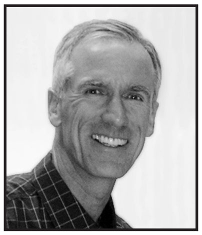
Southwest Research-Extension Center

Field Day 2018

K-State Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service



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Southwest Research-Extension Center Head

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Bob was appointed head of the Western Kansas Agricultural Research Centers in 2006. His research interests include grazing management systems, grassland ecology, and forage establishment.

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Mary provides administrative leadership to the Southwest Extension Units, working primarily with agents and Extension Council members.

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Jonathan's extension and research programs focus on irrigation systems, water conservation practices, irrigation scheduling, water quality, new and emerging relevant technologies (such as soil, water, and plant sensors; remote sensing; and GIS), and crop water management.

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Debra works with local agents on projects, program development, and training. Her research focuses on families, rural social systems, and community developmental processes.

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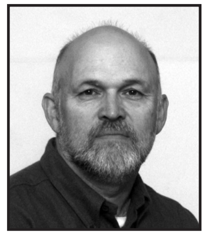
Randall joined the staff in 1991. His research focus is on weed control in corn.



Jeff Elliott
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Jeff joined the staff as an animal caretaker in 1984 and was promoted to Research Farm Manager in 1989.

Anserd (AJ) Foster
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AJ joined the staff in July 2015. His extension duties are to provide leadership for extension educational programs in crops, soils, weeds, forages, and rangelands. His main area of expertise is soil fertility. He also has interests in cropping systems management in different environments.

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John joined the staff in 2006. His research involves crop rotations, forages, and integrated weed management.

SOUTHWEST RESEARCH-EXTENSION CENTER

Field Day 2018

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Weather Information for Tribune

D. Bond and J. Slattery

In 2017, annual precipitation of 23.45 in. was recorded, which is 5.55 in. above normal. Only five months had above-normal precipitation. May (5.00 in.) was the wettest month, while both April and July recorded greater than 4 in. of precipitation. The largest single amount of precipitation was 2.10 in. on April 30. November and December were the driest months with only a recorded trace of precipitation.

Snowfall for the year totaled 24.7 in.; January, April, and May had 2.7, 16.0, and 6.0 in., respectively, for a total of 9 days of snow cover. The longest consecutive periods of snow cover, 4 days, occurred January 5–8 and April 29–May 2.

Record-high temperatures were recorded on 6 days: February 22 (79°F); March 20 (91°F), 21 (87°F), and 24 (89°F); and November 18 (80°F) and 28 (84°F). A record-high temperature was tied on November 15 (80°F). No record-low temperatures were recorded. A record-low temperature was tied on May 24 (33°F). July was the warmest month with a mean temperature of 76.5°F. The hottest day of the year (103°F) occurred on June 22. The coldest day of the year (-8°F) occurred on January 7. January was the coldest month with a mean temperature of 30.4°F.

Mean air temperature was above normal for 9 months. February had the greatest departure above normal (7.3°F), and August had the greatest departure below normal (-4.6°F). Temperatures were 100°F or higher on 6 days, which is 5 days below normal. Temperatures were 90°F or higher on 52 days, which is 11 days below normal. The latest spring freeze was May 4, which is 2 days earlier than normal; the earliest fall freeze fell on October 10, which is 3 days later than normal. This produced a frost-free period of 159 days, which is 5 days more than the normal of 154 days.

Open-pan evaporation from April through September totaled 59.58 in., which is 11.82 in. below normal. Wind speed for this period averaged 4.1 mph, which is 1.2 mph less than normal.

The 2017 weather information for Tribune is summarized in Table 1.

