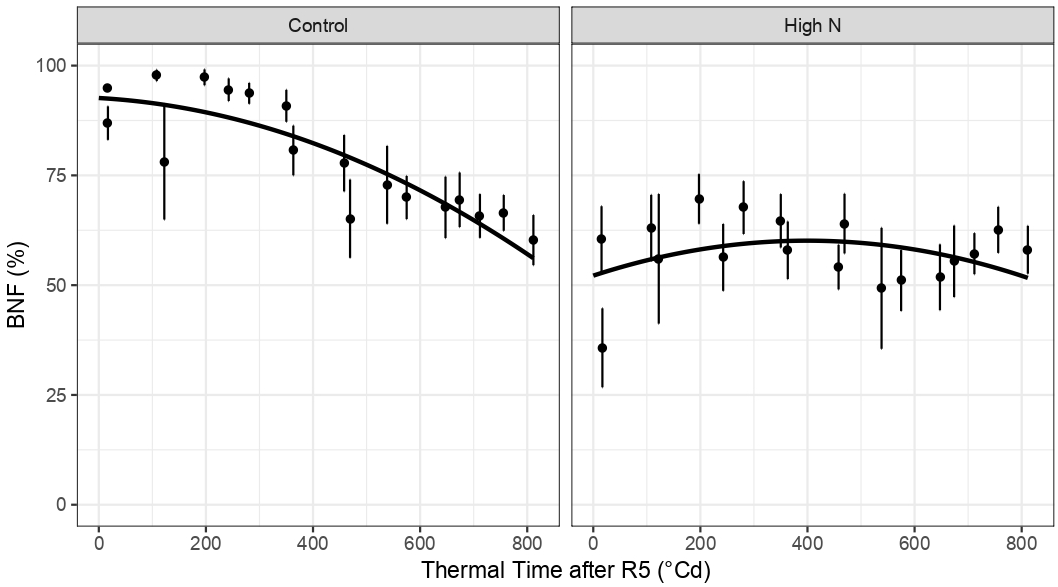

Figure 3. Changes in biological N fixation (BNF) percentage during the seed-filling period (SFP) for both nitrogen (N) conditions. Each data point is the average for each year and the vertical lines represent their standard errors.

Nutritional Quality of Soybean Seeds Relative to Canopy Portion

L.H. Moro Rosso, W.D. Carciochi, and I.A. Ciampitti

Summary

Soybean [*Glycine max* (L.) Merr.] seed quality (nutritional composition) is affected by genetic × environment × management (G × E × M) interactions. Even at the plant level, where differences might not be largely apparent, seed quality is known to change. This study aims to 1) compare seed yield and nutritional quality within the vertical profile of soybean plant canopy, and 2) explore potential interactions for different genotypes. A field experiment was conducted in Manhattan, KS, during the 2018 growing season. Treatments were composed by six genotypes and evaluated at four canopy portions: upper, middle, and lower sections of the main stem and branches. The study was set in a complete randomized block design with three replications. Seed yield and seed size were determined at physiological maturity, as well as seed quality (e.g., protein and oil concentrations). For seed yield, the contribution of the branches was directly affected by the genotype, while the other portions presented a similar yield across genotypes. Seed size was greater in the upper and middle portions of the plant canopy, and seed size of the branches was always comparable to the average of the main stem sections. Overall, oil concentration was lower in branches and did not differ along the sections of the main stem. On the other hand, the protein concentration was greater in the upper portion of the plant. Further research should explore seed quality responsiveness to the timing of pod-setting and seed-filling within the soybean canopy.

Introduction

Consumers, industry, and farmers are facing concerns about the nutritional quality of soybean seeds due to soybean's worldwide importance as a food crop. Consequently, plant breeders have been trying to enhance the composition of soybean meal while maintaining a high yield potential. Crop physiology studies might help to maximize genetic improvements and provide a better understanding of the plant allocation of nutritional components to the seeds. This study aims to 1) compare seed yield and nutritional quality within the vertical profile of soybean plant canopy, and 2) explore potential interactions for different genotypes.

Procedures

Site Characteristics

The experimental field was located at the Ashland Bottoms Research Farm, Ashland Bottoms, KS (39.14° North, 96.64° West). The area was under rainfed conditions during the 2018 growing season. Soil parameters were collected for initial characterization. The area presented a pH in water of 7.6; a texture of 18% clay, 54% silt, and 28% sand; 90 ppm of phosphorus (Mehlich); and 2.1% of soil organic matter (SOM), considering a soil layer of 6-inch depth.

Soybean was sown on April 27 and harvested on October 10, 2018. The harvesting date was defined based on the overall field onset of the R8 stage (full maturity) (Fehr et

al., 1971). The average plant density was 83,000 plants per acre with a row spacing of 30 inches. Additional nutrients were not applied, and the crop was kept free of weeds, diseases, and insects.

Weather data were obtained from the closest land station (Ashland Bottoms) (Kansas Mesonet, 2017). The average temperature during the growing season was 75°F, with maximum and minimum daily averages of 85°F and 63°F, respectively. Cumulative precipitation during the growing season was 24.9 inches. The average relative humidity was 70%.

Experimental Design

The experiment was set in a complete randomized block design with three replications. Treatments were composed of six soybean genotypes (Table 1) and each plot had six rows (15-feet width) with 50-ft length (Figure 1a). At harvest, plant samples from each plot were partitioned into upper, middle, and lower sections of the main stem, apart from the branches (collected all together) (Figure 1c). Overall, portions of the main stem had five nodes each.

Measurements

The measurements were divided into groups by yield and nutritional quality. The first group accounts for seed yield (bu/a) at 13% moisture, and seed size (lb/1000 seeds). The second group accounts for protein and oil concentrations (%) on a wet basis (13% moisture). Seeds were collected by manually harvesting three rows, excluding the borders, each with 5-ft length (15 linear feet) (Figure 1b). Quality data were obtained by the near infrared (NIR) method (Pazdernik et al., 1997).

Statistical Analysis

Statistical analyses were done in the following steps: 1) parameters of the entire plant were used to characterize the genotypes (single fixed factor); and 2) parameters considering canopy portion × genotype were tested as fixed factors. In both cases, linear mixed models were adjusted, accounting for block as a random component. The analysis of variance (ANOVA) assumptions were tested, and the Tukey test was adopted for means comparison when significant responses were found ($P < 0.05$). Analyses and graphs were processed with the R software (R Core Team, 2018).

Results

Before looking at the distribution of seed yield within the canopy portions and the behavior of nutritional quality parameters, a comparison between genotypes was conducted. Table 2 presents the means and their comparisons for seed yield, seed size, protein and oil concentrations. All variables are accounting for the entire canopy and were statistically affected by the genotype.

When considering the canopy portion, interactions were found for seed yield (Figure 2), seed size (Figure 3), and oil (Figure 4), while protein was only affected by single effects (Figure 5). Differential seed yield and nutritional quality throughout the plant canopy might be related to nutrient remobilization, branching, and growth rate, as well as the pod-setting and seed-filling variability. According to Huber et al. (2016), these differences in seed composition throughout the canopy can be studied to improve soybean quality by harvesting specific portions separately.

Seed yield from the three sections of the main stem was similar across genotypes, but the contribution from the branches was inconsistent. This could be explained by the uniform division of the main stem sections, while branching is directly related to the genotype and plant density.

Overall, seed size was greater in the middle and upper portions, while seed size in branches was comparable to the average of the entire main stem. The limited number of main stem sections probably hid a smaller seed size in upper nodes of the main stem.

The oil concentration pattern throughout the canopy was affected by the evaluated genotype. The tested genotypes might have variability coming from the plant architecture and duration of seed filling, even within the plant canopy. This variability could expose the seeds to diverse environmental conditions, which will have strong impacts on the oil concentration.

For protein concentration, a diminishing pattern was documented from the upper to the lower section of the plant, as reported by Collins and Cartter (1956). However, there are few recent publications exploring environmental and physiological factors to explain this trend. In addition, the allocation of amino acids should also be investigated in forthcoming studies.

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Table 1. Soybean genotype tested for yield and nutritional quality distribution within the plant canopy portions. All provided by DuPont Pioneer (Corteva Agriscience, Johnston, IA)

Genotype	Variety	Year of release	Maturity group
A	P39T67R	2014	3.9
B	P35T58R	2013	3.5
C	94Y23	2013	4.2
D	93M90	2003	3.9
E	P31T11R	2016	3.1
F	P34T43R2	2014	3.4

Table 2. Seed yield, seed size, and nutritional quality parameters for the entire plant

Genotype	Variety	Seed yield	Seed size	Protein	Oil
		------ bu/a ------	- lb/1000 seeds -	---------- % (w/w)† ----------	
A	P39T67R	82.7 a*	0.338 b	31.46 ab	20.03 bc
B	P35T58R	78.3 ab	0.327 b	29.80 b	21.08 ab
C	94Y23	70.0 abc	0.372 a	32.52 a	19.62 c
D	93M90	64.8 bc	0.342 b	33.43 a	19.48 c
E	P31T11R	61.4 c	0.344 b	31.41 ab	21.98 a
F	P34T43R2	57.5 c	0.342 b	32.54 a	19.58 c

*Means followed by the same letter did not differ by the Tukey test at 5% significance.
†Concentration of the seed components on a wet basis (13% moisture).

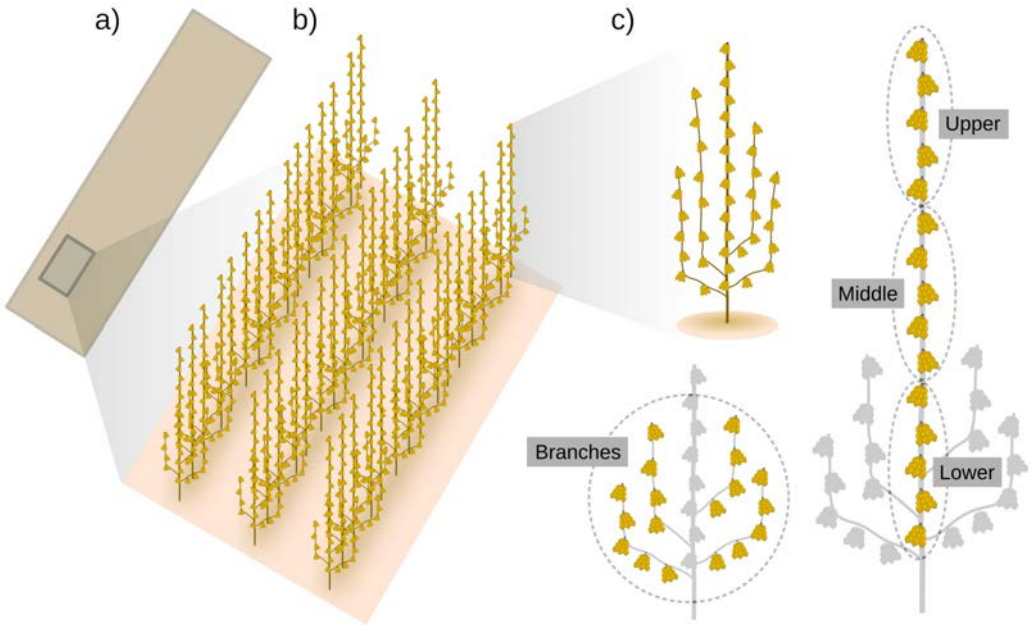

Figure 1. Experimental plots (a) with the harvested area for seed yield and nutritional quality measurements (b). All the plants from the three rows were divided between upper, middle, and lower sections of the main stem, apart from the branches (collected all together) (c).

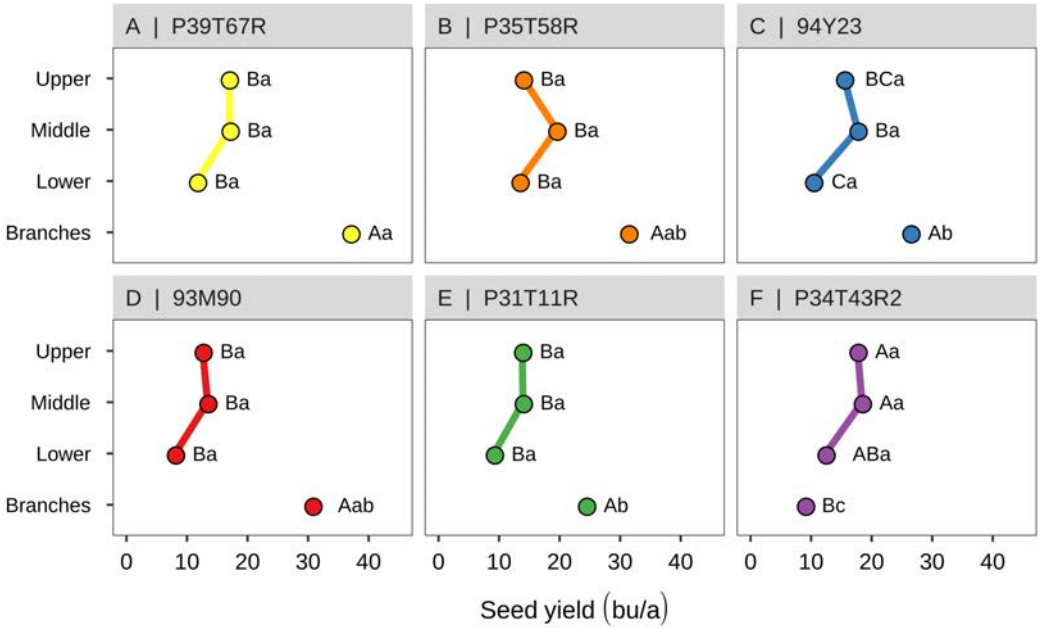

Figure 2. Vertical canopy profile for soybean seed yield (bu/a) for different genotypes. Since the interaction between factors was significant, the Tukey test is comparing genotypes in the same plant portion (lowercase letters) and the portions for each genotype (uppercase letters).

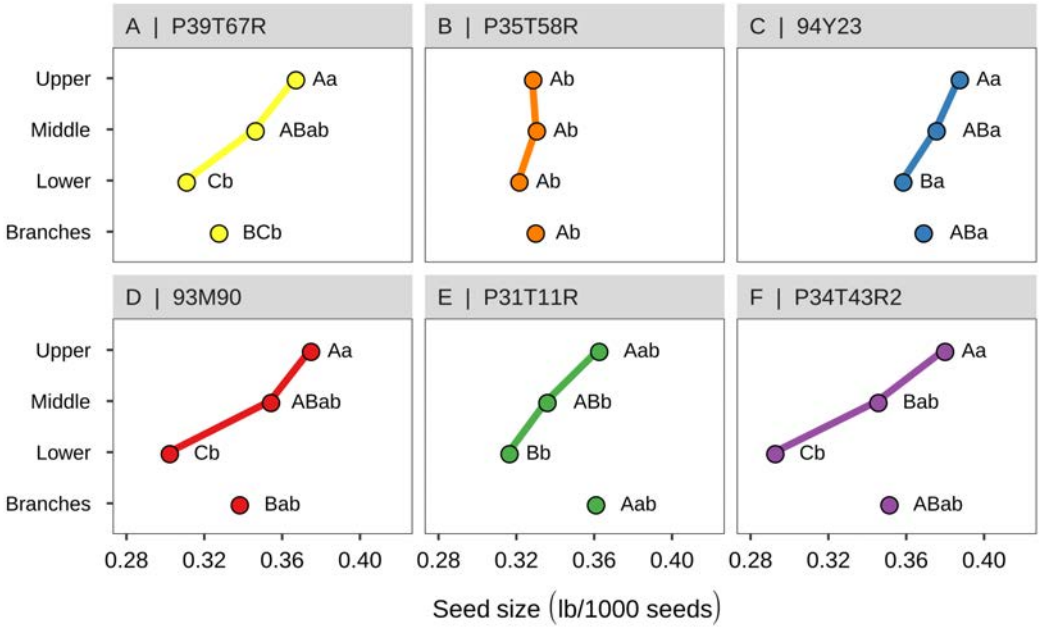

Figure 3. Vertical canopy profile for seed size (lb/1000 seeds) for different soybean genotypes. Since the interaction between factors was significant, the Tukey test is comparing genotypes in the same plant portion (lowercase letters) and the portions for each genotype (uppercase letters).

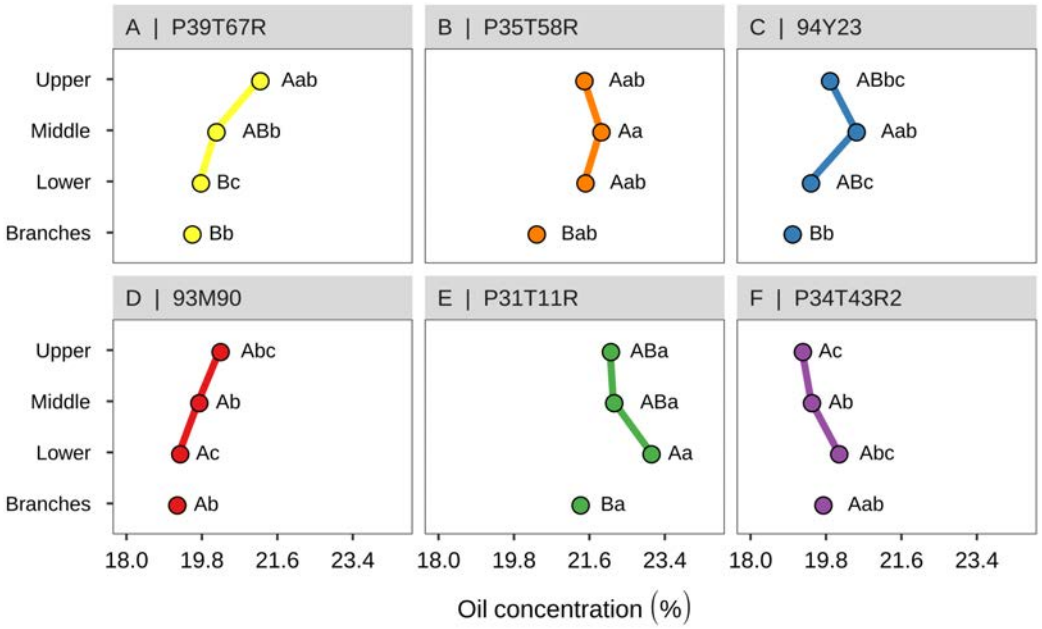

Figure 4. Vertical canopy profile for oil concentration (%) on a 13% moisture basis for different genotypes. Since the interaction was significant, the Tukey test is comparing genotypes in the same plant portion (lowercase letters) and the portions for each genotype (uppercase letters).

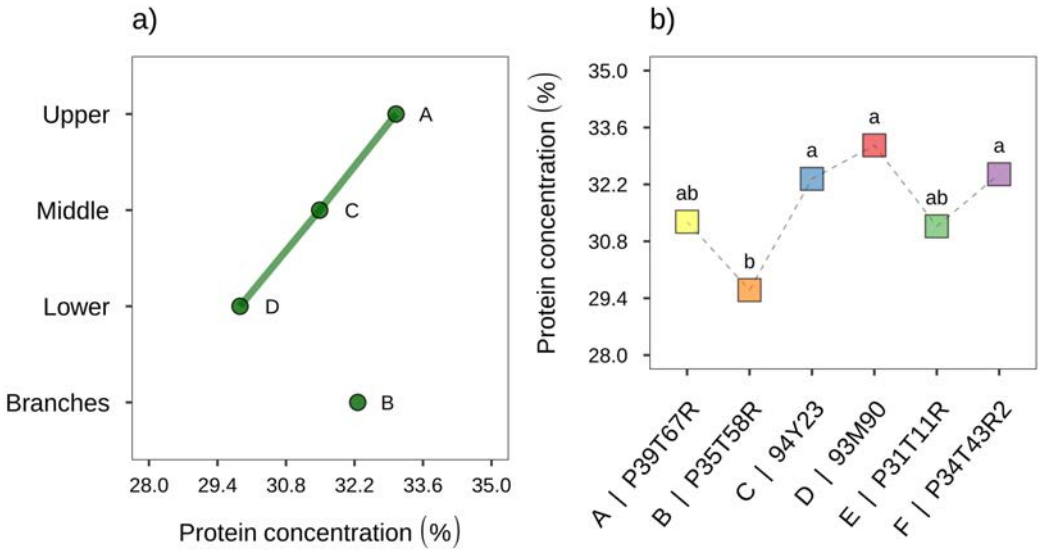

Figure 5. Vertical canopy profile for protein concentration (%) on a 13% moisture basis (a), and genotype comparison (b). Both single factors were significant in the analysis of variance (ANOVA). The letters represent the means comparison by the Tukey test for each factor, at 5% significance.

Inoculation Timing Effect on Biological Nitrogen Fixation and Soybean Productivity

M.A. Secchi, A.R. Torres, L.H. Moro Rosso, and I.A. Ciampitti

Summary

Soybean [*Glycine max* (L.) Merr.], as other legume species, has the characteristic of fixing nitrogen (N) from the atmosphere via the biological N fixation (BNF) process. When a proper symbiosis relationship between soybeans and specific bacteria has been established, the plants can obtain up to 98% of the total N need. However, several factors can negatively affect BNF, impairing its contribution to nutrient demand and reducing crop productivity. In this scenario, additional inoculation could help the plant to overcome potential N gaps in BNF. Therefore, the goal of this project was to investigate if additional inoculation at different growth stages of the soybean growing season could increase nodulation, improve BNF (N contribution) and productivity of two varieties from maturity groups (MG) III and IV. To address this objective, different strategies for N supply were tested in a greenhouse and two field locations (Ashland Bottoms and Ottawa, KS) during the 2018 growing season. Trials were arranged in a complete randomized block design with four replications. The main outcomes of this study were that nodulation (total number of nodules per plant), plant dry biomass, relative abundance of ureide (RAU (%), indirect measurement of BNF), and productivity did not differ between inoculated treatments.

Introduction

Soybean (*Glycine max* L.) crop has a high content of oil and protein in the seeds. Argentina, Brazil, and the United States comprise 13, 33, and 35%, respectively, of the estimated global soybean production (USDA FAS, 2018). Soybean can establish symbiotic association with soil bacteria called rhizobia, obtaining on an average up to 50–60% of their needs through biological nitrogen (N) fixation (BNF). For high yielding soybean varieties, the gap between plant N demand and BNF supply becomes larger, and thus, more N might need to be potentially available from the soil to satisfy this demand. Symbiosis may fail for several factors such as stress, in the form of drought, excessive soil moisture, and high temperatures; soil pH; inadequate coverage of the seeds by the inoculum during inoculation; high soil inorganic N (ammonium and nitrate) levels; low soil phosphorus (P); and soil deficiency in molybdenum (needed for the formation and function of the nitrogenase enzymes) (Ciampitti et al., 2018).

Moretti et al. (2017) showed that even when initial nodulation is successful, additional spray inoculation at different soybean growth stages can promote nodulation, and the plant can overcome autoregulation of nodulation (AON) exerted by the host (Reid et al., 2011; Wang et al., 2014), resulting in improvement in grain yield. However, there is no information about the effect of additional inoculations in the US.

The main objective of this project was to investigate if additional inoculation at different stages of soybean growth can increase nodulation, improve BNF and productivity in two soybean maturity groups (MG).

Procedures

Site Characteristics

During the 2018 growing season, soybean N strategies were carried out in a greenhouse setting and in two field locations, Ashland, KS, (39.13N, -96.61 W) and Ottawa, KS (38.54 N, -95.24 W).

For the field studies, a soil initial characterization was done at 6-in. depth for the following soil chemical parameters: soil pH, P levels (Mehlich P), cation exchange capacity (CEC), organic matter (OM), calcium (Ca), magnesium (Mg), and potassium (K); and at 24-in. depth for nitrates ($N\text{-}NO_3^-$) and ammonium ($N\text{-}NH_4$). For the greenhouse study, substrate samples were collected in order to determine all soil chemical parameters (Table 1).

Experimental Design

For the greenhouse study, the plants were sown in pots with 1.6 gallons of volume, in a 70% of substrate Berger BM1 all-purpose and 30% of sand, mixed and steamed preparation; with 4 replications. For field studies, the plot size was 10-ft wide × 60-ft long with six replications. The greenhouse study was arranged in a split-plot randomized block design and field studies were arranged in a complete randomized block design.

Treatments

Five treatments were evaluated

1. non-inoculated (Control),
2. inoculation at sowing (Sowing),
3. inoculation at sowing + inoculation at V4 (Sowing + V4),
4. inoculation at sowing + inoculation at R1 (Sowing + R1),
5. non-inoculated but fertilized with 300 lb/a (Full-N).

Two soybean varieties were used, AG30X8 (MG 3.0) and AG45X6 (MG 4.5), both from Asgrow (Monsanto Company, Saint Louis, MO), with the Roundup Ready 2 Xtend events. The inoculant applied was VAULT HP plus integral (BASF, Ludwigshafen, RP, Germany). Additional inoculation mixed with a high volume of water, 4 inches away from the plants was applied toward the substrate or soil early in the morning to avoid losses due to high temperatures. The fertilizer N source was liquid urea ammonium nitrate (UAN), 28-0-0 (N-P-K) and was equally split into three applications: at planting, flowering (R1), and the beginning of seed filling (R5) following the plant N uptake curve for this crop. For field studies, herbicides and hand weeding were used to maintain no weed interference during the entire growing season; the target seeding rate was 140,000 seeds per acre. For the greenhouse experiment, the pots were sterilized. The irrigation system was disinfected (3 minutes with alcohol 80%, sodium hypochlorite (NaOCl) 5.25%, and distilled water) as seeds (2 minutes with ethanol 80%, followed by 1-minute bleach 1.25%, and washed very carefully 5 times with distilled water).

Measurements

Stand counts were performed measuring 5-ft sections per row, 4 rows in each plot, at the V4 stage (four fully developed trifoliate) in order to estimate final plant density in all replications (Table 2).

Measurements were nodule number and nodule dry weight, BNF by an indirect method - RAU (relative abundance of ureides, %), dry biomass accumulation and productivity (pod biomass for greenhouse and yield for field studies).

For the greenhouse, all measurements were at V4, V4+14 days, R1, R1+14 days, R6, and R7 growth stages.

For field studies, all measurements were at V4, R1, R1+14 days, R6, and R7 growth stages. Yield was collected from the central two rows (5 × 60 feet).

Weather Information

Irrigation was provided to the greenhouse pots in order to avoid water limitations. Precipitations were lower during the beginning of the growing season for field studies, being 26.7 (Ashland) and 25.6 (Ottawa) inches of rainfall during the growing season, 75% after R2 growth stage (full flowering).

Results

The total number of nodules per plant and nodule dry weight did not differ between inoculated treatments (Figure 1). Between maturity group (MGs), the nodulation followed a similar trend throughout the growing season. Field studies followed the same trend.

Regarding BNF, for the greenhouse study, the ureide-N concentration was similar across all the inoculated treatments being greater than the non-inoculated strategies (Full-N and control). The lower biomass production in the control is related to a lower N availability, which diminishes the N demand and consequently the BNF. This behavior was compensated by the N supply of the full-N strategy, allowing the plants to attain comparable biomass to the inoculated treatments (Figure 2).

Pod biomass in the greenhouse, as an indicator of the seed yield per plant, was not affected by soybean variety and presented lower values only for the control (Figure 3). In the field setting, in terms of yields, there were no significant differences across all treatments.

Preliminary Conclusions

- Additional inoculation at V4 or R1 growth stage did not improve soybean nodulation and BNF in greenhouse and field conditions.
- Soybean yield was not affected by the inoculation strategy under field conditions.

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Table 1. Chemical characteristics of substrate mix (greenhouse experiment, GH) and soil (field experiments, FD) at 6-in. and 24-in. depth, collected right before the onset of the experiment

Site	Depth	pH	P	K	Ca	Mg	Na	CEC [a]	NH_4	NO_3^-	SOM [b]
	inches		----------	----------	*ppm*	----------	----------	*$meq_c/100g^{-1}$*	------	*ppm*	------ *%*
GH	---	6.7	12.2	73	1363.5	303.4	28.9	9.7	2.8	6.8	5.1
FD	0 – 6	6.1	52.5	313	1972.8	204.6	15	17			2.2
Ashland	0 – 24								7.3	10.1	
FD	0 – 6	5.9	13.7	141	255.9	393.5	90	27.6			3.97
Ottawa	0 – 24								12.8	1.38	

P = phosphorus. K = potassium. Ca = calcium. Mg = magnesium. Na = sodium. CEC = cation exchange capacity. NH_4 = ammonium. NO_3- = nitrate. SOM = soil organic matter (loss on ignition).

Table 2. Final plant density (plants × 1000/a) per treatment in field experiments at Ottawa and Ashland, KS, during the 2018 growing season

Location	Maturity group	Control	Sowing	Sowing + V4	Sowing + R1	Full-N
Ottawa	3.0	122	130	124	130	120
	4.5	114	134	122	122	110
Ashland	3.0	117	120	118	118	115
	4.5	126	120	120	115	108

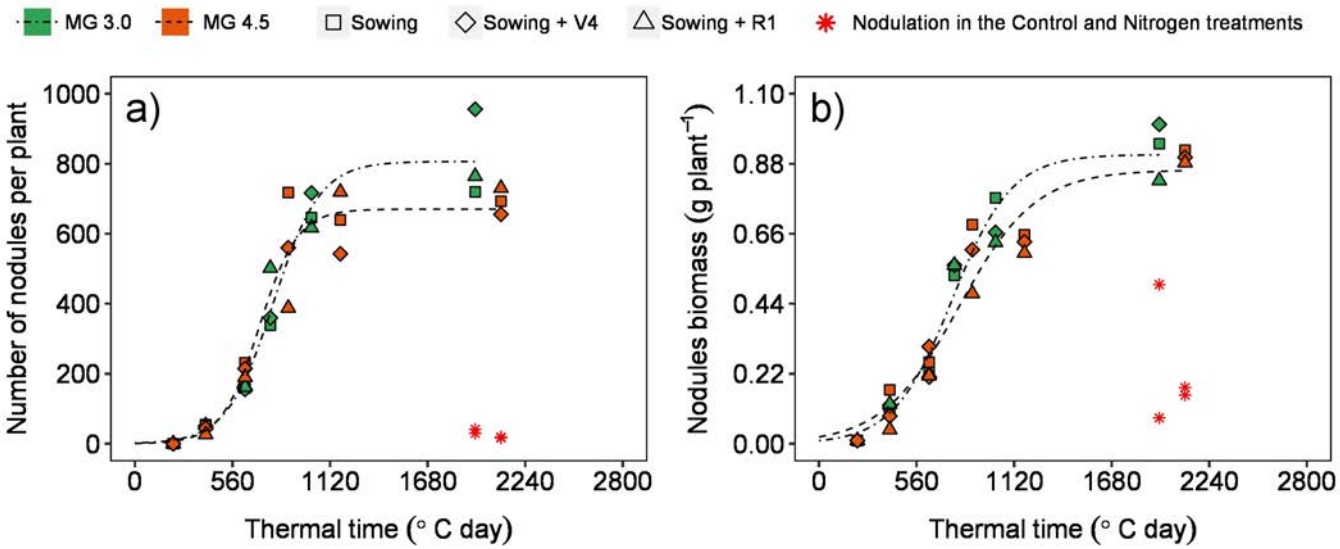

Figure 1. Number of nodules (a) and nodule dry biomass (b), in g/plant, for the inoculated treatments in soybean maturity group (MG) 3.0 and 4.5 in the greenhouse study. Points represent the least square means (lsmeans) from each model. A non-linear logistic function was fitted.

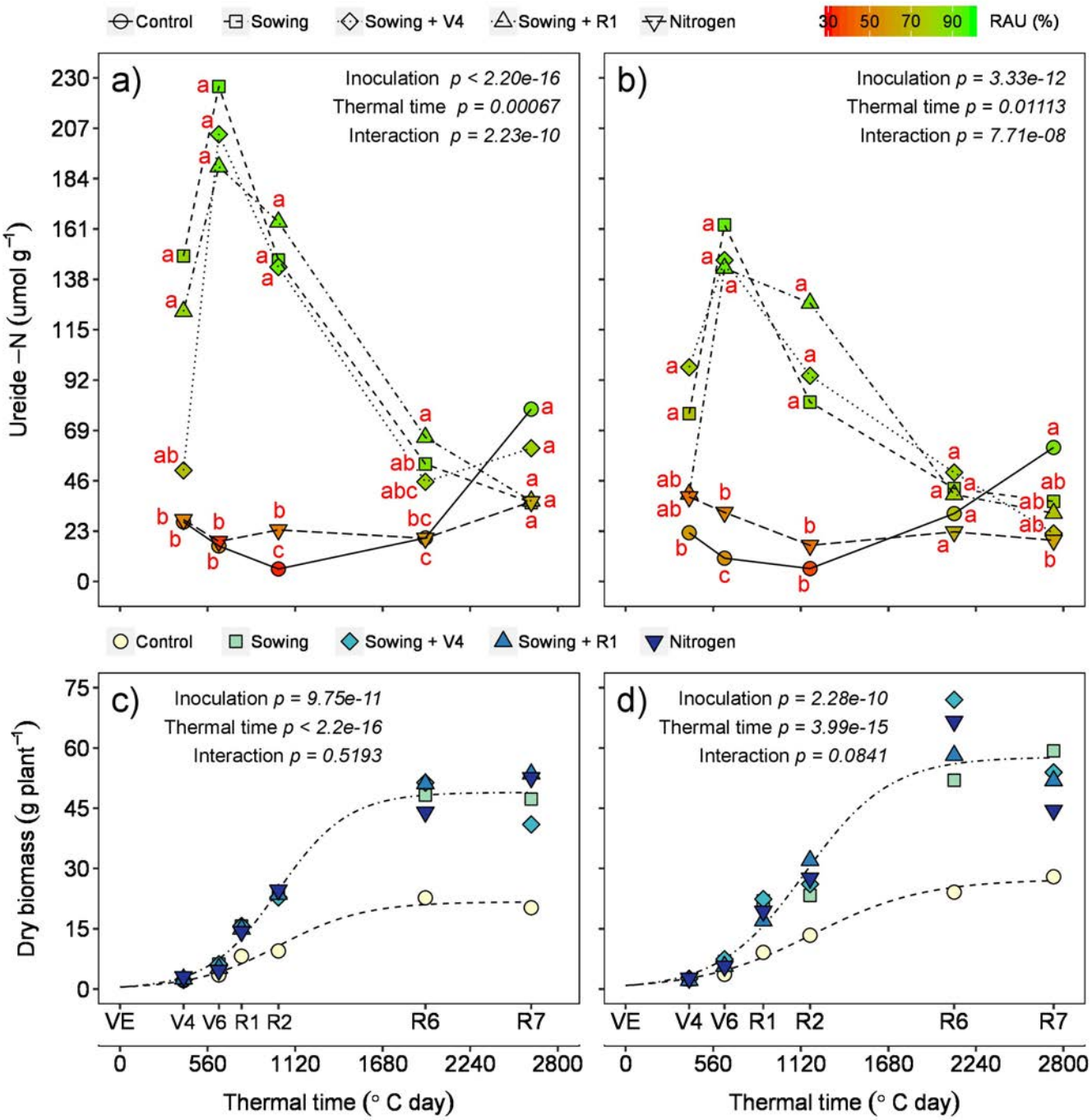

Figure 2. Ureide-N concentration, µmol/g, for MG 3.0 (a) and 4.5 (b). The color gradient is showing the Relative Abundance of Ureide-N (RAU, %). Points represent the least square means (lsmeans) from each model. Plant biomass accumulation, g/plant, for MG 3.0 (c) and 4.5 (d) is fitted by a non-linear logistic function. Letters are comparing inoculation strategies inside each sampling time by the Tukey test at 5% significance. Data from the greenhouse experiment.

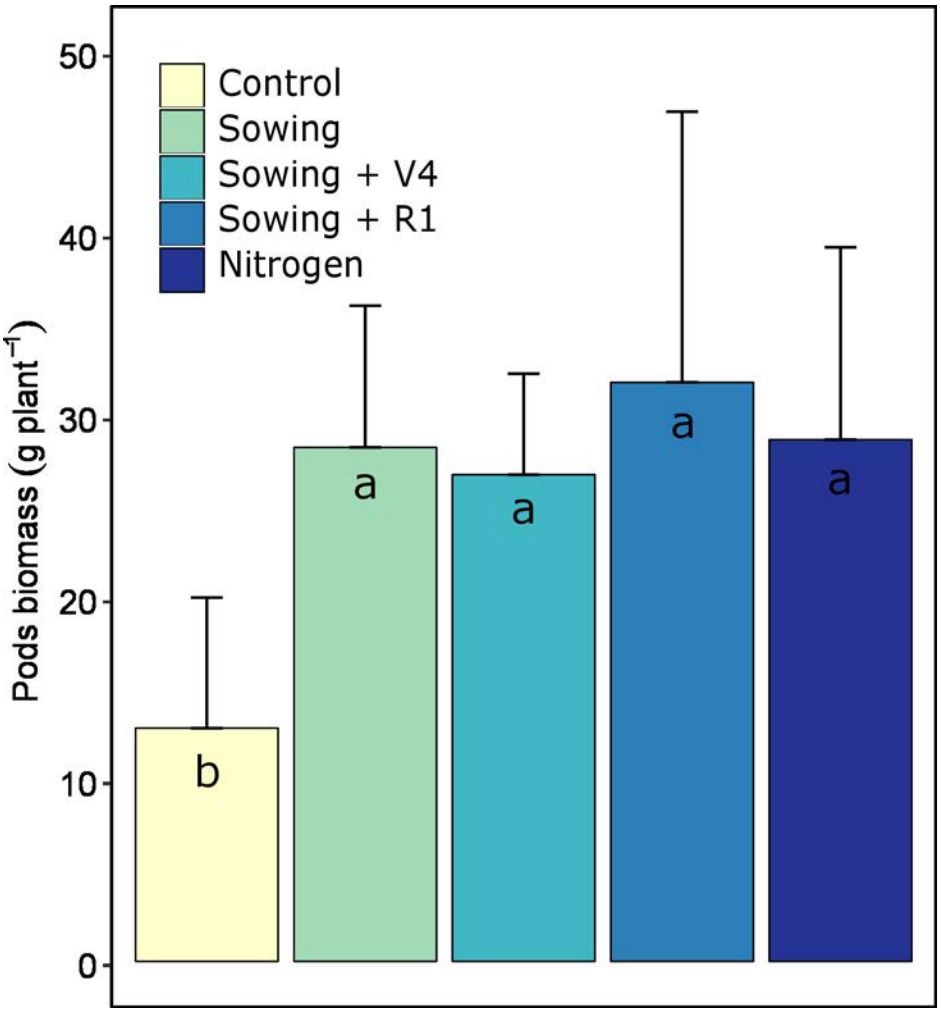

Figure 3. Pod dry biomass, g/plant, for the greenhouse study affected only by the inoculation strategy. Error bars are the standard deviation.

Planting Date and Maturity Group Interaction for Soybean Productivity and Seed Quality in East Central Kansas

L.P. Pott, L.H. Moro Rosso, W.D. Carciochi, J. Kimball, E.A. Adee, and I.A. Ciampitti

Summary

Soybean seed quality is an important component for soybean meal. Different factors affect seed quality, such as genetics, environment, and management (G × E × M). The objectives of this study were to 1) evaluate the effect of planting date and maturity group in soybean seed quality (protein and oil concentrations) and 2) investigate the relationship between soybean seed quality and productivity (seed weight and yield). Three field experiments were conducted during the 2018 growing season evaluating the combination of two factors, planting date and maturity group, with three levels of each one (early, medium, and late). Field measurements included: seed yield, seed weight, and seed quality, mainly represented by determination of seed protein and oil concentrations. The main outcomes of this study were: 1) early planting date resulted in the highest protein and oil concentrations, while late planting date presented the lowest concentrations for those seed quality components; and 2) protein concentration was negatively correlated with seed yield (r = -0.66).

Introduction

Soybean as an oil seed crop serves as a source of feed for animals, protein for human consumption, and biofuel feedstock (Masuda and Goldsmith, 2009). Besides the seed yield of the crop, seed quality and its composition are key points for soybean meal. Soybean seed quality is affected by genetic, environment, and management factors (G × E × M) and their interactions (Medic et al., 2014).

The main environmental factors affecting soybean seed productivity (seed weight and seed yield) and seed quality (protein and oil concentrations) are temperature, solar radiation, water availability, and soil nutrient supply (Rotundo et al., 2009), while crop management such as irrigation (Bellaloui and Mengistu, 2008), planting date, and maturity group also may affect soybean seed quality (Assefa et al., 2018).

The first step to improve seed nutritional quality is to explore potential impacts of specific management practices on soybean seed quality. The objectives of this study were to 1) evaluate the effect of planting date and maturity group on soybean seed quality (protein and oil concentrations) and 2) investigate the relationship between soybean seed quality and productivity (seed weight and yield).

Procedures

Site Characteristics

The experiments were conducted in three locations in Kansas—Manhattan, Topeka, and Ottawa. Soil samples were collected from 0- to 6-in. soil depth layer in each location, to characterize initial conditions. The soil parameters analyzed were pH, clay content, soil organic matter (SOM), and phosphorus (P) (Mehlich). Results of soil tests are shown in Table 1.

Experimental Design

Treatments consisted of the combination of two factors (planting date and maturity group) with three levels of each one (early, medium, and late) (Table 1). Planting date and maturity group were treated as categories for having the same levels of each factor across locations (Table 1). The three locations in this study were considered as the random effect.

The experiment was conducted in a completely randomized block design with four replications for each treatment. The plots were 5- × 40-ft, with 4 rows in 30-in. row spacing. The experimental area was kept free of weeds, pests, and diseases during the growing season.

Measurements

Soybean seed yield was determined with a plot combine (by harvesting the two central rows, 40-ft long) and expressed at 13.5% seed moisture content. Seed weight, protein, and oil concentration were measured in a sample collected from the plot combine. Concentration of protein and oil (dry basis) was determined by NIR spectroscopy technique (Pazdernik, et al., 1997).

Weather Information

The weather information was retrieved from Kansas Mesonet Weather Data Library, Kansas State University. The maximum and minimum temperatures, precipitation, and solar radiation for the growing season are shown in Figure 1.

Statistics

Results were subjected to an analysis of variance (ANOVA) to test the effect of planting date, maturity groups, and their interaction with all the measured variables. After analysis, treatments were compared by Tukey test analysis ($P < 0.05$). Relationships between soybean seed quality (protein and oil concentrations) and productivity (seed yield and weight) were analyzed with Pearson ′s correlation, and when relationships had significant differences, linear regression was performed.

Results

Seed Yield and Weight

Soybean seed yield was not affected by planting date or maturity group (Table 2). However, seed weight was affected by planting date but not by the maturity group factor (Table 2). The largest seed weight was obtained with early planting date (173.1 mg), while the late planting date produced the smallest seed weight (160.9 mg), expressed in mg per seeds.

These results led to analysis of the environmental factors during the soybean growing season. The daily temperature and solar radiation were greater with the early planting date, while precipitation was greater with the late planting date (Figure 1). The temperature with early planting date was around 17% higher compared to late planting date, and with 55% more solar radiation, while the late planting date presented 30% more precipitation relative to early planting date. These weather conditions could increase the seed weight with early planting date, because high temperatures and radiation stimulates crop growth primarily through increased photosynthesis and leaf area.

Protein and Oil Concentrations

There were not interactions between the factors evaluated in this study with the seed quality, protein, and oil concentrations. Protein and oil concentrations differed among planting dates. Early planting date showed the highest protein and oil concentrations (43.5% and 22.0%, respectively), while late planting date presented the lowest (41.7% and 21.4%, respectively). However, there was no effect of maturity group on these variables (Table 2).

The environmental factors such as temperature, solar radiation, and precipitation may have influenced protein and oil concentrations as well as seed weight. In addition, the higher precipitation with the late planting date could affect the quality of the seeds if more precipitation is received due to a delay in the optimal harvest time.

Relationship Between Soybean Seed Quality and Productivity (Seed Weight and Yield)

The relationship between seed protein concentration and yield was significant. Protein concentration was negatively correlated with soybean seed yield ($r = -0.66$) (Figure 2). Factors such as dilution of tissue nutrients due to increased photosynthesis and plant size (biomass and yield) may contribute to this lower protein concentration as yields improved.

Since seed quality (protein and oil concentration) is dependent on other factors ($G \times E \times M$) and their interactions, future studies should explore the effect of these factors to separate their potential influence and contribution to seed quality formation.

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Table 1. Soil characterization before planting time and experimental factors in the three locations

					Experimental factors					
	Soil characterization				Planting date			Maturity group		
Location	pH	Clay	SOM	P	Early	Medium	Late	Early	Medium	Late
		-------- % --------		ppm						
Manhattan	7.1	32	2.8	36.6	20-Apr	7-May	23-May	3.0	3.4	4.1
Topeka	7.5	16	1.3	46.3	30-Apr	18-May	6-Jun	3.2	3.9	4.3
Ottawa	6.6	30	2.8	44.1	10-May	4-Jun	29-Jun	3.4	4.1	4.5

SOM = soil organic matter.

Table 2. Analysis of variance and means for seed yield, seed weight, protein and oil concentrations. Means from Manhattan, Topeka, and Ottawa, KS

Factor	Seed yield	Seed weight	Protein	Oil
	bu/a	mg	---------- % ----------	
Planting date				
Early	39.6 *ns	173.1 a	43.5 a	22.0 a
Medium	41.9	167.8 ab	42.1 b	21.9 a
Late	39.3	160.9 b	41.7 b	21.4 b
Maturity group				
Early	37.4 *	167.5 *	42.6 *	21.9 *
Medium	41.4	166.6	42.4	21.8
Late	42.1	167.7	42.3	21.7
ANOVA				
Planting date	*ns	$P = 0.017$	$P < 0.0001$	$P = 0.003$
Maturity group	ns	ns	ns	ns
Planting date × maturity group	ns	ns	ns	ns

*ns = no significant difference.

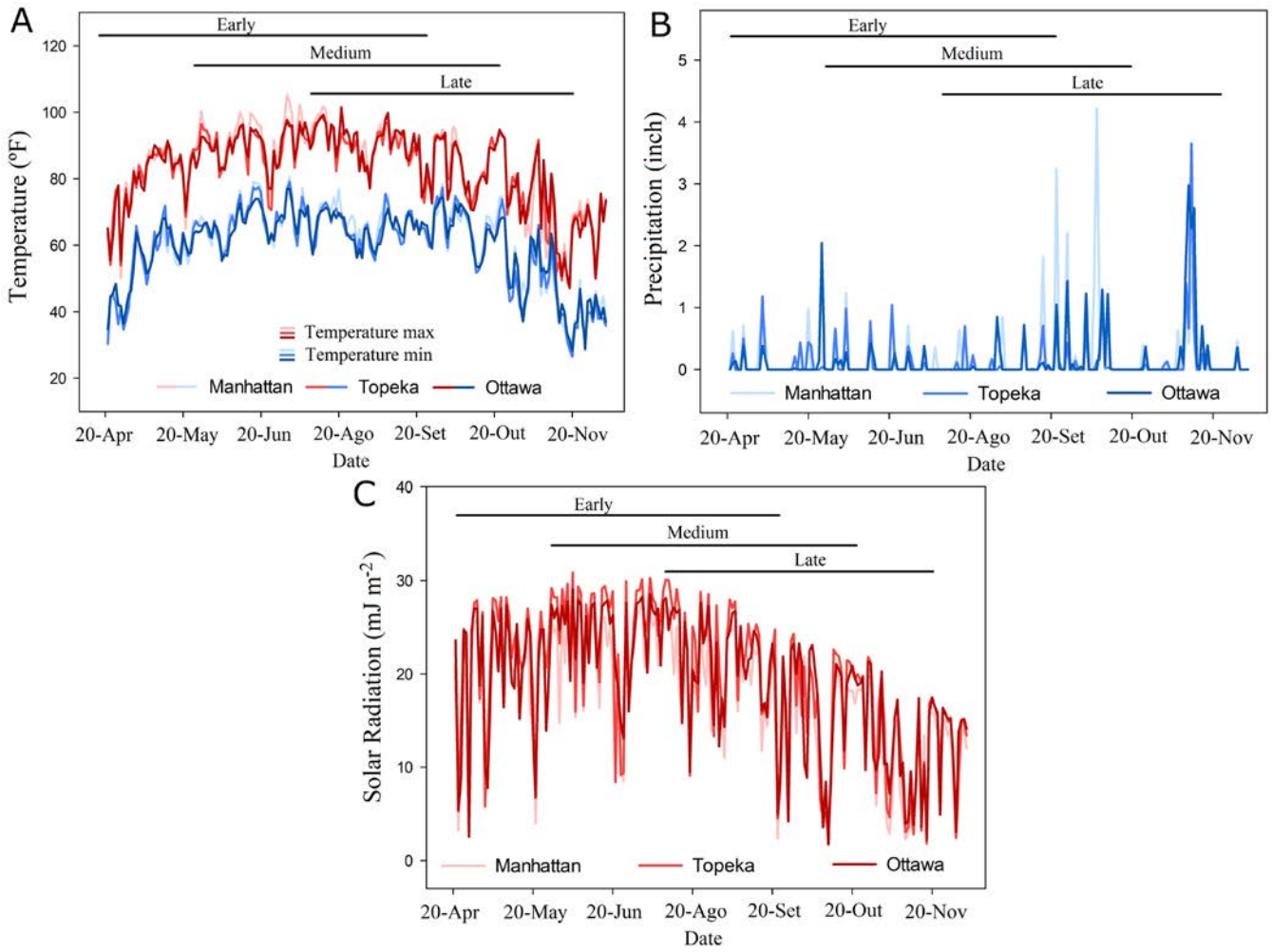

Figure 1. Daily maximum and minimum temperatures for the growing season (A), daily precipitation (B), and daily solar radiation (C) in Manhattan, Topeka, and Ottawa, KS. Horizontal lines represent the medium dates for growing season for each planting date.

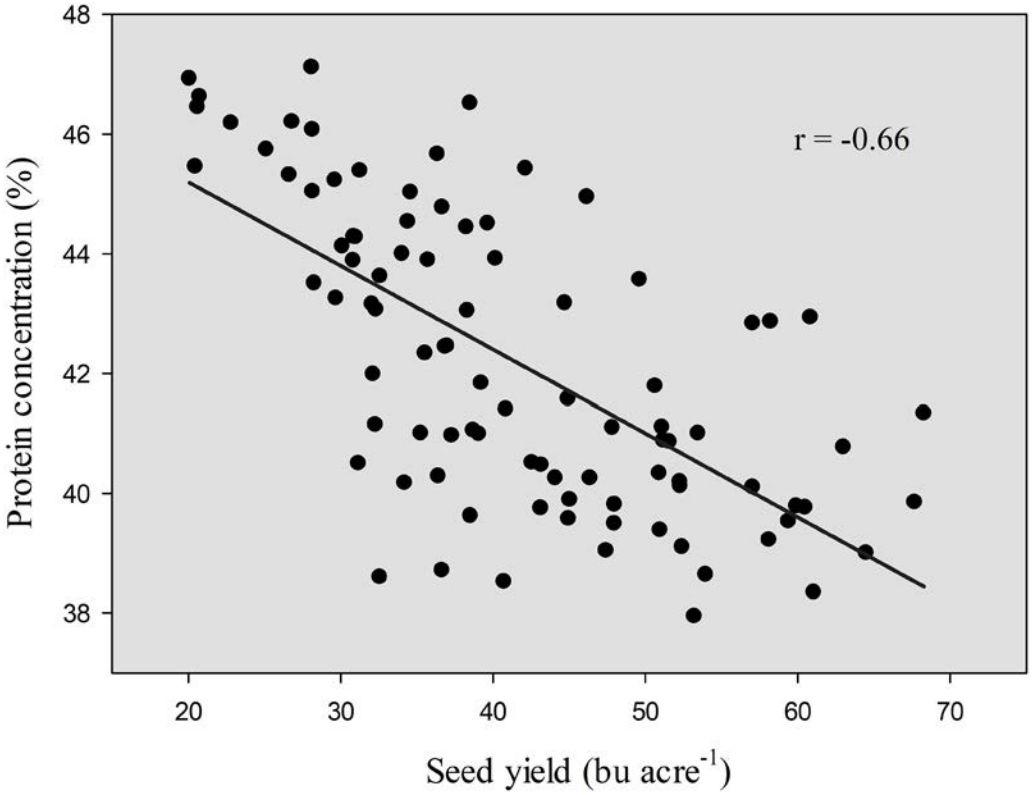

Figure 2. Relationship between protein concentration and soybean seed yield. Protein concentration presented as %, dry basis; and seed yield was expressed in 13.5% moisture content.

Effects of Spring-Planted Cover Crops on Weed Suppression and Winter Wheat Grain Yield in Western Kansas

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

Summary

Herbicide resistant (HR) weeds pose a major challenge to continuous no-tillage (NT) dryland crop management systems. Integrating cover crop (CCs) in dryland crop rotations could suppress weeds and provide a weed management option for HR weeds in NT systems. Field experiments were conducted to investigate weed suppression potential of spring-planted CCs and their impacts on subsequent winter wheat grain yields. The CCs were oat/triticale, oat/triticale/pea, spring pea, and chem-fallow (standard) over 3 years and 2 locations in western Kansas. A weedy-fallow check was added to compare weed suppression of CCs in 2 out of the 3 years. Results showed CC mixtures of oat/triticale or oat/triticale/pea produced more biomass than spring pea by mid-June. Averaged across years, CC dry matter (DM) produced in Colby was 3560 lb/a with spring pea, 5850 lb/a for oat/triticale, and 5700 lb/a for the 3-way mixture of oat/triticale/pea. Similarly, DM production at HB Ranch (located 5 miles north of Brownell) was 2160 lb/a for spring pea, 4420 lb/a for oat/triticale or 4330 lb/a for oat/triticale/pea. Regardless of study location, growing a CC resulted in > 95% suppression of total weed biomass relative to the weedy-fallow check. Compared to chem-fallow, growing a CC reduced soil water content at winter wheat planting in 3 out of the 6 site-years (2017 at Colby, 2016 and 2017 at HB Ranch). At Colby, CCs reduced winter wheat grain yields in 2018 but not in 2016 or 2017. Except 2016, growing oat/triticale or oat/triticale/pea CC reduced wheat yields at HB Ranch. When averaged across the 3 years, wheat grain yields were 31 bu/a with chem-fallow, 30 bu/a after spring pea, and 34 bu/a with oat/triticale or oat/triticale/pea CC in Colby. Similarly, at HB Ranch, wheat grain yields averaged 50 bu/a with chem-fallow, 46 bu/a for spring pea, and 40 bu/a with either oat/triticale or oat/triticale/pea CCs.

Introduction

Winter wheat-summer crop-fallow (W-S-F) is a common dryland cropping system in semiarid regions of the central Great Plains (CGP), where soil moisture is often the limiting factor for continuous cropping. The fallow phase of the production system conserves soil water, which could stabilize wheat yields and prevent crop failure in drier years. Weed control during fallow period is accomplished through a combination of tillage and herbicide application in a minimum tillage system or herbicide alone in NT.

Over the years, growers have relied heavily on postemergence herbicides to achieve weed control during the fallow phase in NT. Multiple herbicide applications are generally needed to prevent replenishment of the weed seedbank during the fallow phase of the cropping cycle. Glyphosate is widely used in fallow fields to provide preplant weed control (burndown) and in wheat stubble after harvest. Generally, about three to four applications of glyphosate are applied in NT fallow prior to winter wheat planting. Increased selection pressure imposed by these repeated glyphosate applications

has resulted in evolution of glyphosate resistance. For example, glyphosate-resistant (GR) kochia (*Kochia scoparia* L.), Palmer amaranth (*Amaranthus palmeri* S. Watson), horseweed [*Conyza canadensis* (L.)], and Russian-thistle (*Salsola tragus*) biotypes have recently been identified in NT fallow cropping systems across the CGP. The severity of these GR weed problems present a great challenge to NT crop production systems in this region.

Growing CCs during fallow as part of the crop rotation can suppress weeds and provide a significant weed management option for HR weeds in NT systems. This approach of utilizing CCs for weed suppression is gaining popularity among NT dryland producers because of HR weeds. However, CCs utilize soil moisture that could reduce subsequent crop yields particularly in dry years. Therefore, the objectives of this study were to 1) evaluate weed suppression potential of CCs, and 2) quantify CC effects on soil water availability at winter wheat planting and subsequent wheat grain yields in dryland systems.

Procedures

Field experiments were initiated in spring 2015 at the Kansas State University experiment fields at HB Ranch near Brownell, KS, and the experiment field near Colby, KS, to investigate weed suppression potential of CCs in dryland systems. Study design was a split-plot with four replications in randomized complete block. Main plots were three crops in each phase of a winter wheat-sorghum-fallow rotation, and subplots were four CC treatments of chem-fallow, oat/triticale, oat/triticale/pea, and spring pea for grain. In 2016 and 2017 growing seasons, a weedy-fallow check strip was added to quantify weed suppression potential of the CC treatments. The CCs were planted in the spring (by mid-March) of the fallow phase of the rotation. Each phase of the crop rotation was present within each block in each year of the study. The spring pea plots had a preplant herbicide application of Prowl H_2O and Spartan during each year of the study. Three herbicide applications were usually made to control weeds in the fallow plots. The field site at Colby had GR weeds, so paraquat was mostly used for weed control during fallow at this location.

Cover crop biomass, weed biomass, weed density, and weed community diversity were measured on each plot in June 2016 and 2017. At each sampling time, individual weed species were identified and counted within two quadrats (2.7 ft^2) placed randomly in each plot. Total aboveground biomass of weed species and CCs within each quadrat were harvested by clipping at the soil surface, and separated into different sampling bags (weeds or CC). The samples were weighed fresh, oven-dried at 120°F until constant weight, and weighed again for DM determination.

Soil water content at winter wheat planting was determined gravimetrically to 3 ft in 2015 and to 5 ft in 2016 and 2017. Two soil cores were taken from each plot and data averaged for a single soil water content measurement. Winter wheat 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 with the PROC MIXED procedure in SAS version 9.4 (SAS Inst., Cary, NC) was used to examine weed and CC biomass, soil water content, and winter wheat yields as a function of CC treatments.

Results

Cover Crop and Weed Biomass

Results showed DM production of CCs varied over the two study locations. In general, spring CC biomass at Colby was greater than that at HB Ranch. The differences were mostly because of differences in residual soil nutrients at each location. The Colby location had been in NT corn production for more than 15 years prior to the current study, resulting in significant accumulation of nitrogen, phosphorus, and soil organic matter compared to the HB Ranch location that was in conventional tilled wheat-sorghum fallow production prior to the study in 2015 (data not shown). Irrespective of location, total aboveground biomass produced from oat/triticale or oat/triticale/pea was greater than that of spring pea alone (Figure 1a and Figure 1b). Averaged across the 2 years, total DM production ranged from 3560 lb/a for spring pea to 5850 lb/a for oat/triticale in Colby (Figure 1a). Similarly, total DM produced with spring pea was 2160 lb/a compared to 4420 lb/a with oat/triticale CC at HB Ranch (Figure 1b).

Total weed DM varied over location, with greater weed biomass produced at Colby than HB Ranch. Compared to the uncontrolled weedy-fallow, growing a CC resulted in a significant decrease in weed biomass production. At Colby, weed biomass ranged from 78 lb/a when spring pea was grown to 1760 lb/a for the weedy-fallow (Figure 1a). This represented approximately 96% weed suppression. Weed suppression was 86 and 90% for oat/triticale and oat/triticale/pea CC treatments, respectively, in Colby. The significant weed suppression with spring pea was possibly due to the preplant herbicide use compared to no herbicide application in the other CCs. In addition, spring pea in 2017 at Colby were very competitive and provided complete ground cover while the cereals didn't have complete canopy closure. This allowed light penetration between the rows to help weed growth. Similarly at the HB Ranch, weed biomass ranged from as low as 4 lb/a with oat/triticale or oat/triticale/pea to 680 lb/a for the weedy-fallow (Figure 1b). This corresponds to 99% weed suppression compared to the check treatment. Growing spring peas resulted in 95% weed suppression at HB Ranch. Averaged across sites and years, CCs had a significant effect on weed population density. Weed counts were 27 plants ft^2 for the weedy-fallow, 9 plants ft^2 for spring pea, 12.8 plants ft^2 for oat/triticale, and 6 plants ft^2 for oat/triticale/pea treatments. Kochia was the dominant weed species found in Colby, while kochia and large crabgrass dominated at the HB Ranch. The CCs reduced the ability of many weeds to emerge and grow, with the CCs shading out weeds below the canopy and decreasing their biomass production. The relatively smaller weed biomass under the CC likely enhanced chemical control of these weeds with herbicides at termination of the CCs (data not shown).

Soil Water Content and Wheat Yield

In 2015, growing a CC had no effect on soil water content at winter wheat planting, except the grain pea treatment, at both study locations (Figure 2a). Spring pea yields in 2015 averaged 1600 lb/a in Colby and 850 lb/a at HB Ranch resulting in significant water use. Grain pea yields in 2016 averaged 840 lb/a in Colby and 590 lb/a at HB Ranch. Forage peas were grown in 2017 instead of grain peas (because the wrong pea seed was supplied). Growing a CC or grain pea in 2016 decreased soil water content at winter wheat planting in both Colby and HB Ranch. Growing a CC had no effect on soil water content at wheat planting in 2017 at Colby but did cause a significant decrease in soil water content at HB Ranch (Figure 2a). Differences were due to greater

precipitation amounts after termination of CC at Colby (7.7 inches from June to August) compared to HB Ranch (4.9 inches from June to August). This resulted in more soil water replenishment at the Colby site.

Winter wheat yields after CCs corresponded well with soil water content at winter wheat planting. Wheat yields after CCs were not affected in 2016 except when peas were grown for grain at HB Ranch (Figure 2b). Relatively drier surface soil (top 2 inches) at winter wheat planting in 2016 and drought in spring 2017 reduced wheat establishment and significantly decreased yields at Colby. Significantly decreased winter wheat yields were observed in 2017 and 2018 when CCs were grown ahead of wheat at HB Ranch (Figure 2b). The lesser water use by spring pea in 2016 (less plant stands) and 2017 (forage pea) resulted in less impact on subsequent wheat yields at this site. Averaged across the 3 years, growing CCs or grain pea ahead of wheat at HB Ranch reduced winter wheat yields compared to chem-fallow. Wheat yields at HB Ranch ranged from 40 bu/a with oat/triticale/pea CC to 50 bu/a with chem-fallow (Figure 3). At Colby, however, CC or grain pea had no effect on wheat yields when averaged across the 3 years (Figure 3). Over the 3-year study, wheat yields with chem-fallow were 31 bu/a, similar to 30 bu/a with grain pea, but 2 or 3 bu/a less than that obtained with oat/triticale and oat/triticale/pea CCs. This observation was possibly due to greater weed pressure in the chem-fallow treatments at the Colby site compared to the HB Ranch site. Averaged across the 3 years and CC treatments, winter wheat yield at HB Ranch was 44.1 bu/a, which was significantly greater than that achieved in Colby (32.1 bu/a). This was mostly because of differences in precipitation amounts received at the locations but also differences in weed pressure.

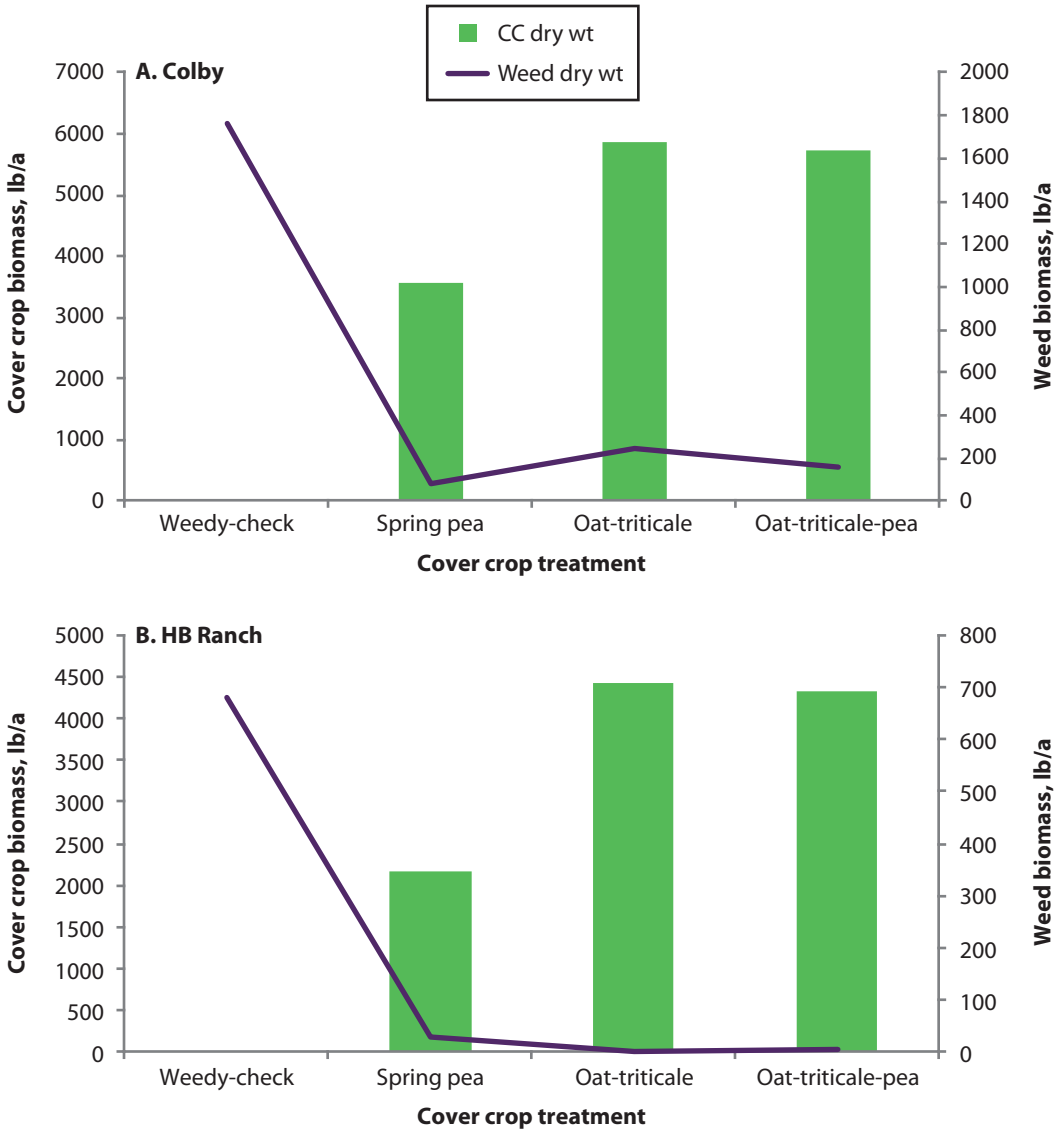

Figure 1. Average cover crop and weed biomass measured in June 2016 and 2017 at Kansas State University experiment fields located at Colby, KS (a), and at the HB Ranch (b) near Brownell, KS (b).

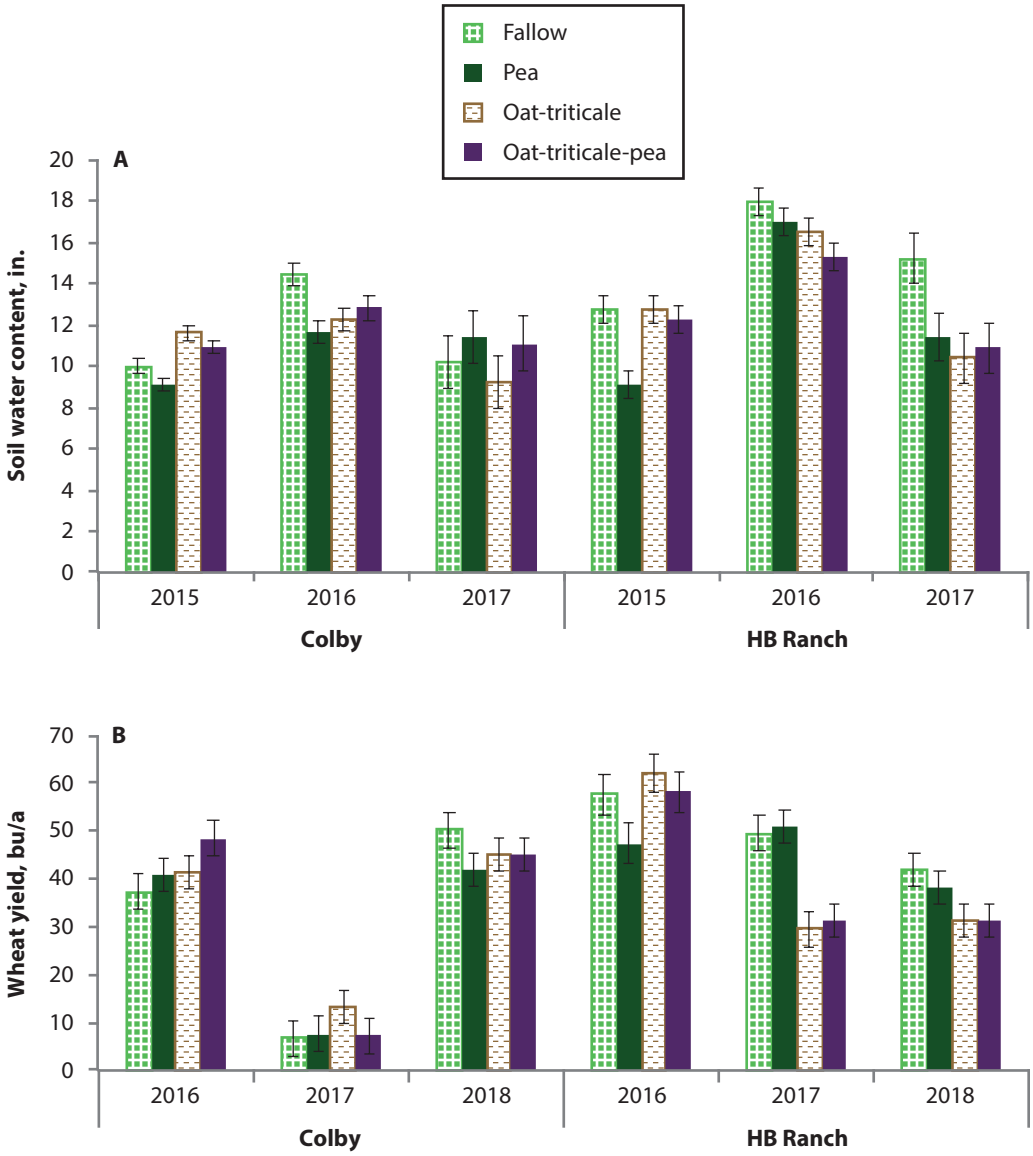

Figure 2. Soil water content at wheat planting (a) and winter wheat yield (b) as affected by cover crops grown over three years at Kansas State University experiment fields located at Colby, KS, and the HB Ranch near Brownell, KS.

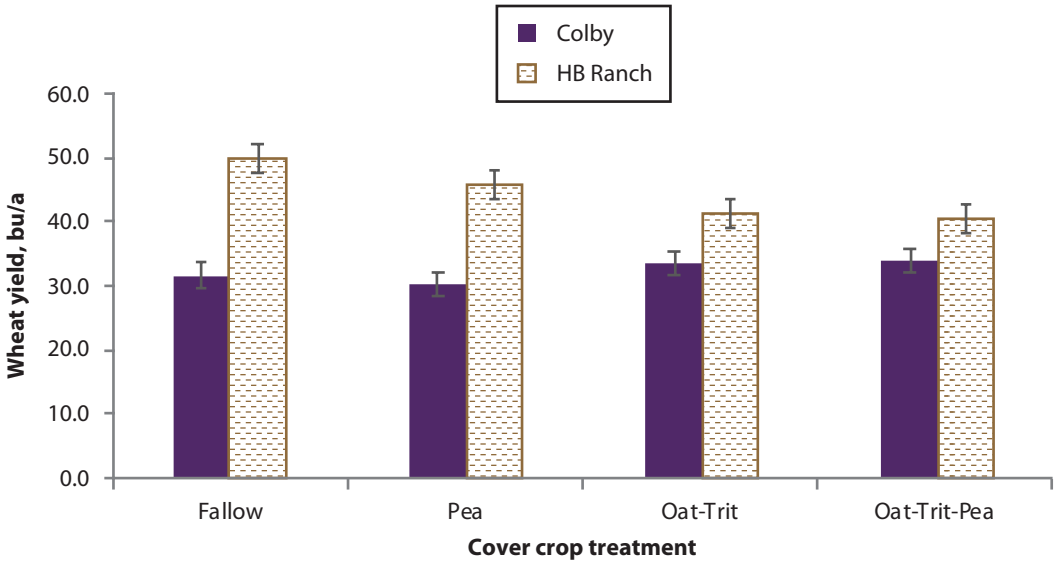

Figure 3. Cover crop effect on winter wheat grain yield averaged across three growing seasons at Kansas State University experiment fields located at Colby, KS, and the HB Ranch near Brownell, KS.

Cover Crop Management Effects on Soil Water Content and Winter Wheat Yield in Dryland Systems

A.K. Obour, J.D. Holman, and J.R. Jaeger

Summary

Integrating cover crop (CCs) 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 CC for forage on soil water content, subsequent crop yields, and soil health. Cover crop treatments evaluated were single, two-, three-, and six-species mixtures of oat, triticale, peas, radish, turnips, and buckwheat compared to chem-fallow. The study was conducted in a wheat-sorghum-fallow rotation system with all crop phases present in each block and year of the study. Results showed that decreasing the proportion of grass species in a CC mixture tended to reduce the amount of forage dry matter (DM) produced. Across the 3 years, forage DM production ranged from 3000 lb/a for the 2-way oat/triticale mixture to 2200 lb/a for the 6-species mixture. However, forage crude protein concentration and digestibility were greatest when peas were included in the mixture. Growing a CC in place of chem-fallow reduced soil water content at winter wheat planting in 2 of the 3 study years. Averaged across years, growing CC ahead of wheat reduced winter wheat yields compared chem-fallow, ranging from 3 bu/a less with spring peas to 13 bu/a when oat CC was hayed. Over the 3-year study, wheat yields with haying or grazing a CC were similar to yields when CC was left as cover. Cover crop treatments had no effect on grain sorghum yields.

Introduction

Cropping system diversification with CCs can provide several benefits. These include improving soil quality, nutrient cycling, weed and pest suppression, and 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 CC 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 CC in dryland systems are using them not only for soil health improvement but 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 windows 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 crop mixtures, and 2) evaluate the impacts of removing cover crops for forage on soil water content, subsequent crop yields, and soil health.

Procedures

Field experiments were initiated in spring 2015 at the Kansas State University experiment fields at HB Ranch near Brownell, KS, to address the above objectives. 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 a 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 are adequate and the precipitation outlook is favorable. This treatment was left fallow when available soil water content at CC planting is < 12 in., and summer and fall precipitation outlook is not favorable. The CC treatments were either grazed, hayed, or left as cover. Grazing and haying of CCs was done at heading, and CCs were all terminated by the second week in June with glyphosate and 2,4-D in 2015. Paraquat and Aim EC were used to terminate CCs in 2016 and 2017.

Cover crops were harvested at heading to determine forage DM production and nutritive value. Forage harvests were performed the last week in May 2016 and first week in June 2016 and 2017. During each harvest, a 3-ft × 30-ft forage strip was harvested from each plot using a Carter plot forage harvester (Carter Manufacturing Company, Inc.) to a 6-inch stubble height. Fresh weights of samples were recorded, sub-samples were weighed, and oven dried at 50°C for at least 48 hours in a forced-air oven for DM determination. Oven-dried samples 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 water content at winter wheat planting was measured at 3 ft in 2015, and at 5 ft in 2016 and 2017. Two soil cores were collected from each plot and data averaged for a single soil water content measurement. 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 with the PROC MIXED procedure in SAS version 9.4 (SAS Inst., Cary, NC) was used to examine forage production, soil water content, and winter wheat and grain sorghum yields as a function of cover crop management options.

Results

Forage Dry Matter and Nutritive Value

Results over three growing seasons showed CC species or mixtures planted had good forage production potential. Forage DM produced varied over the three years because of variations in soil water availability and air temperature in the spring. Averaged across the 3 years, forage DM ranged from 2225 lb/a for the cocktail treatment to 3026 lb/a for oat/triticale mixture or spring triticale alone. This result suggests decreasing the proportion of grass species in the mixture tends to reduce the amount of forage biomass produced (Table 1).

Forage CP concentration and IVDMD were greater when peas were included in the mixture compared to mixtures with only grass species (Table 1). Similarly, ADF and NDF concentrations were lower for the three-way (oat/triticale/pea) and cocktail compared to oat or triticale alone, and oat/triticale mixture. The CP requirement for growing replacement heifers with body weight (BW) of 1200 lb at maturity ranged from 8.1% (with growing BW of 960 lb) to 10.2% (with growing BW of 660 lb) assuming the forage contains ≥ 60% total digestible nutrients (NRC, 2000). Therefore, average CP concentration of the CCs species and mixtures in this study were greater than the minimum CP requirement for growth or maintenance of grazing beef cattle.

Soil Water Content and Wheat Yield

In 2016, except for the grain pea treatment, growing a CC had no effect on soil water content at winter wheat planting. Spring pea yields averaged 850 lb/a in 2015, resulting in significantly greater water use. Growing a CC in 2016 and 2017 resulted in a significant decrease in soil water content at winter wheat planting (Figures 2a and 3a). Poor pea stands and less grain pea production in 2016 resulted in less water use compared to other CC treatments.

Winter wheat yields after CC corresponded well with soil water content at winter wheat planting. Wheat yields after CCs were not affected in 2016 except when peas were grown for grain (Figure 1b). However, a significant decrease in winter wheat yields was observed in 2017 when CCs were grown ahead of wheat (Figure 2b). The lesser water use by peas in 2016 resulted in less impact on subsequent wheat yields. Winter wheat yields with triticale alone or a pea CC (forage peas were grown in 2017 instead of grain peas because the wrong pea seed was supplied) were similar to the fallow treatment in 2018. Yields from the remaining CC treatments were less than that of fallow. Averaged across the 3 years, growing a CC ahead of wheat reduced winter wheat yields compared to chem-fallow. Wheat yields ranged from 36.6 bu/a when oat CC was hayed to 49.4 bu/a with fallow (Figure 4). Over the 3-year study, haying or grazing a CC had no significant effect on wheat yields compared to yields when CC was left as cover (Figures 1b, 2b, and 3b). Similarly, soil moisture at winter wheat planting was not different among CC treatments or management options (Figure 4a). This finding suggests CC could be utilized for forage with similar impact on subsequent crop yields compared to when grown as a true CC. Though not shown in this report, CC management had no effect on sorghum grain yield in this study.

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National Research Council. 2000. *Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000*. Washington, DC: The National Academies Press. https://doi.org/10.17226/9791.

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Table 1. Forage yield and nutritive content[1] at heading, before grain fill of various cover crops and mixtures averaged over 3 years at the Kansas State University experiment fields at HB Ranch near Brownell, KS

Treatment	Yield	CP	ADF	NDF	IVDMD
	lb/a			%	
Oat-triticale (flex)[2]	3014 a[4]	11.6 c	37.1 b	62.9 bc	72.7 ab
Oat-triticale	3026 a	11.6 c	38.3 ab	64.8 ab	71.2 bc
Oat	2383 ab	11.9 bc	37.1 b	62.1 c	73.8 a
Triticale	2981 a	12.1 bc	38.8 a	65.3 a	69.7 c
Oat-triticale-pea	2440 ab	14.4 a	37.1 b	61.5 c	73.6 a
Cocktail[3]	2225 b	13.0 ab	37.2 b	61.8 c	73.8 a

[1]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).
[2]Only planted when there was adequate moisture.
[3]Species were spring oat, triticale, forage pea, buckwheat, turnip, and radish.
[4]Values within a column followed by the same letter (s) are not significantly different ($P < 0.05$).

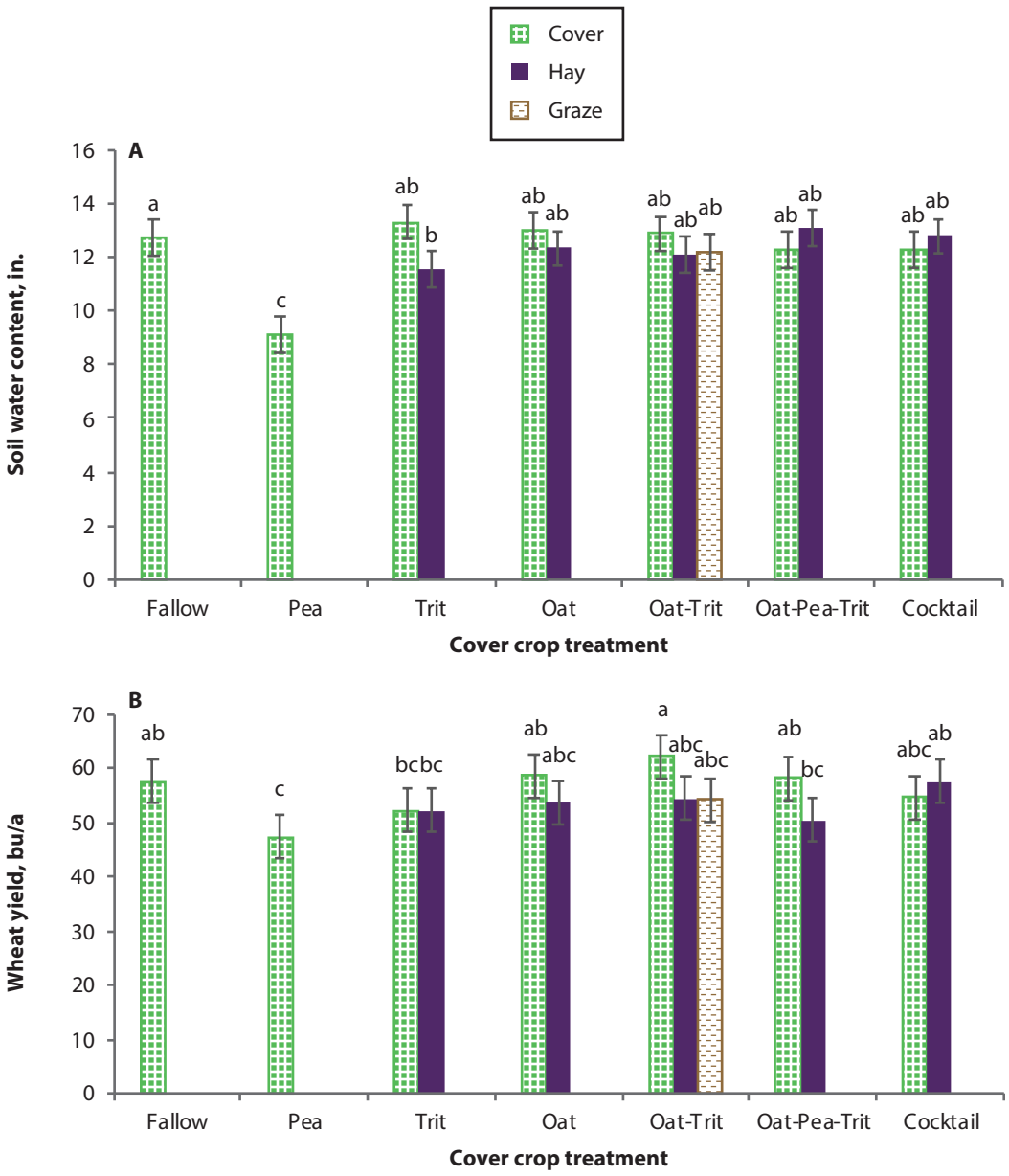

Figure 1. Cover crop management effect on soil water content (a) measured in fall 2015 and subsequent winter wheat yield (b) in 2016 at the Kansas State University experiment fields at HB Ranch near Brownell, KS.

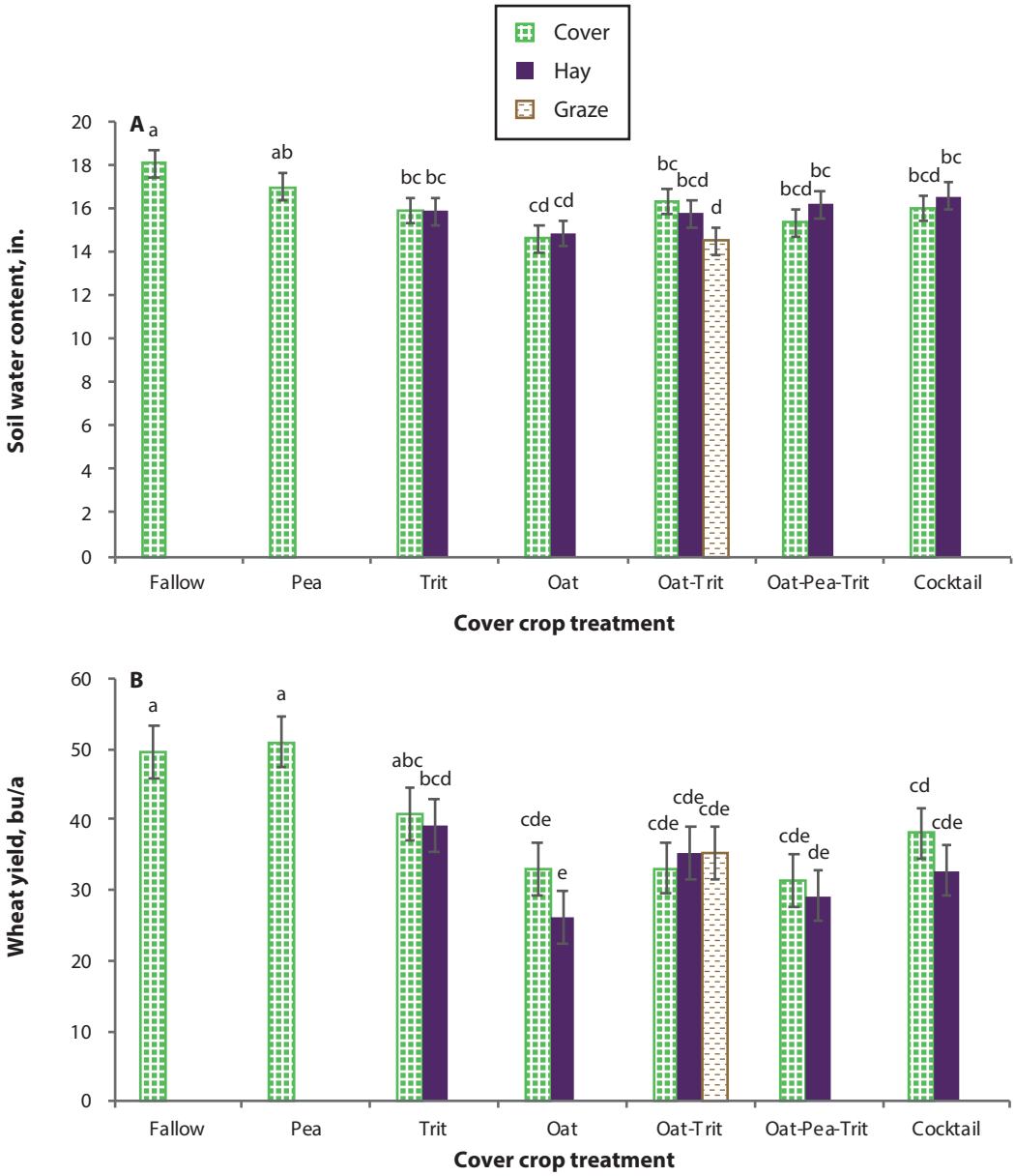

Figure 2. Cover crop management effect on soil water content (a) measured in fall 2016 and subsequent winter wheat yield (b) in 2017 at the Kansas State University experiment fields at HB Ranch near Brownell, KS.

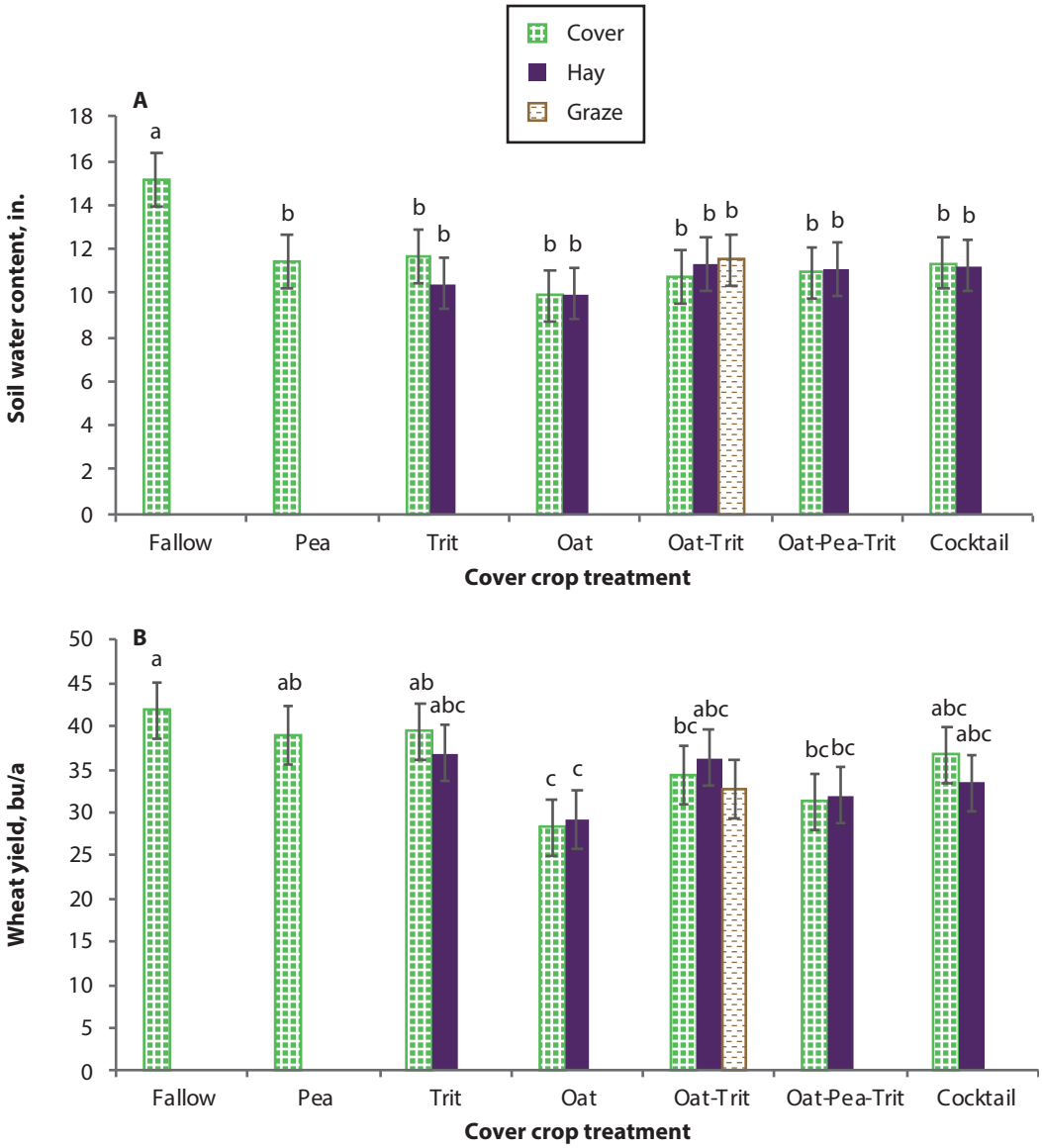

Figure 3. Cover crop management effect on soil water content (a) measured in fall 2017 and subsequent winter wheat yield (b) in 2018 at the Kansas State University experiment fields at HB Ranch near Brownell, KS.

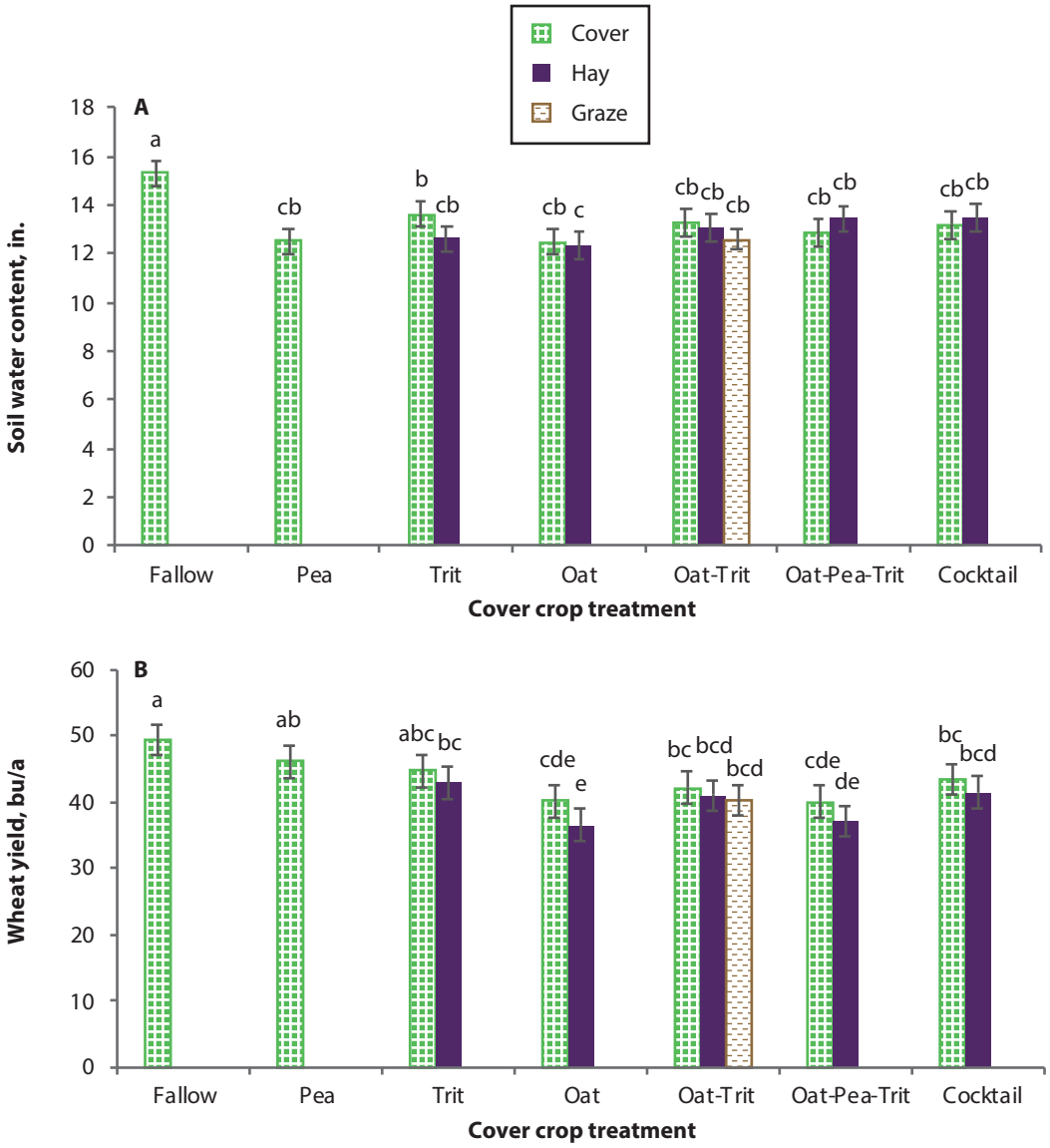

Figure 4. Soil water content (a) and winter wheat grain yield (b) as influenced by cover crop management averaged across three growing seasons (2015-2018) at the Kansas State University experiment fields at HB Ranch near Brownell, KS.

Integrated Wheat Management for Improved Wheat Yield and Protein in Kansas

B.R. Jaenisch and R.P. Lollato

Summary

In Kansas, seven to nine million acres of winter wheat are sown annually with grain yields averaging about 40 bu/a. Variety selection and management strategies are critical decisions to maximize wheat yield. Thus, the main objective of this experiment was to evaluate four wheat varieties and their response to six management strategies at three locations in Kansas. These strategies included a farmer practice, enhanced fertility, economical intensification, increased foliar protection, water-limited yield, and increased plant productivity. Locations were pooled based on tillage practice and environment within Kansas; conventional till in central (Hutchinson and Belleville), and no-till in western (Leoti). In the conventional till analysis, enhanced fertility increased grain yield from 63 bu/a in the farmer practice to 72 bu/a and no other management strategy further increased yields. Thus, WB4303, WB4458, and WB-Grainfield produced a similar grain yield of 72 bu/a; however, Zenda yield was less (68 bu/a). The water-limited yield treatment increased protein concentration from 11.7% in the farmer practice to 14.1%. Protein concentration was 13.1% and 13.6% for WB-Grainfield and WB4303, respectively. In the no-till analysis, the farmer practice and increased plant productivity yielded 51 bu/a and the enhanced fertility increased yields to 64 bu/a. Joe yielded 61 bu/a, which was significantly greater than WB4458 and Byrd (~57 bu/a). In the conventional till, farmer practice measured a protein concentration of 11.2%, which was increased to 12.8% and 13.2% by enhanced fertility and increased plant productivity, respectively. The wheat varieties WB-Grainfield, Joe, and Byrd all had a protein concentration of 12.4%, and WB4458 increased protein concentration to 13.3%. The grain yield and protein concentration of different varieties responded to increases in management input intensity depending on tillage practices and environments. Improved agronomic management based on variety-specific characteristics can help increase wheat productivity in Kansas.

Introduction

In Kansas, seven to nine million acres of winter wheat are sown annually with an average grain yield of about 40 bu/a. Variety selection and management strategies are critical decisions to maximize wheat yield and protein concentration. First, a variety has to be adapted to the specific environment (good yield record) and have other desirable agronomic traits such as high yield potential, strong straw strength, disease resistance, acid soil tolerance, or heat or drought stress tolerance. However, with many wheat varieties currently on the market, detailed information about how individual varieties respond to management is not available. Likewise, most of the wheat research conducted in Kansas and in the Great Plains has been performed under standard management levels and average yield conditions, with very few efforts to characterize how intensifying wheat management might improve crop yields. For instance, Jaenisch et al. (2019) reported that foliar fungicides were effective tools to improve wheat yield and profitability under

disease-conducive environments, and higher seeding rates in no-till, lower yielding environments. Meanwhile, Lollato et al. (2019) suggested that wheat yield response to seeding rate was null in high yielding environments, with extremely low populations allowing for achievement of high yields. These gaps warrant further research to evaluate variety-specific performance in a range of environments and their response to different management strategies.