Table 1. Climatic data, Southwest Research-Extension Center, Tribune, Kansas

	Precipitation		Monthly average temperatures						Wind		Evaporation	
			2017		Normal		2017 extreme					
Month	2017	Normal	Max	Min	Max	Min	Max	Min	2017	Normal	2017	Normal
	--------- in. ---------		----------------------------- °F -----------------------------						------ MPH ------		--------- in. ---------	
January	0.80	0.49	43.3	17.5	44.0	16.2	68	-8	---	---	---	---
February	0.06	0.52	58.2	23.4	47.5	19.4	79	7	---	---	---	---
March	1.21	1.22	65.3	27.1	56.3	26.8	91	11	---	---	---	---
April	4.67	1.45	66.3	37.3	65.7	34.9	90	26	5.3	6.0	7.13	8.27
May	5.00	2.38	72.7	43.1	75.1	46.4	93	27	4.5	5.6	8.86	11.75
June	2.46	2.94	89.3	56.2	85.7	56.6	103	49	4.0	5.2	12.54	14.04
July	4.53	2.85	91.5	61.5	91.8	61.7	102	48	3.6	5.2	12.54	15.58
August	1.66	2.33	84.5	56.0	89.4	60.4	95	49	3.4	4.7	9.21	12.16
September	2.70	1.18	82.6	50.4	81.5	50.6	98	41	3.9	5.0	9.30	9.60
October	0.36	1.49	70.6	37.4	68.9	37.1	88	19	4.2*	4.5*	5.92*	6.09*
November	T	0.55	60.5	28.6	54.9	25.7	84	17	---	---	---	---
December	T	0.50	48.0	14.8	44.7	17.0	69	-5	---	---	---	---
ANNUAL	23.45	17.90	69.4	37.8	67.1	37.7	103	-8	4.1	5.3	59.58	71.40

Max = maximum.
Min = minimum.
Normal latest freeze (32°F) in spring: May 6. In 2017: May 4.
Normal earliest freeze (32°F) in fall: October 7. In 2017: October 10.
Normal frost-free (>32°F) period: 154 days. In 2017: 159 days.
Normal for precipitation and temperature is 30-year average (1981–2010) from National Weather Service.
Normal for latest freeze, earliest freeze, wind, and evaporation is 30-year average (1981–2010) from Tribune weather data.
*Normal for October wind and evaporation is 10-year average (2001–2010) from Tribune weather data; October not included in annual totals.
T = trace.

Weather Information for Garden City, 2017

J. Elliott

Precipitation for 2017 totaled 20.37 in. This was 1.13 in. above the 30-year average of 19.24 in. and followed a year of below normal moisture. Excellent moisture in March and April resulted in favorable spring planting conditions. May through July precipitation was diminished to about half of the 30-year-average. September recorded 3.29 in. and resulted in good conditions for early planted wheat. Blowing dust occurred on March 7 and October 27. Quarter sized hail and damaging wind were noted on October 7. The largest precipitation events were 2.93 in. (11 in. of heavy, wet snow) on March 29 through May 2, and 3.00 in. rain on September 24 through 26.

Measurable snowfall occurred in January, April, and May. Annual snowfall totaled 17.0 in. compared to an average of 19.7 inches. Seasonal snowfall (2016-2017) was 18.5 in.

Average daily wind speed was 4.86 mph compared to the 30-year average of 5.10 mph. Open pan evaporation was measured daily from April through October, and totaled 77.77 in. This was 7.51 in. above the 30-year mean of 70.26 in.

Our mean annual temperature was 55.8°F which was 2.1°F above the 30-year average of 53.7°F. Triple-digit temperatures were observed on 17 days in 2017, with the highest being 105°F on June 12 and July 22. Twelve record high temperatures were equaled or exceeded in 2017: 88°F on February 11, 76°F on February 20, 80°F on February 22, 94°F on March 20, 85°F on March 24, 92°F on April 20, 94°F on May 16, 98°F on September 15, 96°F on September 23, 79°F on November 18, 76°F on November 28, and 74°F on December 4. The highest temperature recorded for the month of March was 94°F on March 20.

Sub-zero temperature occurred once in 2017. The lowest temperature was -8°F noted on January 7. Two record low temperatures were equaled or exceeded: 42 on September 6, and 16 on October 18.

The last spring freeze was 32°F on May 4, which was five days later than the 30-year average. The first fall freeze was 31°F on October 15, which was three days later than normal. This resulted in a 164-day frost-free period, which is one day shorter than the 30-year average.