Materials and Methods

Field experiments were conducted in a split-plot design with four replications for the growing season of 2018. Treatments were arranged in complete factorial structure with whole plot as management and sub-plot as winter wheat variety. Locations included North Central Experiment Field in Belleville (moderately well-drained Crete silt loam, 0–1% slopes), South Central Experiment Field in Hutchinson (well-drained Ost loam, 0–1% slopes), and Horton Seed Services in Leoti (well-drained Richfield silt loam, 0–1% slopes). All locations were grown under rainfed conditions and were chosen to help capture the variability in the environment throughout central and western Kansas and its role on maximizing winter wheat yields.

Wheat was sown into fallow conditions (no crop in the past 10–14 months) with a Great Plains 506 no-till drill (7 rows spaced at 7.5 inches) with plot dimensions of 4.375-ft wide × 30-ft long at all locations. Seed was treated with 5 oz Sativa IMF Max across the whole study so fungicide or insecticide was not a limiting factor. Conventional till sites included Belleville and Hutchinson (field cultivated multiple times prior to sowing), and conversely, Leoti was no-till following fallow after a grain sorghum crop.

In the fall of 2017, soil samples were taken at sowing at each location for soil nutrient analysis. Samples were taken by a hand push probe at two depths, 0–6 in. and 6–24 in., and a total of 15 cores were pulled per depth and combined to represent a composed sample at each location. Weeds were controlled to ensure they were not limiting factors by a pre- and post-emergence herbicide application. Insect pressure was not experienced in 2018.

Treatment combinations were designed to represent an integrated systems approach that a producer may perform during the growing season. Thus, four winter wheat varieties were sown at each location and these varieties were evaluated for their response to six management strategies. Wheat varieties were selected based on their adaptability to dryland cropping systems and response to management. In conventional till, varieties seeded were WB4303, WB4458, WB-Grainfield, and Zenda. No-till varieties seeded included Byrd, WB4458, WB-Grainfield, and Joe. Management strategies included a farmer practice (FP), enhanced fertility (EF), economical intensification (EI), increased foliar protection (IFP), water limited yield potential (Y_w), and increased plant productivity (IPP). The FP consisted of a seeding rate of 1.1 million seeds/a and nitrogen (N) application for a yield goal of the ten-year county wheat grain yield average. Enhanced fertility consisted of 100 lb of MESZ/a placed with the seed and additional N for a 100 bu/a yield goal applied at Feekes 3. Economical intensification consisted of EH plus one fungicide application at Feekes 10.5. Increased foliar protection consisted of EH plus two fungicide applications at Feekes 6 and 10.5. Water-limited yield potential consisted

of IPP plus a micronutrient (sulfur, zinc, manganese, boron) application at Feekes 6. Increased plant productivity consisted of Y_w; however, the seeding rate was reduced to 430,000 seeds/a. A detailed description of treatments is in Table 1.

A pressurized CO_2 backpack sprayer with a three-nozzle boom was used to apply the N, fungicide, and micronutrients. Thus, N was applied with a streamer nozzle (SJ3-03-VP), and the rate varied between locations due to the N carryover from the previous growing season. Likewise, the backpack sprayer was used with a flat fan (XR11002) to apply a single or dual fungicide and micronutrient applications. Single fungicide was applied at 7 oz/a, dual fungicide at 13 oz/a, and micronutrient at 2 gal/a, respectively with a constant volume of 15 gallons of water/a.

Results

Weather

The 2017–18 wheat growing season had a cold and dry winter and early spring, and a hot and dry late spring/early summer. The drought and cool temperatures kept the wheat crop dormant until late April and the reduced rainfall in the spring reduced spring tillering and incorporation of fertilizer in the root zone, thus decreasing spikes per foot. Belleville and Hutchinson received 60% and 55%, respectively, of their annual rainfall during the growing season. Likewise, Leoti received 75% of its annual rainfall for the season, but two inches of rainfall were received a week before harvest when the crop was already mature. Not considering this rainfall, the total was 41% for the growing season. Temperatures were above normal for May and June, thus crop development was accelerated in the later part of the cycle, which decreased yield potential as grain filling was reduced. This experiment was sown into fallow to measure the genetic potential of these varieties, and the yields were above normal. Wheat yields ranged from 63–75 bu/a in Belleville and Hutchinson and 51–64 bu/a in Leoti.

Wheat Grain Yield

A significant treatment effect for grain yield occurred for both variety and management but not the interaction, at all locations. In the conventional till, EF increased grain yield from 63 bu/a for the FP to 72 bu/a and no other management strategy further increased yields (Table 2). Interestingly, decreasing plant population to 430,000 seeds/a as compared to 1.1 million seeds per acre did not reduce wheat yield. This was likely due to a combination of high fertility and pesticide inputs and planting in the early side of the optimum sowing date (see comparison between 'Water limited yield' and 'Increased plant productivity' in Table 2). The varieties WB4303, WB4458, and WB-Grainfield all had statistically similar yields of approximately 72 bu/a; however, Zenda resulted in a lower yield of 68 bu/a.

In the no-till, management strategies responded differently than the conventional till. The FP and IPP both had the lowest yield of 51 bu/a, suggesting that reducing plant population in this location was detrimental to yields. This was likely because the location was planted in the later portion of the optimum planting dates due to above average rainfall in the early portion. The EH and EI increased yields to 64 and 62 bu/a, respectively. However, the Y_w produced yields of 60 bu/a which was lower than EH, EI and IFP. The variety Joe yielded 61 bu/a, which was significantly higher than WB4458

and Byrd that produced yields of 58 and 57 bu/a, respectively. WB-Grainfield produced the lowest yield of 55 bu/a in the no-till.

Grain Protein Concentration

A significant treatment effect for grain protein concentration was measured for both main effects of variety and management but not for the interaction. In the conventional till, the Y_w increased grain protein concentration from 11.7% in the FP to 14.1%, and the EH, IFP, and IPP produced a similar protein concentration. WB-Grainfield and WB4303 measured the lowest (13.1%) and highest (13.6%) protein concentrations across all wheat varieties, respectively. WB4458 produced a similar protein to WB4303 and Zenda produced similar protein to WB-Grainfield. In the no-till, grain protein concentration was 11.2% for the FP and increased to 12.8% by the EH, EI, IFP, and Y_w, then further increased to 13.2% by the IPP. The wheat varieties WB-Grainfield, Joe, and Byrd all produced a similar protein concentration of 12.4%, however, WB4458 had greater protein concentration (13.3%).

Preliminary Conclusions

These preliminary results suggested that seeding rates can be reduced when high inputs are provided, but for this system to work, sowing needs to occur in the early portion of the optimal season. Also, moisture is required to ensure tillering and spike number. Different varieties responded similarly to input levels, but had different yield potentials; thus, careful evaluation of long-term and several locations of variety performance data are needed to justify variety selection. Protein concentration increased mainly due to the greater fertilizer amount in the EF treatment. Varieties differed in protein concentration; thus, if a producer has the opportunity to receive a premium for high protein wheat, variety selection for this trait should also be considered. This experiment reinforced the use of integrated management strategies, and provides new information on the production of tillering/spike capacity and protein concentration of these varieties.

Acknowledgments

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Table 1. Treatment description of six management strategies studied for possible options to increase wheat yield.

	Management strategy					
Treatments	FP	EF	EI	IFP	Y_w	IPP
Nitrogen application for yield goal, bu/a	40	100	100	100	100	100
Seeding rate, million seeds/a	1.1	1.1	1.1	1.1	1.1	0.43
In-furrow starter fertilizer	No	Yes	Yes	Yes	Yes	Yes
Fungicide	No	No	1x	2x	2x	2x
Micronutrients	No	No	No	No	1x	1x

FP = farmer practice. EF = enhanced fertility. EI = economical intensification. IFP = increased foliar protection. Y_w = water-limited yield potential. IPP = increased plant productivity.

Table 2. Average winter wheat grain yield (bu/a) and wheat grain protein concentration (%) as affected by management strategy and winter wheat varieties for the conventional till (Belleville and Hutchinson), and no-till (Leoti) for the 2017–18 Kansas growing season

	2017–18			
Treatment	No-till	Conventional till	No-till	Conventional till
	bu/a		%	
Management strategy				
Farmer practice	51±2†c‡	63±3b	11.2±0.2c	11.7±0.3c
Enhanced fertility	64±2a	72±3a	12.8±0.2b	13.6±0.3ab
Economical intensification	62±2ab	74±3a	12.8±0.2b	13.4±0.3b
Increased foliar protection	60±2ab	72±3a	12.9±0.2ab	13.8±0.3ab
Water limited yield potential	60±2b	75±3a	12.9±0.2ab	14.1±0.3a
Increased plant productivity	51±2c	74±3a	13.2±0.2a	13.6±0.3ab
Winter wheat varieties				
Zenda	NA	68±2b	NA	13.3±0.2bc
WB4303	NA	72±2a	NA	13.6±0.2a
WB-Grainfield	55±1c	72±2a	12.4±0.1b	13.1±0.2c
WB4458	58±1b	73±2a	13.3±0.1a	13.5±0.2ab
Joe	61±1a	NA	12.4±0.1b	NA
Byrd	57±1b	NA	12.4±0.1b	NA

†Standard error of the difference.

‡Letter differences indicate that treatment was significantly different at $P < 0.05$ from the other treatments within the same column under each respective treatment of either management strategy or winter wheat variety.

Winter wheat varieties sown were KSU Zenda, WB 4303, WB Grainfield, and WB 4458 in conventional till, and WB Grainfield, WB 4458, CSU Byrd, and KSU Joe in no-till. Management strategies evaluated were farmer practice, enhanced fertility, economical intensification, increased foliar protection, water-limited yield potential, and increased plant productivity.

Wheat Variety Response to Seeding Rate in Kansas During the 2018–19 Growing Season

R.P. Lollato, L. Molssato, C. Rapolla, G. Zhang, and A. Fritz

Summary

Different wheat varieties might require different seeding densities to maximize yield. Thus, the main objective of this project was to better understand the response of different wheat varieties to different seeding rates. Three field experiments were conducted during the 2017–18 growing season evaluating six wheat varieties subjected to five different seeding rates (0.6, 0.95, 1.3, 1.65, and 2.0 million seeds per acre). Crop was managed for a 70 bu/a yield goal and pests were controlled using commercially available pesticides. We measured final stand and grain yield, and all statistical analyses were performed for relating emerged plants per acre to grain yield. At each individual environment and across varieties, grain yield usually maximized at approximately 0.9 million emerged plants per acre. There were significant differences among varieties in grain yield, with Joe and Tatanka usually outperforming the remaining tested varieties. Across environments, grain yield usually maximized at populations between 0.6 and 0.7 million plants per acre for less responsive varieties (1863, Everest, and Tatanka), at approximately 0.9 million plants per acre for average responsive varieties (Joe, Bob Dole, KanMark, and Zenda), and greater than 1.05 million emerged plants per acre for more responsive varieties (Larry and AG Icon). These preliminary data suggest that there is the potential to manage each wheat variety according to its individual tillering potential, but more data are needed to take definite conclusions about each variety's optimum seeding rate. Thus, this experiment is being conducted at five sites during the 2017–18 growing season.

Introduction

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

Procedures

Experiments were conducted in three Kansas locations during 2017–18, including Hutchinson, Hays, and Leoti. Trials were planted at the optimum date in Hutchinson (10/5/2017), and towards the late side of the optimal date in Hays (10/3/2017) and in Leoti (10/9/2017). Trials were established in a randomized complete block design with four replications. Five varieties (i.e. KanMark, Larry, Zenda, Tatanka, and Joe) were planted at all locations, and Bob Dole and an experimental line were also planted in Hutchinson and Hays. The five studied seeding rates were 0.6, 0.95, 1.3, 1.65, and 2 million seeds per acre. Plots in Hutchinson and Leoti were 7 rows wide at a 7.5 inch row spacing by 30-ft long; while plots in Hays were 6-ft wide (six 10-inch spaced rows) by 10-ft long.

Management practices adopted at all locations consisted of best management practices as described by Kansas State University for insects, weeds, and diseases. Nitrogen (N) fertilization at all locations was performed with a yield goal of approximately 70 bushels per acre. Agronomic measurements included stand count approximately 3–4 weeks after planting and grain yield at harvest maturity. Plots were harvested using a small plot combine at all locations, and grain yield was adjusted to a 13% moisture basis.

Results

Growing Season Weather

The weather during the 2017–18 growing season had sufficient moisture for a uniform emergence at all locations, but was dry during the fall, winter, and spring. Growing season precipitation total was about 50% of the long-term precipitation at all locations, somewhat limiting grain yield. However, precipitation was well-distributed, and thus, yields were still relatively high, especially in Hutchinson.

Stand Establishment

The trials were sown into adequate moisture at all locations, which ensured good germination and stand establishment. Nonetheless, average percent establishment (final stand over targeted seeding rate) was closer to the target at lower seeding rates as compared to higher seeding rates at all locations (Figure 1). Beyond 233, 265, and 283,000 plants per acre, actual stands only increased 59, 52, and 43% as compared to the target in Hays, Hutchinson, and Leoti, respectively (Figure 1).

Wheat Grain Yield Response to Seeding Rate and Variety by Location

There was a great difference in yield potential among study locations, with average yield across all varieties and plant population densities ranging from 31 bushels per acre in Hays, to 69 bu/a in Leoti, to 81 bu/a in Hutchinson. At all individual studied locations, grain yield was significantly affected by variety, but plant population was only significant in Hays and Leoti (Figure 2).

In Hays, grain yield increased in a quadratic shape in response to seeding rate, with agronomic optimum yield at about 1,500,000 plants per acre. Varieties significantly affected wheat yield, with the highest yields achieved by KanMark, Joe, and Tatanka (Figure 2). Meanwhile, Bob Dole and the experimental line resulted in the lowest yield. In Leoti, wheat yield responded linearly to increases in seeding rate across the range of seeding rates studied. This was likely a function of the relatively late sowing

date (October 7, 2017) as compared to the optimum (around September 25). Varieties yielded differently as well, with Joe and Larry resulting in the highest yield, while Zenda resulted in the lowest yield (Figure 2). In Hutchinson, there was no wheat yield response to plant population (Figure 2). This was likely because the trial was sown at the optimum time and had enough time, moisture, and fertility to tiller in the fall. This trial was also higher yielding, suggesting less response to seeding rate at higher yielding environments. Similar findings were reported by Lollato et al. (2019). However, there was a significant variety effect, with Joe, Larry, and Tatanka resulting in the highest yields; while Bob Dole, KanMark, and Zenda resulted in the lowest yields (Figure 2).

Wheat Variety Response to Plant Population

In order to combine locations to evaluate wheat variety response to population, we used the yields relative to the maximum yield achieved by each variety in each location (Figure 3). This analysis suggested that the different varieties responded differently to seeding rate. For instance, the yield of Joe and KanMark followed a quadratic response to plant population, with maximum yields achieved at about 1,300,000 plants per acre for Joe and 1,000,000 plants per acre for KanMark (Figure 3). The grain yield response of Bob Dole and Zenda, on the other hand, increased with increases in plant population to values beyond the ones included in this study. These responses were likely affected by the late-sowing of the three site years included in this analysis. Meanwhile, the responses of Larry and Tatanka were almost null, non-significant quadratic models (Figure 3).

Preliminary Conclusions

The data collected in this research suggest that wheat yield response to plant population is weak or non-existing in high yielding environments planted at the optimum time; and is quadratic or linear in site years with lower yield environments planted towards the late side of the optimum sowing date. While we cannot conclude firmly about each variety's response to seeding rate, we showed evidence for variety-specific response across the three site years. These data will be combined with another six site years of seeding rate studies to increase the power of the data and to allow for stronger conclusions and improve recommendations for each variety.

Acknowledgments

We thank the Kansas Wheat Alliance for partially funding this field research. We also thank the undergraduate students and visiting scholars within the K-State Wheat Production Group for all their efforts to help us collect field data for this project.

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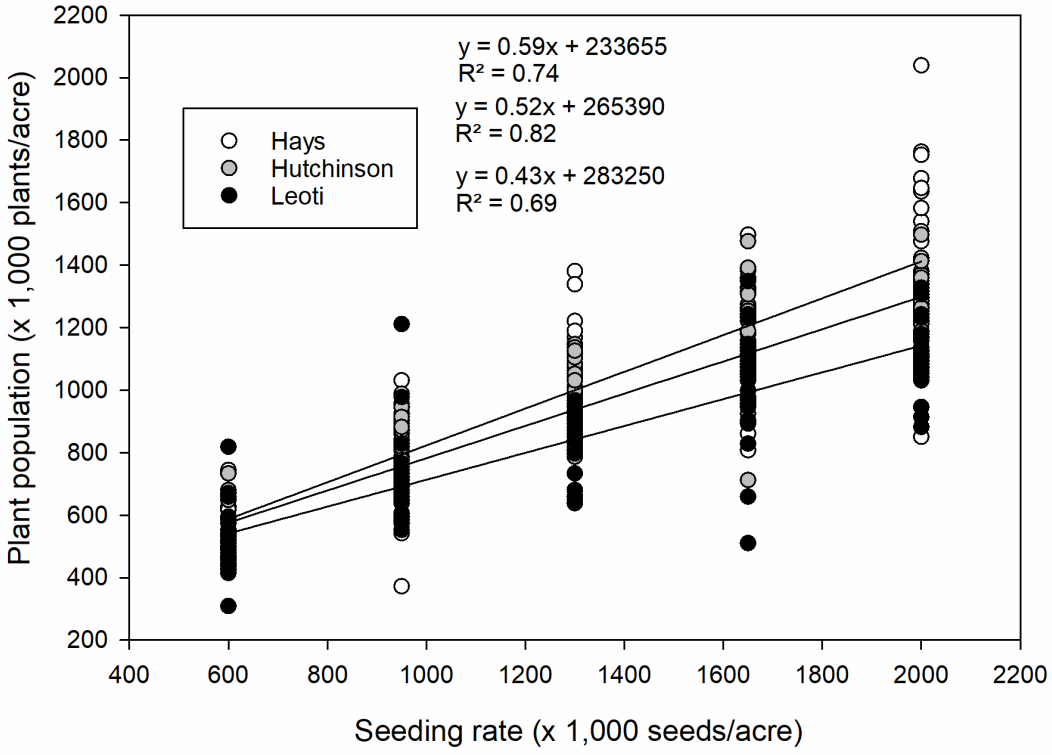

Figure 1. Final plant stand as affected by seeding rate in Hutchinson, Leoti, and Hays, during the 2017–18 growing season.

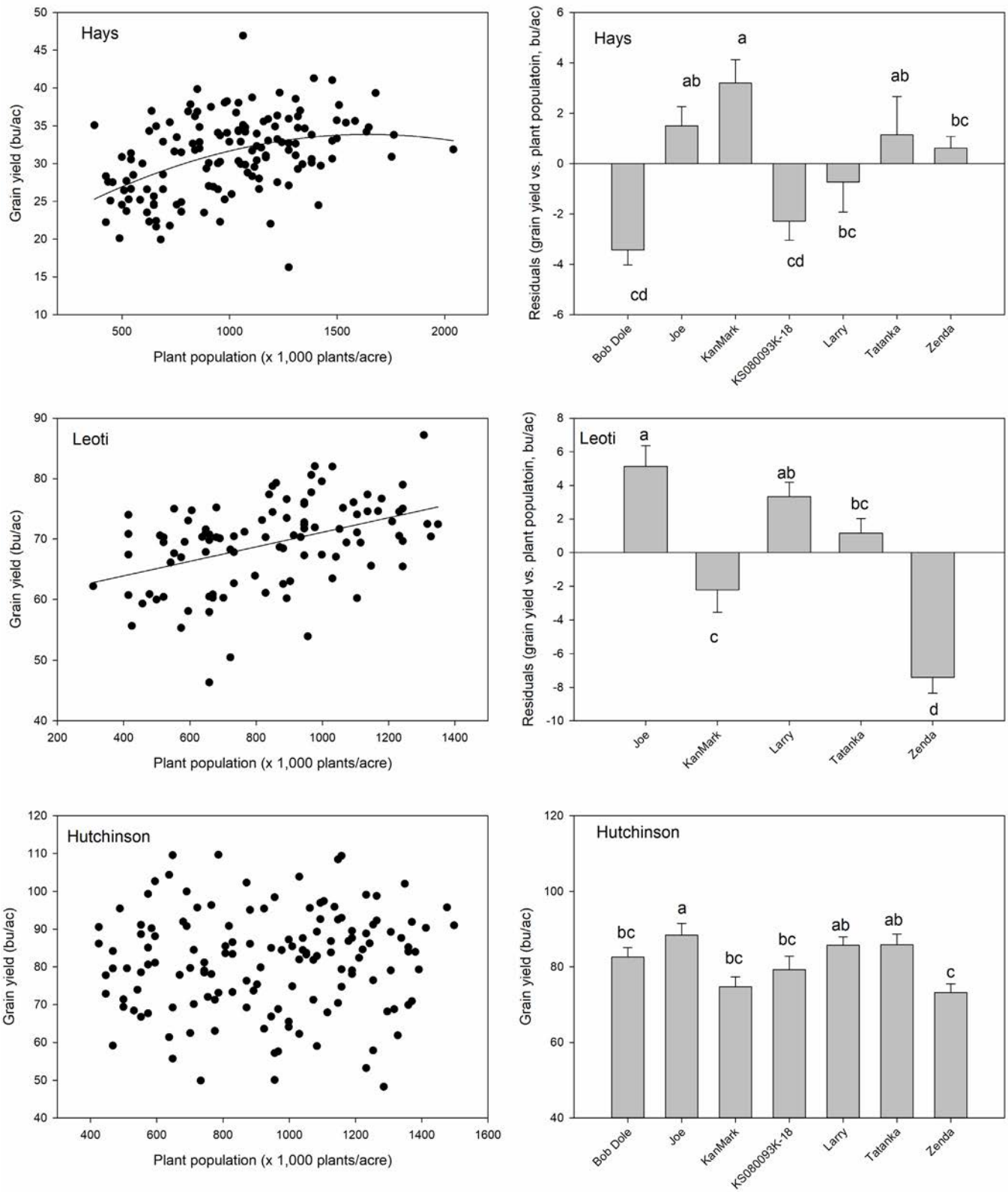

Figure 2. Wheat grain yield response to plant population (left panels) and variety (right panels) at Hays (top panels), Leoti (middle panels), and Hutchinson (lower panels). When regression between seeding rate and yield was significant, the effect of variety was evaluated as the residuals between the regression and each observation (deviation from the regression line).

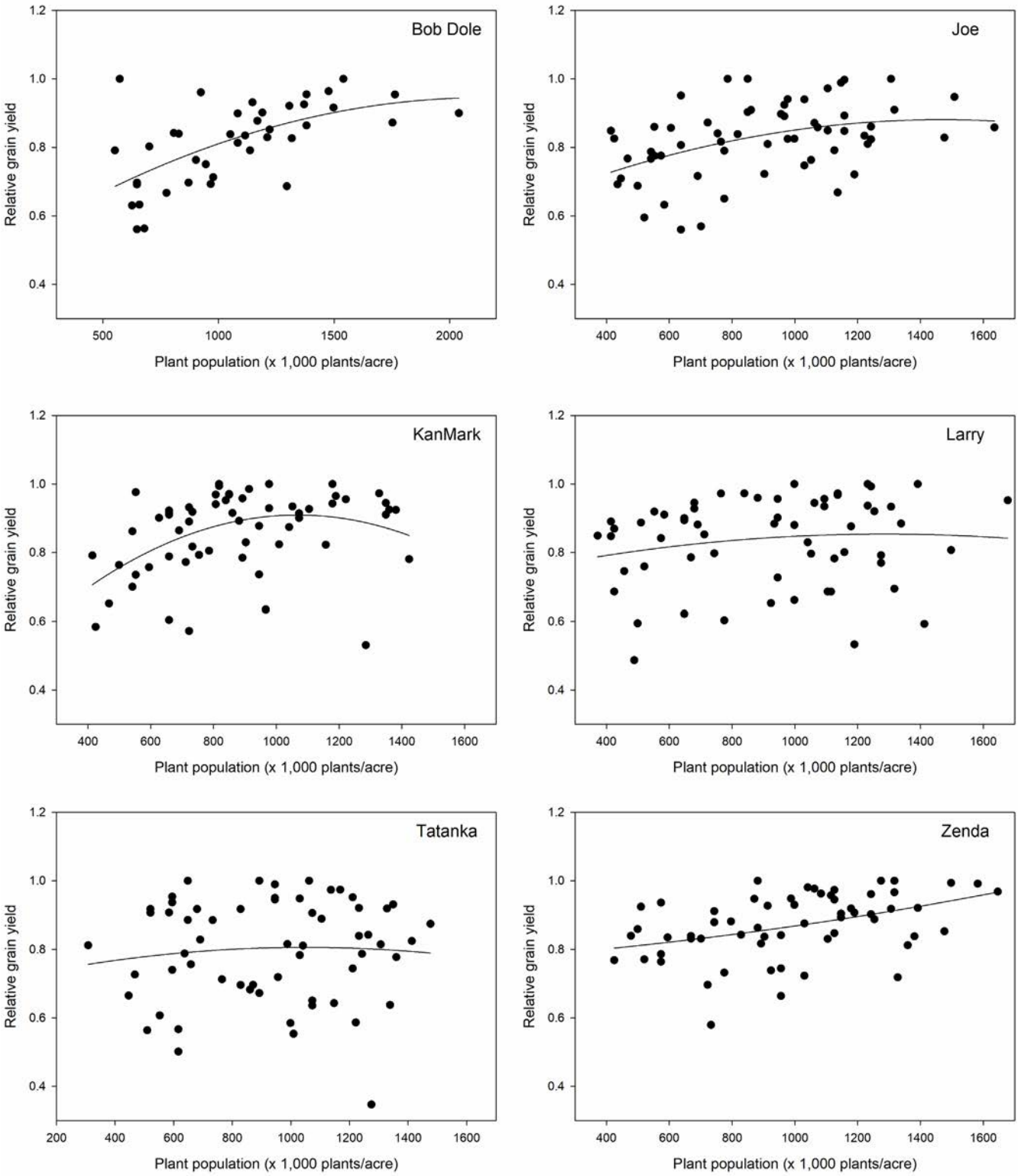

Figure 3. Relative wheat grain yield (calculated nested within location) as affected by plant population for six wheat varieties pooled across the three locations.

Intensive Wheat Management for Yield and Quality: The Role of Variety, Environment, and Management Practices

R.P. Lollato, B.R. Jaenisch, and D. Marburger

Summary

Management (M), variety (V), and environment (E) greatly influence wheat yield and quality. With the objective of determining the partial influence of V, E, and M, we conducted a field experiment where we imposed four management intensities to five wheat varieties during six site-years in Kansas and Oklahoma. Management intensities were 1) low-input (N fertility for a yield goal of 60 bu/a); 2) high-input (foliar fungicide, sulfur and chloride fertilizers, growth regulator, and nitrogen (N) fertility for a yield goal of 100 bu/a); 3) high-input minus fungicide; and 4) high-input minus additional N. We selected commonly grown wheat varieties with contrasting yield potential and quality characteristics. We used a split-plot design with M as whole-plots (established in randomized complete block design), and V as sub-plot (completely randomized within whole-plot). Variance component analyses suggested that E accounted for 63% of the variability in wheat yield and 55% of the variability in grain test weight; G accounted for 1 and 23% of the variability in yield and test weight, and M accounted for 1% of the variability of both. The interactions V × G and E × M accounted for 4 and 9% of the variability in yield, and 10 and 1% of the variability in test weight, respectively. Analysis of variance pooled across the entire dataset considering V and M fixed and E random suggested a significant G × M interaction on yield, which ranged from 49–61 bu/a. Meanwhile, both V and M affected test weight, which ranged from 52–58 lb/bu for the different V and from 55–57 lb/bu for the different M. These results suggest that E has the greatest impact in yield and quality, but there is room for yield improvement through V-specific M, and for quality improvement through V and M separately.

Introduction

Wheat yields in Kansas average about 40 bu/a, which corresponds to about 52% of their potential that is estimated at 77 bu/a (Lollato et al., 2017; Lollato et al., 2019). While managing the crop for the yield potential is typically not economical, this large gap between actual and potential yield suggests that yields could be economically improved to ~54 bu/a, or 70% of the potential (Lobell et al., 2009). Increases in wheat yield will result from improving management of high-yielding cultivars, and will ultimately be dictated by the interaction with environment. Beyond yield, wheat quality attributes are also important for the end user. The effects of G and M combined can account for as much as 46% of the variability in wheat quality, while the effects of environment range from 3–76%, depending on growing season and quality parameter (Rozbicki et al., 2015). Given the large yield gap in Kansas and the importance of yield and quality to maximize producers' profitability, our objectives were to estimate the partial influence of G, E, and M on winter wheat yield and quality, and to explore opportunities to better manage both attributes.

Procedures

Field trials were conducted during two winter wheat growing seasons, including the 2016–17 (Manhattan and Hutchinson, KS) and the 2017–18 (Manhattan and Belleville, KS; and Stillwater and Perkins, OK). The treatments evaluated here were selected as a follow-up study to that conducted by Jaenisch et al. (2019). We used a split-plot design with main plots arranged as randomized complete block design and sub-plots completely randomized within main plots with four replications. Main plots were four management strategies: 1) low-input (N fertility for a yield goal of 60 bu/a); 2) high-input (two foliar fungicide applications, sulfur and chloride fertilizers, plant growth regulator, and additional N fertilizer for a yield goal of 100 bu/a); 3) high-input minus foliar fungicide; and 4) high-input minus additional N fertilizer. Sub-plots were five commonly grown hard red winter wheat varieties with contrasting yield potential and quality characteristics: WB4458, WB-Grainfield, WB4269, WB4303, and WB4515. Grain yield and grain test weight were measured at harvest maturity and corrected to 13.5% moisture content.

We performed a two-way analysis of variance (ANOVA) using PROC GLIMMIX in SAS v. 9.4 (SAS Inst. Inc., Cary, NC) for the data combined across environments. Fixed effects were variety, management, and their interaction. Random effects were environment, block nested within environment, and the interaction of management and block nested within environment. An analysis of adaptability was performed in which yield gain (the difference between high-input and low-input) was regressed against mean environment yield for each variety. The slope of this relationship was assessed to understand variety-specific yield adaptability.

Results

Environment accounted for the largest proportion in both yield and test weight variability (63 and 55%, respectively) (Table 1). For grain yield, the next largest factors accounting for the variability were the interactions E × M (9%) and E × G (4%). The largest manageable factor accounting for grain test weight variability was G (23%) and E × G (10%).

The varieties WB-Grainfield, WB4303, WB4458, and WB4515 followed the same trend, in that the low input and the high input minus fungicide treatments had the lowest yield, while the high-input had the highest yield (Figure 1). Removing N from the high-input did not decrease yields to the same extent as removing foliar fungicide. On the other hand, the variety WB4269 did not respond significantly to improved management (Figure 1).

The most responsive variety was WB4303, with a yield gain of 0.59 bu/a in response to the high-input treatment for each bu/a increase in mean environment yield (Figure 2). The varieties WB4269, WB4515, and WB-Grainfield all responded similarly to increases in yield environment, at about 0.35-0.38 bu/a for every bu/a environment yield increase (Figure 2). The yield gain from the variety WB4458 was about 7 bu/a and was independent of environment yield.

Differences in grain test weight between varieties were as large as 6 lb/bu, with WB4303 resulting in the lowest test weights among the studied varieties (Figure 3). Meanwhile,

WB-Grainfield and WB4458 had a lower test weight than WB4269, which had lower test weight than WB4515. Regarding management, removing foliar fungicide from the high-input treatment reduced grain test weight by 2 lb/bu.

Preliminary Conclusions

These data confirm that the environment is the major player for both yield and test weight. However, it also suggests that there is room to optimize management for grain yield according to environment and variety. For grain test weight, there was also room to select varieties with higher test weight and, to a lower extent, apply foliar fungicide.

Acknowledgments

We thank Andrew Esser, Keith Thompson, Dustan Ridder, and Robert Calhoun for helping us with project establishment, management, and harvest at the experiment fields. We also thank the Kansas Wheat Commission for partial funding for this research. Finally, we thank Grain Craft for analyzing all the samples collected from this research for milling and baking quality (data not shown in this report).

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Table 1. Variance component analysis of the individual effects of variety (V), management (M), environment (E), and their interactions on wheat grain yield and grain test weight variability

	Yield		Test weight	
Source of variation	Variance	% Variance	Variance	% Variance
V	3	1	5	23
M	2	1	0	1
V × M	1	0	0	0
E	150	63	12	55
E × V	10	4	2	10
E × M	21	9	0	1
V × E × M	0	0	0	2
Block (E)	21	9	0	1
Error	30	13	1	6
Total	238	100	22	100

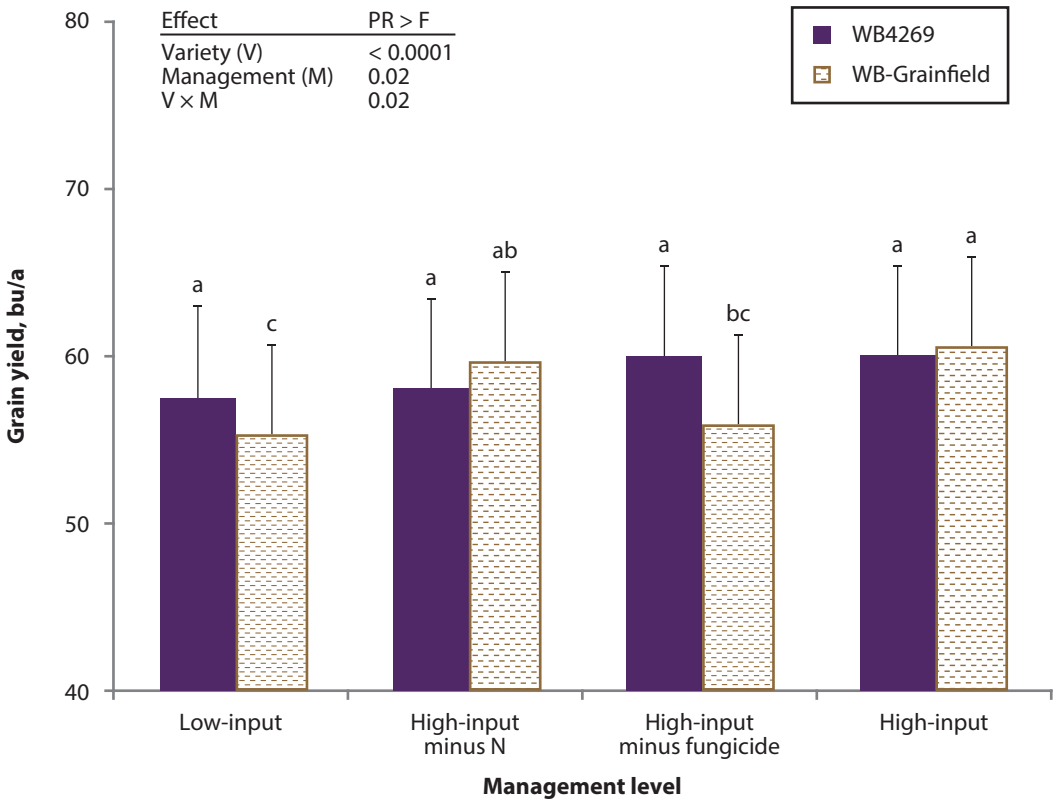

Figure 1. Wheat grain yield as affected by variety and management level. Significance of effects from analysis of variance is shown in the inset table. Bars followed by the same letter indicate lack of statistical difference between management practices within variety.

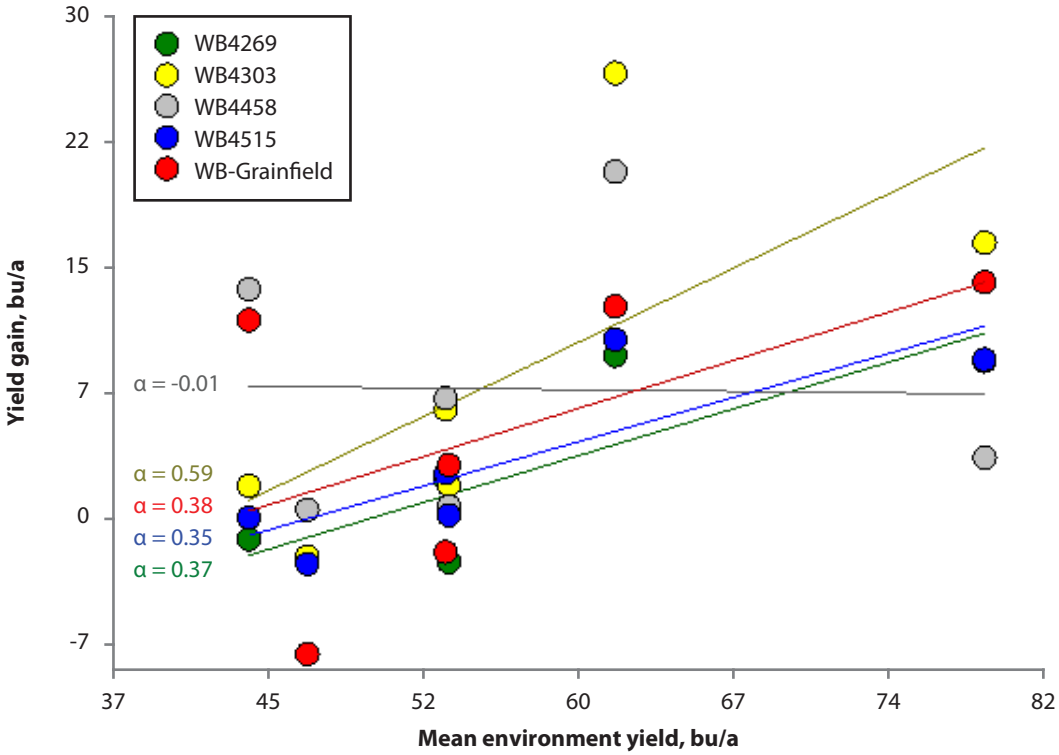

Figure 2. Variety-specific yield gain in response to intensive management according to the mean environment yield. Yield gain was calculated as the mean yield in the high-input management minus the mean yield in the low-input management at each environment. The slopes of the linear regression (α) are also shown, representing each variety's responsiveness to increases in environmental yield potential.

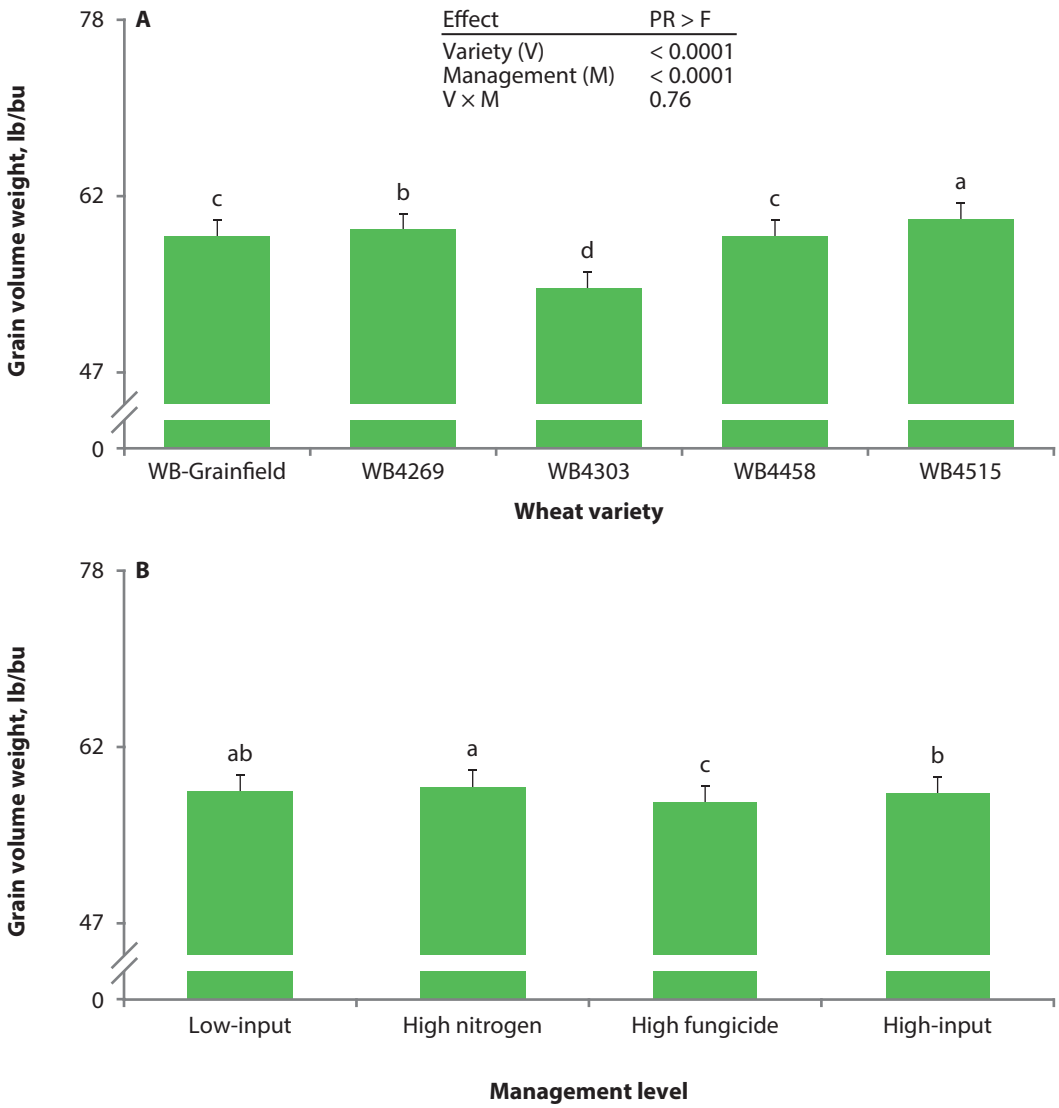

Figure 3. Wheat grain test weight response to (a) variety and (b) management level. Significance of effects from analysis of variance (ANOVA) is shown in the inset table.

Plant Growth Regulators to Decrease Wheat Height in High Fertility Scenarios

F.D. Spolidorio and R.P. Lollato

Summary

Lodging is a common concern in wheat production, and its intensity depends on many factors including the straw strength of the variety, nitrogen (N) levels, and plant growth regulator (PGR). However, there are limited data exploring how current Kansas wheat varieties respond to PGR applications at different fertility levels. Thus, our objective was to assess the effects of PGR on wheat varieties exposed to different levels of N fertilization. A field trial was established in a split-split-plot design and four replications in two Kansas locations (Great Bend and Ashland Bottoms) during the 2017–18 growing season. Factors evaluated were two N levels as whole plots (e.g., for a yield goal of 55 versus 73 bu/a), two varieties as sub-plot (below average straw strength with 1863 and above average straw strength with WB-Grainfield), and PGR (control versus 14.4 fl oz/a of Palisade applied at jointing). Due to an extremely dry growing season, biomass production was decreased and no lodging was observed. Still, the application of PGR decreased plant height at both locations by 0.6–1 inch, although this decrease depended on fertility level at the Great Bend site. WB-Grainfield was typically taller than 1863, regardless of location evaluated. Despite its effect of reducing plant height, grain yield was unaffected by PGR application. In Great Bend, grain yield was only affected by variety; while an interaction of variety × fertility affected grain yield in Ashland Bottoms. These results are promising as there was no yield drag from PGR applications despite an extremely dry growing season.

Introduction

Lodging is a common concern in wheat production, potentially decreasing wheat yield due to reduced light interception and difficulty in harvesting lodged crops (Berry et al., 2004). Lodging is an especially important concern in high-yielding systems and irrigated fields (Lollato and Edwards, 2015; Lollato et al., 2019). Factors affecting a wheat crop's lodging potential include excessive N fertilization (Berry et al., 2000) and variety selection, with straw strength of individual varieties as an important consideration. Sometimes, producers consider the use of PGRs as an alternative to potentially reduce lodging (Nafziger et al., 1986). According to Jaenisch et al. (2019), the most commonly used PGRs are ethephon, chlormequat chloride, and trinexapac-ethyl. Although PGRs can reduce the risk of lodging, their effects on grain yield have been inconsistent (Nafziger et al., 1986; Mohamed et al., 1990; Knott et al., 2016), and data on the effects of PGR on Kansas wheat are scarce. Thus, more research is needed to elucidate the effects of PGR on different modern hard red winter wheat varieties with contrasting straw strengths. Thus, our objective was to assess the effects of PGR on wheat varieties exposed to different levels of N fertilization.

Procedures

Field trials were conducted during the 2017–18 growing season at two Kansas locations (Ashland Bottoms and Great Bend). Trials were planted at the optimum sowing

window at 75 lb of seed per acre. The trials were established in a split-split plot design with fertility as the main factor, variety as the sub-factor, and PGR as the sub-sub factor. The two fertility levels evaluated included N rates sufficient to achieve a yield goal of 55 bu/a (hereafter referred to as 'standard fertility') and 73 bu/a (hereafter referred to as 'high fertility'). Wheat varieties selected for this trial were 1863 (poor straw strength) and WB-Grainfield (good straw strength). Plant growth regulator treatments were either a control (no PGR application) or Palisade (12% trinexapac-ethyl) applied at 14.4 fl oz/a during jointing (Feekes GS 6). Measurements included lodging scores, plant height at maturity, and grain yield corrected to 13.5% moisture content.

We performed a three-way analysis of variance (ANOVA) using PROC GLIMMIX in SAS v. 9.4 (SAS Inst. Inc., Cary, NC) for the data by locations. Fixed effects were fertility, variety, PGR, and all possible interactions. Random effects were replication and the interaction of fertility and block.

Results

The weather during the 2017–18 wheat growing season was not conducive to lodging. All trials had a good stand establishment due to precipitation prior to or immediately after sowing, but a dry fall, winter, and spring limited crop biomass production and consequently, lodging.

Nonetheless, the application of PGR decreased plant height at both studied locations (Figures 1 and 2). In Ashland Bottoms, plant height was affected by PGR, and by the interaction between variety and fertility (Figure 1). Application of Palisade at jointing decreased wheat height at maturity by 1 inch, and the increased fertility increased plant height for both varieties (1 inch for 1863 and 2.3 inches for WB-Grainfield) (Figure 1). In Great Bend, plant height was affected by the main effect variety, and by the interaction between fertility and PGR (Figure 2). For the variety effect, WB-Grainfield was approximately 1.1 inches taller than 1863 (Figure 2). For the PGR × fertility interaction, application of Palisade did not affect plant height at the standard fertility level, but decreased plant height by 0.6 inch in the high fertility treatment level (Figure 2).

Grain yield was affected either by variety (Great Bend) or by the interaction between variety and fertility (Ashland Bottoms), with no effect of PGR (Figure 3). In Great Bend, WB-Grainfield yielded about 840 lb/a more than variety 1863 (Figure 3). In Ashland Bottoms, the high fertility treatment increased wheat grain yields by 225 lb/a for the variety 1863, and by 836 lb/a for the variety WB-Grainfield.

Preliminary Conclusions

These data are resulting from a single growing season in which weather conditions were not conducive to lodging. Thus, more data are needed to evaluate the effects of PGR on higher yielding conditions. Nonetheless, these results are promising, as no yield drag resulted from the application of PGR despite resulting in shorter plants.

Acknowledgments

We thank Dustan Ridder for helping us with project establishment, conduction, and harvest at the experiment fields. We also thank the Kansas Wheat Commission for partial funding for this research.

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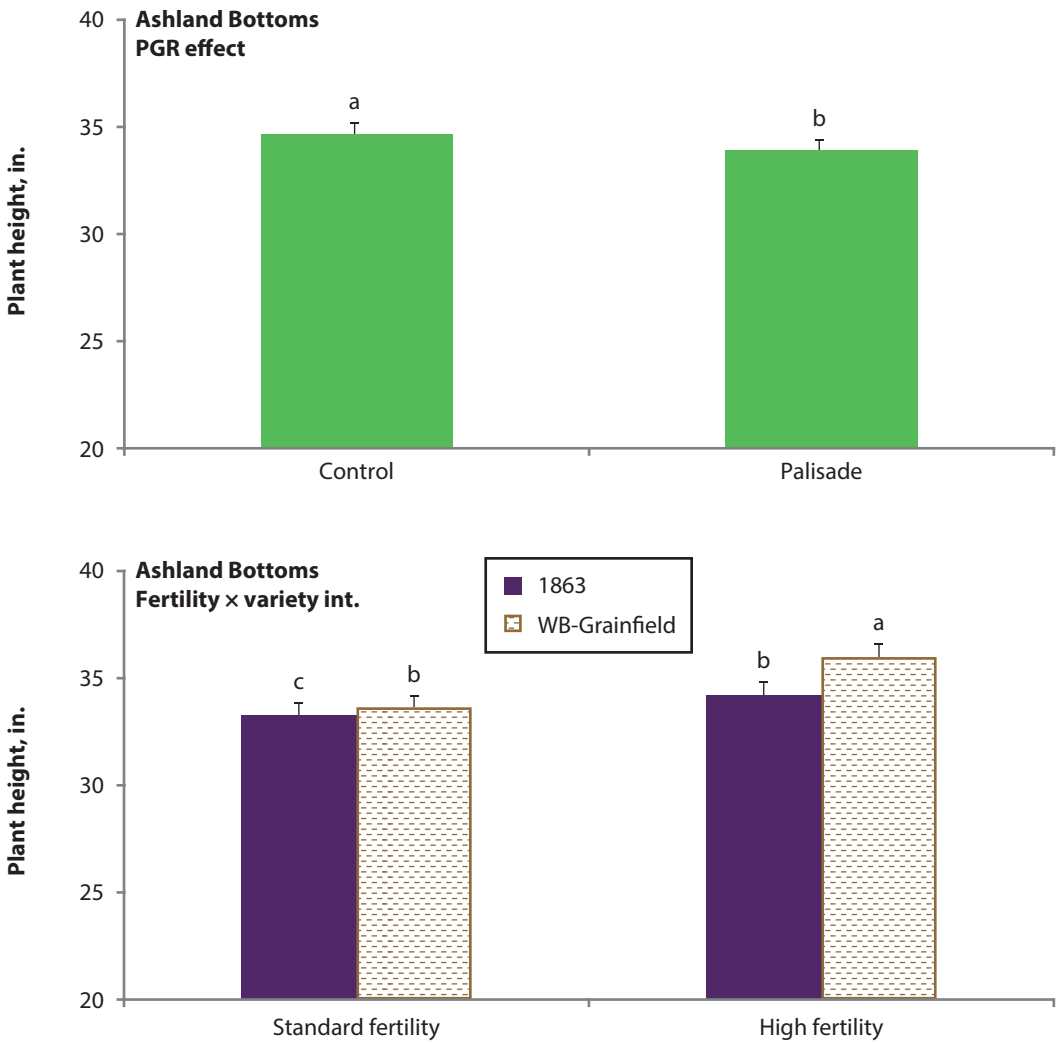

Figure 1. Wheat plant height at maturity in Ashland Bottoms, KS, for the main effect plant growth regulator (PGR) (upper panel) and for the interaction between fertility and variety (lower panel). Bars followed by the same letter indicate lack of statistical difference between management practices.

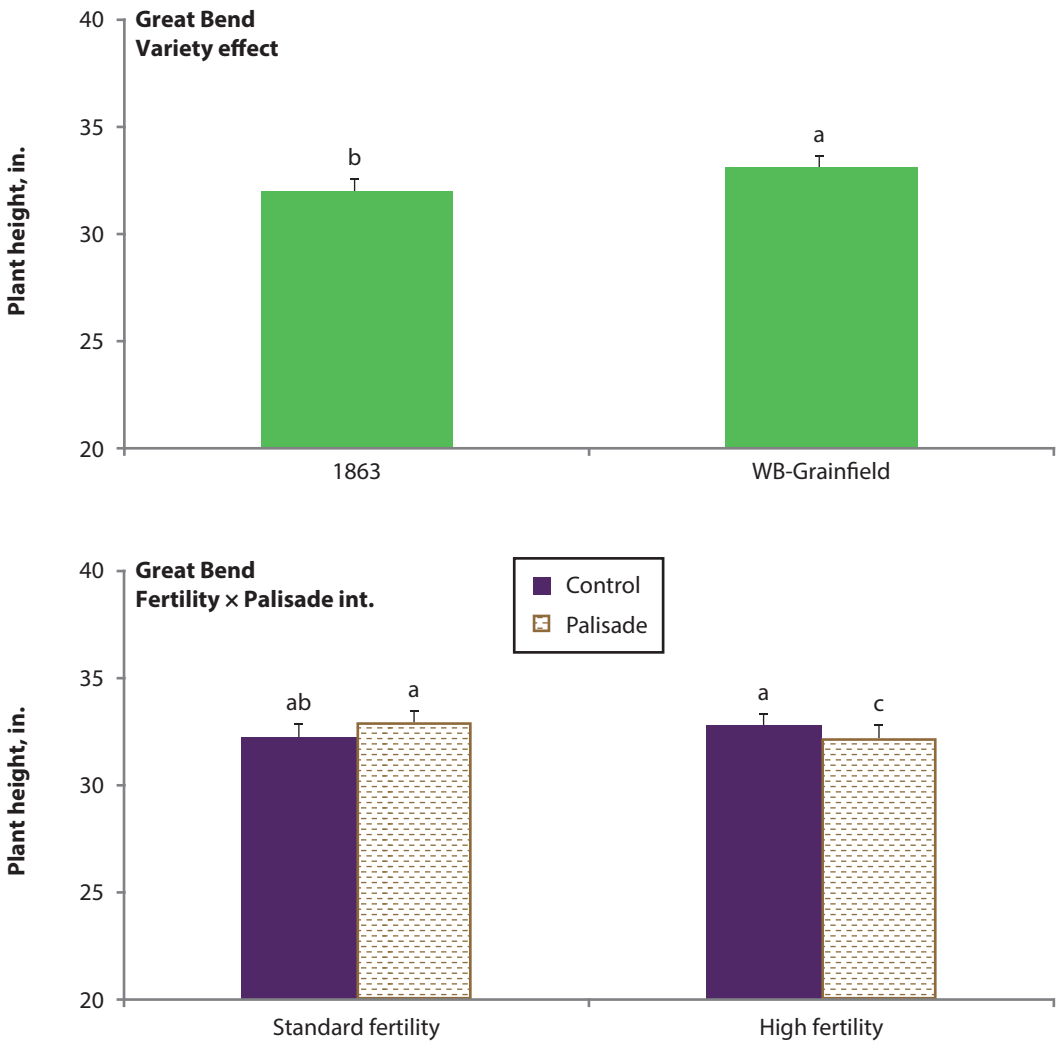

Figure 2. Wheat plant height at maturity in Great Bend, KS, during the 2017–18 growing season for the main effect variety (upper panel) and for the interaction between fertility and plant growth regulator (lower panel). Bars followed by the same letter indicate lack of statistical difference between management practices.

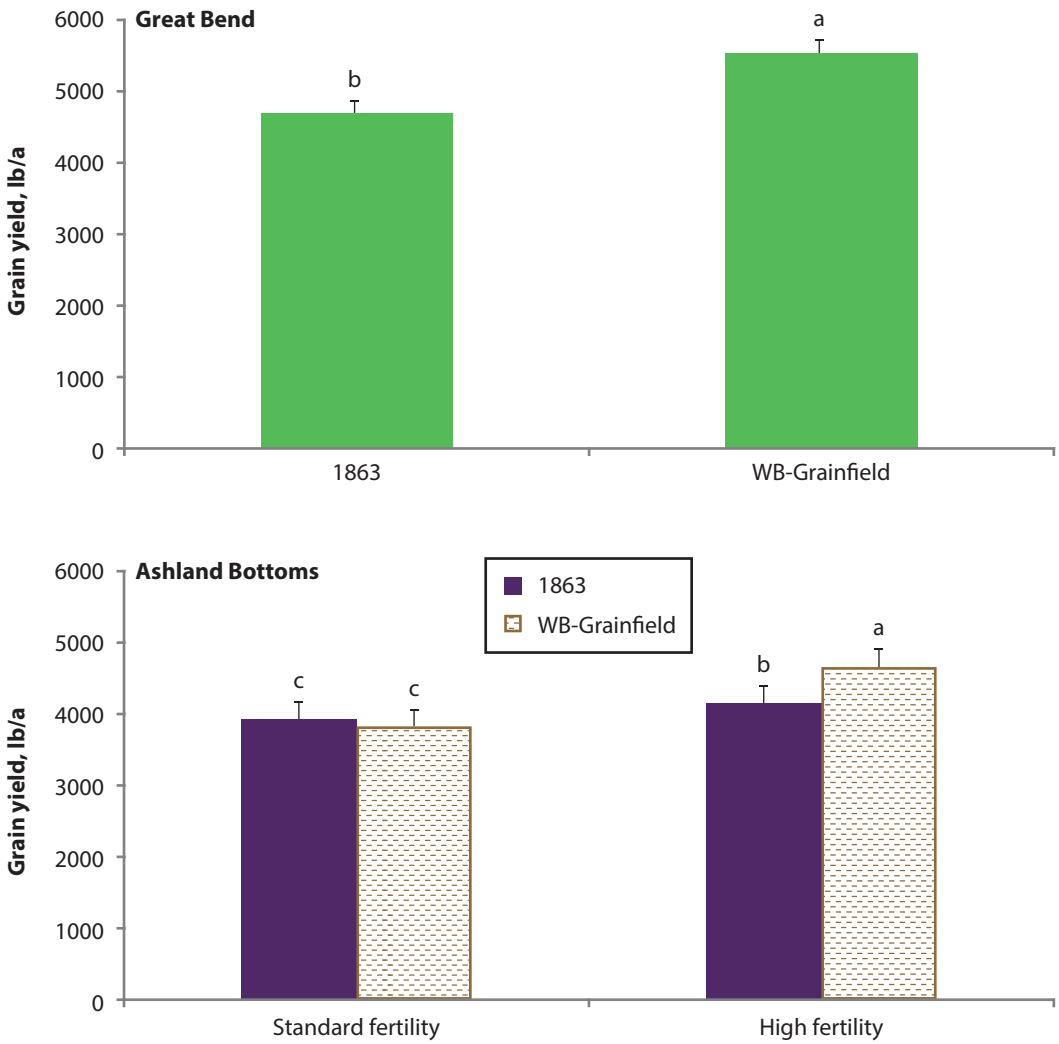

Figure 3. Wheat grain yield in Great Bend (upper panel) and Ashland Bottoms (lower panel), KS, during the 2017–18 growing season for the main effect variety (upper panel) and for the interaction between fertility and variety (lower panel). Bars followed by the same letter indicate lack of statistical difference between management practices.

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

R.E. Maeoka and R.P. Lollato

Summary

Limited information exists on the interaction between historical and modern wheat varieties and in-furrow fertilizer. Our objectives were to estimate grain yield and differences in dynamics of biomass accumulation of historical and modern winter wheat varieties as affected by different fertilization practices. Two field trials were established during the 2017–2018 growing season in Kansas. Eight winter wheat varieties released between 1920 and 2016—Kharkof (1920), Scout 66 (1966), Karl 92 (1988), Jagger (1994), Jagalene (2001), Fuller (2006), KanMark (2014) and Larry (2016)—were sown using one of two different fertilizer treatments: either the university recommendation (control with no in-furrow fertilizer due to high testing soil-P levels) or a treatment where 100 lb/a MESZ were applied in-furrow. Grain yield was greater in semi-dwarf varieties relative to tall varieties. In-furrow fertilizer showed greater grain yield in comparison with no fertilizer treatment. Whole plant biomass accumulation at maturity did not change over decades. In-furrow fertilizer presented larger biomass accumulation than no fertilizer treatment. Harvest index increased from tall to semi-dwarf varieties. More site-years of this study are needed to determine whether there is a need for re-evaluation of current fertility recommendations for semi-dwarf wheat varieties, considering that no interaction between variety and fertility was observed.

Introduction

Improvements in wheat yield over time were a combination between advances in wheat breeding (e.g. introduction of dwarfing genes) and better agronomic management practices (e.g. fertilizer input and pesticide usage). However, the increased grain yield potential of semi-dwarf wheat varieties may have had the hidden consequence of a shift in the nutrient requirements of the modern wheat plants. Therefore, current fertilizer recommendations need to be tested to determine whether an update is needed to match nutrient necessities of modern varieties and increase the return over investment. The objectives of this project were to evaluate whether historical and modern winter wheat varieties respond differently to in-furrow fertilizer in high P-level soils and to determine the partial contribution from genetic and agronomic management to wheat yield gain and biomass accumulation and partitioning.

Procedures

Experiments during the 2018 harvest year were established in Belleville and Hutchinson, KS. Both experimental sites were characterized to have more than 40 ppm extractable phosphorus (P), which is double the minimum required by a wheat crop (about 20 ppm). A complete factorial treatment structure was established in split-plot design with four replications, with main plots arranged as randomized complete block design and sub-plots completely randomized within main plots. Main plots were eight winter

wheat varieties released between 1920 and 2016 that were divided by height: tall, Kharkof (1920), Scout 66 (1966); and semi-dwarf, Karl 92 (1988), Jagalene (2001), Fuller (2006), KanMark (2014) and Larry (2016). Sub-plots were two fertilization treatments 1) control with no in-furrow fertilizer, and 2) 100 lb/a applied in-furrow as 12-40-0-10-1 (N-P-K-S-Zn).

Wheat was sown October 12, 2017, at Belleville, and October 19, 2017, at Hutchinson, at a seeding rate of 60 lb/a (approximately 1.28 million seeds/a). All the locations were planted under conventional tillage methods following a previous wheat crop. Plots were 30-ft long × 4.38-ft wide, with seven 7.5-in. spaced rows. At both locations, high levels of inherent soil nitrogen (N) were available so no fall N fertilization was necessary. Topdress N (46-0-0) was applied early spring (Feekes 5–6) across the entire experiment with a yield goal of 90 bushels per acre. Two foliar fungicide applications were performed (Feekes 6–7, Feekes 10.5) to avoid foliar diseases and consequently yield losses. Similarly, commercial herbicide products were sprayed to ensure weeds were not a limiting factor. No significant insect pressure was observed, therefore insecticide applications were not warranted. Plots were harvested for grain using a self-propelled small-plot combine. Grain moisture was measured at harvest and grain yield was corrected for 13.5% moisture content. Aboveground biomass was collected at harvest maturity. Harvest index was calculated, dividing grain yield by whole plant biomass at harvest maturity. Analysis of variance considered varieties and fertilization practice as fixed effects, and location and replication nested within location as random effects.

Results

Growing Season Weather

Overall, the 2017–18 growing season was excessively dry for both locations, especially during fall, winter, and early spring. However, precipitation prior to sowing allowed good stand establishment, and favorable conditions in late spring contributed to grain yield. Seasonal mean temperatures were similar to the 30-year average.

Grain Yield

There were significant variety and fertility effects on wheat grain yield. Grain yield ranged from 58 bu/a for Kharkof to 94 bu/a for Jagalene (Figure 1A). On average, tall varieties yielded around 65 bu/a, while semi-dwarf varieties yielded around 88 bu/a (Figure 1A). Besides variety effect, in-furrow fertilizer significantly increased grain yield relative to no fertilizer treatment by approximately 6 bu/a (Figure 1B).

Overall, we observed a low yield gain during the period between 1920 and 1966; then, a substantial yield gain period between 1966 and early 1990s; and a decrease in the pace of progress afterwards. The genetic progress across the entire study period was ~0.35 bu/a/yr.

Dynamics of Biomass Accumulation

There was a significant fertility effect on wheat aboveground biomass accumulation at maturity, but virtually no difference among varieties other than numerical. On average, tall varieties accumulated approximately 9658 lb/a and semi-dwarf varieties accumulated 9879 lb/a (Figure 2A). Karl 92 showed the lowest biomass accumulation across varieties (9013 lb/a), around 865 lb/a fewer than the average for semi-dwarf varieties

(Figure 2A); however, this difference was not statistically significant. In-furrow fertilizer treatment significantly increased biomass accumulation at maturity relative to no fertilizer treatment by approximately 584 lb/a (Figure 2B). There was significant variety effect on harvest index. Harvest index is the quotient between grain yield and whole plant biomass at maturity, and it ranged from 0.39 for Kharkof to 0.56 for Jagalene (Figure 2C). Significant improvements in harvest index at the same biomass levels of semi-dwarf varieties improved the ability to allocate more biomass into the grain without increasing the whole plant biomass. In-furrow fertilizer treatment had the same harvest index relative to no fertilizer treatment.

Acknowledgments

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

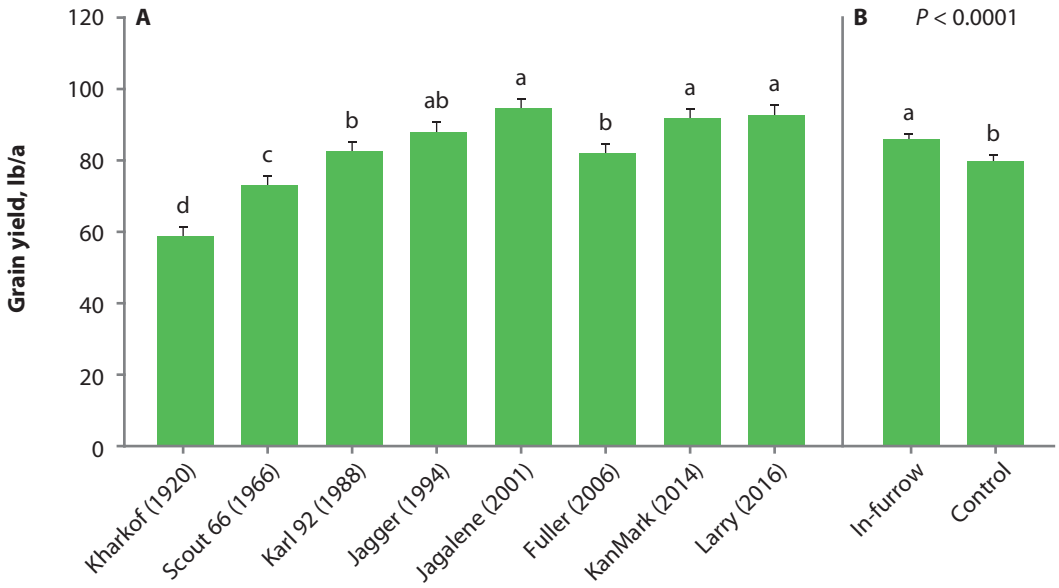

Figure 1. Grain yield of varieties released between 1920 and 2016 (A), grain yield comparison of in-furrow fertilizer treatment and control (bars show mean and standard error) (B) during the 2017–18 growing season in Kansas.

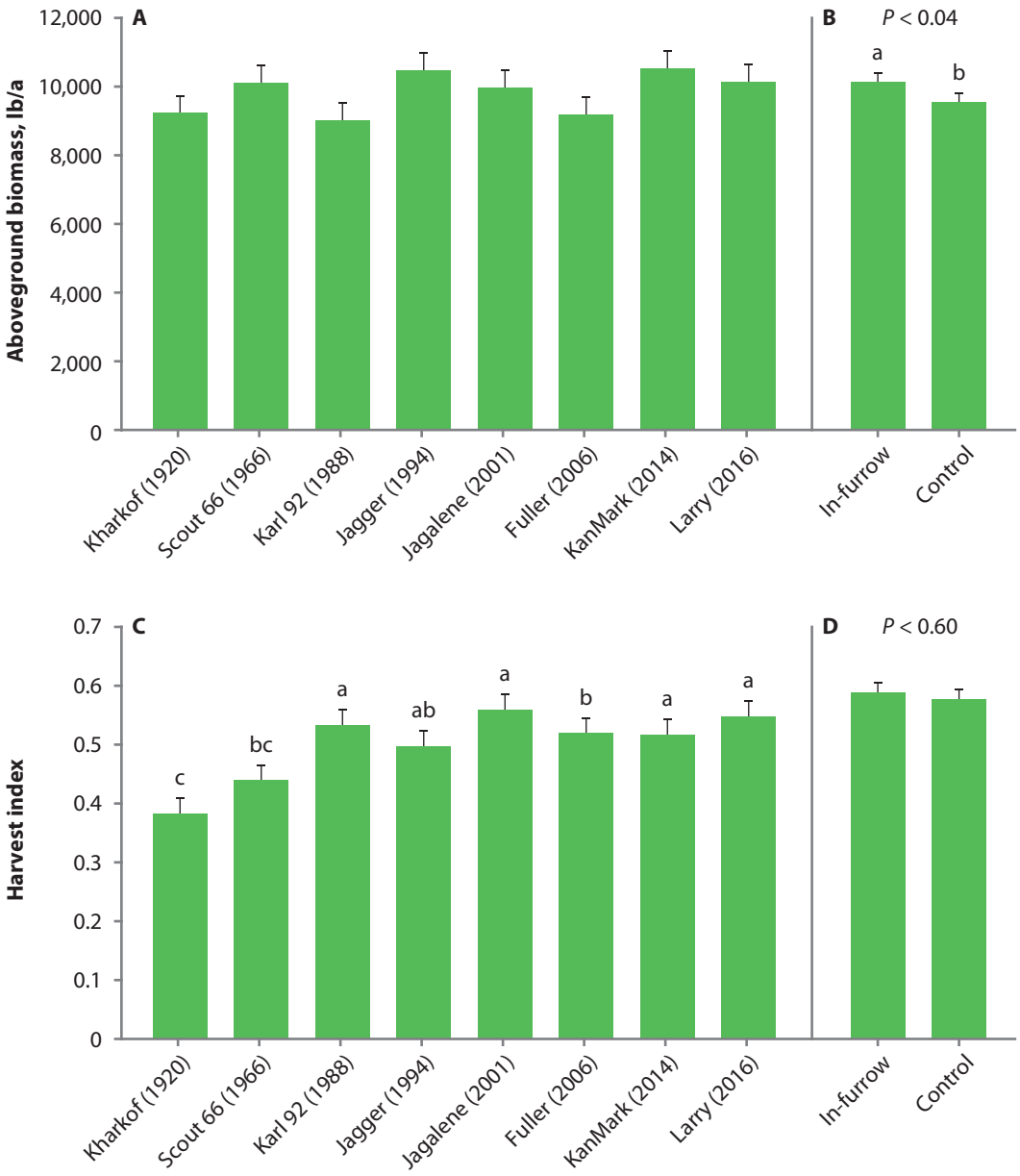

Figure 2. Dynamics of biomass accumulation as affected by year of variety release at maturity (A), biomass accumulation comparison of in-furrow fertilizer treatment and control (bars show mean and standard error) (B), harvest index as affect by year of variety release (C), harvest index comparison of in-furrow fertilizer treatment and control (bars show mean and standard error) (D) during the 2017–18 growing season in Kansas.

Herbicide Strategies for Managing Glyphosate- and Dicamba-Resistant Kochia in Roundup Ready 2 Xtend Soybean

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

Summary

Kochia populations with multiple resistance to glyphosate and dicamba are an increasing concern for growers in the High Plains region, including Kansas. A field study was conducted at the Kansas State University Agricultural Research Center near Hays, KS, to evaluate and develop herbicide options for controlling glyphosate- and dicamba-resistant kochia in Roundup Ready 2 Xtend soybean. The study site was uniformly infested with a glyphosate- and dicamba-resistant kochia population prior to soybean planting. Fifteen herbicide treatments (programs), including PRE alone and PRE followed by (*fb*) POST-applied herbicides, were investigated in a randomized complete block design with four replications. All PRE treatments included Roundup PowerMax for control of other weed species. Results indicated that a single PRE application of Spartan alone or with Engenia, Panther PRO, and Zidua plus Valor SX provided season-long control of glyphosate- and dicamba-resistant kochia. A single PRE application of Engenia or Zidua alone only provided 70 to 78% kochia control at 6 weeks after POST (WAPOST) application. However, PRE-applied Zidua alone or with Engenia, Engenia alone, Spartan + Zidua, and Spartan + Sencor followed by a sequential POST application of a tank-mixture containing Engenia and Roundup PowerMax provided ≥ 95% kochia control at 6 WAPOST. Kochia biomass reduction was > 92% with a majority of the treatments; exceptions were Zidua PRE alone (59% reduction), Engenia alone (76% reduction), and Zidua + Engenia (88% reduction) treatments. Soybean grain yield for a majority of the tested treatments did not differ, and ranged from 23 to 25 bu/a. These results suggest that effective PRE herbicide options are available for managing glyphosate- and dicamba-resistant kochia in Roundup Ready 2 Xtend soybean.

Introduction

Managing herbicide-resistant (HR) kochia (*Bassia scoparia* L.) is a significant challenge for growers in the High Plains region, including western Kansas. So far, several kochia populations have been reported with resistance to one or more of four herbicide sites of action, including sulfonylurea (ALS inhibitors), atrazine (photosystem II inhibitors), dicamba (synthetic auxins), and glyphosate (Heap, 2019). Since the discovery of glyphosate-resistant (GR) kochia in 2007, the use of dicamba, a synthetic auxin herbicide, has increased dramatically in kochia control programs. A significant decline in dicamba price over the last decade is another reason for this change in dicamba use pattern. However, kochia populations with multiple resistance to glyphosate and dicamba have become more evident in the region during recent years (Kumar et al., 2019; Westra, 2016).

The recent commercialization of Roundup Ready 2 Xtend soybean will further allow growers to use postemergence (POST) applications of low-volatile dicamba formulations (Xtendimax, Fexapan, and Engenia) for managing difficult-to-control weed

species, including GR kochia. This increasing selection pressure from dicamba applications may possibly enhance the risk of widespread evolution of kochia populations with multiple resistance to glyphosate and dicamba. To avoid this situation, effective and alternative herbicide strategies (multiple sites of action) will be needed. The main objectives of this research were to 1) evaluate and develop effective herbicide programs for managing glyphosate- and dicamba-resistant (multiple resistant) kochia in Roundup Ready 2 Xtend soybean, and 2) determine the ultimate impact of those herbicide programs on soybean grain yield in western Kansas.

Procedures

A field study was conducted at the Kansas State University Agricultural Research Center near Hays, KS. The study site was under no-till dryland wheat stubble. A Roundup Ready 2 Xtend soybean variety AG34X7 was planted on May 22, 2018. The study site was uniformly infested with a kochia population with multiple resistance to glyphosate and dicamba prior to soybean planting. This kochia population had survived up to 64 fl oz/a rate of Clarity and 44 fl oz/a rate of Roundup PowerMax in a separate greenhouse study. Fifteen different herbicide treatments, including PRE alone and PRE *fb* POST-applied herbicides were evaluated (Table 1). A nontreated control was included for treatment comparison. All PRE treatments were applied at their recommended field rates in combination with Roundup PowerMax at 32 fl oz/a. All POST treatments were a mixture of Roundup PowerMax at 32 fl oz/a and Engenia at 12.8 oz/a. All PRE treatments were applied on May 23, 2018, and POST treatments were applied on June 26, 2018. Treatments were applied with CO_2-pressurized backpack sprayer equipped with Turbo Teejet Induction nozzles (Spraying Systems Co., Wheaton, IL), calibrated to deliver 15 gallons per acre spray solution. Experiments were conducted in a randomized complete block design with four replications. The plot size was 10 × 30 ft. Percent kochia control was visually evaluated at 3 weeks after PRE (WAPRE), and again at 3 and 6 weeks after POST (WAPOST) treatments on a scale of 0 to 100% (0 being no control and 100 being complete control). Kochia biomass reduction (% of nontreated weedy check) was also determined by collecting shoot biomass using a square meter quadrat from the center of each plot prior to soybean harvest. Soybean grain yield was recorded by harvesting the middle two rows from each plot using a plot combine. Data on percent kochia control, shoot biomass reduction, and soybean grain yield were subjected to ANOVA using PROC MIXED in SAS v. 9.3 software (SAS Inst., Cary, NC). Means were separated using Fisher's protected least significant difference test at $P < 0.05$.

Results and Discussion

No visible soybean injury was observed with any PRE or/and POST herbicide programs tested (data not shown). Results indicated that Spartan alone or with Engenia, Panther PRO, and Zidua + Valor SX treatments provided complete, season-long control of glyphosate- and dicamba-resistant kochia (Figure 1). Furthermore, the addition of Engenia to Zidua PRE improved kochia control compared to the Zidua alone treatment (82 vs. 57% control) at final rating. Kochia control with the Prowl + Outlook treatment did not exceed 70% at 6 WAPOST. PRE-applied Engenia, Zidua alone or with Engenia *fb* POST application of Roundup PowerMax + Engenia provided 100% control at 6 WAPOST (Figure 1). Consistent with percent control, kochia biomass reduction (% of nontreated) was > 92% with a majority of the treatments; exceptions

were PRE treatments of Zidua alone (59% reduction), Engenia alone (76% reduction), or Zidua + Engenia (88% reduction) (Figure 2). Soybean grain yield for a majority of the tested PRE and PRE *fb* POST herbicide treatments did not differ, and ranged from 23 to 25 bu/a (Figure 3). Soybean grain yield for PRE-applied Zidua, Engenia, and Prowl + Outlook treatments averaged approximately 18 bu/a.

Conclusions

Based on these results, growers should utilize two-pass herbicide programs, including PRE herbicides such as Spartan alone or with Engenia, Panther PRO, Zidua + Valor SX, Zidua + Engenia followed by a sequential POST application of Roundup PowerMax + Engenia for effective and season-long control of glyphosate- and dicamba-resistant kochia in Roundup Ready 2 Xtend soybean.

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Table 1. List of selected herbicide programs tested for managing glyphosate- and dicamba-resistant kochia in Roundup Ready 2 Xtend soybean at the Kansas State University Agricultural Research Center near Hays, KS, in 2018

Herbicide programs [a]	Treatments	Rate (oz/a)	Timing
Nontreated	T1	---	---
Spartan + Roundup PowerMax	T2	6 + 32	PRE
Spartan + Engenia + Roundup PowerMax	T3	6 + 6.4 + 32	PRE
Zidua + Engenia + Roundup PowerMax	T4	1.3 + 6.4 + 32	PRE
Zidua + Roundup PowerMax	T5	1.3 + 32	PRE
Engenia + Roundup PowerMax	T6	32 + 12.8	PRE
Panther PRO + Roundup PowerMax	T7	12 + 32	PRE
Valor SX + Zidua + Roundup PowerMax	T8	2.3 + 1.75 + 32	PRE
Prowl + Outlook + Roundup PowerMax	T9	32 + 16 + 32	PRE
Spartan + Roundup PowerMax *fb* Roundup PowerMax + Engenia	T10	6 + 32 *fb* 32 + 12.8	PRE *fb* POST
Spartan + Roundup PowerMax + Engenia *fb* Roundup PowerMax + Engenia	T11	6 + 32 + 6.4 *fb* 32 + 12.8	PRE *fb* POST
Zidua + Roundup PowerMax + Engenia *fb* Roundup PowerMax + Engenia	T12	1.3 + 32 + 6.4 *fb* 32 + 12.8	PRE *fb* POST
Zidua + Roundup PowerMax *fb* Roundup PowerMax + Engenia	T13	1.3 + 32 *fb* 32 + 12.8	PRE *fb* POST
Roundup PowerMax + Engenia *fb* Roundup PowerMax + Engenia	T14	32 + 12.8 *fb* 32 + 12.8	PRE *fb* POST
Authority Supreme *fb* Roundup PowerMax + Engenia	T15	8 *fb* 32 + 12.8	PRE *fb* POST
Authority MTZ *fb* Roundup PowerMax + Engenia	T16	14 *fb* 32 + 12.8	PRE *fb* POST

[a]PRE = preemergence. POST = postemergence. *fb* = followed by.

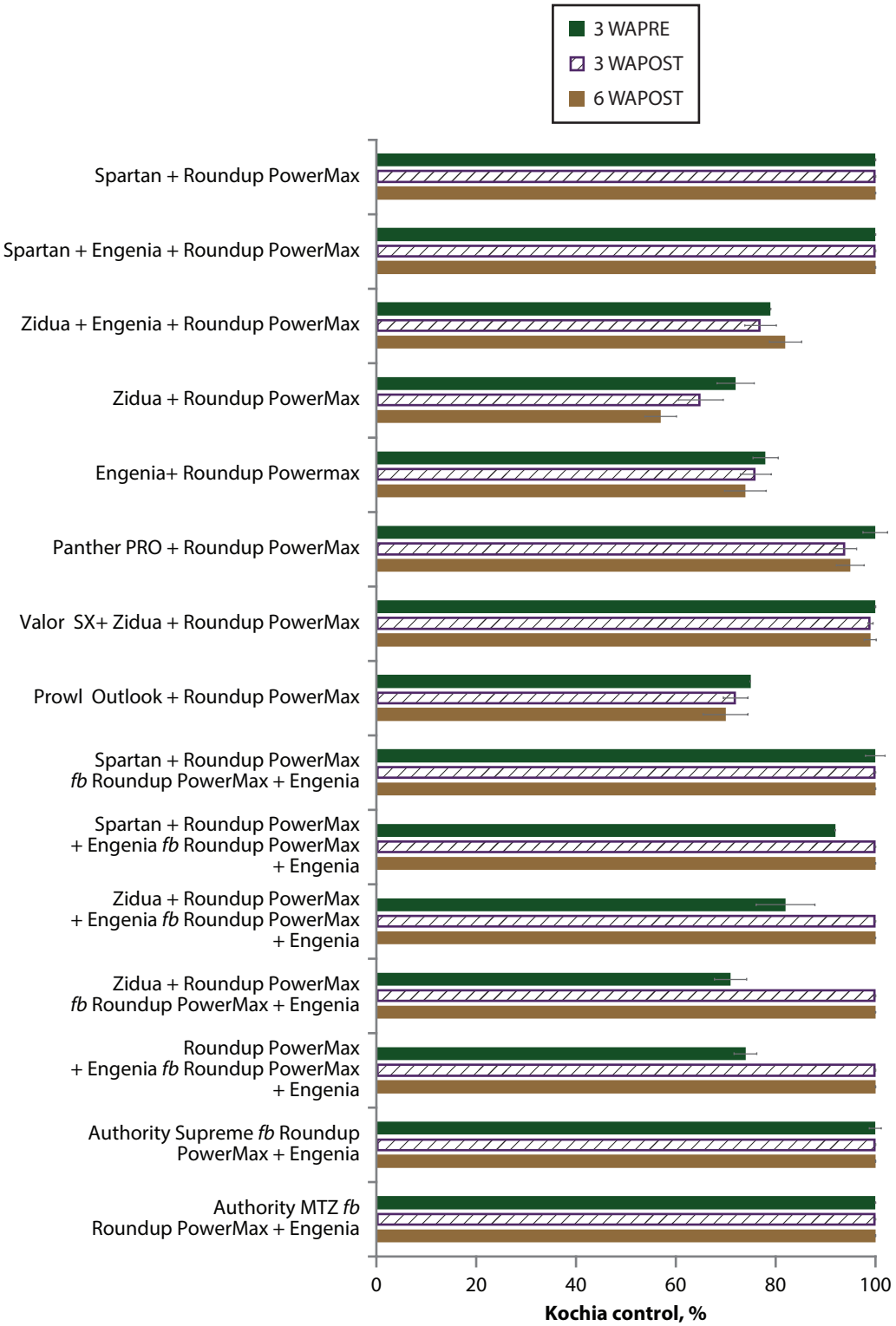

Figure 1. Visual control (%) of glyphosate- and dicamba-resistant kochia with selected herbicide programs in Roundup Ready 2 Xtend soybean at the Kansas State University Agricultural Research Center near Hays, KS, in 2018. WAPOST = weeks after POST. WAPRE = weeks after PRE. Please see Table 1 for the full list of treatments.

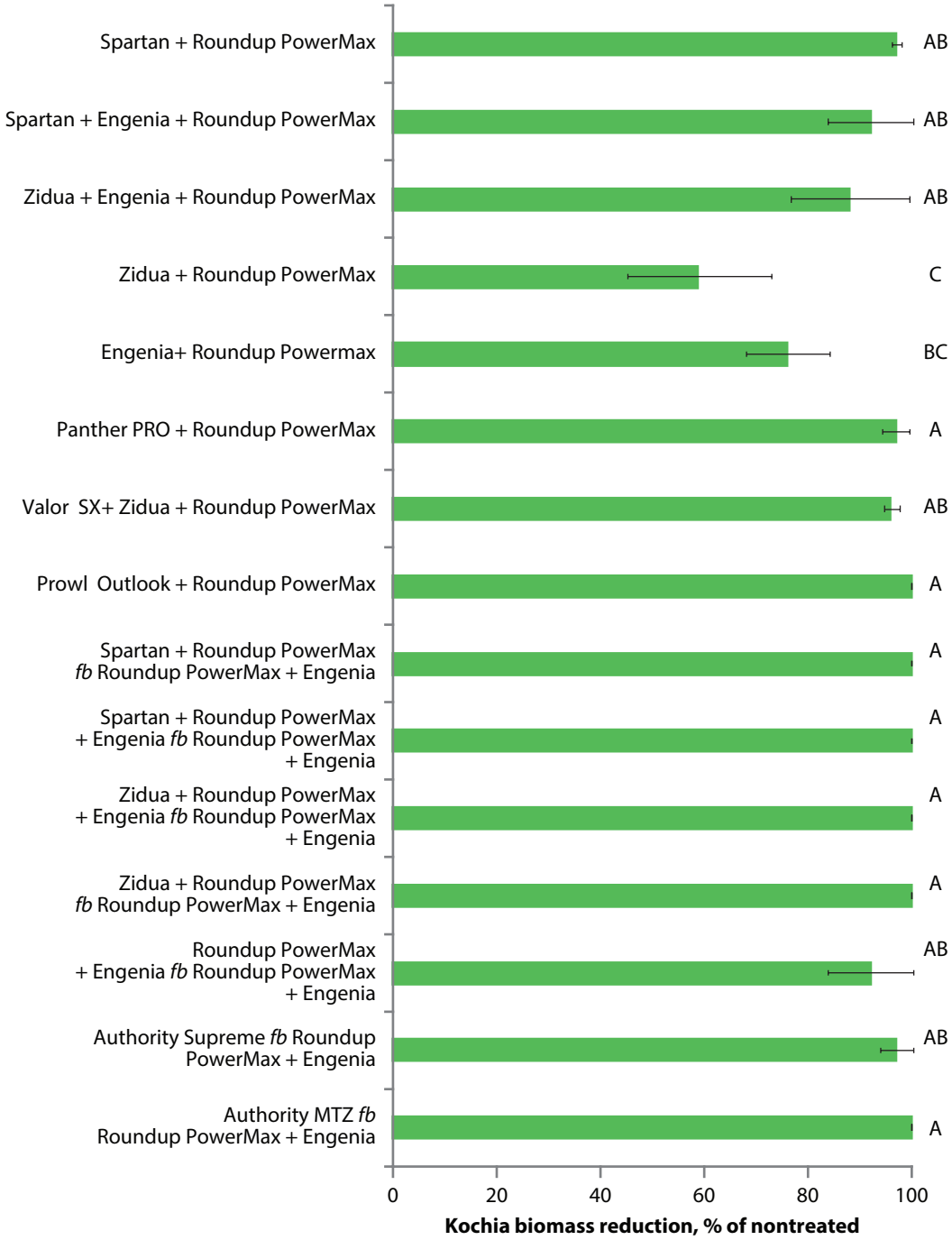

Figure 2. Kochia biomass reduction (% of nontreated) with selected herbicide programs in Roundup Ready 2 Xtend soybean at the Kansas State University Agricultural Research Center near Hays, KS, in 2018. Bars with similar letters are not different based on Fisher's protected LSD test at $P < 0.05$. Please see Table 1 for the full list of treatments.

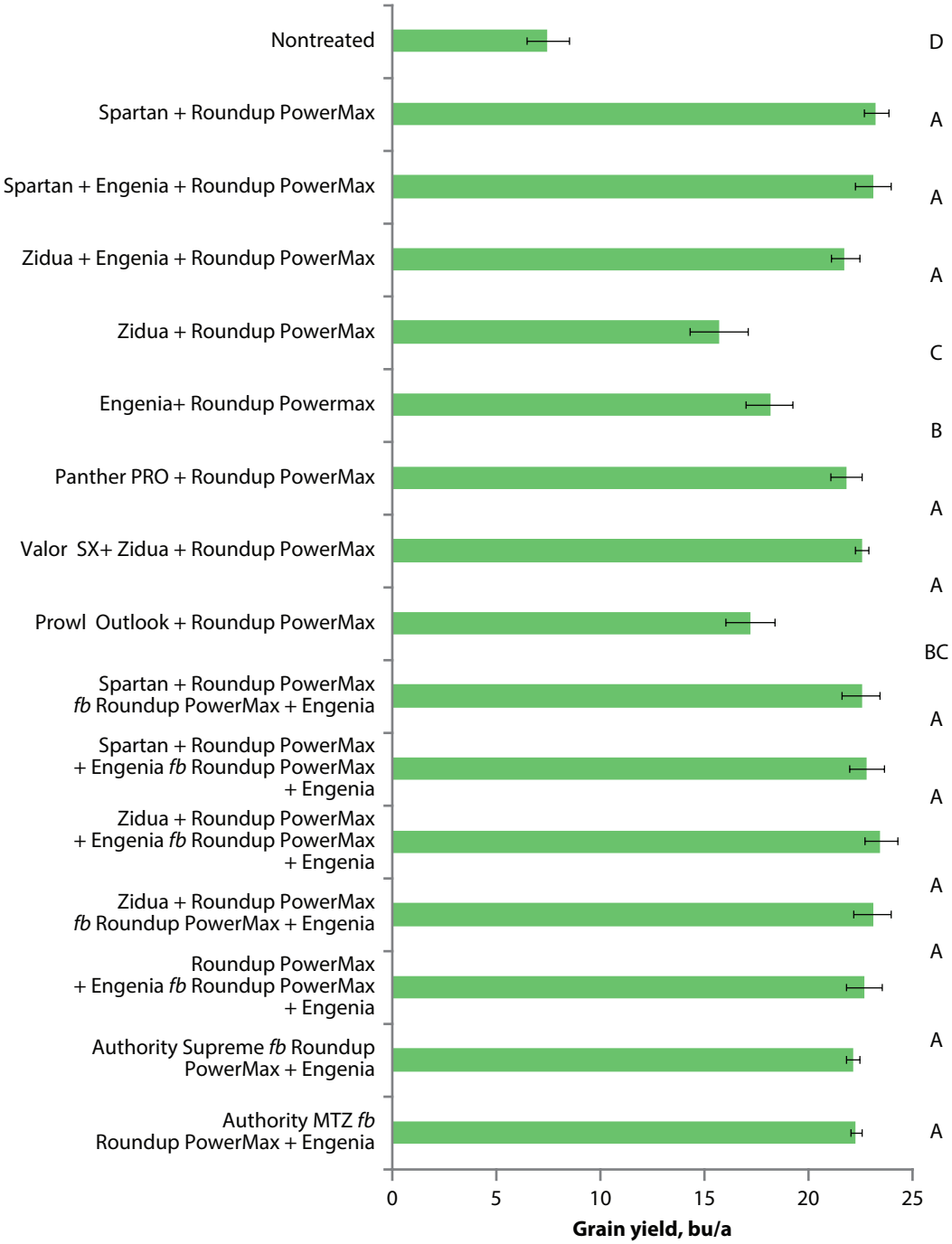

Figure 3. Effect of selected herbicide programs on Roundup Ready 2 Xtend soybean grain yields at the Kansas State University Agricultural Research Center near Hays, KS, in 2018. Bars with similar letters are not different based on Fisher's protected LSD test at $P < 0.05$. Please see Table 1 for the full list of treatments.

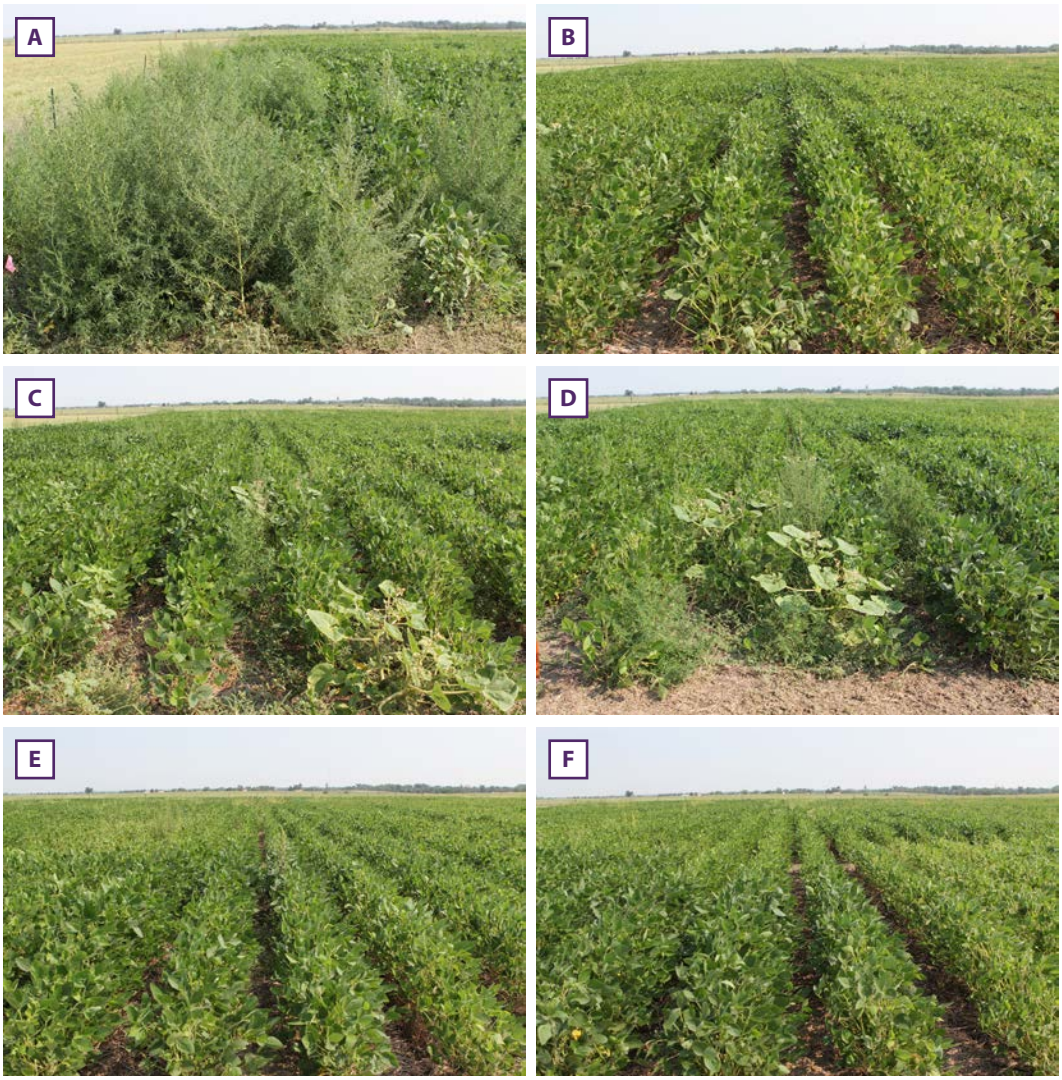

Figure 4. Visual response of glyphosate- and dicamba-resistant kochia in nontreated weedy check (A), Spartan alone (B), Zidua + Engenia (C), Zidua alone (D), Panther PRO (E), and Authority Supreme followed by Roundup Powermax + Engenia (F) treatments at 6 weeks after POST.

Effective Herbicide Options for Controlling Glyphosate-Resistant Palmer Amaranth in Roundup Ready 2 Xtend Soybean

V. Kumar, R. Liu, T. Lambert, D.E. Peterson, C. Minihan, and P.W. Stahlman

Summary

Glyphosate-resistant (GR) Palmer amaranth has become a serious challenge for soybean producers in the mid-south and central United States, including Kansas. Field experiments were conducted at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS, and Kansas State University Ashland Bottoms (KSU-AB) research farm near Manhattan, KS, to determine the effectiveness of preemergence (PRE) and PRE followed by (*fb*) postemergence (POST) herbicide programs on GR Palmer amaranth control in Roundup Ready 2 Xtend soybean. The study site at Hays was infested with GR Palmer amaranth population prior to soybean planting; whereas, the Manhattan site had natural infestation of GR Palmer amaranth. Eleven treatments, including PRE alone and PRE *fb* POST-applied herbicides were investigated. All PRE treatments included Roundup PowerMax for control of other weed species, while POST treatments were mixtures of Roundup PowerMax and Engenia herbicides. A single PRE application of Fierce XLT and Panther PRO had ≥ 90% control of GR Palmer amaranth; whereas, control with Authority Elite and Zidua PRO did not exceed 83% at 6 weeks after POST (WAPOST). Combined over two locations, all PRE *fb* POST treatments had excellent control (≥ 96%) of GR Palmer amaranth at 6 WAPOST. No significant differences for soybean grain yield were observed among herbicide treatments at the Hays site; whereas, an approximate 10% increase in grain yield was observed with PRE *fb* POST vs. PRE alone programs at the Manhattan site. Based on these results, the two-pass programs (PRE *fb* POST) investigated in this research can be effectively used for season-long control of GR Palmer amaranth in Roundup Ready 2 Xtend soybean.

Introduction

Palmer amaranth (*Amaranthus palmeri* S. Wats) has become a serious management concern for Kansas farmers. Palmer amaranth is commonly found in cropland and noncropland areas of the central and western parts of Kansas. It generally infests corn, sorghum, soybean, sunflower, fallow fields, and postharvest wheat stubble in this region. Palmer amaranth initiates its emergence during early summer (mid to late May) and manifests an extended period of emergence throughout the growing season. Palmer amaranth also grows rapidly and produces huge amounts of seeds (a single female plant can produce 0.6 million seeds) (Keeley et al., 1987). Season-long competition of Palmer amaranth at 0.9 plants ft^{-2} has been found to reduce soybean grain yield by 68% (Klingaman and Oliver, 1994).

Glyphosate was an effective POST herbicide for Palmer amaranth control until the evolution of glyphosate-resistant (GR) populations across Kansas, which was discovered

in 2011 (Heap, 2019). As per the recent survey, resistance to glyphosate has become fairly common among Palmer amaranth populations in Kansas. Furthermore, multiple herbicide-resistant (MHR) Palmer amaranth is also a serious management challenge 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 more recently to 2,4-D (synthetic auxins) in Kansas (Heap, 2019; Kumar et al., 2019).