The 2017 climate information for Garden City is summarized in Table 1.

Table 1. Climate data, Southwest Research-Extension Center, Garden City

	Precipitation		Monthly temperatures						Wind		Evaporation	
			2017				2017 extreme					
Month	2017	Avg.	Max	Min	Mean	30-year avg.	Max	Min	2017	30-year avg.	2017	30-year avg.
	-------in.--------		---------------------------- °F -----------------------------						----- mph ------		-------in.--------	
January	1.54	0.46	43.5	19.7	31.6	30.4	72	-8	3.39	4.50	--	--
February	0.00	0.55	61.4	23.3	42.3	33.9	88	6	4.36	5.24	--	--
March	2.55	1.31	66.2	29.5	47.8	42.9	94	10	5.95	6.31	--	--
April	4.03	1.74	67.5	41.1	54.3	52.3	92	29	6.88	6.42	7.35	8.21
May	1.47	2.98	75.5	45.3	60.4	62.8	95	31	6.35	5.76	10.22	10.04
June	1.25	3.12	92.2	60.6	76.4	72.6	105	53	5.73	5.37	15.83	11.96
July	2.02	2.80	93.8	65.8	79.8	77.9	105	55	4.30	4.59	14.47	13.22
August	2.46	2.51	86.8	59.4	73.1	76.3	97	50	3.29	4.11	11.16	11.28
September	3.29	1.42	84.8	54.6	69.7	67.7	98	42	4.98	4.73	12.14	9.22
October	1.75	1.21	73.1	40.1	56.6	54.9	90	16	4.94	4.89	6.60	6.33
November	0.01	0.55	60.2	29.7	44.9	41.6	79	18	4.19	4.80	--	--
December	0.00	0.59	49.0	16.2	32.6	31.4	74	3	4.01	4.45	--	--
Annual	20.37	19.24	71.1	40.4	55.8	53.7	105	-8	4.86	5.10	77.77	70.26

Normal latest spring freeze (32°F): April 29. In 2017: May 4.
Normal earliest fall freeze (32°F): October 12. In 2017: October 15.
Normal frost-free period (>32°F): 165 days. In 2017: 164 days.
30-year averages are for the period 1981-2010. All recordings were taken at 8:00 a.m.

Determining Profitable Forage Rotations

J. Holman, A. Obour, A. Schlegel, T. Roberts, and S. Maxwell

Summary

Annual forages are an important crop in the High Plains, yet the region lacks recommended annual forage rotations compared to those developed for grain crops. Forages are important for the region's livestock and dairy industries and are becoming increasingly important as irrigation capacity and grain prices decrease. Forages require less water than grain crops and may allow for increased cropping system intensity and opportunistic cropping. A study was initiated in 2012 at the Southwest Research-Extension Center near Garden City, KS, comparing several 1-, 3-, and 4-year forage rotations with no-tillage and minimum-tillage. Data presented are from 2013 through 2017. Tillage generally increased winter triticale yields 1,250 lb/a compared to no-till yields, due in part to increased plant available water. Plant available water at planting winter triticale averaged 5.2 in./a in min-till and 3.4 in./a in no-till. Double-crop forage sorghum yielded 22% less than full-season forage sorghum and yields were not affected by tillage. Oat yields were lower than forage sorghum or winter triticale yields. Subsequent years will be used to further compare forage rotations, develop crop-water relationships, and establish partial enterprise budgets.

Introduction

To stabilize crop yields, dryland rotations in western Kansas commonly include fallow to accumulate soil water. Fallow is relatively inefficient at storing and utilizing precipitation when compared to storage and utilization of precipitation received during the growing season. Fallow periods increase soil erosion and organic matter loss (Blanco and Holman, 2012), and represent a large economic cost to producers. Forages are valuable feedstuff to the cow/calf, stocker, cattle feeding, and dairy industries throughout the region (Hinkle et al., 2010). Forages grown in place of fallow can increase precipitation use efficiency, improve soil quality, and increase profitability (Holman et al., 2018). This study tests several forage rotations for water use efficiency, forage quality, yield, and profitability.