The recent introduction of Roundup Ready 2 Xtend soybean will allow growers to use POST applications of low-volatile dicamba formulations (Xtendimax, Fexapan, and Engenia) for managing GR weed biotypes, including GR Palmer amaranth. However, increasing dicamba applications may possibly enhance the risk of evolving Palmer amaranth resistant to dicamba. Therefore, effective and alternative herbicide options (multiple sites of action) would be needed for controlling GR Palmer amaranth in Roundup Ready 2 Xtend soybean. The main objectives of this research were to evaluate and develop effective herbicide programs for GR Palmer amaranth control in Roundup Ready 2 Xtend soybean in Kansas.

Procedures

Two field experiments were established: at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS, and at the Kansas State University Ashland Bottoms (KSU-AB) research farm near Manhattan, KS. Soybean plots were established in no-till wheat stubble at the KSU-ARC; whereas, the study site at KSU-AB was under conventional tillage system. Experiments at both sites were established in randomized complete block designs, with 4 replications and a plot size of 10 × 30 ft. The study site at KSU-AB had a natural infestation of GR Palmer amaranth; whereas, a seedbank of GR Palmer amaranth was artificially established at KSU-ARC site. A Roundup Ready 2 Xtend soybean, Asgrow AG34X7 was planted at 156,900 seeds/a on May 22, 2018, at KSU-ARC. Similarly, a Roundup Ready 2 Xtend soybean variety Asgrow AG39X7 was planted at 130,000 seeds/a on June 4, 2018, at the KSU-AB site. Eleven different herbicide programs, including PRE alone, POST alone, and PRE followed by (*fb*) POST-applied herbicides were tested (Table 1). A nontreated control and hand-weeded check were also included. All PRE treatments were applied at their recommended field-use rates in combination with Roundup PowerMax at 32 fl oz/a. All POST treatments were a mixture of Roundup PowerMax at 32 fl oz/a and Engenia at 12.8 oz/a. The selected PRE herbicide programs were applied at each location immediately after soybean planting. POST treatments were applied on June 22, 2018, at KSU-ARC, and July 16 at KSU-AB. Treatments were applied with a CO_2-pressurized backpack sprayer equipped with Turbo Teejet Induction (TTI) nozzles (Spraying Systems Co., Wheaton, IL), calibrated to deliver 15 gallons per acre spray solution. Data on soybean injury and visual Palmer amaranth control on a scale of 0 to 100% (0 being no control and 100 being complete control) were collected at biweekly intervals throughout the growing season after PRE herbicide treatments at both sites. Soybean grain yield was recorded by harvesting the middle two rows from each plot using a plot combine. Data on Palmer amaranth control (%), and soybean grain yield (bu/a) were subjected to ANOVA using PROC MIXED in SAS v.

9.3 (SAS Inst., Cary, NC) software. Means were separated using Fisher's protected least significant difference test at $P < 0.05$.

Results and Discussion

No visual soybean injury was observed with any PRE and/or POST herbicide programs tested (data not shown). Combined over two locations, a single PRE application of Fierce XLT at 5 oz/a and Panther PRO at 12 oz/a provided 90 to 100% control of GR Palmer amaranth throughout the season (Figure 1). In contrast, GR Palmer amaranth control with PRE-applied Authority Elite at 28 oz/a and Zidua PRO at 6 oz/a was moderate and did not exceed 83% at final rating. However, a sequential POST application of a tank-mixture of Roundup PowerMax and Engenia improved GR Palmer amaranth control of all PRE programs at both sites (Figure 1). Interestingly, GR Palmer amaranth control with a single POST application of Roundup (32 fl oz/a) plus Engenia (12.8 fl oz/a) did not differ from two applications of Roundup (32 fl oz/a) plus Engenia (12.8 fl oz/a) mixture (PRE *fb* POST or POST *fb* POST) at the final rating. Soybean grain yield from a majority of the herbicide programs did not differ and ranged from 18 to 22 bu/a at Hays; whereas, an approximate 10% increase in grain yield was observed with PRE *fb* POST vs. PRE alone programs at Manhattan (Figure 2).

Conclusions

Based on these results, growers should utilize two-pass herbicide programs, including PRE options such as Fierce XLT, Panther PRO, Authority Elite, or Zidua PRO followed by a sequential POST application of Roundup PowerMax + Engenia for effective and season-long control of GR Palmer amaranth in Roundup Ready 2 Xtend soybean.

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Table 1. List of selected herbicide programs tested for controlling glyphosate-resistant (GR) Palmer amaranth in Roundup Ready 2 Xtend soybean at the Kansas State University Agricultural Research Center near Hays, KS, and Ashland Bottoms research farm near Manhattan, KS, in 2018

Herbicide programs[a]	Treatments	Rate (oz/a)	Timing
Authority Elite	T1	28	PRE
Zidua PRO	T2	6	PRE
Fierce XLT	T3	5	PRE
Panther PRO	T4	12	PRE
Authority Elite *fb* Roundup PowerMax + Engenia	T5	28 *fb* 32 + 12.8	PRE *fb* POST
Zidua PRO *fb* Roundup PowerMax + Engenia	T6	6 *fb* 32 + 12.8	PRE *fb* POST
Fierce XLT *fb* Roundup PowerMax + Engenia	T7	5 *fb* 32 + 12.8	PRE *fb* POST
Panther PRO *fb* Roundup PowerMax + Engenia	T8	12 *fb* 32 + 12.8	PRE *fb* POST
Roundup PowerMax + Engenia *fb* Roundup PowerMax + Engenia	T9	32 + 12.8 *fb* 32 + 12.8	PRE *fb* POST
Roundup PowerMax + Engenia *fb* Roundup PowerMax + Engenia	T10	32 + 12.8 *fb* 32 + 12.8	POST *fb* POST
Roundup PowerMax + Engenia	T11	32 + 12.8	POST
Nontreated	T12	---	---
Hand-weeded	T13	---	---

[a]PRE = preemergence. POST= postemergence. *fb* = followed by.

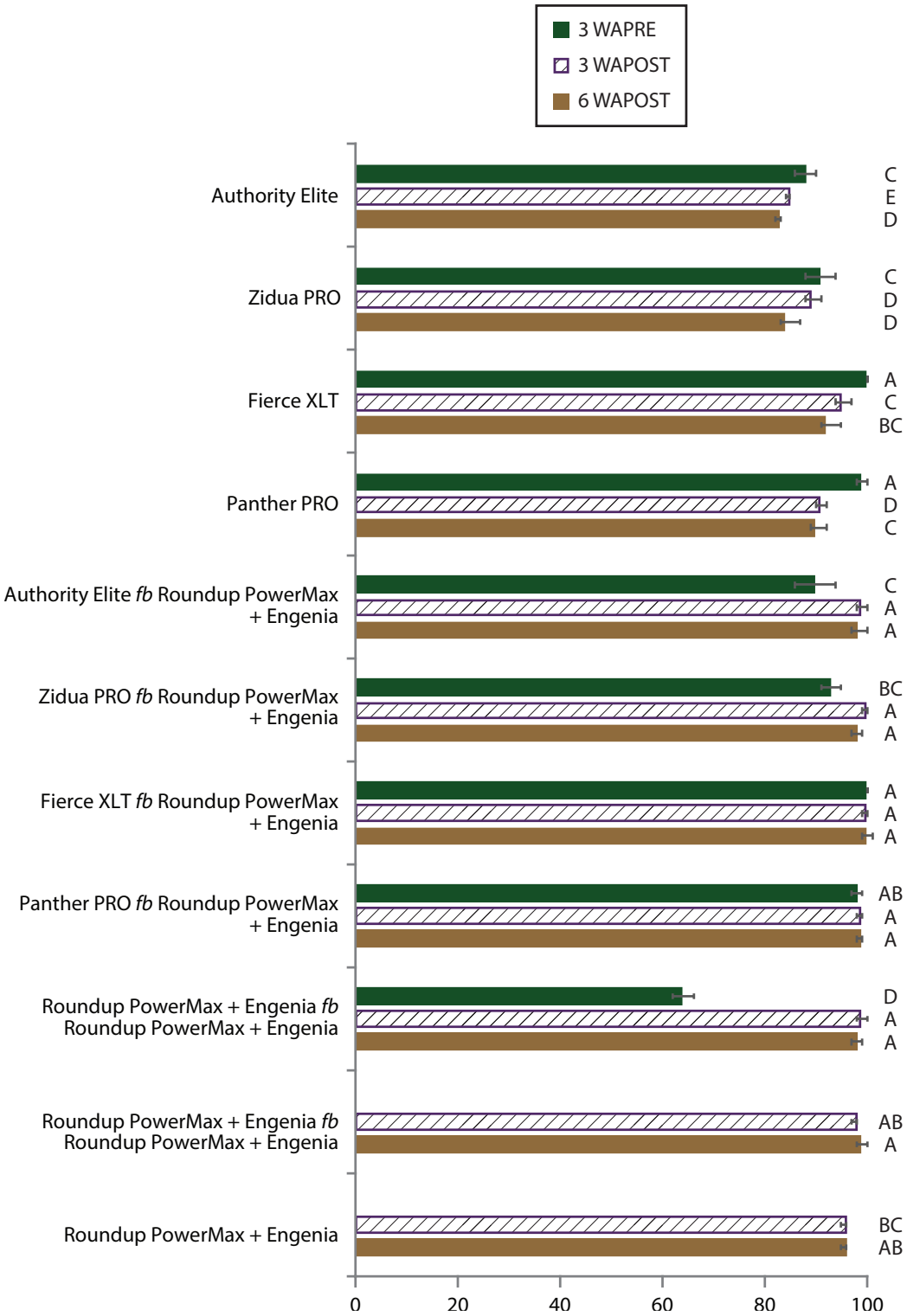

Figure 1. Effect of selected herbicide programs on visual control (%) of glyphosate-resistant Palmer amaranth in Roundup Ready 2 Xtend soybean combined over two locations. WAPRE = weeks after PRE. WAPOST = weeks after POST. Bars within each graph with similar letters are not different based on Fisher's protected LSD test at $P < 0.05$. Please see Table 1 for the full list of treatments.

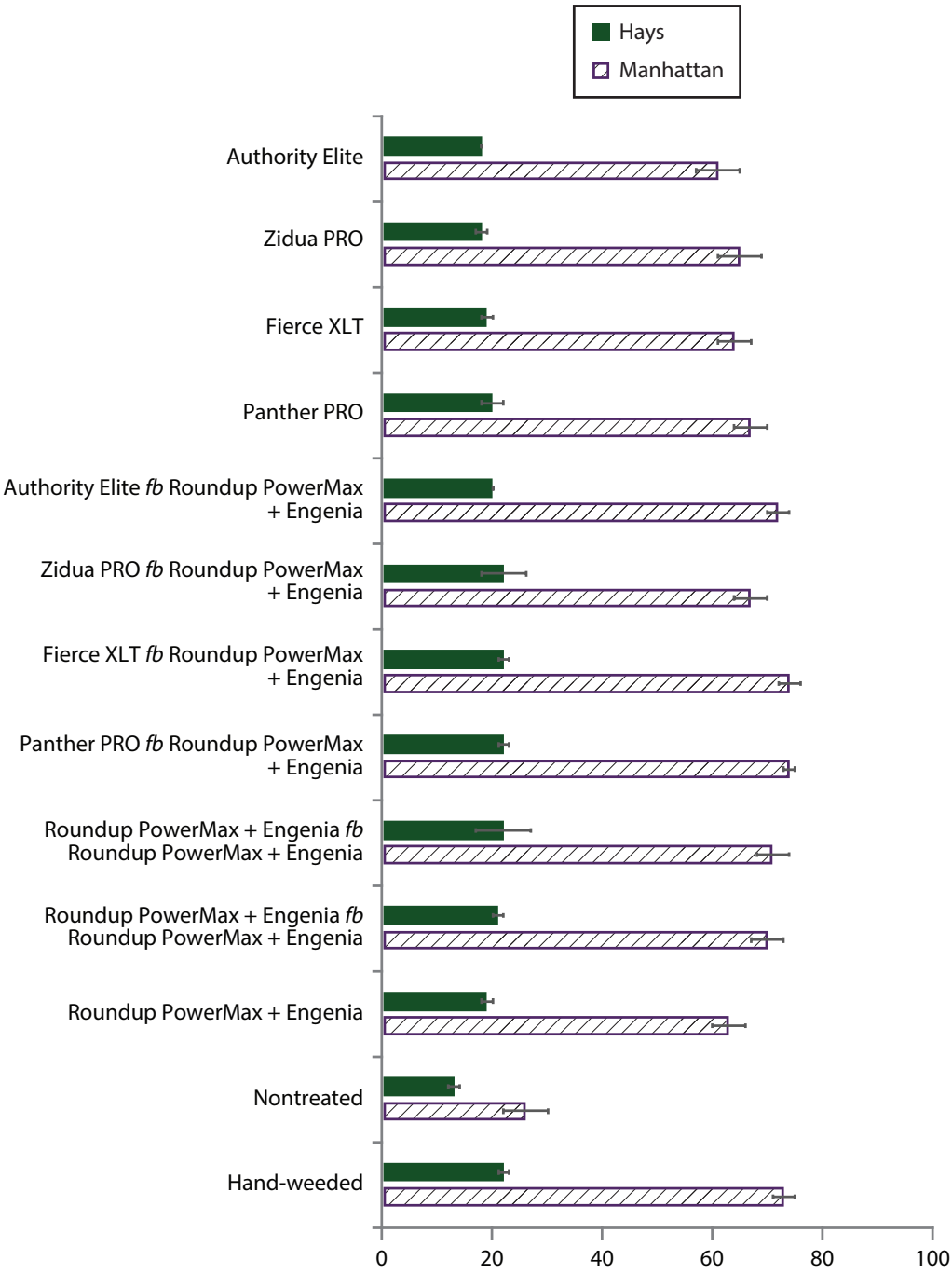

Figure 2. Effect of selected herbicide programs on soybean grain yields at the Kansas State University Agricultural Research Center near Hays, KS, and Ashland Bottoms research farm near Manhattan, KS, in 2018. Please see Table 1 for the full list of treatments.

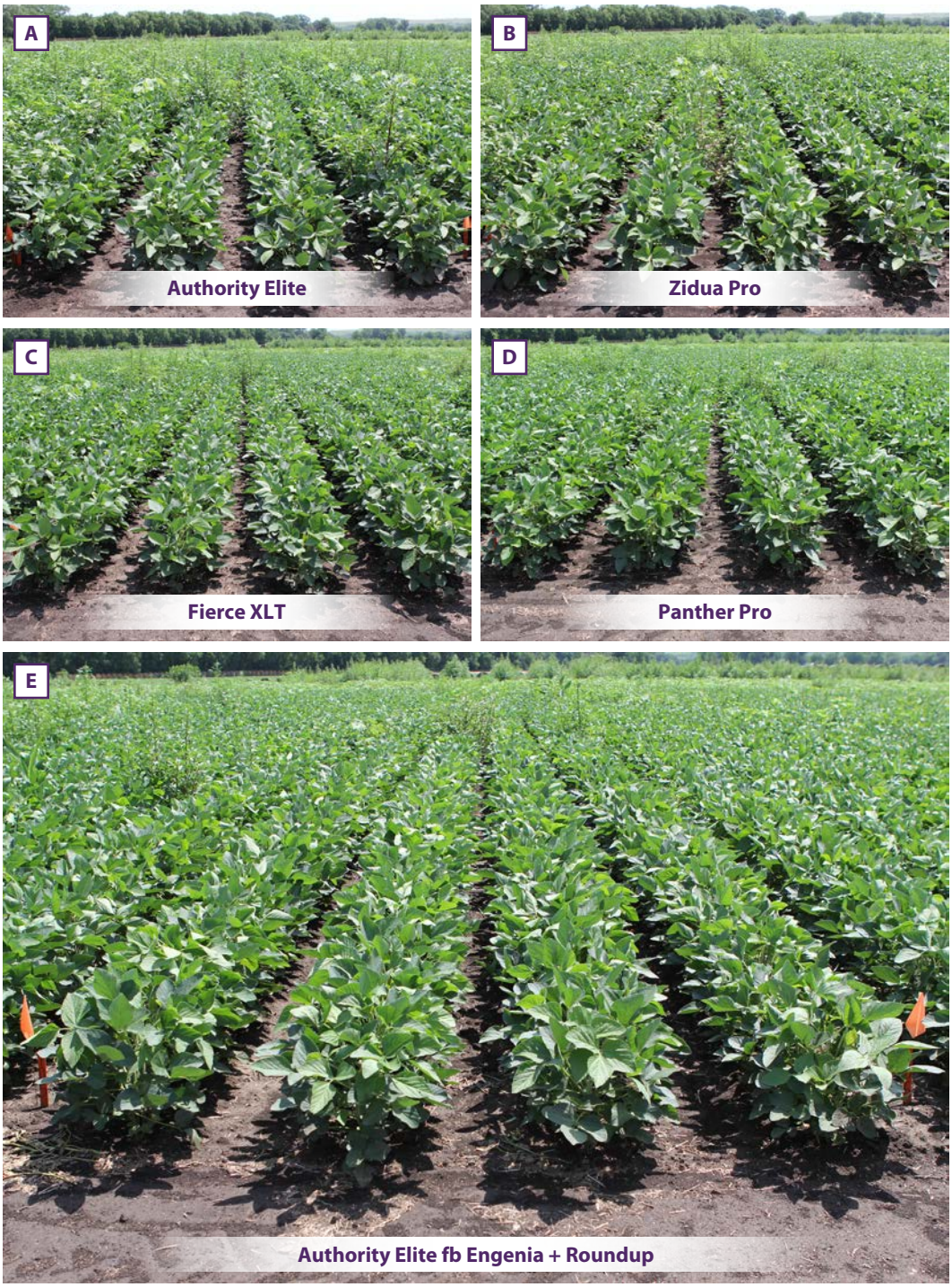

Figure 3. Visual response of glyphosate-resistant Palmer amaranth control in Roundup Ready 2 Xtend soybeans with PRE applied Authority Elite (A), Zidua Pro (B), Fierce XLT (C), Panther Pro (D), and Authority Elite PRE followed by Roundup PowerMax + Engenia POST (E) at 3 WAPOST in Manhattan, KS. WAPOST = weeks after POST.

Characterization and Management of Glyphosate- and HPPD-Inhibitor-Resistant Palmer Amaranth in Kansas Corn Production

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

Summary

Multiple herbicide-resistant (MHR) Palmer amaranth is an increasing management concern for Kansas grain producers. The main purpose of this research was to 1) characterize the resistance levels to glyphosate (Roundup PowerMax) and mesotrione (Callisto) in an MHR Palmer amaranth population collected from Stafford County, KS, compared to a known herbicide-susceptible (SUS) population; and 2) to evaluate the effectiveness of preemergence (PRE), PRE followed by (*fb*) early post emergence (EPOST), and PRE *fb* late POST (LPOST) herbicide programs for controlling this MHR population in Roundup Ready and LibertyLink corn. To achieve these objectives, a whole plant dose-response study was conducted in a greenhouse at the Kansas State University Agricultural Research Center near Hays, KS; and a field study was conducted in Stafford County, KS (from where the MHR population was originally collected). Dose-response study indicated that the MHR population had 7.2- and 3.5-fold resistance to glyphosate and mesotrione, respectively, on the basis of visual control (LD_{50} values). Results from field study indicated that PRE application of Clarity + Acuron in combination with Aatrex, Callisto, Dual II Magnum, or Sencor *fb* a sequential EPOST application of Acuron alone or in combination with Aatrex, Callisto, or Dual II Magnum provided 80 to 95% control of MHR Palmer amaranth population in corn throughout the season. Furthermore, control with PRE applied Clarity + Acuron *fb* a LPOST application of Acuron + Status or Acuron + Liberty averaged 85% at the final rating. Based on these results, the tested Palmer amaranth population from Stafford County has evolved multiple resistance to glyphosate and mesotrione. Two-pass herbicide programs, including PRE *fb* EPOST or LPOST investigated in this research can provide adequate control of this population throughout the season in Roundup Ready and LibertyLink corn.

Introduction

Palmer amaranth (*Amaranthus palmeri* L.) is a problematic, summer annual broadleaf weed species in agronomic crops across central and western parts of Kansas. It is a dioecious (male and female flowers on separate plants) plant species that belongs to the pigweed family (Amaranthaceae). Palmer amaranth initiates its emergence around late spring (mid to late May) and manifests an extended period of emergence throughout the season and produces numerous seeds (up to 0.6 million seeds per female plant) (Keeley et al., 1987; Klingaman and Oliver, 1994). Glyphosate was an effective POST herbicide for Palmer amaranth control until the evolution of glyphosate-resistant (GR) populations, which were first discovered in Kansas in 2011 (Heap, 2019). The recent survey suggests that glyphosate resistance has become fairly common among Palmer amaranth populations in Kansas. Furthermore, multiple herbicide-resistant (MHR)

Palmer amaranth is also an increasing concern for Kansas growers. Palmer amaranth populations that have 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 more recently to 2,4-D (synthetic auxins) have been reported in Kansas (Heap, 2019; Kumar et al., 2019).

An MHR Palmer amaranth population showing an inadequate control with glyphosate (Roundup PowerMax) and mesotrione (Callisto) herbicides was identified in Stafford County, KS, in 2017. The main objectives of this research were to 1) characterize the response of suspected MHR Palmer amaranth population to Roundup PowerMax and Callisto herbicides in the whole plant dose-response assays, and 2) to evaluate and develop effective herbicide programs in corn for controlling this MHR Palmer amaranth population.

Procedures

Greenhouse Study

Fully-matured seeds of MHR Palmer amaranth population were collected from Stafford County, KS. Seeds of a susceptible (SUS) Palmer amaranth population were collected from the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS. Whole plant dose-response experiments were conducted in greenhouse conditions at KSU-ARC near Hays, KS. Seedlings of MHR and SUS Palmer amaranth population were grown in 4 × 4 $in.^2$ plastic pots containing commercial potting mixture. Experiments were conducted in a randomized complete block design (blocked by population) with 12 replications. Young Palmer amaranth seedlings (3–4 inches tall) from each population were separately sprayed with Roundup PowerMax at doses of 0, 16, 32, 64, 128, and 256 fluid oz/a. Ammonium sulfate (AMS) at 2% (wt/v) was included with all Roundup PowerMax doses. Doses for Callisto herbicide included 0, 0.75, 1.5, 3, 6, and 12 oz/a along with 1% v/v of crop oil concentrate (COC) and 2.5% v/v of urea ammonium nitrate (UAN, 28%). All herbicide treatments were applied using a cabinet spray chamber equipped with a flat-fan nozzle tip (TeeJet 8001EXR) calibrated to deliver 14 gallons per acre of spray solution at 40 psi. The treated plants were returned to the greenhouse and watered and fertilized as needed. For both herbicides, data on percent visual control (0 = no control, 100 = dead plant) were visually assessed at 7, 14, and 21 days after treatment. Data were analyzed using a 3-parameter log-logistic model in *R* software using the following equation (Ritz et al., 2015):

$$Y = \{D/1+\exp [B (\log X - \log E)]\} \quad [1]$$

Where Y represents % visual control, D is the upper limit, B is the slope of each curve, E is the herbicide dose required to achieve 50% control (referred to as LD_{50}), and X is the herbicide dose. Nonlinear regression parameter estimates and standard errors for each population were determined using the *drc* package in R software. Resistance level (referred as R/S ratio) to Roundup PowerMax and Callisto herbicides was estimated by dividing the LD_{50} value of MHR population by the LD_{50} value of the SUS population.

Field Study

A field study was conducted in 2018 on a grower field in Stafford County, KS (from where MHR Palmer amaranth population was collected). A Roundup Ready and

LibertyLink corn hybrid was planted at 30,000 seeds/a on April 24, 2018. The experiment was established in a randomized complete block design, with 4 replications and a plot size of 10 by 30 ft. Ten different herbicide programs, including PRE alone, PRE followed by (*fb*) early POST (EPOST), and PRE *fb* late POST (LPOST) were tested (Table 1). A nontreated control was also included. All PRE and POST treatments were applied in combination with Roundup PowerMax at 27 fl oz/a. PRE herbicide programs were applied immediately after corn planting (April 24, 2018); while EPOST and LPOST treatments were applied on May 17 and June 1, 2018, respectively. All herbicide treatments were applied with a CO_2-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 being no control and 100 being complete control) were collected at 3 weeks after PRE (WAPRE), 2 weeks after early POST (WAEPOST), and 2 and 7 weeks after late POST (WALPOST). Data on Palmer amaranth control (%) 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

Multiple Resistance to Glyphosate and Mesotrione

The glyphosate dose-response study revealed that the LD_{50} (effective dose of Roundup PowerMax required to obtain 50% control) value of MHR Palmer amaranth population was 131 fl oz/a, and was significantly higher than the 18 fl oz/a value obtained for the SUS population (Figure 1). On the basis of visual control data (LD_{50} values), the MHR population showed 7.2-fold level resistance to glyphosate relative to the SUS population (Figure 1). In a separate mesotrione (Callisto) dose-response study, the MHR population also exhibited 3.5-fold resistance to mesotrione herbicide on the basis of visual control data (LD_{50} values) (Figure 2). In comparison, a Palmer amaranth population from Barton County, KS, has recently been reported with multiple resistance to 2,4-D, glyphosate (Roundup PowerMax), chlorsulfuron (Glean), atrazine (Aatrex), and mesotrione (Callisto) (Kumar et al., 2019).

Herbicide Programs for MHR Palmer Amaranth Control

A single PRE application of Clarity + Corvus + Aatrex and Clarity + Acuron provided more than 90% control of MHR Palmer amaranth at 3 WAPRE; however, control declined in late-season and did not exceed 75% at final rating (7 WALPOST) (Figures 3 and 4). In contrast, control with all PRE applied Clarity + Acuron in combination with Aatrex, Callisto, Dual II Magnum, or Sencor followed by a sequential EPOST application of Acuron alone or in combination with Aatrex, Callisto, or Dual II Magnum ranged from 80 to 95% throughout the season (Figure 3). Similarly, control with PRE applied Clarity + Acuron followed by a LPOST application of Acuron + Status or Acuron + Liberty averaged 85% at the final rating (Figure 3).

Conclusions and Implications

The greenhouse study confirmed that MHR population from Stafford County had evolved multiple resistance to glyphosate and mesotrione herbicides. Results from the field study indicated that two-pass herbicide programs, including PRE tank-mixtures of Clarity + Acuron in combination with Aatrex, Callisto, Dual II Magnum, or Sencor

followed by a sequential EPOST tank-mixtures of Acuron alone or in combination with Aatrex, Callisto, or Dual II Magnum can provide adequate control of MHR population in corn throughout the season.

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Table 1. List of herbicide programs tested for controlling MHR Palmer amaranth in Roundup Ready and LibertyLink corn in Stafford County, KS, in 2018.

Herbicide programs[a,b,c]	Rate (oz/a)	Timing
Clarity + Corvus + Aatrex	8 + 5.6 + 24	PRE
Clarity + Acuron	8 + 96	PRE
Clarity + Acuron + Aatrex *fb* Acuron + Aatrex	8 + 48 + 8 *fb* 48 + 8	PRE *fb* EPOST
Clarity + Acuron + Aatrex + Dual II Magnum + Callisto *fb* Acuron + Aatrex + Dual II Magnum + Callisto	8 + 48 + 8 + 8 + 1 *fb* 48 + 8 + 8 + 1	PRE *fb* EPOST
Clarity + Acuron + Callisto *fb* Acuron + Callisto	8 + 64 + 1 *fb* 32 + 1	PRE *fb* EPOST
Clarity + Acuron + Dual II Magnum *fb* Acuron + Dual II Magnum	8 + 64 + 8 *fb* 32 + 8	PRE *fb* EPOST
Clarity + Acuron + Aatrex *fb* Acuron + Aatrex	8 + 64 + 8 *fb* 32 + 8	PRE *fb* EPOST
Clarity + Acuron + Sencor *fb* Acuron	8 + 48 + 3 *fb* 48	PRE *fb* EPOST
Clarity + Acuron *fb* Acuron + Status	8 + 48 *fb* 48 + 2.5	PRE *fb* LPOST
Clarity + Acuron *fb* Acuron + Liberty	8 + 48 *fb* 48 + 22	PRE *fb* LPOST
Nontreated	-	-

[a]PRE, preemergence. EPOST = early postemergence. LPOST = late postemergence. *fb* = followed by.
[b]All PRE and POST herbicide treatments were applied with Roundup PowerMax at 27 fl oz/a.
[c]Treatments were applied with appropriate adjuvants as dictated by each herbicide label.

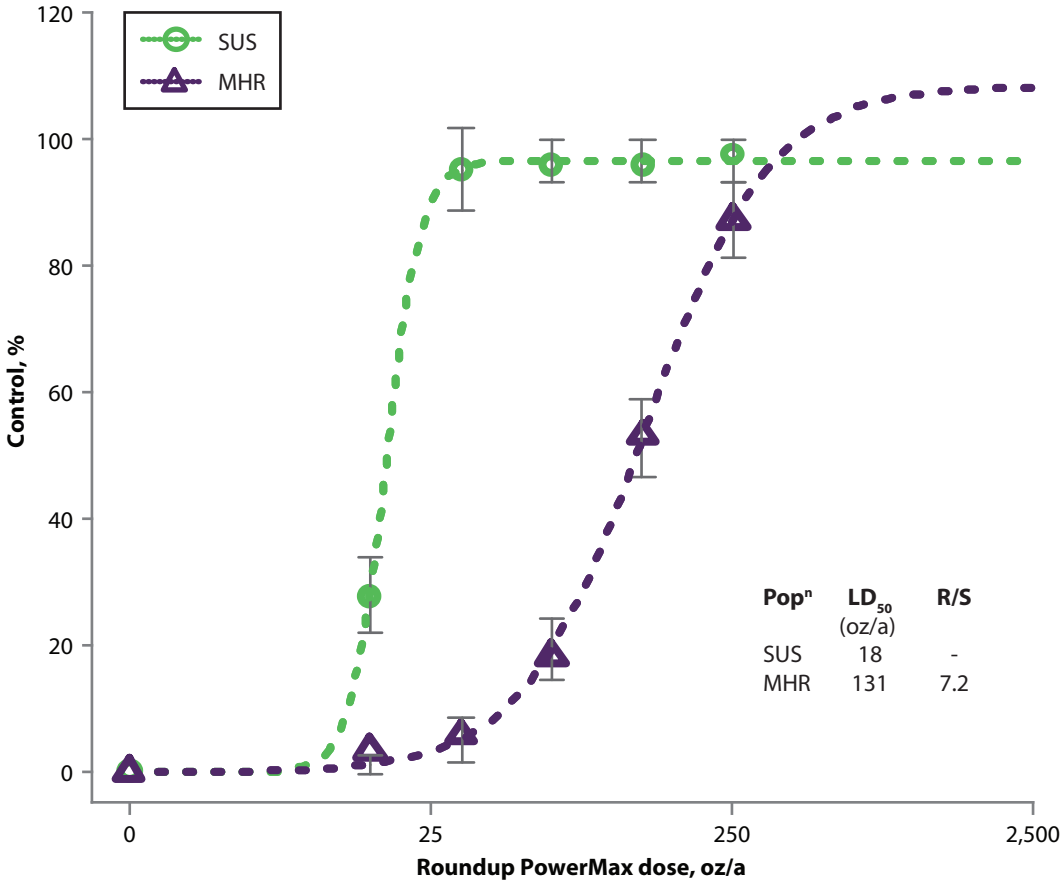

Figure 1. Percent visual control of a susceptible (SUS) and multiple herbicide-resistant (MHR) Palmer amaranth populations treated with various Roundup PowerMax doses at 21 days after treatment. R/S = resistance level ratio. Pop = population. LD_{50} is the estimated amount of Roundup PowerMax (oz/a) required to achieve 50% control of SUS and MHR population.

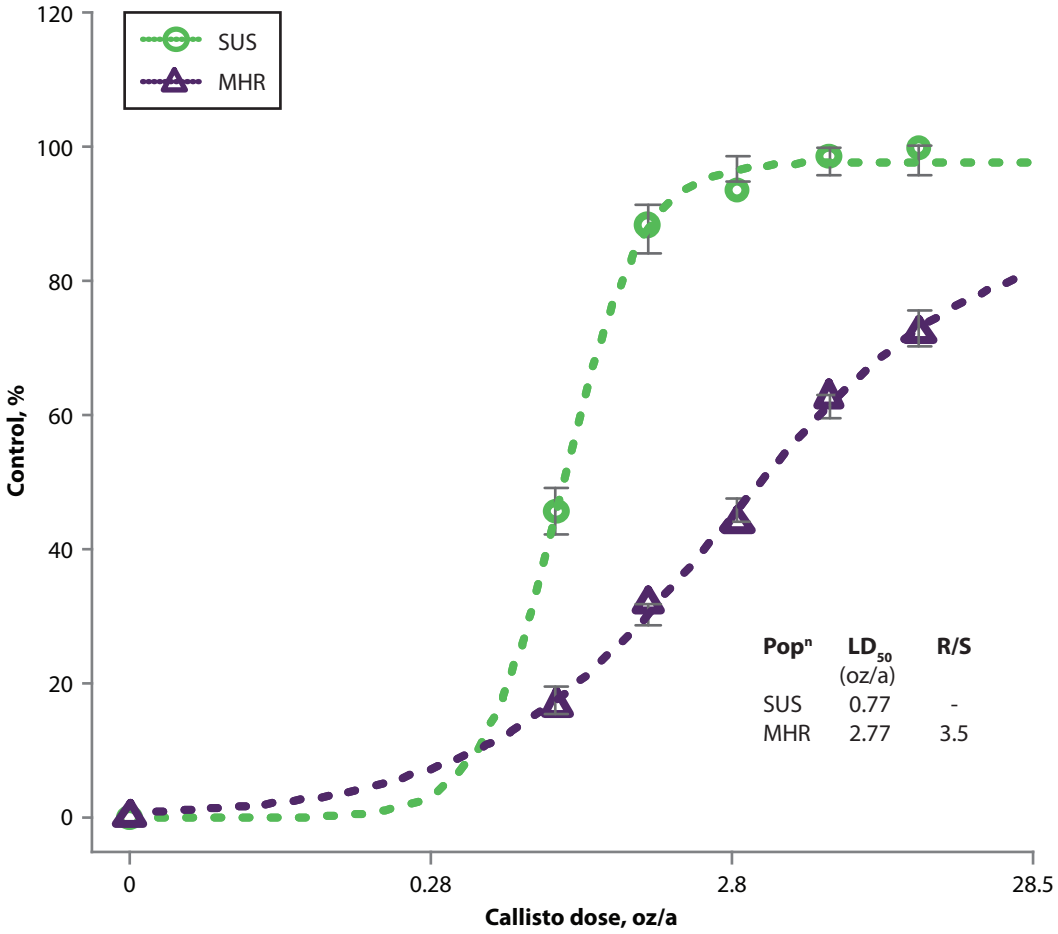

Figure 2. Percent visual control of a susceptible (SUS) and multiple herbicide-resistant (MHR) Palmer amaranth populations treated with various doses of Callisto herbicide at 21 days after treatment. R/S = resistance level ratio. Pop = population. LD_{50} is the estimated amount of Callisto herbicide (oz/a) required to achieve 50% control of SUS and MHR population.

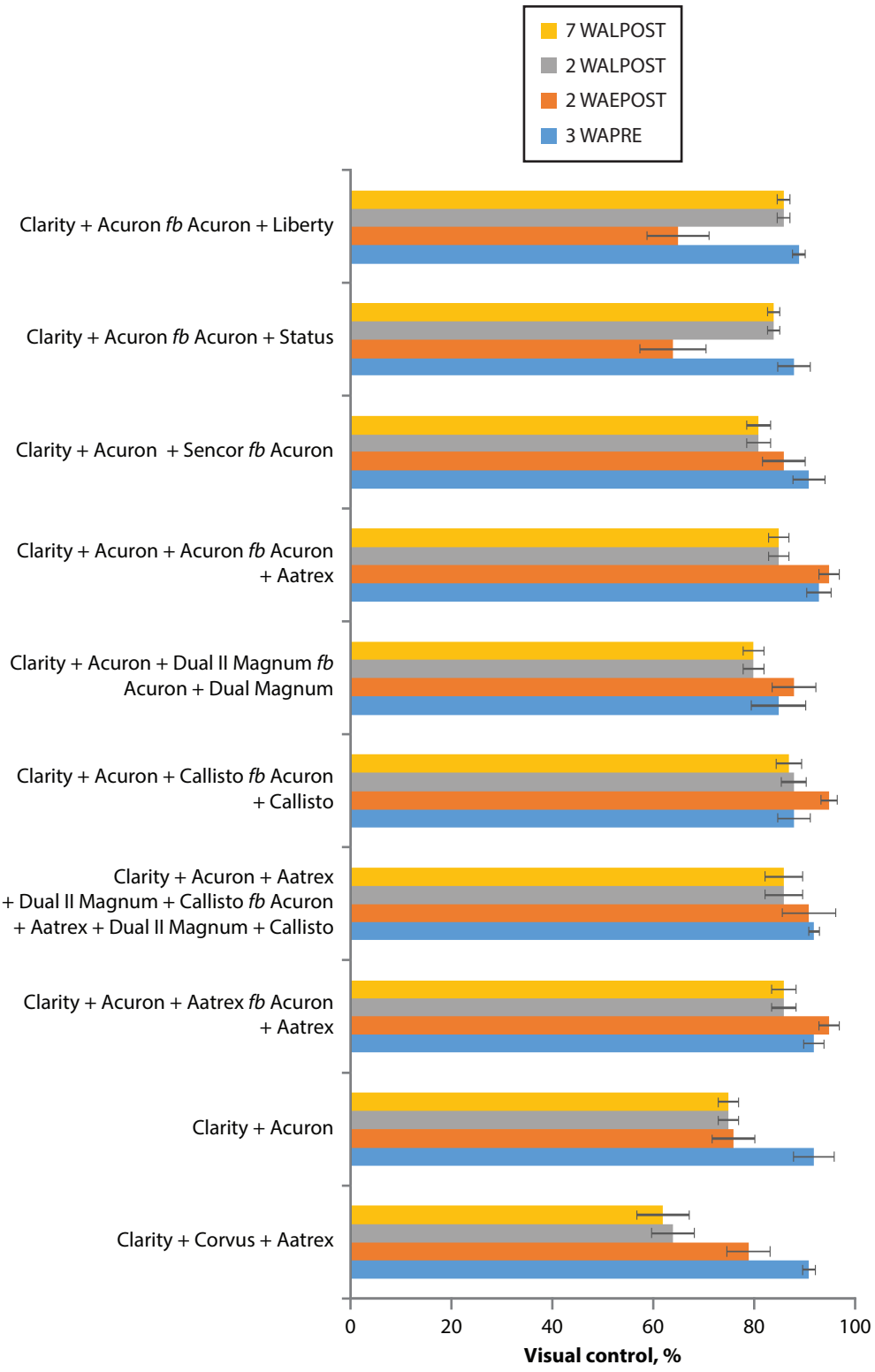

Figure 3. Percent visual control of multiple herbicide-resistant (MHR) Palmer amaranth with various preemergence (PRE), PRE followed by (*fb*) early post emergence (EPOST), and PRE *fb* late POST (LPOST) herbicide programs throughout the growing season in corn. WALPOST = weeks after late POST. WAEPOST = weeks after early POST. WAPRE = weeks after early PRE.

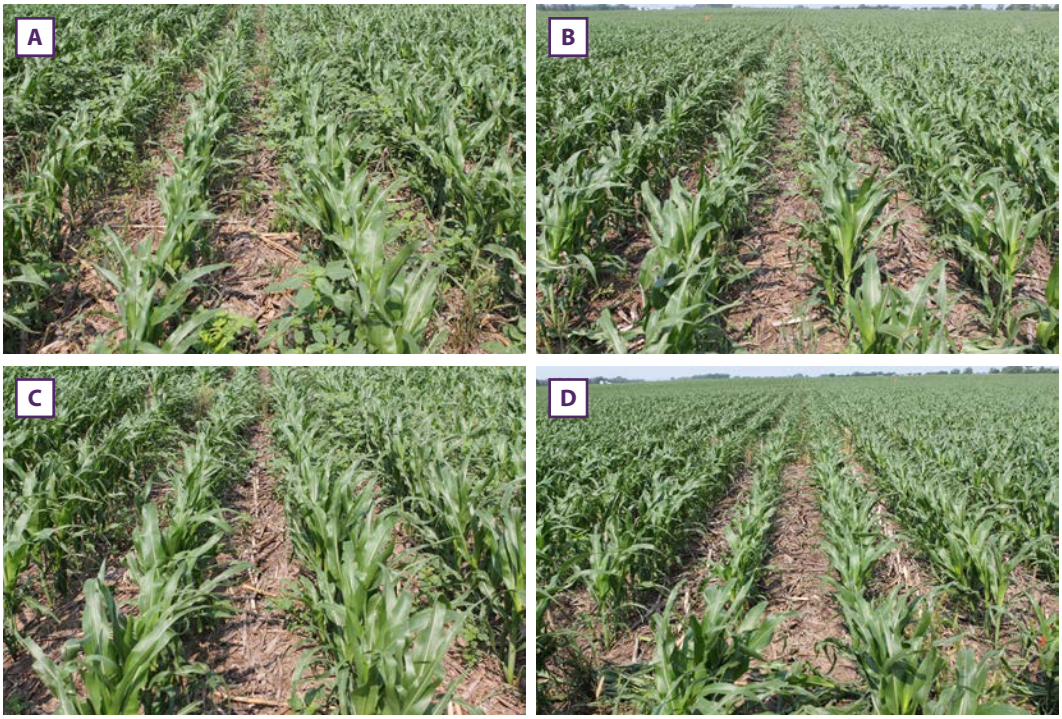

Figure 4. Visual response of multiple herbicide-resistant (MHR) Palmer amaranth in Roundup Ready and LibertyLink corn with various herbicide programs at 2 weeks after early post emergence (POST): Nontreated (A), preemergence (PRE) applied Clarity + Corvus + Atrazine (B), PRE applied Clarity + Acuron (C), PRE applied Clarity + Acuron + Dual II Magnum followed by early POST applied Acuron + Dual II Magnum (D).

Influence of Cultural Practices and Herbicide Programs for Managing Glyphosate-Resistant Palmer Amaranth in Cold-Tolerant Sorghum

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

Summary

The widespread evolution of glyphosate-resistant (GR) Palmer amaranth (*Amaranthus palmeri* S. Wats) has become a serious management concern for grain sorghum producers in western Kansas. To develop an integrated weed management (IWM) system, a field study was conducted at the Kansas State University Agricultural Research Center (KSU-ARC) in Hays, KS, in 2018, to evaluate the effect of sorghum hybrid, row spacing, and herbicide programs on GR Palmer amaranth control, shoot dry weight reduction, and sorghum grain yield. Treatments included two cold-tolerant grain sorghum hybrids: Pioneer 87P06 (commercial check) and ATx645/ARCH12012R (developed by the KSU-ARC breeding program); row spacing of 15-in. (narrow) and 30-in. (standard); and three herbicide programs: 1) a preemergence (PRE) application of Degree Xtra at 2.5 qt/a, 2) PRE applied Degree Xtra at 2.5 qt/a followed by (*fb*) a sequential postemergence (POST) application of Huskie at 15 fl oz/a, and 3) a nontreated weedy check. The experiment was conducted in a randomized complete block design with a factorial arrangement of treatments and 3 replications. Sorghum hybrids were planted on April 17, 2018, in no-till wheat stubble using a seeding rate of approximately 69,696 seeds per acre. Plots were uniformly infested with a GR Palmer amaranth population prior to sorghum planting. Results indicated that both PRE alone and PRE *fb* POST programs provided an excellent, season-long control (> 97%) of GR Palmer amaranth. In nontreated weedy plots, GR Palmer amaranth density was not affected by sorghum hybrid or row spacing; however, its shoot dry weight was reduced by 37% with 15-in. compared to 30-in. rows. Sorghum grain yield of Pioneer 87P06 was increased by 27% in 15-in. compared to 30-in. rows; whereas, row spacing had no effect on grain yield of ATx645/ARCH12012R hybrid. These preliminary results suggest that combination of narrow row spacing (15-in.) and PRE application of Degree Xtra can potentially be utilized for effective and season-long control of GR Palmer amaranth in early-planted (cold-tolerant) grain sorghum.

Introduction

Palmer amaranth (*Amaranthus palmeri* S. Wats) is a problematic weed species in Kansas cropping systems, including grain sorghum. It is a summer annual dicot with extended period of emergence (May through end of September). Palmer amaranth has aggressive growth characteristics and is highly competitive. It is a prolific seed producer (a single female plant can produce up to 0.6 million seeds) (Keeley et al., 1987). Due to its extended period of emergence and rapid growth, it demonstrates greater competitive ability and causes significant crop yield losses. Season-long infestation of Palmer amaranth at a density of 0.15 plants ft^{-2} is known to cause up to 63% yield reduction in grain sorghum (Ward et al., 2013).

In recent years, herbicide-resistant (HR) Palmer amaranth has become a serious challenge to Kansas growers. Glyphosate-resistant (GR) Palmer amaranth was first documented in Kansas in 2011 (Heap, 2019). A more recent field survey has revealed that resistance to glyphosate is fairly common among Palmer amaranth populations across western and central parts of Kansas. In addition, a single Palmer amaranth population with multiple resistance to sulfonylureas (ALS inhibitors), atrazine (PS II inhibitor), mesotrione (HPPD inhibitor), glyphosate (EPSPS inhibitor), and 2,4-D (synthetic auxins) has also been reported recently from a Kansas sorghum field (Heap, 2019; Kumar et al., 2019). The increasing reports of Palmer amaranth populations with resistance to glyphosate and other herbicide chemistries necessitate the development of integrated weed management (IWM) strategies for effective Palmer amaranth control in grain sorghum production.

Cultural practices such as hybrid selection and narrow row spacing alone or in conjunction with herbicides can alter crop-weed competition and can potentially be utilized for weed control. Therefore, the main objectives of this research were to 1) evaluate the effect of sorghum hybrid, row spacing, and herbicide programs on GR Palmer amaranth control in cold-tolerant grain sorghum, and 2) determine the ultimate impact of these factors on sorghum grain yield.

Procedures

A field study was conducted at the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS, in 2018. The experiment was set up in a randomized complete block design with factorial combination of treatments and 3 replications. The three treatment factors included sorghum hybrids, row spacing, and herbicide programs. Two cold-tolerant sorghum hybrids were investigated: a commercial hybrid Pioneer 87P06, and ATx645/ARCH12012R from the K-State breeding program. The two row spacing included 30-in. (standard spacing) and 15-in. (narrow spacing). Herbicide programs included preemergence (PRE) alone, PRE followed by (*fb*) postemergence (POST), and a nontreated weedy check. Degree Xtra at 2.5 qt/a was used in PRE program. Huskie at 15 fl oz/a was used in POST program. Field study was established on April 17, 2018. Seeds of GR Palmer amaranth population were uniformly broadcasted prior to sorghum planting.

Data on percent visual control of Palmer amaranth (on a scale of 0 to 100%, 0 = no control, 100 = complete control) were collected at biweekly intervals throughout the growing season. Palmer amaranth biomass was also collected using two 0.5 square yard quadrats from the center of each plot prior to sorghum harvest. Data on sorghum grain yields were also recorded for each plot using a plot combine. All data were subjected to ANOVA using PROC MIXED in SAS v. 9.4 (SAS Inst., Cary, NC) and means were separated by Fisher's protected least significant difference test ($P < 0.05$).

Results

Results indicated that both PRE alone and PRE *fb* POST programs provided excellent and season-long control (97%) of GR Palmer amaranth (Figure 1). Interestingly, a sequential POST application of Huskie at 15 fl oz/a did not improve the GR Palmer amaranth control, when applied to PRE program (Figure 2). In nontreated weedy plots, GR Palmer amaranth density was not affected by sorghum hybrid or row spacing (data

not shown). However, the shoot dry weights of Palmer amaranth were reduced by 37% with 15-in. compared to 30-in. row spacing (Figure 3). Results from earlier studies at K-State reported that weed growth in 10-in. spaced sorghum rows was reduced by 24% compared to 20-in. spaced rows and by 45% when compared to 30-in. spaced rows (Staggenborg et al., 1999). In another study, it was concluded that grain sorghum was equally competitive in 15- and 30-in. row spacing when weed pressure was low, but as weed pressure increased, grain sorghum was more competitive in 15-in. row spacing (Limon-Ortega et al., 1998). In the current study, sorghum grain yield of Pioneer 87P06 was increased by 27% in 15-in. compared to 30-in. rows; whereas, row spacing had no effect on grain yield of ATx645/ARCH12012R hybrid (Figure 4).

Conclusions and Implications

Based on these results, the combination of narrow row spacing (15-in.) and PRE application of Degree Xtra at 2.5 qt/a has a potential to be used for effective and season-long control of GR Palmer amaranth in early-planted (cold-tolerant) grain sorghum. Future research would be needed to further validate these results by repeating this study in Hays and other locations across western Kansas.

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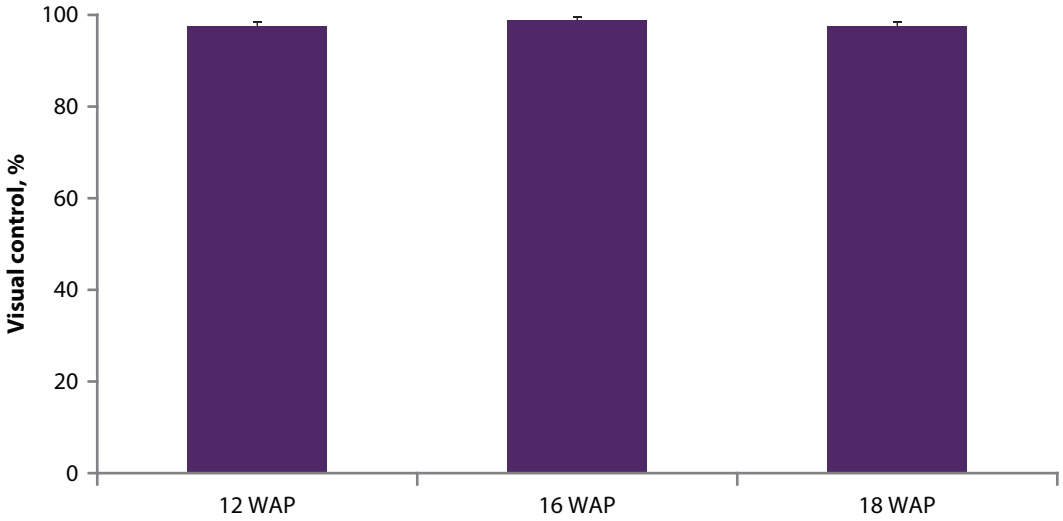

Figure 1. Effect of PRE herbicide program on visual control (%) of glyphosate-resistant Palmer amaranth at 12, 16, and 18 weeks after planting (WAP) of grain sorghum.

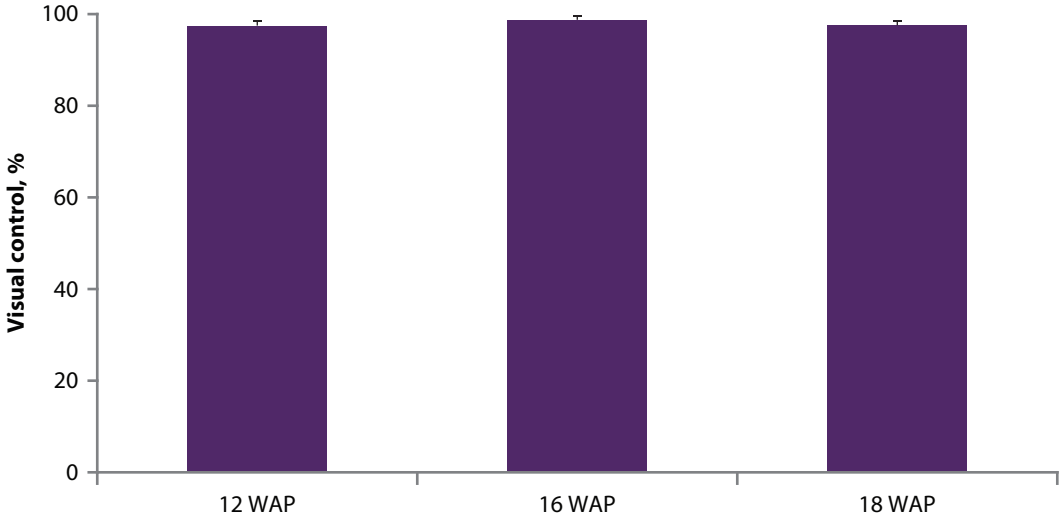

Figure 2. Effect of preemergence followed by (*fb*) postemergence herbicide program on visual control (%) of glyphosate-resistant Palmer amaranth at 12, 16, and 18 weeks after planting (WAP) of grain sorghum.

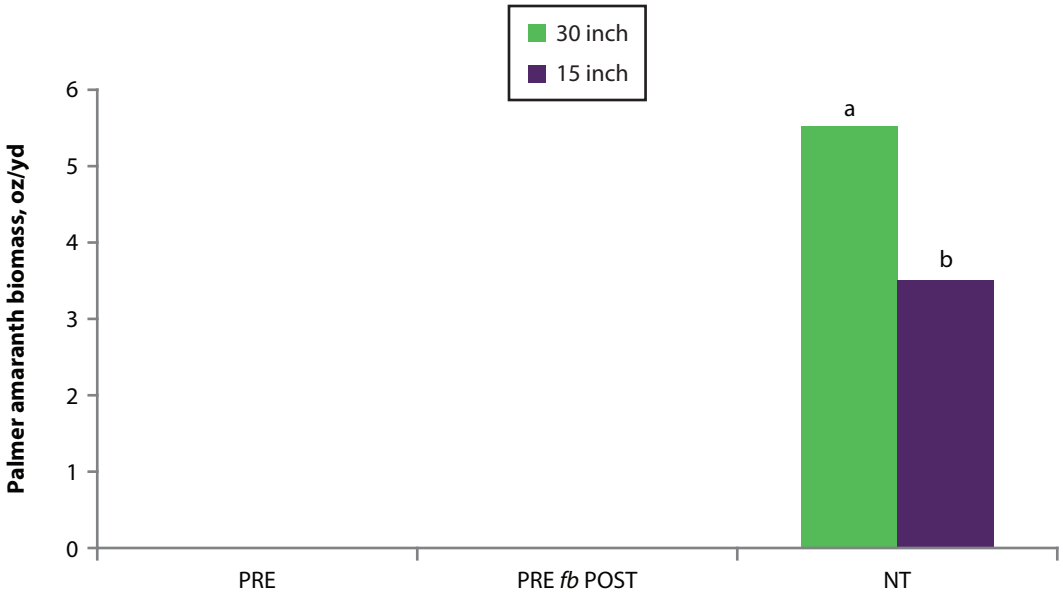

Figure 3. Effect of row spacing on glyphosate-resistant Palmer amaranth biomass (oz/yd) prior to sorghum harvest. PRE = preemergence. *fb* = followed by. POST = postemergence. NT = no-till. Bars with similar letters are not different based on Fisher's protected LSD test at $P < 0.05$.

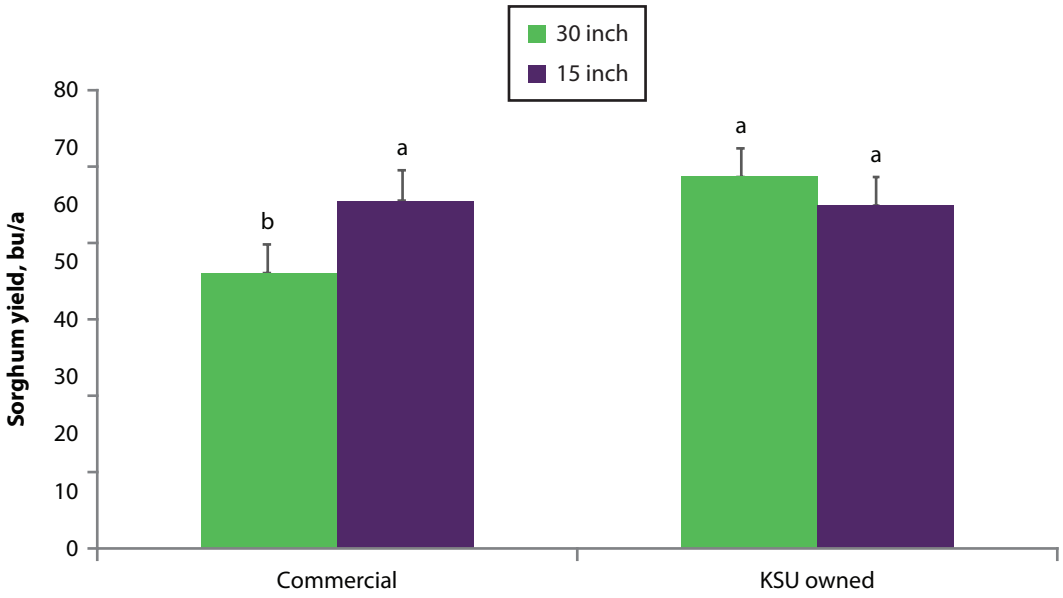

Figure 4. Interaction of row spacing and hybrids on sorghum grain yield (bu/a). Bars with similar letters are not different based on Fisher's protected LSD test at $P < 0.05$.

Sugarcane Aphid Resistance in Pearl Millet

D.D. Serba and J.P. Michaud

Summary

Sugarcane aphid, (*Melanaphis sacchari* (Zehntner) (Hemiptera: Aphididae)) has become an important pest of sorghum in the US. This recent invasion is assumed to be either as a result of a host shift from sugarcane in the south or introduction of a specialized strain from tropical Africa. If host shift happened through adaptive change to infest sorghum, other closely related species such as pearl millet are in danger from this voracious pest. The resistance level of pearl millet genotypes representing A-, B-, R-lines and germplasm were evaluated under climate-controlled growth chamber along with resistant and susceptible sorghum hybrids. Ten plants of the genotypes were planted in a row in a tray per replicate. Cuttings infested with a stock colony of aphids maintained on the susceptible sorghum line were evenly distributed across the soil in each tray to ascend the plants at will. The damage was scored two times (5 and 8 days after infestation) using a scale of 1 to 9 (1 = no visible damage, 9 = dead). The statistical analysis of data found that there are significant differences among genotypes for aphid feeding damage. However, none of the pearl millet genotypes were affected to the level of susceptible sorghum. Four genotypes of pearl millet had resistance levels similar to the resistant sorghum. No statistical differences were observed among the A, B, and R-lines and the germplasm—implying that the cytoplasmic male-sterility system, nuclear restorer gene, and sterility maintainer counterparts have no impact on SCA resistance and susceptibility in pearl millet.

Introduction

Sugarcane aphid (SCA), (*Melanaphis sacchari* (Zehntner) (Hemiptera: Aphididae)) has been an important pest of sugarcane (*Saccharum officinarum* L.) and other graminaceous crops in many tropical and subtropical regions (Singh et al., 2004). Recently, SCA has become a serious insect pest of sorghum (*Sorghum bicolor* L.) in the US. It is not yet clear whether this recent invasion resulted from a host shift from sugarcane–which SCA has infested in Louisiana and Florida for many years–or whether it represents the arrival of a novel strain, possibly from northern Africa where it is known to occur on sorghum. A sexual aphid lineages are able to undergo rapid adaptive changes without much genetic differentiation in shifting from one host plant to another (Nibouche et al., 2015).

The sugarcane aphid feeds and reproduces on grain and forage sorghum (sudangrass, sorghum/sudan hybrids, forage sorghum, and shattercane) and Johnsongrass. The widespread occurrence of the insect and the economic losses incurred over the past four years poses a threat to grain sorghum and sorghum family forage production. There is also the potential for SCA to spread to other crops such as pearl millet, a related crop with potential importance in sorghum growing regions of the central Great Plains. Besides causing direct feeding damage on susceptible cultivars, SCA can also increase the plant's susceptibility to other aphids such as greenbug, (*Schizaphis graminum* (Rondani)) (Michaud et al., 2017) and bird cherry-oat aphid, (*Rhopalosiphum padi* L). (Bayoumy et al., 2016). This probably occurs via elicitation of higher nitrogen content

in the phloem, a factor which is usually limiting for aphid growth and reproduction. Though direct feeding damage is not yet a significant problem on pearl millet, facilitation of other aphid species may cause additional problems.

Plant resistance to insects can be a cost-effective pest control method because it is based on the plant's own self-defense mechanisms. Resistance is a typically heritable plant trait that results in a plant sustaining less damage because it impedes pest feeding, growth, and reproduction. Plant resistance has economic, ecological, and environmental advantages over the application of chemicals to control insect pests. It is economical because, once implemented, no further inputs are required to protect crop yields from the pest and money is saved in comparison to susceptible varieties that require protection with insecticides. Reduced use of insecticides has ecological and environmental benefits by increasing species diversity and ecosystem stability. Therefore, host plant resistance (HPR) to insects is an effective, economical, and environment-friendly method of pest control. The most attractive feature of HPR to farmers is that no extra investment in pest control is usually required. Host plant resistance will not only assist in reducing pesticide use, it will delay the evolution of resistance to insecticides in insect populations, as well as lead to increased activity of beneficial organisms and reduction in pesticide residues in food products.

Pearl millet is being considered as an alternative crop in the drought-prone areas of the central Great Plains (CGP). It has great potential as a source of grain as well as summer grazing and cut forage. However, there is limited information as to levels of susceptibility and/or resistance to SCA in millet lines. Preliminary evaluation of hybrid pearl millet (HPM) for SCA susceptibility in Texas suggested HPM was a poor host for SCA, and could be advocated as an alternative to SCA-susceptible forage sorghums (Trostle et al., 2015). However, the level of SCA resistance in different parental backgrounds and in the germplasm was not assessed. Furthermore, any possible effects of cytoplasmic male sterility (CMS) system, nuclear restorer gene, or the sterility maintainer recessive allele remain unknown.

This study was conducted to assess the level of SCA resistance in pearl millet and assess genetic variability in SCA resistance, and to investigate if the CMS system, the nuclear restorer and maintainer counterparts affect SCA resistance or susceptibility.

Procedures

A total of 20 pearl millet genotypes were examined: five male-sterile (A-lines), five maintainer lines (B-lines), five restorer lines (R-lines), and five germplasm accessions were all randomly selected from the breeding materials available in the millet breeding program at the Kansas State University Agricultural Research Center - Hays (Table 1).

For each experimental replicate, one row of ten plants of each test genotype and two rows of each sorghum check were planted in a tray filled with a mixture of soil and commercial grow mix. The experiment was arranged in randomized complete block design with four replications and conducted in a climate-controlled growth chamber set at 20°C (68°F), a temperature selected to favor the SCA. The experiment was planted on January 23, 2017, and germinated in a growth chamber at 29°C (84°F). Plants were infested when the seedlings were at the four-leaf stage on February 12, 2017 by spread-

ing cuttings infested with apterous aphids (obtained from a stock colony maintained on the susceptible sorghum line) evenly across the soil of each tray and allowing the aphids to ascend the plants at will. Plant damage was scored five and eight days after infestation, on February 17, 2017, and February 20, 2017, using a scale of 1 to 9 (1 = no visible damage, 9 = dead). The data were subjected to statistical analysis using SAS v. 9.4 (SAS Institute Inc., Cary, NC).

Results

The various millet genotypes showed significant differences in susceptibility to damage by SCA (Table 2). Four pearl millet genotypes were as resistant as the resistant sorghum hybrid HG35W. After the susceptible sorghum hybrid 550610 was killed by the aphids, these pearl millet genotypes and the resistant sorghum hybrid remained alive and intact (Figure 1). Damage scores for pearl millet genotypes ranged from 1.7 to 6.5 on the first scoring date and 2.3 to 7.0 in the second score. Thus, there was significant variation in resistance among pearl millet genotypes, but none were as susceptible as the susceptible check, which scored an average of 8.7 and 8.9 on the first and second scorings, respectively.

Results also indicated that there were no significant differences among the A, B, R-lines, and the germplasm in levels of resistance (Figure 2). This implies that the CMS, the nuclear restorer, and the male-sterility maintainer recessive counterpart have no impact on resistance to SCA. This is an important indication that the A1 male-sterility system has no impact on the level of SCA resistance in pearl millet, at least for the time being. However, large-scale cultivation of crop hybrids based on a single CMS source can pose a hazard to sustainable crop production because of genetic uniformity. For example, maize genotypes containing the CMS system called the Texas, or T-cytoplasm (cms-T) were once widely planted until a large fraction of the entire US corn crop was lost when the cms-T system became susceptible to southern corn leaf blight (SCLB) caused by *Helminthosporium maydis* race T (Scheifele et al., 1970). Therefore, male-sterility systems require diversification to prevent epidemics of either diseases or insect pests.

The widespread economic impact of SCA on sorghum has driven significant research, extension, and industry responses (Villanueva et al., 2014; Brewer et al., 2016; Bowling et al., 2016). Study of cross-resistance from greenbug resistance reported that genotypes resistant to different strains of greenbug were mostly resistant or moderately resistant to sugarcane aphid (Armstrong et al., 2015). Though chemical control measures are not considered desirable long-term solutions from environmental and ecological points of view, insecticides with the active ingredients sulfoxaflor and flupyradifuron provide good control of SCA in sorghum. These are currently sold under the brand names 'Transform' (Dow-Dupont) and 'Sivanto' (Bayer CropScience). Older insecticide formulations containing either organophosphates or pyrethroids are not recommended for use against SCA. Their broad-spectrum activities mean they kill beneficial natural enemies that assist in controlling SCA and can actually exacerbate the problem.
The potential ability of SCA to shift host plants warrants efforts to evaluate SCA performance and damage potential on other related crops such as pearl millet. A greenhouse no-choice experiment showed that SCA could not survive on other cereals such as maize (*Zea mays* L.), teff (*Eragrostis tef* (Zucc.)), proso millet (*Panicum miliaceum* L.), barley (*Hordeum vulgare* L.), and rye (*Secale cereale* L.) but could survive on

sorghum (Armstrong et al., 2015). Therefore, a continuing evaluation of related crops for their susceptibility to SCA is imperative to develop strategies for large-scale deployment of resistance.

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Table 1. Random samples and sorghum checks used for the sugarcane aphid screening

No	A-lines	B-Lines	R-Lines	Accessions	Sorghum checks
1	KPM003A	KPM009B	KPM003R	PI 164421	HG35W (Resistant)
2	KPM011A	KPM013B	KPM007R	PI 279667	550610 (Susceptible)
3	KPM015A	KPM022B	KPM012R	PI 307711	
4	KPM021A	KPM027B	KPM019R	PI 358400	
5	KPM034A	KPM032B	KPM023R	PI 521649	

Table 2. Average damage score of pearl millet parental lines and germplasm accessions to sugarcane infestation evaluated against a resistant and a susceptible sorghum hybrids

Genotype	Score 1	Genotype	Score 2
KPM023R	1.7e	KPM023R	2.3e
KPM021A	2.0e	KPM021A	2.8de
HG35W (R)	2.9de	HG35W	3.0cde
KPM022B	3.3cde	KPM022B	4.3bcde
PI 358400	3.8bcde	PI 164421	4.5bcde
PI 164421	4.0bcde	PI 358400	4.8bcd
KPM009B	4.5bcd	KPM009B	5.0bcd
KPM007R	4.5bcd	KPM007R	5.0bcd
KPM027B	4.7bcd	KPM019R	5.3bc
KPM012R	4.8bcd	KPM027B	5.3bc
PI 521649	4.8bcd	KPM003A	5.5bc
KPM003A	4.8bcd	KPM012R	5.5bc
KPM011A	5.0bcd	KPM011A	5.5bc
KPM019R	5.3bcd	PI 521649	5.8b
KPM003R	5.3bcd	KPM003R	5.8b
PI 279667	5.5bcd	PI 279667	6.0b
KPM013B	5.8bc	PI 307711	6.5b
PI 307711	6.0bc	KPM015A	6.5b
KPM015A	6.0bc	KPM013B	6.5b
KPM034A	6.5b	KPM034A	6.8b
KPM032B	6.5b	KPM032B	7.0b
550610 (S)	8.7a	550610	8.9a

Figure 1. Partial view of the pearl millet genotypes and the resistant (sorghum-R) and susceptible sorghum (sorghum-S) checks infested with sugarcane aphid. The picture was taken on the day of final score.

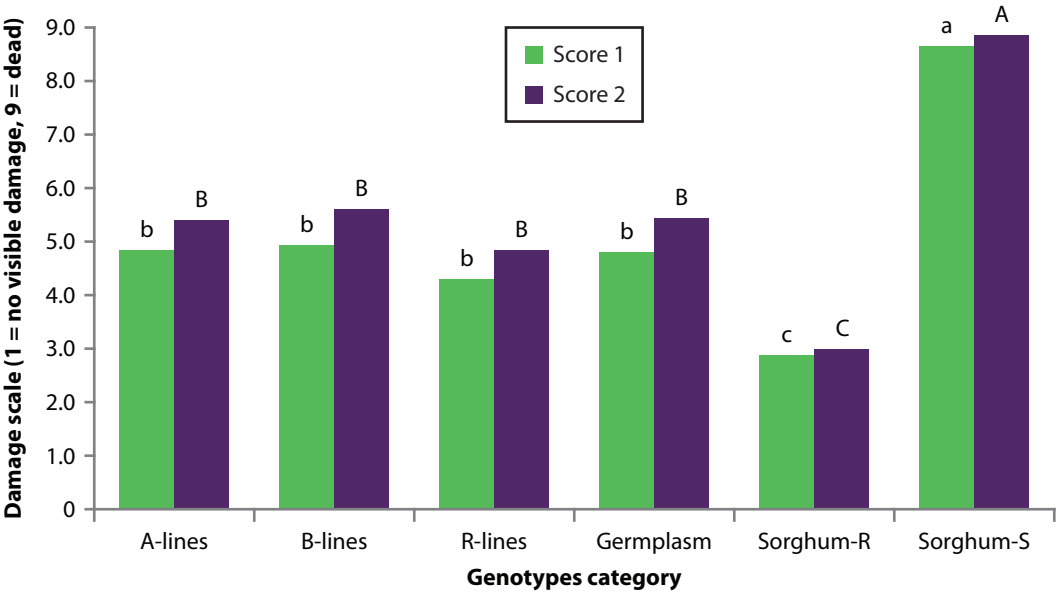

Figure 2. Average sugarcane aphid damage score on pearl millet parental lines and germplasm based on 1 to 9 damage scale. Bars labeled with the same letter (upper or lowercase) were not significantly different.

Harvest Method, Cultivar, and Time of Swathing Effects on Yield and Oil Content of Winter Canola

M.J. Stamm, S.J. Dooley, and K.L. Roozeboom

Summary

Producers want to achieve the highest yield and oil content possible using either swathing or direct cutting to harvest winter canola. Multi-year experiments were conducted to evaluate the effects of harvest method (swathing versus direct cutting) and cultivar on seed moisture, yield, and oil content; and to evaluate the effects of swathing timing on yield and oil content. The harvest method experiments were conducted for two seasons at the Redd Foundation Field near Partridge, KS. The time of swathing experiments were conducted for two seasons near Manhattan, KS. In 2016 and 2017, harvest method had a significant effect on seed moisture, yield, and oil content. Swathing produced seed with lower moisture content and greater yield, but direct cutting produced seed with the highest oil content. Cultivars differed in their response to yield depending on the harvest method used. Some cultivars responded positively to swathing, others responded positively to direct cutting, and some showed no response to harvest method. Time of swathing had a significant effect on yield and oil content. As a rule, as seed color change progressed, yield and oil content increased. All swathing treatments had greater yield than direct cutting except when swathing was done at green seed. Seed from direct cutting had significantly greater oil content than seed from all swathing treatments. Both swathing and direct cutting can be used effectively to harvest winter canola.

Introduction

Producers have two options when harvesting canola. They can swath it into windrows, allow it to dry, and then pick it up, or they can cut it directly when it has reached seed moisture of 10% or less. Each harvest method can be employed effectively in the southern Great Plains, but few studies have compared each method's effects on harvested seed moisture, yield, and oil content. Although canola is typically swathed at 50% seed color change, determining when to swath can be challenging for inexperienced canola producers. Some producers have been led to swath too early, before seed color change begins, which results in poor yields and low oil content. Canola producers are subject to price discounts for low oil content upon delivery of harvested seed to the crusher. Oil discounts typically begin at -3% of contract price and drop 1% for each percent of oil below 38%. Investigating the right time to swath will help producers make a more informed decision and reduce the chance of delivering low oil seed to the crusher.

Procedures

The harvest method experiments took place during the 2015–16 and 2016–17 growing seasons at the Redd Foundation Field near Partridge, KS. The time of swathing experiments took place during the 2016–17 and 2017–18 growing seasons at Manhattan, KS. The cultivars used in the harvest method experiment included Riley, HyCLASS115W,

and Mercedes in 2016; with DKW45-25 substituted for HyCLASS115W in 2017. The cultivars used in the time of swathing study included two hybrids (Hekip and Mercedes) and two open-pollinated cultivars (Riley and DKW16-15). Treatments for the time of swathing experiment were green seed, 10% seed color change (SCC), 50% SCC, 80% SCC, and direct cutting. Dates of planting, swathing, and harvesting for both experiments are summarized in Table 1. Plot size at Partridge was 5 feet by 50 feet and plot size at Manhattan was 5 feet by 25 feet. Seeding rate was approximately 4 lb/a. Best management practices for fertility, weed, and pest control were followed. The swath treatments were imposed using a 5-foot plot swather (Swift Manufacturing, Saskatchewan) to cut and form windrows that were subsequently harvested using a Kincaid 8-XP (Kincaid Manufacturing, Haven, KS) plot combine equipped with a HarvestMaster Classic Grain Gauge (Juniper Systems, Logan, UT). Oil content was estimated using near-infrared spectroscopy (NIR) manufactured by FOSS at the Brassica Breeding and Research program at the University of Idaho, Moscow, ID.

Results

Harvest Method Experiment

Results for the harvest method experiment are presented by year because of differences in the cultivars used.

Moisture

Harvest method had a significant effect on seed moisture in both years (Table 2). Swathing resulted in lower moisture content than direct cutting. Each harvest method resulted in seed with moisture contents less than the recommended harvest moisture content of 10% for canola.

Yield

Although swathing resulted in greater yields in both years, the difference was significant only in 2016 (Table 2). Swathing had 35% greater yields than direct cutting in 2016, but only 1% greater yields in 2017. The interaction between harvest method and cultivar was significant in both years (Table 3). In 2016, the Mercedes-swath treatment produced 70% higher yields than the Mercedes-direct treatment. The Riley-swath and Riley-direct treatments did not differ. HyCLASS115W-swath had 32% higher yields for HyCLASS115W-direct. In 2017, the highest yielding treatment was Mercedes-swath, but this treatment was not different from the DK45-25-direct, Riley-swath, or Riley-direct treatments. Similar to 2016, the 2017 Mercedes-swath treatment was greater than the Mercedes-direct treatment, and Riley did not differ in yield between harvest methods. The DKW45-25-direct treatment had 19% greater yields than DKW45-25-swath treatment.

Oil

In 2016, the direct treatment had significantly higher oil content than the swath treatment, a difference of 0.9% (Table 4). Across harvest treatments, Mercedes had 2.3% greater oil content than Riley and 3.6% greater oil content than HyCLASS115W. There was no significant interaction between cultivar and method for oil. Oil content was not measured in 2017 because of a sampling error at harvest.

Conclusions

The lower moisture content of swathed canola was the result of cutting the crop to begin the dry down process for harvesting. The moisture contents for swathed canola were typical for the region. Swathing returned higher yields than direct cutting in both 2016 and 2017. Cultivars reacted differently to harvest method. The Mercedes-swath treatment had the highest yield in both years. Mercedes is a hybrid, and the 2016 and 2017 growing seasons benefited hybrids because of warm winter temperatures. Mercedes did not respond as well to direct cutting, most likely due to the hybrid having higher moisture content than the other varieties when direct cut. More green pods and seed could have been thrown out the back of the combine as a result. On the other hand, DKW45-25 benefited from direct cutting, HyCLASS115W benefited from swathing, and Riley had nearly equal yields for both harvest methods. Since all harvest treatments were completed on the same day, some of the yield difference could be a result of not fine-tuning the direct harvest treatment to the individual cultivar. Thus, responses might be different in an actual production scenario. Oil content differed by harvest method and cultivar. Direct cutting produced the highest oil content. Mercedes had the highest oil content followed by Riley and HyCLASS115W. The higher oil content from direct cutting may be the result of not cutting the plant off early and allowing it to have the full complement of oil production.

Time of Swathing Experiment

Yield

Yield response to treatment was similar in both years, so data were analyzed across years (Table 5). The 10%, 50%, and 80% SCC treatments yielded significantly more than the green SCC and the direct cutting treatments. The highest yielding treatment was 80% SCC, followed by 50% and 10%. The green SCC and direct cut treatments yielded 26% and 18% less than the 50% SCC treatment, respectively.

Oil

Similar to yield, there was a significant effect on oil content for the time of swathing treatment over two years (Table 5). Direct cutting had the highest oil content, having 1.1% greater oil than 80% SCC and 1.8% greater oil than 50% SCC. The lowest oil content was the green SCC treatment, which was 2.1% less than 50% SCC.

Conclusions

Time of swathing had a large effect on yield and oil content. Yields increased as swathing was delayed to greater SCC progression. Direct cutting resulted in the lowest yields, which could be the result of harvesting before dry down was complete for some cultivars. Adjusting direct harvest dates to match cultivars might have improved yields. In both years, there was no loss of yield from shattering. Direct cutting produced the highest oil contents, more than 1.1% greater than the closest swathing treatment. Also, waiting to swath until a greater degree of SCC may be a way to increase oil content. Producers will have to weigh the advantages and disadvantages of delayed swathing as the risk of shatter loss increases as the crop ripens. It is recommended to hold off on swathing until at least 50% SCC.

Table 1. Planting, swathing, and harvest dates for the harvest method and time of swathing experiments, 2015–2018

		Harvest method experiment		
Location	Season	Planting date	Swathing date	Harvest date
Partridge	2015–16	9/23/15	6/3/16	6/10/16
	2016–17	9/21/16	6/10/17	6/27/17

		Time of swathing experiment						
			Time of swathing					
Location	Season	Planting date	Green seed	10% SCC†	50% SCC	80% SCC	Swath harvest	Direct cut
Manhattan	2016–17	9/30/16	5/26/17	6/2/17	6/5/17	6/8/17	6/12/17	6/15/17
	2017–18	9/20/17	6/4/18	6/7/18	6/9/18	6/11/18	6/13/18	6/16/18

†SCC = seed color change.

Table 2. Moisture content (%) and yield (bu/a) of canola seed by harvest method

	2016		2017	
Method	Moisture	Yield	Moisture	Yield
Direct	9.3 a	26.5 b	9.4 a	51.1 a
Swath	5.6 b	35.7 a	5.8 b	53.4 a

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

Table 3. Canola cultivar yields by harvest method

	2016		2017	
Method	Cultivar	Yield (bu/a)	Cultivar	Yield (bu/a)
Direct	HyCLASS115W	23.8 c	DKW45-25	55.3 a
	Mercedes	27.4 bc	Mercedes	44.4 c
	Riley	28.3 bc	Riley	53.5 abc
Swath	HyCLASS115W	31.5 b	DKW45-25	46.6 bc
	Mercedes	46.5 a	Mercedes	59.6 a
	Riley	29.0 b	Riley	53.9 ab

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

Table 4. Main effect means for oil content in 2016

Method	Cultivar	Oil (%)
Direct	---	40.7 A
Swath	---	39.8 B
---	HyCLASS115W	38.6 c
---	Mercedes	42.2 a
---	Riley	39.9 b

Values within a column followed by the same uppercase or lowercase letter are not different at $\alpha = 0.05$.

Table 5. Yield and oil content of canola at different stages of seed color change (SCC) compared to direct cutting, 2017 and 2018

Timing	Yield	Oil
	bu/a	%
Direct	42.7 b	40.0 a
80% SCC	51.4 a	38.9 b
50% SCC	50.5 a	38.2 c
10% SCC	49.6 a	37.9 c
Green	40.0 b	36.1 d

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

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 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.

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 with a field cultivator. Starting in the fall of 2012 through fall of 2017, the treatments were conducted with the TurboMax or a Great Plains Sub-soiler Inline Ripper SS0300. Spring tillage in 2013–2016 was conducted with the TurboMax and a field cultivator in 2017 on the required treatments. Starting in the fall of 2017, the vertical tillage treatments were made using a Kuhn Krause Excelerator 8005. Each tillage treatment had 4 replications.

Dry fertilizer (11-52-60 nitrogen (N), phosphorus (P), and potassium (K)) was applied to the entire field prior to fall tillage in 2012 and to the soybean stubble in 2013 and 2014. In the fall of 2015 and 2016, 14-52-40-10 (N, P, K, and sulfur (S)) was applied to the soybean stubble prior to fall tillage. Nitrogen (150 lb in 2012 and 2013; and 180 lb in 2014, 2015, 2016, 2017, and 2018) 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 are included in Table 1.

Irrigation was set 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 and 2018.

Results

Yields of corn or soybeans did not differ due to tillage in the setup year of the study (Table 2). The yields were respectable considering the extreme heat and drought experienced in this growing season. The growing conditions were better in 2013, resulting in higher yields in both corn and soybeans, but no significant differences between tillage treatments (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 yielded higher than the shallow tillage in corn, but not in soybeans. 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 being the more conventional annual tillage and the vertical tillage systems. Combining data from 2013–2018 for analysis showed corn yields are favored by deep tillage, and soybean yields 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 2014–2018 did not show any differences (Table 3). We anticipated that it will 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 specific 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. Yield-limiting conditions may vary between fields based on soil type and environmental conditions during a season and over the long term.

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

	2012		2013		2014		2015	
Crop:	Corn	Soybean	Corn	Soybean	Corn	Soybean	Corn	Soybean
Planting date:	12-Apr	14-May	30-Apr	15-May	21-Apr	21-May	14-Apr	1-Jun
Hybrid/variety:	Pioneer P1395	Pioneer P93Y92	Pioneer P1498 HR AQ	Pioneer P94Y01	Pioneer P1105AM	Asgrow 3833	Pioneer P1105AM	Midland 3884NR2 + ILeVO
Seeding rate:	30.6K	155K	30K	144K	32K	140K	31.7K	144K
Row spacing (inches):	30	30	30	30	30	30	30	30
Harvest date:	31-Aug	5-Oct	27-Sep	8-Oct	11-Sep	9-Oct	10-Sep	13-Oct
Irrigation (inches)								
May	0.77	0.77	0	0	0	0	0	0
June	4.25	0.73	1.58	1.58	0	0	1.58	0.74
July	4.63	4.19	3.51	3.51	4.74	1.55	2.29	0.74
August	0.73	4.66	0.77	2.27	2.19	2.19	2.87	2.87
September	0	0	0	2.18	0	0	0	0

	2016		2017		2018	
Crop:	Corn	Soybean	Corn	Soybean	Corn	Soybean
Planting date:	11-Apr	31-May	24-Apr	26-May	23-Apr	7-May
Hybrid/variety:	AgriGold 6538	Stine 42RE02	Midland 534	Pioneer P39T67 + ILeVO	Golden Harvest 11B63	Midland 4373 RR2
Seeding rate:	31.7K	140K	32K	140K	32K	140K
Row spacing (inches):	30	30	30	15	30	15
Harvest date:	19-Sep	17-Oct	20-Sep	17-Oct	31-Aug	17-Oct
Irrigation (inches)						
May	0	0	0	0	0	0
June	2.24	0.74	2.88	0.00	4.71	0
July	4.40	4.40	3.63	1.82	4.85	3.11
August	0.70	1.54	1.81	1.81	1.71	1.67
September	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 2013–2018 at Kansas River Valley experiment fields

	Corn yield						Average corn yield	Average stand
	bu/a							Plants/a
Tillage treatment	2013	2014	2015	2016	2017	2018	2013–2018	2014–2018
No-tillage	221	243	205	183 b*	226	206	214 b	32,538
Fall subsoil/spring field cultivate	217	259	213	202 a	233	214	222 a	32,188
Fall vertical tillage	196	259	207	189 b	226	210	215 b	32,150
Fall subsoil after sb/vertical tillage after corn	219	256	214	195 a	234	209	224 a	31,788
Pr>F#	0.48	0.27	0.1	0.005	0.59	0.7	0.02	0.07

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

Table 4. Effects of tillage treatments on soybean yields in 2013–2018 at Kansas River Valley experiment fields

	Soybean yield						Average soybean yield
	bu/a						
Tillage treatment	2013	2014	2015	2016	2017	2018	2013–2018
No-tillage	62.4	52.8	69.7	80.2	67.4	69.3 ab*	66.9 c
Fall subsoil/spring field cultivate	64.3	54.6	73.1	76.1	72.8	74.9 a	69.3 a
Fall vertical tillage	64.4	55.5	72.8	78.6	68.1	75.0 a	69.1 ab
Fall subsoil after sb/vertical tillage after corn	66.3	53.4	70.9	75.7	70.1	66.6 b	67.2 bc
Pr>F#	0.52	0.59	0.23	0.11	0.098	0.03	0.035

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

Pursuing the Best Management Strategies for Corn-Soybean Rotation Systems in North Central Kansas

A.A. Correndo and I.A. Ciampitti

Summary

The aim of this study was to evaluate different management strategies for improving yield productivity in corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] rotation systems. During the 2018 season, a long-term corn-soybean experiment was continued in Scandia, KS, evaluating five management strategies under rainfed and irrigated conditions. For corn, average yields were 146 bu/a and 172 bu/a under rainfed and irrigated conditions, respectively. For soybean, rainfed and irrigated average seed yields were similar (47–50 bu/a), attributed to herbicide injury on the irrigated plots. For both crop and water scenarios, intensifying the crop management (by modifying seeding rate, row spacing, fertilization program, and pest control) significantly increased yields as compared to the farmer's strategies.

Introduction

The "Exploitable Yield Gap" could be defined as the difference between the actual yield (current farmer yield) and the attainable yield (improved yield achieved by adjusting management practices). Management practices such as row spacing, seeding rate, fertilization, pest, and disease control affect the size of the yield gap. A management system is a combination of production practices. The aim of this study was to evaluate the combination of production practices to identify the best management strategies for closing yield gaps in a corn-soybean system.

Procedures

A long-term study under a corn-soybean rotation, established in 2014, was continued during the 2018 cropping season at the North Central Kansas Research Station (Scandia, KS; 39°49'41.60"N, 97°50'22.07"W) in a Crete silt loam soil (fine, montmorillonitic, mesic Typic Argiduolls/Pachic Argiustolls). Prior to planting and before tillage operations (April 2018), six cores per soil sample were collected per plot at 0–6 inches soil depth in both rainfed and irrigated areas. Samples were analyzed for pH, soil organic matter (SOM, %), and extractable (M-3) phosphorus (P), potassium (K), calcium (Ca), and magnesium (Table 1).

Similar to the previous seasons (2014–2017), the experiment consisted of five treatments in a randomized complete block design with five replications (Table 1) in plots 20-ft wide × 50-ft long. Corn served as previous crop for soybean, and soybean served as precedent crop for corn. Both corn (DKC64-69RIB) and soybean (P39T67R) were planted on May 4, 2018. Crops were mechanically harvested on November 1, 2018, (soybean) and November 6, 2018, (corn) from the two (farmer practice (FP) and comprehensive fertilization (CF)) or four central rows (production intensification

(PI), ecological intensification (EI), and advanced plus (AD)). Yields were corrected to 15.5% moisture for corn, and 13% moisture for soybean.

Weather data were gathered from the Kansas Mesonet Weather Data Library, Kansas State University (Figure 1). Cumulative precipitations and mean temperatures for the 2018 growing season were compared to the historical data (1980–2017) from the North Central Kansas Research Station (Scandia, KS) (Figure 2).

Data Analysis

The yield data were executed by performing an analysis of variance (ANOVA) split by crop and water condition. For each crop × water condition, a mixed model was considered with treatment as the fixed factor and block as the random factor. When significant treatment effect was observed ($P \leq 0.05$) with ANOVA, mean comparisons were performed using the Tukey's *P*-value adjustment. Analyses were carried out using the '*nlme*' and '*emmeans*' packages of R software.

Results

Weather

The total rainfall during the planting-maturity period was approximately 19.6 inches for corn and 22.6 inches for soybean. Its distribution pattern marked a relatively dry period at the beginning of the season, followed by a peak by mid-June and another dry period until late July, then the rainfall became more regular until early September, relatively accompanying the grain filling period for both crops. In early October (with the corn already mature), 3 inches of rainfall was registered while soybean was finishing seed filling. In terms of cumulative precipitations, the 2018 growing season was near the historical average mean for the April-October period; slightly below the average precipitation for corn (reaching maturity by late September), while slightly above the average for soybean (reaching maturity by early to mid-October). In terms of mean temperatures, the 2018 was one of the warmest seasons since 1980 (Figure 2).

Corn Grain Yield

The grain yields for the rainfed condition ranged from 104 bu/a (FP) to 185 bu/a (EI) while for the irrigated condition, yield ranged from 135 bu/a (PI) to 209 bu/a (EI) (Figure 3). Under rainfed conditions, the effect of treatment was significant ($p_R = 0.04$), but only differing for yield between the FP (lowest yield, 104 bu/a) and the EI (highest yield, 185 bu/a) treatments. Under irrigated conditions, treatment effect was also significant ($p_I = 0.009$). The EI (209 bu/a) and AD (195 bu/a) strategies showed the highest yields (not differing from each other), while FP (144 bu/a) and PI (135 bu/a) showed the lowest ones. The yield gap (%, over FP), expressed as the difference between the maximum yielding treatment and the FP, was estimated at 78% for rainfed corn and 45% when irrigated. Under both water conditions, adding fertilizer to corn (CF) reduced the yield gap, but an additional increase in plant density and reduction in row spacing (EI) were necessary to completely close the gap.

Soybean Seed Yield

The seed yields for the rainfed condition ranged from 31 bu/a (FP) to 65 bu/a (EI) while for the irrigated condition, yields ranged from 34 bu/a (PI) to 62 bu/a (AD) (Figure 4). The irrigated soybean crop suffered herbicide injury just before the begin-

ning of the seed-filling period, so yield was negatively affected. Despite the latter, under both water conditions, the effect of treatment was significant ($p_R = 0.0022$; $p_I = 0.0048$). In both cases, the FP strategy always showed the lowest yields, while CF and PI reduced the yield gap, but not significantly, and the EI and AD strategies always resulted in significantly higher yields as compared to FP. Regarding the yield gap, it was estimated at 112% for the rainfed condition and at 82% when irrigated.

Overall, intensified management systems based on a high seeding rate, combined with a narrow row spacing and a balanced nutrition program, increased yields compared to the farmer practice scenario.

Table 1. Soil chemical analysis (0–6 inches) before planting corn and soybean at irrigated and rainfed areas in Scandia, KS, during the 2018 cropping season

Crop	pH	Soil organic matter	Phosphorus	Potassium	Calcium	Magnesium
		%	---------- mg/kg ----------			
Irrigated						
Corn	6.15	2.62	14	481	2014	359
Soybean	6.09	2.46	11	443	2075	381
Rainfed						
Corn	5.82	2.96	15	494	2632	507
Soybean	5.91	2.85	15	485	2104	360

Table 2. Treatments evaluated in corn-soybean systems at Scandia, KS, during the 2018 cropping season

Treatments:	Farmers' practices	Comprehensive fertilization	Production intensity	Ecological intensification	Advanced
Seeding rate:	Medium corn: 28,000 pl/a soybean: 110,000 pl/a		High corn: 40,000 pl/a soybean: 134,000 pl/a		
Row spacing:	Wide (30 in.)		Narrow (15 in.)		
Fertilization	No	*NPKS	No	NPKS+ 1x(Fe, Zn, B)	NPKS+ 2x(Fe, Zn, B)
Fungicide	No	No	No	1x	2x
Insecticide	No	No	No	1x	2x
Herbicide	Yes	Yes	Yes	Yes	Yes

*Nitrogen (N) was only applied to the corn plots.
P = phosphorus. K = potassium. S = sulfur. Fe = iron. Zn = zinc. B = boron.

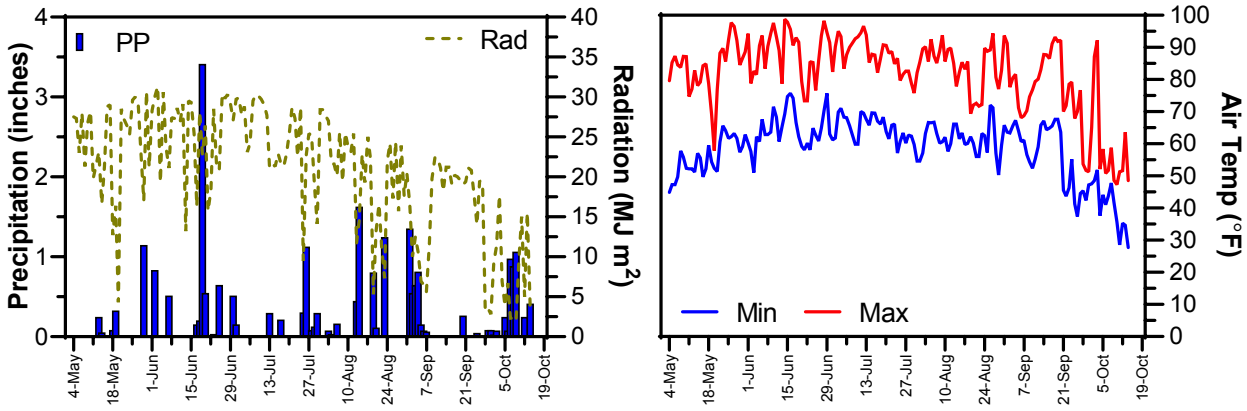

Figure 1. Daily precipitation (blue bars, inches), global radiation (dashed line, MJ/m²) on the left, and daily air temperature (minimum = blue line, and maximum = red line) on the right, for the 2018 corn-soybean season at Scandia, KS.

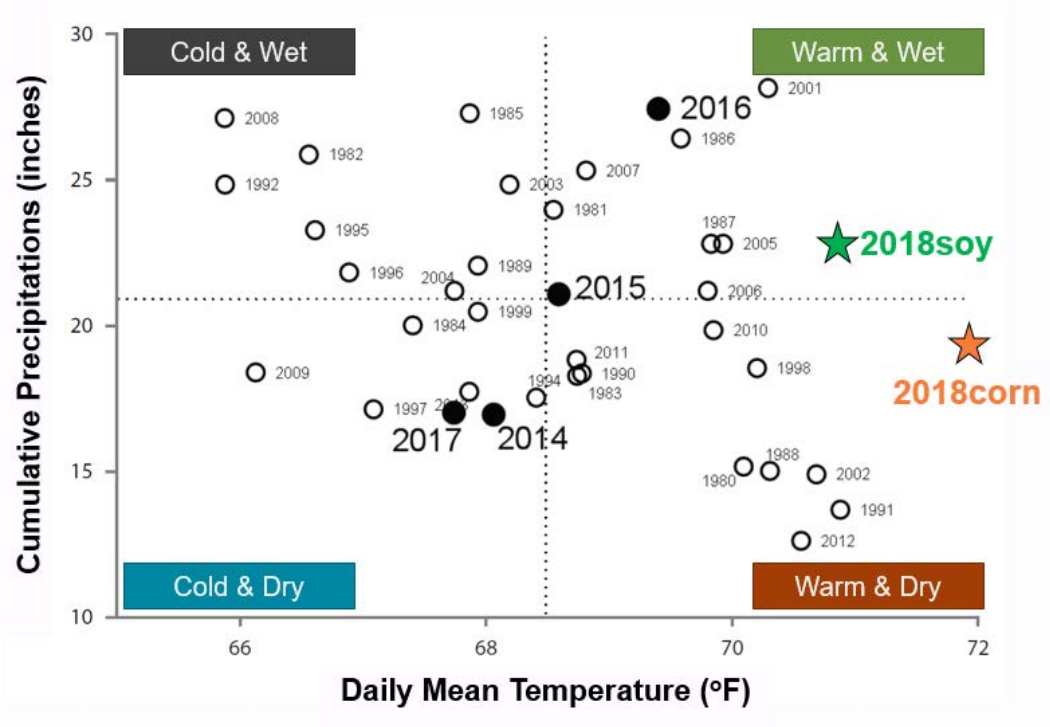

Figure 2. Yearly (1980–2016) mean temperature and precipitation for the period April-October. Filled symbols indicate seasons when the experiment was performed. Dotted vertical and horizontal lines indicate mean temperature (°F) and cumulative precipitation (in.) for the period.

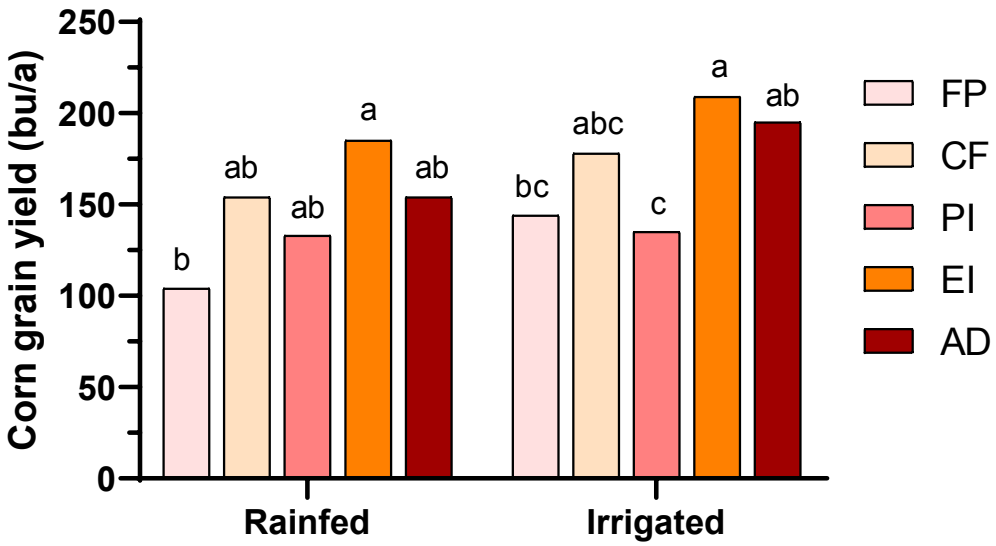

Figure 3. Corn grain yield by treatment for dryland and irrigated conditions in Scandia, KS, 2018. For each water condition, different letters indicate statistical differences ($P < 0.05$). FP = farmer practices, CF = comprehensive fertilization, PI = production intensification, EI = ecological intensification (CF+PI), AD = advanced plus.

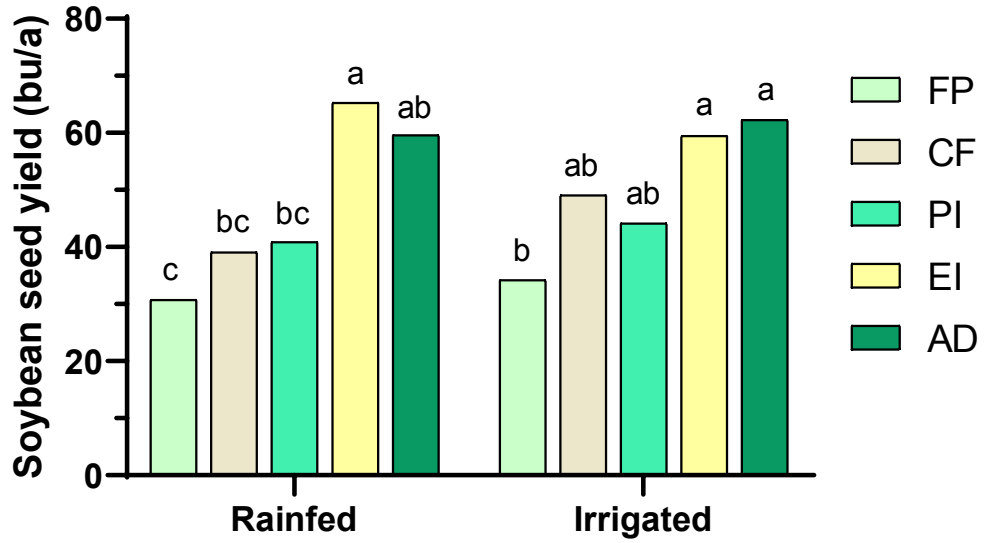

Figure 4. Soybean seed yield by treatment for dryland and irrigated conditions in Scandia, KS, 2018. For each water condition, different letters indicate statistical differences ($P < 0.05$). FP = farmer practices, CF = comprehensive fertilization, PI = production intensification, EI = ecological intensification (CF+PI), AD = advanced plus.

Evaluating Sorghum Senescence Patterns Using Small Unmanned Aerial Vehicles and Multispectral Imaging

I. Barnhart, L.H. Moro Rosso, M.A. Secchi, and I.A. Ciampitti

Summary

Grain sorghum is an important crop in cropping systems worldwide. Many different genetic lines are tolerant to post-flowering heat and drought stress because they express the "stay-green" trait which causes a delay in senescence patterns. Traditional methods of senescence identification are labor-intensive and time consuming. However, remote sensing is a proposed method of identifying sorghum senescence. A study using small unmanned aircraft systems (sUAS) as a remote sensing platform was conducted in Concordia, KS. Twenty sorghum varieties with 3 replications were sown in a randomized block design. The aircraft used was a DJI S-1000 equipped with a MicaSense RedEdge 3 multispectral camera. Two successful flights were completed after the flowering period (September 13 and October 4, 2018). Subsequent ground-truthed senescence ratings were taken on both days, with each leaf of 4 sample plants being assigned a senescence score between 100 and 0 (100 indicating no visible leaf senescence and 0 indicating complete leaf senescence). Data processing was done using Agisoft Photoscan Pro to generate an orthomosaic image and ArcGIS Pro for vegetation index generation and data extraction. Three vegetation indexes (VI) were generated: the normalized difference vegetation index (NDVI), normalized difference red edge (NDRE), and soil adjusted vegetation index (SAVI). The NDRE was the only significant VI of the three found to predict whole plant senescence. It also had the strongest correlation coefficient when analyzed with ground-truthed senescence scores. When comparing NDVI, NDRE, and SAVI data, the NDRE index is the best indicator of grain sorghum senescence.

Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is an important crop in cropping systems around the world. It is well adapted to semi-arid regions around the world and is mostly grown where water stress is expected. One of the most damaging forms of stressors to crops is post-flowering drought stress or "terminal drought," which can greatly reduce grain yields. Several genetic lines of sorghum have a form of tolerance to this late-stage stressor known as the non-senescence or "stay-green" (SG) trait. This trait is characterized by the ability to maintain green leaf color and resist leaf death for longer periods of time under post-flowering drought stress. When compared to their non-SG counterparts, SG lines of grain sorghum have been shown to produce higher grain yields when subjected to yield-limiting conditions such as heat and drought stress. In addition, they also show increased tolerance to stem rots and lodging under these same conditions and do not show yield penalties when exposed to ideal growing conditions.

Many breeders consider these traits of much agronomic importance. Stay-green measurements involve characterizing leaf senescence patterns using traditional methods such as visual leaf scoring and taking chlorophyll readings. However, these methods can

be labor-intensive and time-consuming. With the rise of remote sensing use in agriculture, a proposed method of improving sorghum senescence identification includes using small unmanned aircraft systems (sUAS) to collect multispectral data. Therefore, the objective of this experiment was to identify sorghum senescence patterns using sUAS multispectral imagery.

Procedures

Twenty hybrids with three replications were sown in a randomized block design in a field near Concordia, KS (97° 34' 12" N, 39° 36' 36" W). The field's soil type was a Muir silt loam. Plot size was 17.5-ft long × 5-ft wide.

The sUAS used was a DJI S-1000 multi-rotor aircraft. The sensor attached to the aircraft was a MicaSense RedEdge 3 multispectral camera, which captures 5 separate bands per image: Blue (465-485 nm bandwidth), green (550-570 nm), red (663-673 nm), red edge (712-722 nm), and near infrared (820-860 nm). The sensor is capable of collecting data at a spatial resolution of 8 cm/pixel at an altitude of 120 m above ground level (AGL). The sensor also has a field of view of 47.2°.

Two successful flights were flown on September 13 and October 4, 2018. The camera was calibrated immediately before and after each flight to ensure image quality. The flight path was planned before flight using a mobile ground station and the software 'DJI Ground Station Pro.' Each flight was conducted at an altitude of 30 m AGL, was flown with an 80% front and side overlap, and traveled at a speed of 2 m/s. To ensure uniform lighting distribution, the flights were conducted ±2 hours of solar noon. The MicaSense camera was set to an 'overlap' mode for image capturing, which is the recommended setting for image capturing. Images were stored in a micro SD card as GEOTIFF images.

Subsequental ground-truth measurements were taken to measure plant senescence. Four consecutive plants were designated as sample plants to measure for senescence. Each sorghum leaf was scored based on a visual score of 100 (no visible senescence) to 0 (complete senescence). The leaves were scored starting from the flag leaf to the first leaf such that every leaf afterwards was completely senesced. The leaf scores were averaged, with the resulting score assigned to the plot as a senescence score.

Data processing was completed in two phases: orthomosaic generation and data extraction (Figure 1). During the first phase, individual GEOTIFF images taken during flight were stitched together to form a multi-band orthomosaic using Agisoft Photoscan Professional. This process involves generating a sparse point cloud, dense point cloud, digital elevation model (DEM), and then an orthomosaic photograph. In the second phase, the orthomosaic was uploaded into ArcGIS Pro, where three vegetation indices (VI) were generated: the normalized difference vegetation index (NDVI), the normalized difference red edge (NDRE), and the soil adjusted vegetation index (SAVI). Prior to this, plot boundaries were established using the 'fishnet' tool in ArcGIS Pro. To mask reflectance values of features such as soil, the image was classified using a supervised Maximum Likelihood Classification (MLC) approach (Figure 2). Five image classes were generated: leaves, soil, shadows, dead plants, and grain heads. Through a conditional tool in ArcGIS Pro, the vegetation index was then combined with the

'leaves' class. Data were then extracted, characterized by plot location, and exported to a results table for statistical analysis. Statistical analysis included correlation analysis using Pearson's Correlation Coefficient.

Results

To test the ability of each VI to determine whole plant senescence, correlation between the VIs and the ground-truthed senescence scores was performed (Figure 3). The difference in scores (both ground-truthed and VI scores) between September 13 and October 4 were taken and plotted in a correlational analysis. There was a significant relationship found between the whole-plant senescence ground-truthed scores and the NDRE index (Table 1). An intermediate correlation coefficient was found with the NDRE, with the NDVI and SAVI indexes both demonstrating weak correlation coefficients.

Conclusions

When compared to other indexes that can be generated with multispectral imagery, the NDRE index is the most successful in identifying whole-plant sorghum senescence patterns throughout the post-flowering crop stages. Further research should be conducted comparing multiple VIs with a greater number of flights following the flowering stage.

Table 1. Vegetation scores for each index computed for the 2018 experiment; the only significant index was the NDRE ($\alpha = 0.05$), which also had a higher correlation coefficient value (0.38)

Vegetation index	Degree of freedom	*P*-value	r
NDVI	47	0.06	0.26
NDRE	47	0.006	0.38
SAVI	47	0.07	0.26

NDVI = normalized difference vegetation index. NDRE = normalized difference red edge. SAVI = soil adjusted vegetation index. r = correlation coefficient value.

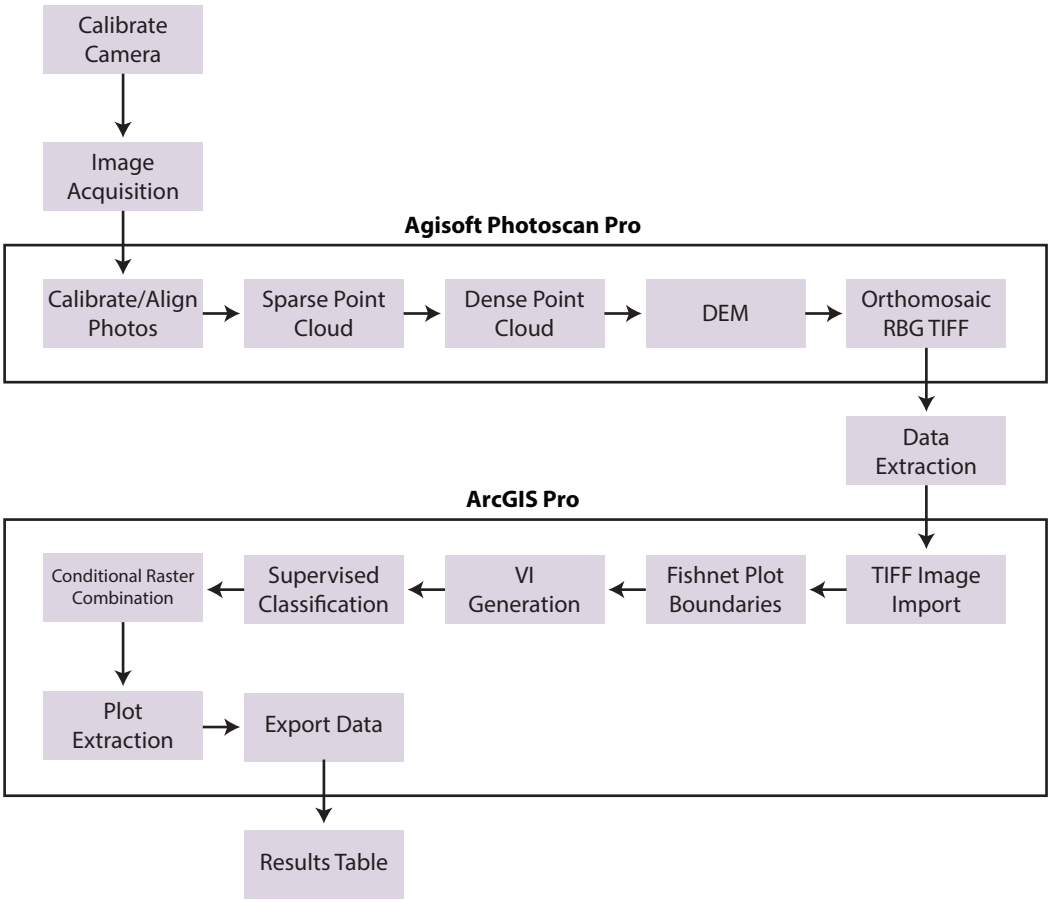

Figure 1. Framework for image processing and data extraction steps.

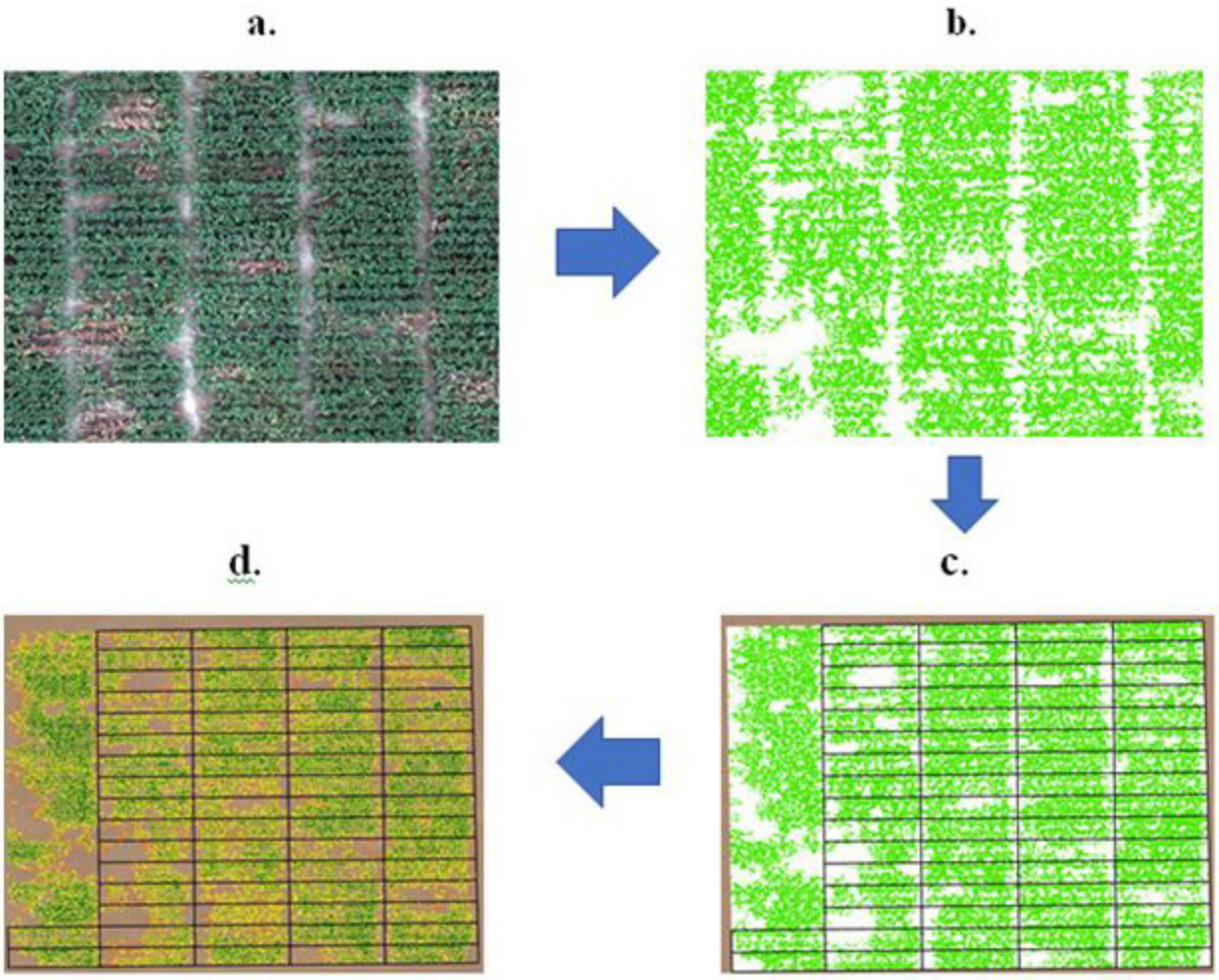

Figure 2. (a) Orthomosaic after processing with Agisoft Photoscan Pro; (b) through a process of supervised maximum likelihood classification, classes for soil, shadows, grain heads, dead plants, and leaves were created; all classes other than leaves were set to a white color to mask out of data extraction; (c) plot boundaries were established using ArcGIS Pro fishnet tool; (d) vegetation indexes were computed and combined with the leaves class using the ArcGIS Pro 'con' tool, allowing for data extraction only from the leaves.

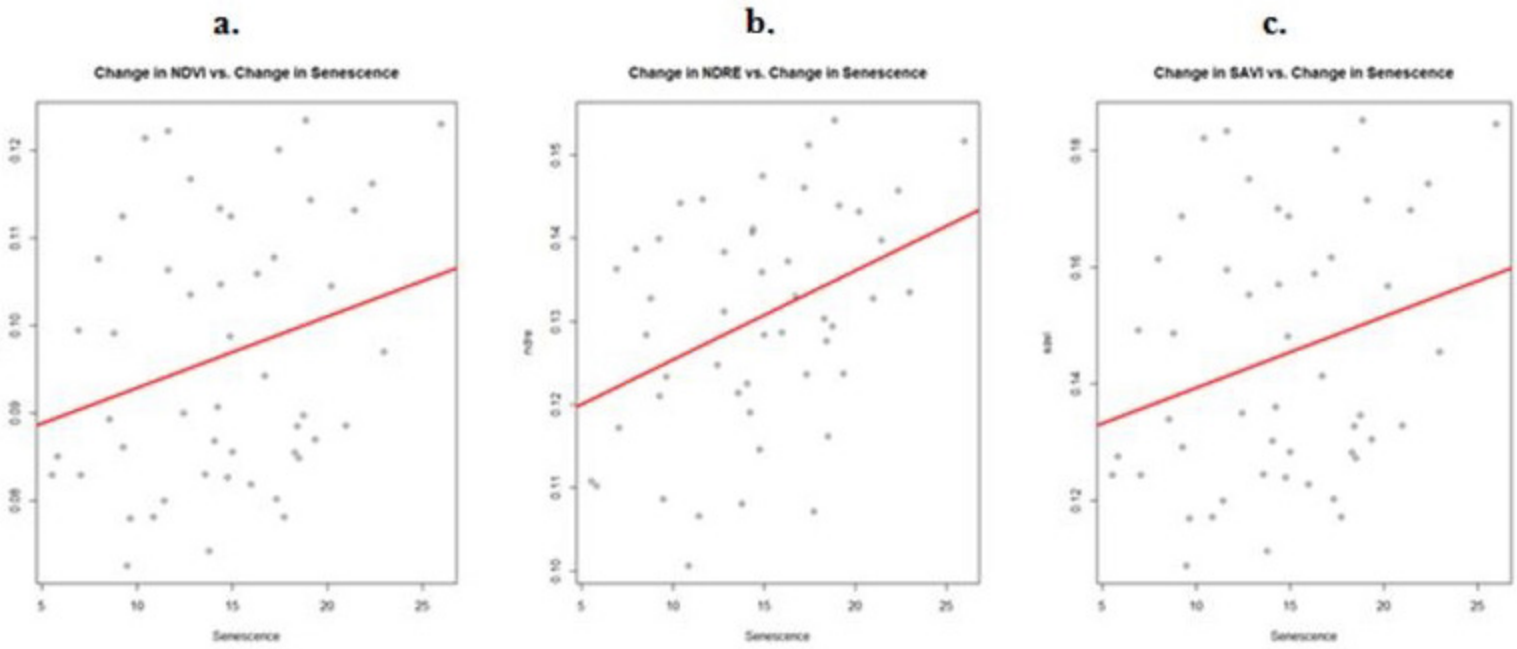

Figure 3. Change in vegetation index values (y-axis) versus the change in ground-truthed senescence values (x-axis) for the (a) NDVI, (b) NDRE, and the (c) SAVI values.

Crop Yield and Yield Stability as Affected by Long-Term Tillage and Nitrogen Fertilizer Rates in Dryland Wheat and Sorghum Production Systems

M. Majrashi, A.K. Obour, and C.J. Moorberg

Summary

A major challenge for agronomists is developing cropping systems that exhibit superior performance across variable environmental conditions, especially precipitation. Long-term field research trials provide a direct measure of the effect of environmental conditions within the context of treatment effects. Here we investigated the impact of tillage practices and nitrogen (N) rates on yields for dryland wheat and sorghum as influenced by weather and precipitation. The study focused on a long-term (40 years) tillage and N fertilizer experiment established in 1975 and managed as a split-split-plot arrangement of rotation (winter wheat-grain sorghum-fallow) with three tillage systems (conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)), and four N application rates (0, 20, 40, and 60 lb N/a) in a randomized complete block design. Results were analyzed using analysis of variance and stability analysis. Yields of winter wheat and grain sorghum significantly decreased with decreases in both tillage intensity and N fertilizer rates. The mean yield for winter wheat was significantly correlated with total precipitation but was not correlated with precipitation during fallow periods or during the growing season. Wheat yield and total precipitation were correlated for the highest N fertilizer rates across all tillage treatments, but not for low N fertilizer rates. Grain sorghum yield was correlated with precipitation during the growing season, particularly for the highest N fertilizer rates. The stability analysis showed grain yield with each tillage practice was more stable with increasing N fertilizer rates.

Introduction

The United States Great Plains region is critically important in the production of winter wheat and grain sorghum. Agricultural production in western Kansas, like most of the Great Plains, is primarily limited by water (Obour et al., 2015). Water limitations are a concern in dryland cropping systems due to limited precipitation and greater climatic variability (Guo et al., 2012). Developing crop production systems that increase water storage in dryland is of utmost importance. Soil water storage plays a crucial role in stabilizing and increasing crop yields (Unger et al., 1997), and conservation tillage is a highly effective mechanism to conserve soil water because of the surface residue cover (Unger et al., 1997). No-tillage or RT have led to reduced erosion, increased soil organic matter, and increased precipitation storage in the Great Plains (Logan et al., 1991; Thomas et al., 2007; Triplett and Dick, 2008).

Nitrogen is the most limiting nutrient for crops and is a key component to increasing crop yield. The soil N cycle is regulated by soil microbes, which facilitate conversion of organic N into readily available plant minerals, such as nitrate and ammonium, through the process of mineralization (Fageria et al., 1991; Montemurro, 2009). The miner-

alization process is influenced by the crop production system, tillage, and N fertilizer application method.

Agricultural research is usually based on short-term studies, but sustainable agriculture requires long-term field and laboratory experiments capable of determining the complex soil-plant-climate management interactions. A stable agronomic system is one in which changes in response to environmental conditions are minimized (Lightfoot et al., 1987). Long-term field experiments play an essential role in understanding the complex plant-soil-climate interactions and their effect on crop yield (Army and Kemper, 1991). It's important to assess interaction effects from year-to-year and within treatments in long-term fertility experiments. However, interpretation of interaction effects using conventional analysis methods (e.g. analysis of variance) is difficult because of the complexity of environmental factors. Stability analysis can be useful for continuous-site experiments where treatments are applied to the same plot over a period of time. Stability analysis allows performance of management practices to be evaluated with respect to environmental factors that change over time within a given location.

Previous research on yield stability analysis has focused primarily on crop genotypes across environments and their interaction (Yate and Cochran, 1938; Finlay and Wilkinson, 1963; Eberhart and Russel, 1966; and Crossa, 1988). However, stability analysis is becoming more commonly used in long-term fertility experiments. Raun et al., (1993) conducted two long-term experiments on wheat (*Triticum aestivum*) and corn (*Zea mays L.*) fertility trials. They used stability analyses to determine that wheat responded poorly to beef manure (302 lb N/a) as an N source compared to a chemical fertilizer treatment. They also used stability analysis in an irrigated corn experiment and determined that sidedressing with anhydrous ammonia resulted in higher yield compared to sidedressing or preplanting with urea-ammonium nitrate (Raun et al., 1993). Daigh et al. (2018), examined long-term tillage management and crop rotations in multiple locations in the Midwest. Using stability analysis, they concluded there is no significant difference in yield between chisel-plow (CP) and NT managed corn/soybean. Further, yield stability analysis of environmental conditions showed no differences between NT and CP yield stabilities among years (Daigh et al., 2018). In a 24-year study, Nielson and Vigil (2018) reported that wheat yield stability was more stable for NT wheat-fallow when compared to CT wheat-fallow, and both NT wheat-fallow and CT wheat-fallow were more stable than more intensive crop rotations.

There is limited information on yield stability under long-term tillage practices and N application rates for wheat-grain sorghum-fallow rotations in dryland production systems in the Great Plains. The present study utilized a long-term field experiment initiated in 1975 to evaluate the effects of tillage and N fertilizer application rates on wheat and grain sorghum yield and yield stability. We hypothesize that increasing N application rates and reducing tillage intensity would increase grain yield and yield stability. The objectives of this study were to evaluate long-term effects of tillage practices and N application rates on grain yield and yield stability of winter wheat and grain sorghum, and to evaluate mean yield correlation with precipitation timing in a dryland winter wheat-grain sorghum-fallow rotation system.

Procedures

This research was conducted utilizing long-term experimental plots initiated in the fall of 1965 at the Kansas State University Agricultural Research Center near Hays, KS (38°86′ N, 99°27′ W, 2000 ft elevation) to investigate tillage intensity (CT, RT, and NT) on grain yields in a winter wheat-grain sorghum-fallow crop production system. The soil at the study site is a Harney silt loam (fine, montmorillonite, mesic Typic Argiustoll; U.S. Department of Agriculture Soil Taxonomy). The experiment was modified in 1975 and has since been managed as a split-split-plot arrangement of crop phase, tillage, and N application rates in a randomized complete block design with four replications. Each phase of the crop rotation and tillage are present in each block in every year of the study. The main plots were the crop phase, which consisted of winter wheat, grain sorghum, or fallow (sorghum stubble). Tillage practice was the subplot factor and N rates were the sub-subplot factor. Each block measuring 198 ft × 100 ft contained the three tillage treatments (CT, RT, and NT plots). Each tillage practice (67 ft × 100 ft) was subdivided by six sub-plot factors (11 ft × 100 ft), and subplots were assigned the four N application rates (0, 20, 40, and 60 lb N/a) with two unfertilized alleys between tillage treatments. Nitrogen rates were increased starting in the fall of 2014 to 0, 40, 80, and 120 lb N/a. The entire study site has not been amended with lime or phosphorus since establishment in 1965.

The data on grain yield for winter wheat and sorghum have been recorded from 1975 to 2003 for wheat and 1975 to 2002 for sorghum, and from 2013 to 2018 for both crops. There were no yield data for wheat or sorghum from 2003 to 2012 or 2002 to 2012 due to changes in research personnel; however, the plots and treatment were maintained throughout the study period. Precipitation data over the study period were documented using the Weather Data Library of Kansas Mesonet station at Hays, which is located 1.5 miles from the study site. Grain yield of both crops was determined by harvesting 5 ft × 100 ft area from the middle portion of each plot using a small combine harvester. Grain moisture content at harvest was determined using a DICKEY-john grain moisture tester (DICKEY-john Inc., Auburn, IL) and data were adjusted to 13.5% moisture content. The precipitation amounts during fallow (P_{fallow}), crop growing season ($P_{growing}$), and total amounts over the entire cycle (P_{total}), i.e. the sum of precipitation during the growing season and preceding fallow period, for each crop were calculated for each year of the study. For winter wheat, the fallow period started at the time of sorghum harvest in October and ended at wheat planting in October of the following year, and the growing season spanned the time from wheat planting in October until wheat harvest the following June. For grain sorghum the fallow period begins at wheat harvest in July and goes until sorghum planting in June of the following year, and the sorghum growing season spanned the time from planting in June until sorghum harvest in October that same year.

Data for winter wheat and grain sorghum yield in all years throughout 1975 to 2014 (data are missing from 2004 for wheat, and from 2003–2012 for sorghum) were analyzed for variance (ANOVA) using PROC MIXED procedure in SAS (v. 9.4, SAS Inst., Cary, NC) and the Tukey's Honest Significant Difference was used for mean comparisons with an alpha (α) of 0.05.

The yield stability analysis was performed using linear regression analysis as described by Raun et al., (1993). For the aim of this study, the stability was adapted to investigate and compare yield stability of winter wheat and grain sorghum under three tillage practices (CT, RT, and NT) within four N application rates (0, 20, 40, and 60 lb N/a) for 30 years as the environment mean yield (as the average yield of all treatments in a given year).

Results

Precipitation Throughout Study Period

The precipitation amounts during fallow (P_{fallow}), growing season ($P_{growing}$), and total (P_{total}) for winter wheat and grain sorghum are presented in Figure 1A and Figure 1B, respectively. These figures illustrate the year-to-year variation in precipitation. The P_{total} for winter wheat growing seasons was highest in 1993, 1994, and 2007 with more than 45 inches. A significant amount of this precipitation came during the fallow period in those years. The highest amount of P_{total} (more than 50 inches) occurred in 1990, and 2013 had less than 24 inches (Figure 1A). The highest total precipitation for grain sorghum for the growing season occurred during 1993 and the least amount of precipitation (22 inches), for the growing season occurred in 1983 (Figure 1B).

Yield Response

Winter wheat grain yield was significantly affected by year, tillage, N rate, and their interactions (Table 1). Tillage × year, and tillage × N rate × year interaction effects on grain sorghum yields were not significant. However, N rate and tillage had effect on sorghum yields (Table 1). The greatest winter wheat yield occurred in 1987; the lowest average yield occurred in 1989 and 2014 (Figure 2A). The highest and lowest average yields for grain sorghum occurred in 1986 and 1983, respectively (Figure 2B). Winter wheat and grain sorghum yields with less intensive tillage and reduced N rates were smaller than those obtained with CT (Table 2). In general, the average yield of both winter wheat and grain sorghum decreased by reducing the intensity of tillage practices and increased by increasing N fertilizer application rate. The average yields of winter wheat and grain sorghum were highest with CT and an N application rate of 60 lb N/a.

The correlation analysis between precipitation and treatment responses are presented in Table 2. For winter wheat, the correlations between winter wheat grain yield and P_{fallow} and $P_{growing}$ were not significant, but grain yield was significantly correlated to P_{total}. No statistically significant difference was found for the PF, for grain sorghum growing season. However, all the 11 mean yield treatment groups were correlated significantly with the GP for the growing season of sorghum grain. Among the treatment groups, only 4 of them (CT, NR 60 lb/a, CT N40, and N60 lb/a) had significant differences in mean yield of grain sorghum with P_{total}. The time trend or a pattern was correlated with winter wheat in relation to the P_{total} for the growing season. Whereas for the mean yield of grain sorghum, the trend was correlated to the precipitation during $P_{growing}$ the given time period only. Individually, reduced tillage and N rate of 40 lb N/a had the highest correlations with winter wheat yield only for the full growing season. Logically, the interaction of those treatments also had the highest correlation with winter wheat yield during that time frame. For grain sorghum, NT during the growing season had the highest correlation for tillage treatments. Applying N at 60 lb/a had the highest correlation with grain sorghum yield. Overall, the highest correlation with grain sorghum

yield occurred with the interaction of the CT and N rate of 60 lb/a. Correspondingly, a correlation exists between the mean tillage practices (CT, RT, and NT) and the sum of the P_{total} in relation to the two highest N rates (40 and 60 lb N/a).

Stability Analysis

The stability analysis provided a valid means of assessing this data set, while also allowing visual observation of treatment interactions with the environment mean (Figure 5 and Table 3). A model was built using linear regression with tillage practices nested within N fertilization rates. These equations significantly corresponded to the environmental mean. Overall, the regression analysis indicates that the R-square of all of the equations were statistically significant at the 5% level. The regression equation with the best fit, highest R-square, for winter wheat was RT with 40 lb N/a. The best fit for grain sorghum was CT with 20 lb N/a. For winter wheat, there was a clear trend in the intercept and slope across all treatments. As the N application rate increased, the intercept decreased and slope increased. This trend held for all tillage treatments. However, the equations for grain sorghum did not show a clear trend in the intercept and slope components as related to the treatments. At the same time, though, the R-squares of all the grain sorghum regression equations were high and statistically significant. The stability analysis for treatments regressed on the environment mean for both winter wheat and grain sorghum demonstrates an advantage of higher N rates with intensive tillage practices.

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Table 1. The analysis of variance for winter wheat yield and grain sorghum of 404 plots in Hays, KS, with three different constant tillage practices (conventional tillage, reduced tillage, and no-tillage) nested with four nitrogen (N) fertilizer rates (0, 20, 40, and 60 lb N/a)

	Yield of winter wheat			Yield of grain sorghum		
Treatment effect	DF†	F Value	Pr > F	DF	F Value	Pr > F
Year	30	447.56	<0.0001	29	155.52	0.0021
Tillage	2	203.37	<0.0001	2	8.31	<0.0001
Year × tillage	60	16.03	<0.0001	58	3.61	0.0842
N rate	3	1818.24	<0.0001	3	134.90	<0.0001
Year × N rate	90	18.50	<0.0001	87	2.94	<0.0001
Tillage × N rate	6	9.29	<0.0001	6	0.81	<0.0001
Year × tillage × N rate	180	1.45	0.0063	174	0.58	0.7621

†DF indicates degrees of freedom.
‡F value is an output from the statistical model.
§Pr > F is the probability of a greater F value, and indicates a p-value for the effect of model on responses at the level of significance. Tests were performed with an α of 0.05.

Table 2. The average yield of winter wheat and grain sorghum and their Pearson Correlation Coefficients with precipitation before, during, and total growing season in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen (N) fertilizer rates (NR) (0, 20, 40, and 60 lb N/a)

	Mean yield of winter wheat				Mean yield of grain sorghum			
		Correlation (r) ‡				Correlation (r) ‡		
	lb/a†	P_{fallow}§	$P_{growing}$§	P_{total}§	lb/a†	P_{fallow}§	$P_{growing}$§	P_{total}§
Year	2050	0.18	0.22	0.36*	3786	0.02	0.37*	0.29
Tillage systems								
CT	2135a	0.20	0.19	0.35*	3811a	0.10	0.39*	0.37*
RT	2091b	0.17	0.28	0.38*	3825a	-0.004	0.28	0.21
NT	1925c	0.15	0.17	0.29	3721b	-0.03	0.41*	0.29
Nitrogen rates (NR)								
NR0	1530d	0.04	0.20	0.20	3136d	-0.05	0.32	0.21
NR20	2006c	0.12	0.21	0.29	3714c	0.02	0.35	0.28
NR40	2266b	0.24	0.22	0.42*	4064b	0.02	0.36*	0.29
NR60	2397a	0.23	0.22	0.41*	4228a	0.07	0.41*	0.36*
Interaction of tillage × N rate								
CT N0	1621g	0.09	0.21	0.25	3217e	0.04	0.31	0.26
CT N20	2099de	0.17	0.17	0.31	3791d	0.07	0.39*	0.34
CT N40	2340bc	0.24	0.18	0.40*	4024bc	0.13	0.35	0.36*
CT N60	2436a	0.24	0.19	0.38*	4206abc	0.14	0.45*	0.43*
RT N0	1585g	0.07	0.25	0.26	3157e	-0.08	0.22	0.11
RT N20	2054e	0.09	0.27	0.30	3729d	-0.01	0.26	0.19
RT N40	2300c	0.21	0.26	0.42*	4162abc	-0.01	0.28	0.20
RT N60	2393ab	0.20	0.26	0.41*	4250a	0.07	0.33	0.30
NT N0	1345h	0.004	0.11	0.09	3030e	-0.09	0.38*	0.23
NT N20	1832f	0.09	0.19	0.24	3623d	-0.008	0.38*	0.28
NT N40	2139d	0.20	0.19	0.35*	4009c	-0.05	0.42*	0.28
NT N60	2337bc	0.22	0.21	0.39*	4228ab	0.008	0.42*	0.32

†Significant differences in yield within each factor or interaction are indicated by letters a-f, where any yields with different letters are significantly different at the $P < 0.05$ level.
‡Significant correlations at the $P < 0.05$ level are indicated by *.
§Precipitation during fallow (P_{fallow}), growing season ($P_{growing}$), and total precipitation (P_{total}).

Table 3. Linear regression analysis of grain yield stability of winter wheat and sorghum on environment mean in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen rates (NR) (0, 20, 40, and 60 lb N/a)

Treatment	Intercept	Std. error†	Slope	Std. error†	Red. DF‡	C.V.§	R^2*
Winter wheat							
CT N0	91	211	0.75	0.0893	29	16	0.86
CT N20	-98	154	1.07	0.0653	29	9	0.90
CT N40	-158	133	1.22	0.0562	29	7	0.94
CT N60	-155	158	1.26	0.0671	29	8	0.92
RT N0	-41	208	0.80	0.0882	29	16	0.74
RT N20	-70	119	1.04	0.0505	29	7	0.94
RT N40	-127	115	1.18	0.0485	29	6	0.95
RT N60	-230	193	1.27	0.0820	29	10	0.89
NT N0	250	227	0.55	0.0964	29	21	0.53
NT N20	253	155	0.79	0.0657	29	11	0.83
NT N40	217	203	0.95	0.0859	29	12	0.81
NT N60	69	213	1.12	0.0903	29	11	0.84
Grain sorghum							
CT N0	129	277	0.82	0.0621	28	13	0.86
CT N20	89	161	0.98	0.0362	28	7	0.96
CT N40	44	219	1.05	0.0490	28	8	0.94
CT N60	368	279	1.03	0.0625	28	10	0.91
RT N0	417	309	0.74	0.0692	28	15	0.80
RT N20	49	224	0.97	0.0503	28	9	0.93
RT N40	-128	209	1.13	0.0468	28	8	0.95
RT N60	164	200	1.08	0.0450	28	7	0.95
NT N0	-194	347	0.85	0.0778	28	17	0.81
NT N20	-344	263	1.04	0.0590	28	11	0.92
NT N40	-411	241	1.16	0.0541	28	9	0.94
NT N60	-183	317	1.16	0.0710	28	11	0.91

†Std. error indicates standard error.
‡Red. DF is residues of degree of freedom.
§C.V. is presented the coefficient of variability.
*R^2 is the coefficient of determination and indicates a significant linear regression model of yield with environment mean at the with an α of 0.05.

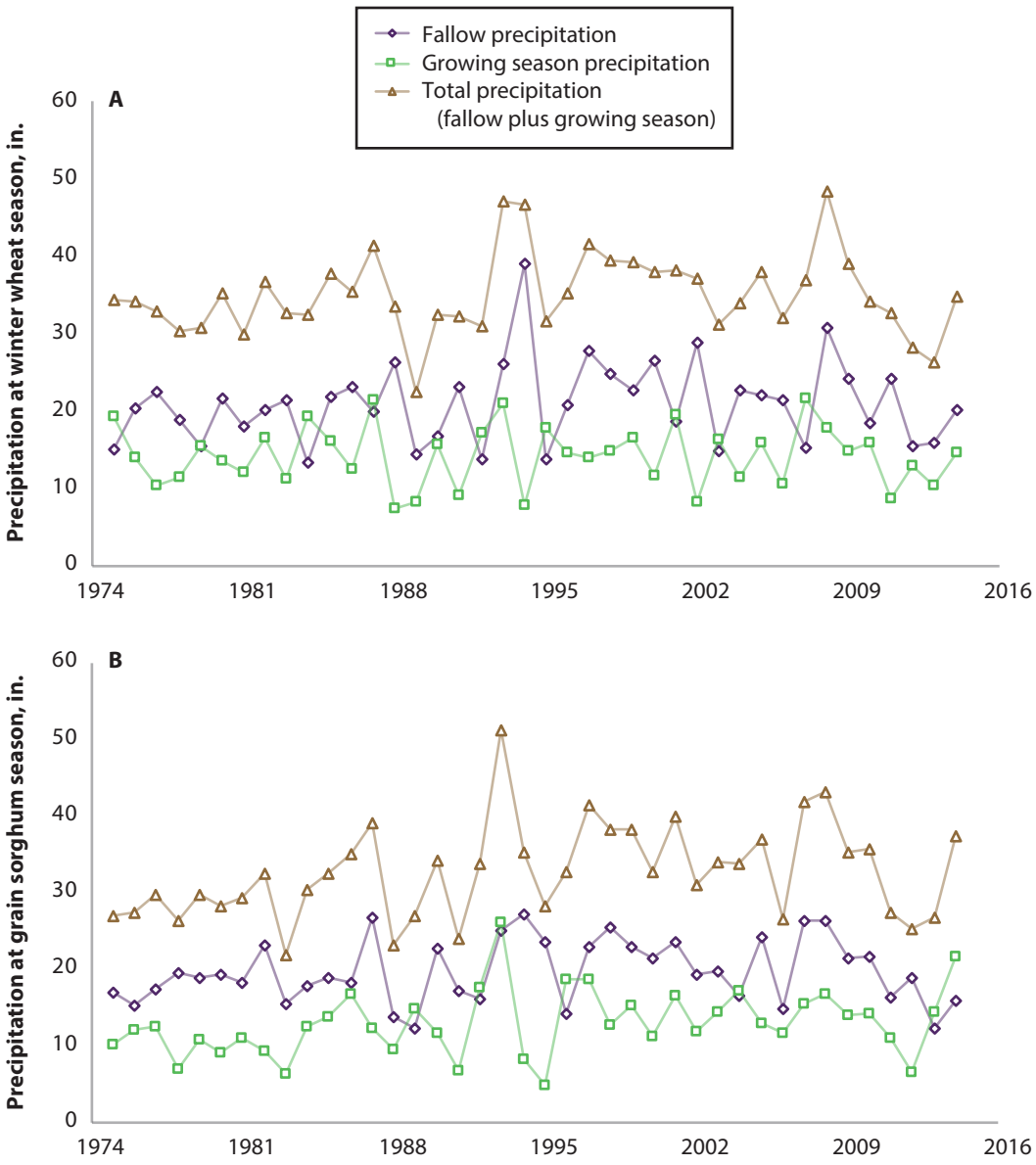

Figure 1. Precipitation during fallow period (P_{fallow}), in the growing season ($P_{growing}$), and fallow plus growing season (P_{total}) of each given year for winter wheat (A) and grain sorghum (B) in Hays, KS.

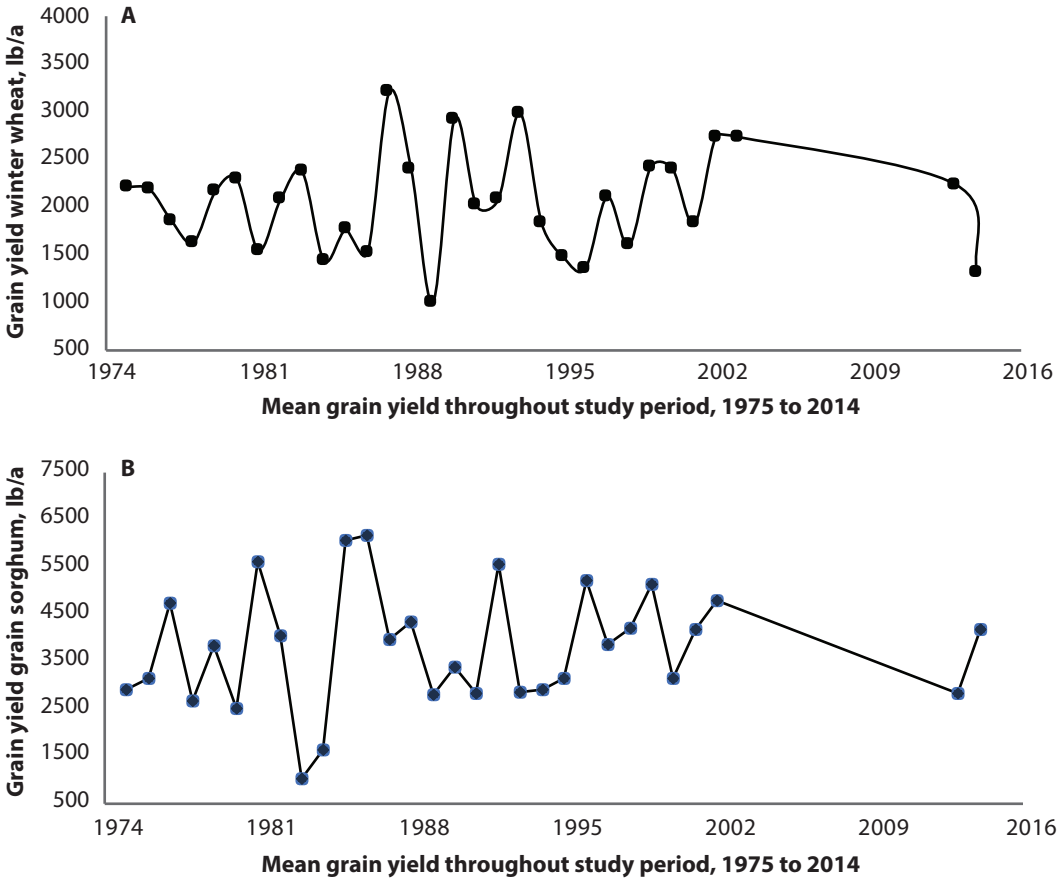

Figure 2. The trend of mean grain yield of winter wheat (A) and grain sorghum (B) across treatments throughout the study period, 1975 to 2014, as affected by years (data are missing from 2004 for wheat, and from 2003–2012 for sorghum).

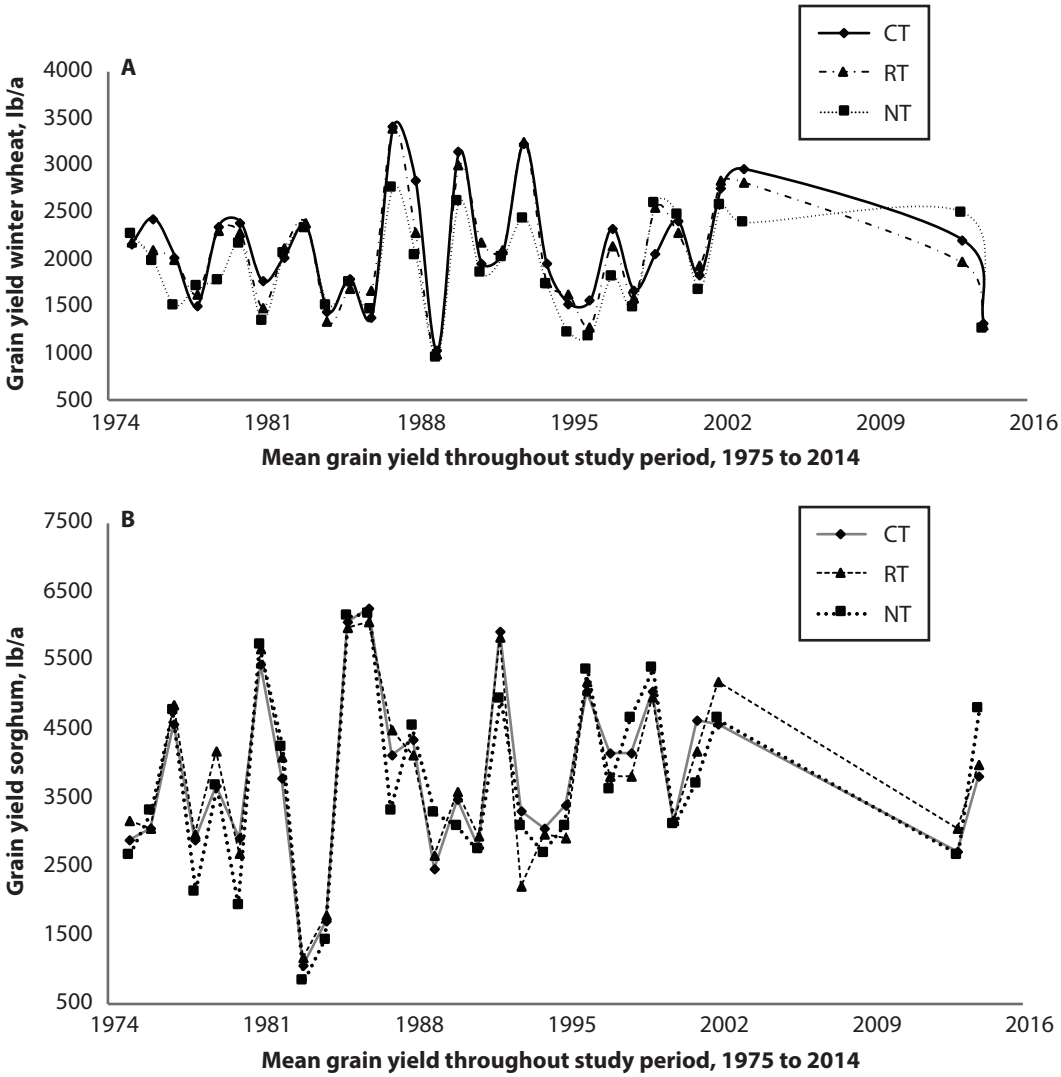

Figure 3. The trend of mean grain yield of winter wheat (A) and sorghum (B) across nitrogen fertilizer rates as affected by tillage practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), throughout the study period, 1975 to 2014.

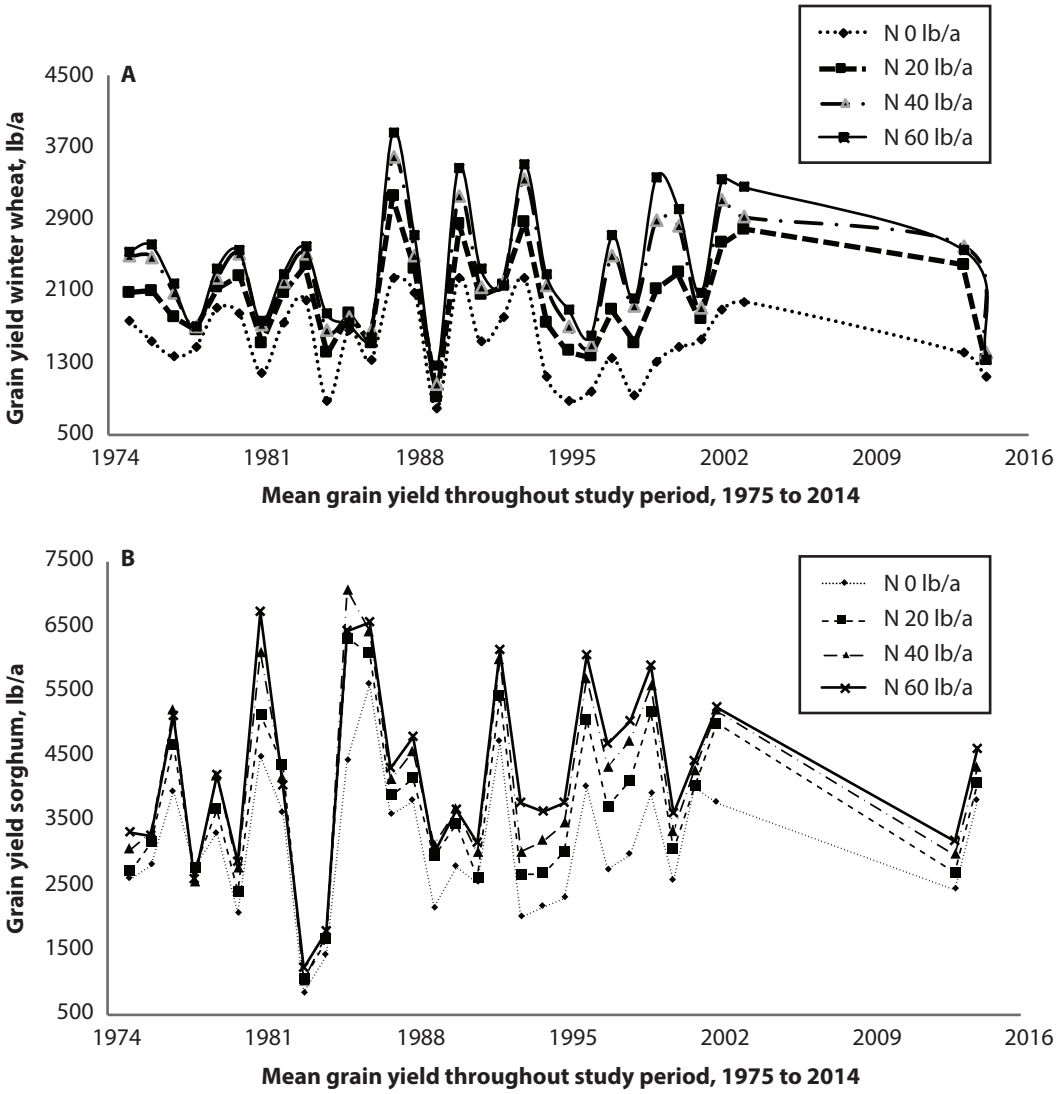

Figure 4. The trend of mean grain yield of winter wheat (A) and sorghum (B) across tillage practices as affected by nitrogen rates throughout the study period, 1975 to 2014.

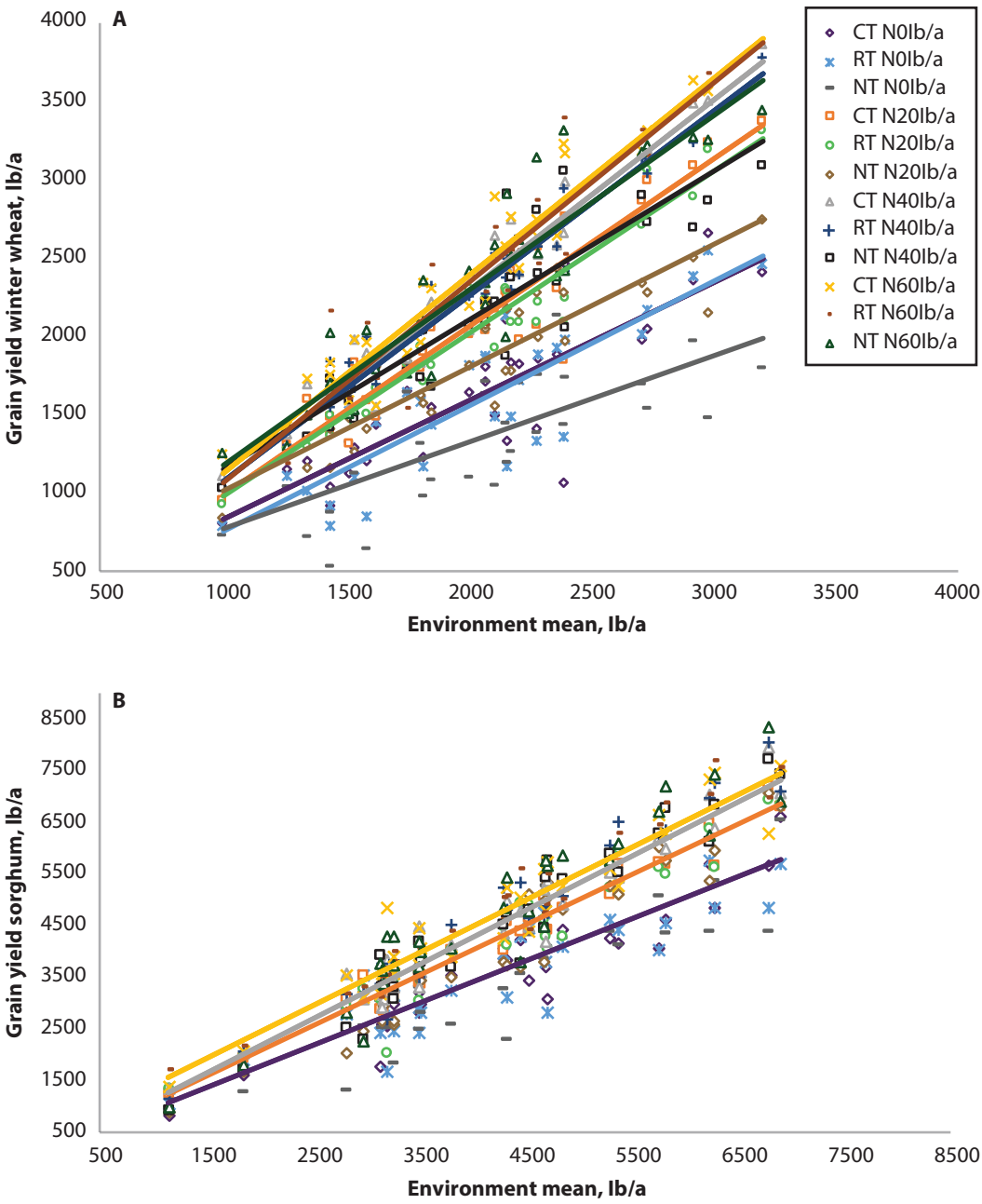

Figure 5. Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment mean at affected by tillage and nitrogen (N) fertilizer rates in Hays, KS. Data are averaged from 1975 to 2014.

Long-Term Tillage and Nitrogen Fertilizer Rates Effect on Grain Yield and Nitrogen Uptake in Dryland Wheat and Sorghum Production

M. Majrashi, A.K. Obour, and C.J. Moorberg

Summary

Winter wheat and grain sorghum rotation is a common cropping system in dryland environments in western Kansas. A long-term field experiment (started in 1975) was conducted in Hays, KS, to examine interaction effects of tillage and nitrogen (N) fertilizer rates on wheat and grain sorghum yields, protein content, N uptake, and N use efficiency (NUE). The experimental design was a split-split-plot arrangement of rotation, tillage, and N application treatments in a randomized complete block design. The main plots were the crop phase (winter wheat, grain sorghum, or fallow), sub-plots were three tillage systems (conventional tillage (CT), reduced tillage (RT), and no tillage (NT)). The sub-sub-plots were four N rates (0, 20, 40, and 60 lb/a), which were modified in fall 2014 to 0, 40, 80, and 120 lb/a. Results showed year-to-year variability in winter wheat and grain sorghum responses to tillage practices and N fertilizer rates. Competition from herbicide-tolerant grass weeds reduced winter wheat yields in NT treatments in dry years but performed similarly to tillage treatments in wet years. However, grain sorghum yields with NT were greater or similar to CT or RT in most years of the study. Grain yields for both crops increased with N fertilizer application rates. Decreasing tillage intensity did increase wheat grain protein concentration only in 2018, which was relatively dry. Applying N fertilizer improved protein concentration, but the effect was more pronounced in years with less than average growing season precipitation. However, N use efficiency decreased at a higher N fertilizer rate particularly in dry years for both crops.

Introduction

The United States Great Plains region is critically important in the production of wheat and sorghum. The adoption of conservation tillage practices, such as no tillage (NT) and reduced tillage (RT) has led to reduced erosion, increased soil organic matter (SOM), and increased precipitation storage in the Great Plains (Logan et al., 1991; Thomas et al., 2007; Triplett and Dick, 2008). Wheat-fallow (W-F) or wheat-summer crop-fallow are the most used wheat production systems in the Great Plains (Anderson, 2005). Grain sorghum produced greater grain yield than the corn crop under the dryer and warmer climate growing conditions because the sorghum crop remained inactive during the period of severe water stress and resumed growth when favorable conditions reappeared (Leonard and Martin, 1963).

The increased use of N fertilizer has resulted in reductions in yield gaps in the major cereal crops (Dobermann and Cassman, 2004). Applying N fertilizer increases crop yield and enhances drought resistance of crops in semiarid regions (Ding et al., 2018). However, environmental ramifications (e.g. greenhouse gas emission, water pollution,

soil quality degradation, and accumulation of soil NO_3-N in soil profile) as well as lower N use efficiency (NUE) are caused by excessive application of N fertilizer (Malhi et al., 1996; Davidson 2009; Morell et al., 2011; Reay et al., 2012; Zhou et al., 2016). Nitrogen is commonly applied to grain crops because it's one of the most limiting nutrients in crop production and heavily influences the sustainability and economic viability of agriculture systems worldwide (Delgado et al., 2010; Grahmann et al., 2013). Nitrogen is an essential nutrient and required in large amounts by crops to optimize yield and water use efficiency (Delgado et al., 2010; Fageria, and Baligar, 2005). Further, Guarda et al., (2004) showed both grain yield and quality are directly related to the N uptake and effective partition by crops.

Long-term research efforts are critically needed to identify superior soil and nutrient management practices for the limited water environments of the Great Plains region. In semi-arid regions, intensifying the frequency of cropping systems has been used as another conservation approach, and has led to greater yield performance (Halvorson et al., 2001). Wheat yields have been shown to match or exceed those of conventional tillage (CT) systems, when NT and RT practices have been implemented for ten years or longer (Pittelkow et al., 2015). However, integrating these practices in some systems has led to a reduction in crop quality and yield, compared with CT practices. This has been attributed to the effects that NT has on N dynamics (Lundy et al., 2015; Pittelkow et al., 2015; and Ruisi et al., 2016). Previous studies reported that the residual NO_3-N within the 0 to 5 ft soil profile is higher with CT and RT compared to NT (Halvorson et al., 2001), particularly with more precipitation. The NT system would be a promising technique of reducing residual soil NO_3-N available for leaching compared to CT and RT. After 5 years, measurement of soil under various tillage practices showed available N (NO_3-N) was higher under NT compared to different tillage plots within 0 to 12 inch (López-Fando and Pardo, 2009) as a dramatic change occurred within 0 to 2.5 inch soil depth. Also, after 16 years of CT and NT on a winter wheat-summer fallow experimental plots in Colorado, available N (NO_3-N) was higher in the upper one inch under NT compared to tilled plots (Tracy et al., 1990). In another study in the semiarid region of Spain, significantly greater available N was found in soils under NT compared to RT or CT (López-Fando et al., 2007). It is important to use appropriate tillage practices that avoid the degradation of soil structure, maintain crop productivity, and provide a sustainable agriculture system.

Adoption of conservation tillage practices (NT or RT) can be used to improve soil properties (physical, chemical, and biological) for the benefit of the environment and soil productivity (Aina, 2011). For example, conservation tillage can increase soil water storage (Anderson, 2009; López-Fando and Pardo, 2009) and improve water and fertilizer use efficiencies (Triplett and Dick, 2008) compared to traditional tillage systems. Winter wheat has a relatively high N demand, and has one of the lowest NUE compared to other cereals (Schlegel et al., 2005; Muurinen et al., 2007). Our objective for this work was to investigate the effects of tillage and N fertilizer rates on wheat and grain sorghum yields, protein content, N uptake, and use efficiency.

Procedures

This research was conducted utilizing long-term experimental plots initiated in the fall of 1965 at the Kansas State University Agricultural Research Center near Hays, KS

(38°86′ N, 99°27′ W, 2000 ft elevation) to investigate tillage intensity (CT, RT, and NT) on grain yields in a winter wheat-grain sorghum-fallow crop production system. The soil at the study site is a Harney silt loam (fine, montmorillonite, mesic Typic Agriustoll; USDA Soil Taxonomy). The experiment was modified in 1975 and has since been managed as a split-split-plot arrangement of crop phase, tillage, and N application rates in a randomized complete block design with four replications. Each phase of the crop rotation and tillage are present in each block in every year of the study. The main plots were the crop phase, which consisted of winter wheat, grain sorghum, or fallow (sorghum stubble). Tillage practice was the subplot factor and N rates were the sub-subplot factor. Each block (198 ft × 100 ft) contained the three tillage treatments (CT, RT, and NT plots). Each tillage practice (67 ft × 100 ft) was subdivided by six sub-plot factors (11 ft × 100 ft), and subplots were assigned the four N application rates (0, 20, 40, and 60 lb N/a) with two unfertilized alleys between tillage treatments. Nitrogen rates were increased starting in the fall of 2014 to 0, 40, 80, and 120 lb N/a. The entire study site has not been amended with lime or phosphorus since its establishment in 1965.

The data on grain yield for winter wheat and sorghum have been recorded from 2015 to 2018; however, the plots and treatment were maintained throughout the study period. Total aboveground biomass for winter wheat (only) was determined in 2015, 2016, 2017, and 2018 by cutting approximately 6 ft^2. Both grain and biomass samples were finely ground, and analyzed for N concentration and carbon content by dry combustion using a LECO CN analyzer (LECO Corporation, St. Joseph, MI). The amount of N removed in the grain was computed by multiplying N concentration by grain yield. Nitrogen use efficiency (NUE) was determined as N mass in grain/N fertilizer rate applied.

Data for winter wheat and grain sorghum yield from 2015 to 2018 were analyzed for variance (ANOVA) using PROC MIXED procedure in SAS (v. 9.4, SAS Inst. Inc., Cary, NC), and the Tukey's Honest Significant Difference was used for mean comparisons with an alpha (α) of 0.05.

Results

Total precipitation amounts after dormancy in winter wheat were substantially below average during the 4-year study period. However, total precipitation in May was generally above average for all of the study years (Table 1). Rainfall during this period is important for normal crop development in winter wheat. Total season precipitation was highest in 2018 and above average for all study years except in 2015, which experienced below average total precipitation during the grain sorghum season. The low precipitation amounts in March and April of 2018 could have a significant impact on winter wheat yields. The long term average total precipitation during the fallow period is 21 inches for winter wheat and 20 inches for grain sorghum. During this study, total precipitation during the fallow period was above average except for the fallow periods preceding the 2016 winter wheat and 2018 grain sorghum crops (Table 1). The long term average precipitation during the growing season is 14 inches for winter wheat and 13 inches for sorghum. Except for 2015, precipitation amounts during the growing seasons were above normal for both crops (Table 1).

Winter wheat yield was significantly affected by year × tillage interaction (Table 2). Grain yield with CT was greatest in most years of the study. Both RT and NT had lower yield when compared to CT in 2015 and 2018, and 2017 for RT only. However, grain sorghum yields showed less significant variation among tillage systems over the 4-year study—with the exception of 2016 when NT had the highest yield compared to CT and RT (Figure 1B). Tillage × year interaction had an effect on winter wheat and grain sorghum yields. Winter wheat yield increased with increasing N fertilizer application rate compared to control (Figure 1C). Similarly, there was a significant difference in sorghum grain yields with varying fertilizer application rates in 2016, 2017, and 2018. Applying N fertilizer had no significant effect on grain sorghum yield in 2015 (Figure 1D). Regardless of N application rate, winter wheat yields in 2018 were lower than in 2015, 2016, and 2017. This was possibly due to less precipitation amounts in the growing season (Table 1). Nevertheless, greater precipitation amounts from May through October of 2018 increased grain sorghum yield compared to the remaining years of the study (Figure 1D).

Grain N concentration was significantly affected by tillage × year interaction. The 2018 winter wheat grain N concentration was the exception, as it was not different among tillage practices (Figure 2A). Grain N concentration was highest with less intensive tillage (RT and NT) treatments compared to CT for winter wheat. However, in grain sorghum, the tillage (CT and RT) treatments had more N concentration in 2015 compared to NT. There was no difference in grain N concentration among tillage practices in the 2016 and 2018 growing seasons for grain sorghum (Figure 2 B). On the other hand, the grain N concentration was greatest with the highest N fertilizer rates (120 lb N/a) across the 4 years of the study for both crops (Figure 2C and D).

There was a significant effect of tillage practices on winter wheat N removal in years 2015, 2017, and 2018, and in 2015 and 2017 for grain sorghum (Figure 3A and B, respectively). However, N removal was not different among tillage practices in 2016 for winter wheat and 2018 for grain sorghum. Across the years, the CT practice had relatively equal grain N removal rates compared to other tillage practices for grain crops (Figure 3A and B). Increasing N application rate did increase N removal in both winter wheat and grain sorghum (Figure 3C and D). This was expected because applying N fertilizer increases grain yield and N concentration in both crops.

The grain NUE (lb/lb) in terms of partial N balance was significantly affected by tillage practices in both 2017 and 2018. Winter wheat NUE was highest with the CT and RT compared to NT in both years (Figure 4A). For grain sorghum (Figure 4B), the grain NUE was also significantly affected by tillage practices. The effect of tillage practices did not show an obvious trend. For example in 2015, CT showed significantly greater NUE compared to NT, but in 2016 NT had the greatest NUE compared to CT or RT. Tillage had no effect on NUE in 2018 (Figure 4B).

There was a significant N fertilizer application rates × year effect on NUE for both crops. The NUE was greatest when N was applied at 40 lb N/a compared to 80 and 120 lb/a for winter wheat (Figure 4C) and grain sorghum (Figure 4D). Generally, increasing N application rates decreased the grain NUE, indicating some of the applied N remaining in the soil may be lost through leaching, volatilization, and deep percolation.

For winter wheat, the grain protein content was not significantly different among tillage practices in 2015, 2016, and 2017. However, in 2018, increasing tillage intensity significantly reduced protein content. This is possibly due to a dilution effect from greater wheat yields, with CT exhibiting the greatest yields and NT exhibiting the lowest yields (Figure 5A). Nitrogen fertilizer application rates × year interaction had an effect on protein content. This interaction occurred because of significantly lesser protein content obtained in 2017. In general, protein content significantly increased with N fertilizer application (Figure 5B). Across the 4-year study, applying N at 120 lb N/a resulted in the highest protein percent content.

For grain sorghum, the grain protein content was highest in 2018 compared to the remaining years of the study regardless of tillage practice or N fertilizer application rates (Figure 5C and D). The grain protein content was highest relatively with CT compared to other tillage practices and increased at the highest N fertilizer rate (120 lb N/a) when compared to other N fertilizer application rates.

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Table 1. Total monthly precipitation and growing season periods of winter wheat and grain sorghum of 404 plots at Hays, KS

	Precipitation				
	2015	2016	2017	2018	LTA[†]
	in				
January	0.46	0.68	1.25	0.45	**0.54**
February	0.71	0.70	0.10	0.15	**0.74**
March	0.09	0.56	1.50	0.77	**1.66**
April	0.96	7.46	7.83	0.74	**2.31**
May	6.44	3.04	4.58	4.86	**3.21**
June	0.76	3.44	3.82	3.92	**2.89**
July	4.11	3.45	1.53	7.82	**3.64**
August	0.46	3.78	3.08	5.60	**3.01**
September	0.42	2.08	2.17	3.44	**1.97**
October	1.75	0.66	1.96	3.09	**1.53**
November	1.83	1.18	0.24	0.46	**0.93**
December	1.77	0.57	0.04	1.68	**0.72**
Total	**19.76**	**27.60**	**28.10**	**32.98**	**23.15**
J to M[§]	**8.66**	**12.44**	**15.26**	**6.97**	**8.46**
Growing season period of winter wheat					
PF[§]	24	15	29	28	**21**
PG[§]	12	21	21	13	**14**
PT[§]	**36**	**36**	**50**	**41**	**35**
Growing season period of grain sorghum					
PF[§]	22	23	27	16	**20**
PG[§]	8	13	13	24	**13**
PT[§]	**30**	**36**	**40**	**40**	**33**

[†]Long-term average (LTA) (43 years, 1975 to 2018).
[§]Precipitation during fallow (PF), growing season (PG), and total precipitation (PT).
January to May (J to M).

Table 2. Analysis of variance summary of the effects of year (YR), tillage (TILL), N fertilizer rate (NR), and their interactions on grain yield (lb/a), N concentration (N conc., %), N removed (NR, lb/a), nitrogen use efficiency (NUE, lb grain/lb N applied), and grain protein content (%) for winter wheat yield and grain sorghum in Hays, KS

Treatment effect	Yield	N conc.	NR	NUE	Protein
Winter wheat[†]					
YR	**<.0001**	**<.0001**	**<.0001**	**0.0001**	**<.0001**
TILL	**0.0002**	0.4919	**0.0003**	**0.0017**	0.5268
YR × TILL	**0.0213**	**0.0077**	**0.0078**	**0.0145**	**0.0077**
NR	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
YR × NR	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
Till × NR	0.0824	0.5295	0.9432	0.5193	0.5317
YR × TILL × NR	0.1464	0.4947	0.2930	0.6595	0.4927
Grain sorghum[†]					
YR	**<.0001**	**<.0001**	0.2251	0.2251	**<.0001**
TILL	**0.0006**	0.0629	0.2102	0.2102	0.0585
YR × TILL	**<.0001**	**0.0214**	**0.0203**	**0.0203**	**0.0202**
NR	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
YR × NR	**<.0001**	**<.0001**	0.3813	0.3813	**<.0001**
Till × NR	0.5508	0.8287	0.9414	0.9414	0.8152
YR × TILL × NR	0.6053	0.9869	0.9696	0.9696	0.9864

[†]*P-value* of treatment effects in bold are significant at $P < 0.05$.

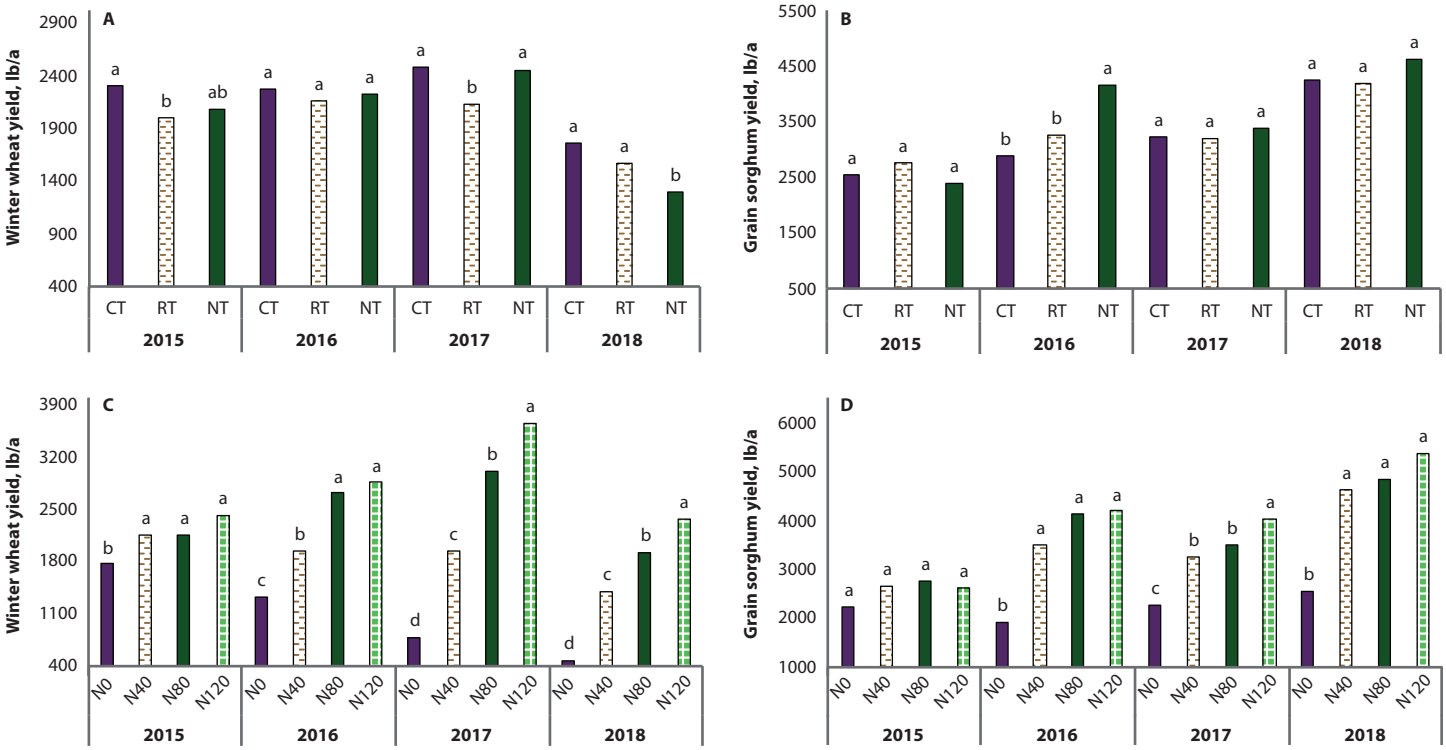

Figure 1. Grain yield (lb/a) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and nitrogen (N) fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different ($P \geq 0.05$).

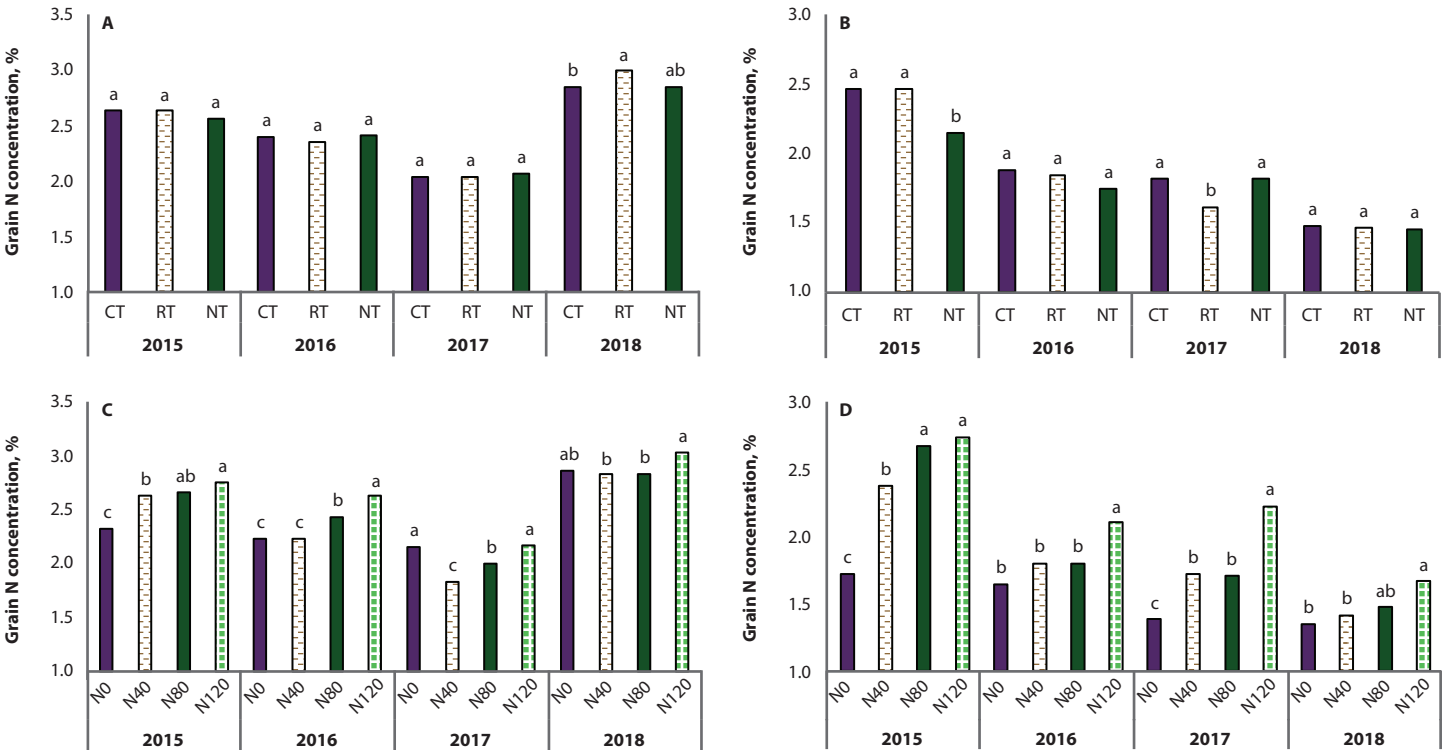

Figure 2. Grain nitrogen (N) concentration (%) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and N fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different ($P \geq 0.05$).

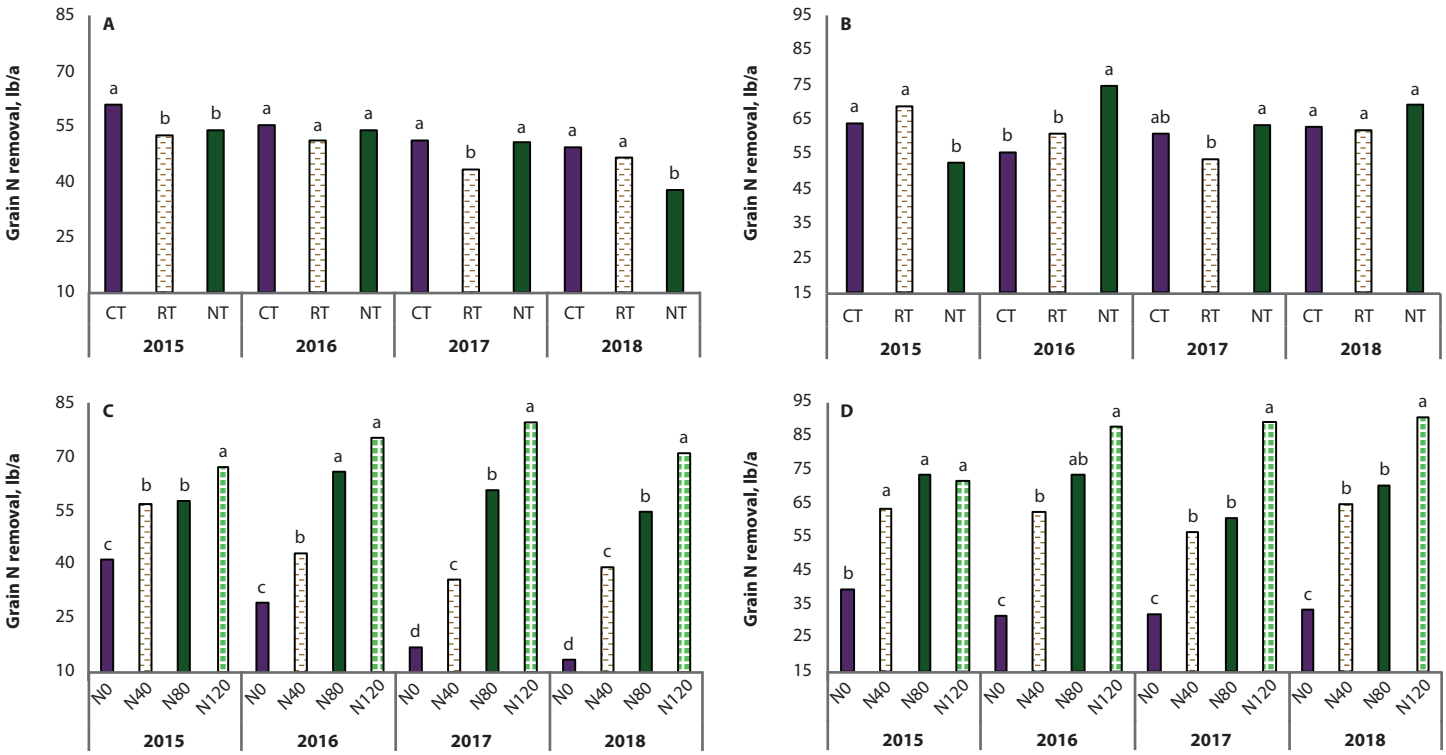

Figure 3. Grain nitrogen (N) removal (lb/a) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and N fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different ($P \geq 0.05$).

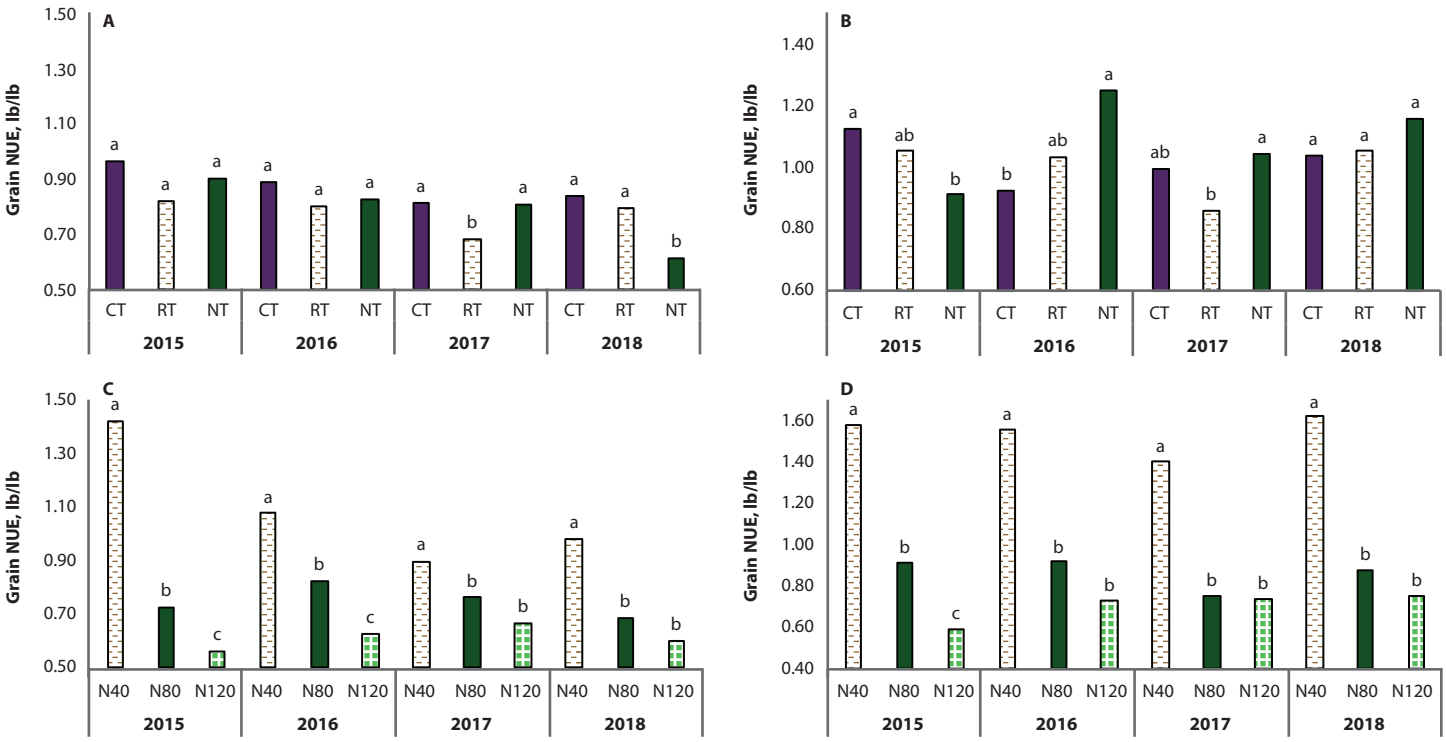

Figure 4. Nitrogen use efficiency (NUE) (lb/lb) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and N fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different ($P \geq 0.05$).

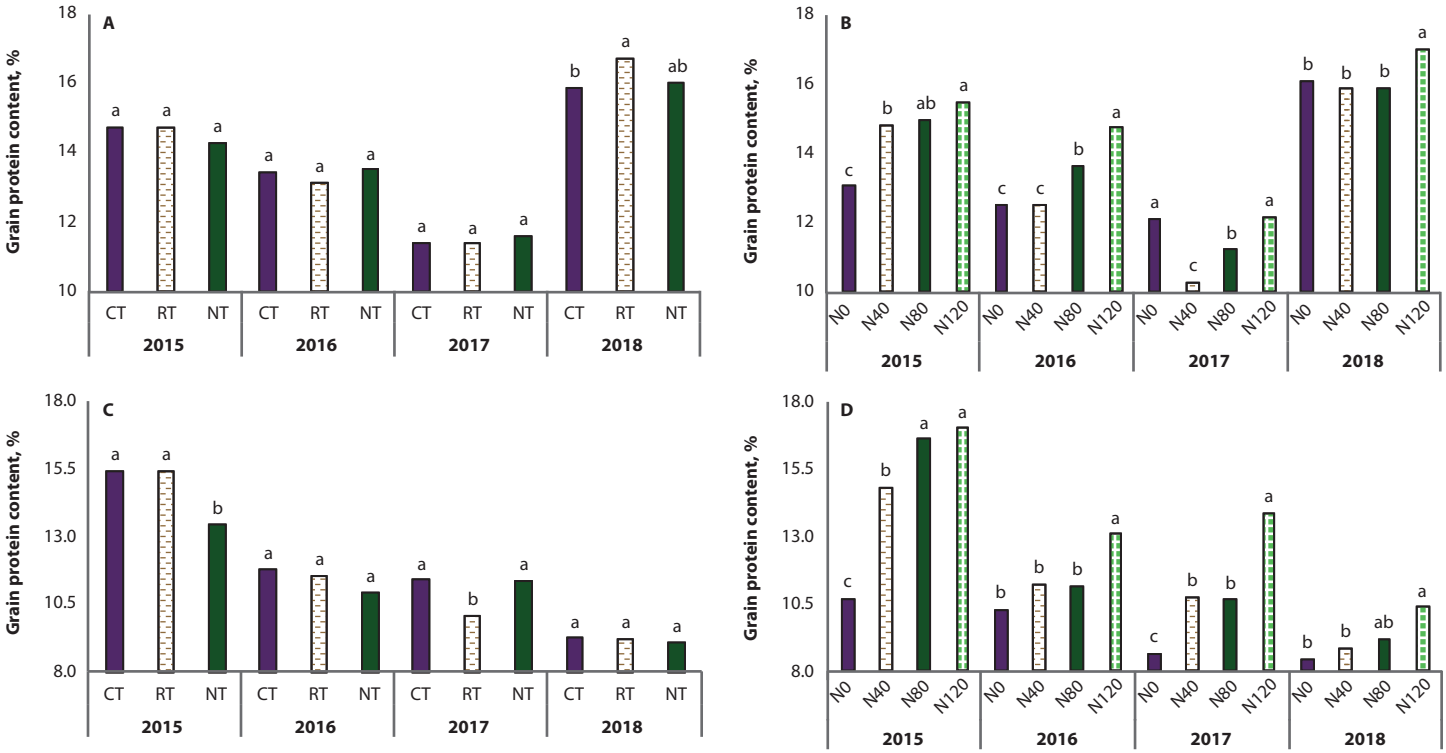

Figure 5. The grain protein content (%) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and nitrogen (N) fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (B), respectively, and for grain sorghum (C) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different ($P \geq 0.05$).

Effects of Cover Crops and Phosphorus Fertilizer Management on Soil Health Parameters in a No-Till Corn-Soybean Cropping System in Riley County, Kansas

L.M. Starr, P.J. Tomlinson, N.O. Nelson, C.L. Stewart, K.L. Roozeboom, G.J. Kluitenberg, and D.R. Presley

Summary

This study was implemented to examine the effects of cover crops and mineral phosphorus (P) fertilizer application on water quality and soil health parameters. The experiment was established in 2014, at the Kansas Agricultural Watershed (KAW) field research facility, Ashland Bottoms Research Farm, Kansas State University, Manhattan, KS. The experiment was a 2 × 3 factorial design with two cover crop treatments (with and without) and three phosphorus fertilizer treatments (none, spring injected P, and fall broadcast P). Measures of nutrient demand (enzyme activity), microbial metabolic activity (soil respiration), and labile carbon (potassium permanganate oxidized carbon) were taken to assess the treatment effects on the nutrient status and relative microbial activity of the soil ecosystem. Results from spring 2018 showed a cover crop main effect for five enzymes (acid and alkaline phosphatase, phosphodiesterase, β-glucosidase, and β-glucosaminidase), soil respiration, and active carbon (C). The main fertilizer effect was in potential β-glucosaminidase activity ($P = 0.02$). There was an interaction effect between phosphorus fertilizer and cover crop for the enzyme arylsufatase.

Introduction

Research has demonstrated improved soil structure, increased water holding capacity, and increased soil organic matter as a result of improved soil health (National Research Council, 2010). Cover crops have been shown to increase soil health (National Research Council, 2010), and have improved soil organic C and aggregation within no-till systems (Blanco-Canqui et al., 2011); however, it is not clear how effective these practices will be for soil health in a no-till system or if there will be any interaction with P fertilizer timing and placement. The effects of the treatments on soil health parameters, such as microbial activity, potential enzyme activity, and labile C pools at a field scale, will add to our understanding of these management options in the context of a common no-till cropping system. Ultimately these results will be used to aid producers with management decisions that will increase the sustainability of their farm enterprise.

Procedures

The experimental site is located at the Kansas Agricultural Watershed (KAW) Field Laboratory, approximately 5.5 miles south west of Manhattan, KS. It consists of an upland agricultural field that is terraced into 18 watershed units that are approximately 1.2–1.6 acres each. The site has a slope of 6–8% on primarily Smolan silty clay loam. The site has been in a continuous no-till, corn-soybean rotation since its establishment in 2014. This experiment is organized in a 2 × 3 factorial treatment design with three

replications in a random block design. The cover crop factor has two levels, cover crop (CC) or no cover crop (NCC), and the fertilizer factor has three types of phosphorus fertilizer application, no fertilizer (NF), spring injected (SI), and fall surface broadcast (FB).

Cover crops have been planted annually since 2015 and have included: winter wheat before soybean in 2016, triticale and rapeseed before corn in 2017, and before soybean in 2018. Each year, the same amount of P was applied in both the spring injected and fall broadcast applications. The fall broadcast treatment was applied as diammonium phosphate (DAP) at 120 lb P/a (55 lb P_2O_5/a), and spring injected application was applied as 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 spring 2018, composite soil samples were collected from 0–2 in., after cover crop termination but prior to spring injected fertilizer P application. These samples were immediately stored at 40°F and analyzed promptly. Samples were assayed for enzyme activity, soil respiration, and active C (Table 1).

Results

The cover crops main effect was significant in all of the assays. Only arylsulfatase showed any interaction with fertilizer treatments (Figure 1). The only main fertilizer effect was documented in β-glucosaminidase activity ($P = 0.02$), an enzyme associated with the decomposition of recalcitrant C compounds in organic residues. β-glucosaminidase activity was increased by 21% in the FB treatment compared to NP but was not different compared to the SI treatment. Cover crops increased the potential enzyme activity, active C, and microbial metabolic activity (as measured by CO_2 respired) compared to the no cover crop treatment (Table 2).

Discussion

Enzymes are excreted by microorganisms and plants to catalyze the decomposition of organic matter (Madigan et al., 2018). Enzymes are excreted in response to nutrient demands of the biota and nutrient availability in the soil. This enzyme function by organisms has been described as "foraging behavior" (Madigan et al., 2018). In this snapshot of soil nutrient dynamics following the termination of the cover crop, cover crops increased the amount of enzyme activity compared to no cover crops. An increase in soil microbial respiration supported the increase in enzyme activity, suggesting a more active and possibly larger microbial community under cover crops. In conjunction with these measures, the active carbon measure indicates a readily available form of C for microbial uptake. This is important, as C is frequently the limiting growth factor for microbial communities (Spohn and Kuzyakov, 2013).

These results suggest cover crops increase the soil health benefits in no-till systems directly after the cover crop termination in the spring. It is difficult to predict whether these benefits will be conferred to the cash crop later in the season, have any beneficial effect on yield, or reduce dependence on chemical inputs. While soil health may be improved by cover crops, the marginal economic or environmental benefits are yet to be determined.

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Table 1. Methods used to measure soil health parameters

Measurement	Method reference
Acid and alkaline phosphatase	Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977
Phosphodiesterase	Browman and Tabatabai, 1978
β-glucosidase	Eivazi and Tabatabai, 1988
β-glucosaminidase	Eivazi and Tabatabai, 1988; Parham and Deng, 2000
Arylsulfatase	Tabatabai and Bremner, 1970a
Active carbon - potassium permanganate oxidized carbon	Weil et al., 2003
Dissolved inorganic nitrogen	Jones and Willett, 2006
Soil respiration - potassium hydroxide trap	Zibilske, 1994

Table 2. Spring 2018 cover crop treatment main effects on soil health measurements from the Kansas Agricultural Watershed (KAW) Field Laboratory, Manhattan, KS

Soil health parameter	Units	Cover crop	No cover crop	% Change	*P*-value
Acid phosphatase	ug p-nitrophenol/ g dry soil hour	106.42	90.89	17%	0.0001
Alkaline phosphatase		33.24	22.83	46%	0.006
Phosphodiesterase		30.25	22.00	38%	0.0001
β-glucosidase		27.91	22.71	23%	0.001
β-glucosaminidase		4.78	2.55	87%	0.0001
Active carbon (C)	mg C/kg dry soil	328.34	268.88	22%	0.001
Soil respiration	mg CO_2 /kg dry soil	0.29	0.21	38%	0.02

The percent change was calculated: % change = [(cover crop – no cover crop)/no cover crop] × 100.

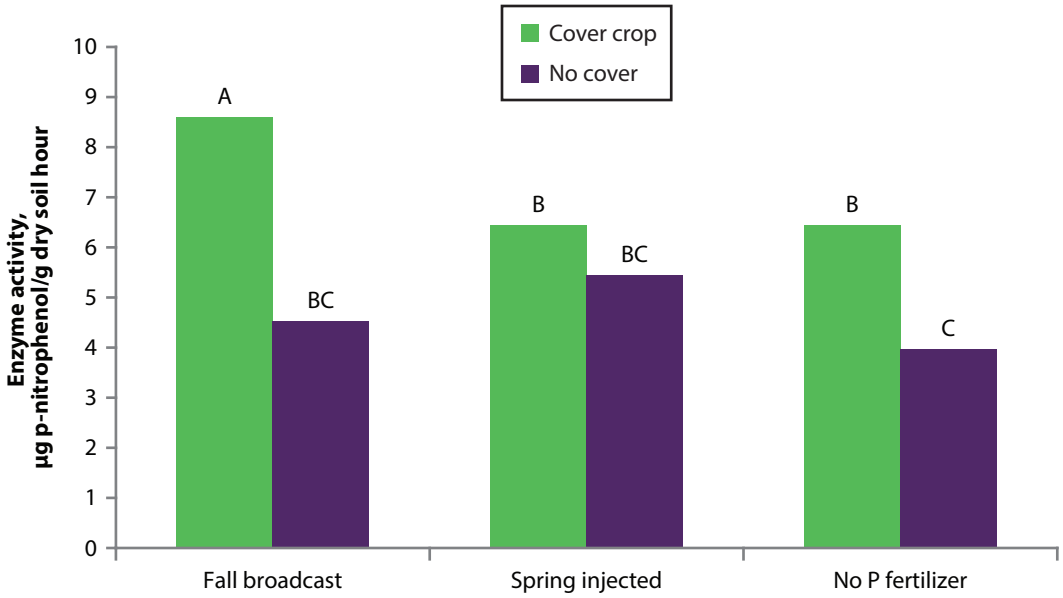

Figure 1. Spring 2018 cover crop treatment interaction with phosphorus (P) fertilizer application treatment on potential arylsulfatase enzyme activity from watersheds at the Kansas Agricultural Watershed (KAW) Field Laboratory, Manhattan, KS.

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