Annual forages are grown for a shorter period and require less water than traditional grain crops. Including annual forages into the crop rotation might enable increasing cropping system intensity and opportunistic cropping. "Opportunistic cropping" or "flex cropping" is the planting of a crop when conditions (soil water and precipitation outlook) are favorable and fallowing when unfavorable. Wheat yields following spring annual forages such as oat (O) were similar to wheat yields following fallow in a wheat-fallow rotation in non-drought years, but wheat yields were reduced in drought years (Holman et al., 2012). This indicates the opportunity to intensify the cropping system in favorable years. Forage producers in the region commonly grow continuous winter triticale (T), winter triticale or summer crop silage, or forage sorghum hay (S), but they lack a proven rotation concept for forages such as that developed for grain crops (e.g. winter wheat-summer crop-fallow). Continuous winter triticale often develops winter annual grass problems, while continuous forage sorghum produces lower quality forage than triticale. Producers are interested in identifying forage rotations that increase pest management control options, spread out equipment and labor resources over the year, reduce the impact of variable weather risks, and increase profitability. Growing forages throughout the year greatly reduces the risk of crop failure due to variable precipitation.

Growing winter triticale (T) or forage sorghum (S) double cropped (T/S/T), yielded 30% less than non-double crop yields (T-S-O) ($P \leq 0.05$) near Garden City, KS, between 2007 and 2010. Double cropping increased forage production's annual yield 40% more than growing one crop annually (Holman et al., 2012). However, crop establishment was more challenging and crop growth was highly dependent on growing season precipitation in the double-crop rotation compared to annual cropping. Due to the high cropping intensity it was also challenging to implement timely field operations in the double crop system. An intermediate cropping intensity of three crops grown in two years or four crops in three years might be a successful crop rotation in western Kansas.

Recently in western Kansas, glyphosate-resistant kochia (*Kochia scoparia*) was identified, and several other grasses (e.g. tumble windmill grass and red three-awn) are already tolerant of glyphosate and other herbicides. Although continuous no-till was shown to provide better water conservation and crop yields, this result is contingent upon being able to control weeds with herbicides during fallow. Limited information is available on the effect of occasional strategic tillage to control herbicide tolerant weeds on forage yield. Yield of forage crops following tillage might not be affected as much as in grain crops, since forages require less water. Information is needed on the effects of occasional tillage in forage based cropping systems.

Study Objectives

1. Identify and characterize profitable forage cropping systems.
2. Determine the effect of occasional strategic tillage on forage system yield, profit, and soil health.

Experimental Procedures

An annual forage rotation experiment was initiated in 2012 at the Southwest Research-Extension Center near Garden City, KS. All crop phases were in place by 2013, with the exception of T-S-O, which had all crop phases in place by 2015. The study design was a randomized complete block design with four replications. Treatment was crop phase (with all crop phases present every year) and tillage (no-tillage or min-tillage). Plots were 30-ft wide × 30-ft long. Crop rotations were one-, three-, and four-year rotations (see treatment list below). Crops grown were winter triticale (×*Triticosecale* Wittm.), forage sorghum (*Sorghum bicolor* L.), and spring oat (*Avena sativa* L.). Tillage was implemented after spring oat was harvested in treatments 3 and 5, using a single tillage with a Minimizer (Premier Tillage Mfg.) sweep plow with 6-ft blades and trailing pickers.

Treatments Included

1. Continuous forage sorghum (no-tillage): (S-S)
2. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: spring oat (no-tillage): (T/S-S-O no-tillage)

3. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: spring oat (single tillage after spring oat, min-tillage): (T/S-S-O min-tillage)
4. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: forage sorghum; Year 4: spring oat (no-tillage): (T/S-S-S-O no-tillage)
5. Year 1: winter triticale/double-crop forage sorghum; Year 2: forage sorghum; Year 3: forage sorghum; Year 4: spring oat (single tillage after spring oat, min-tillage): (T/S-S-S-O min-tillage)
6. Year 1: winter triticale; Year 2: forage sorghum; Year 3: spring oat (no-tillage): (T-S-O)

Winter triticale was planted at the end of September, spring oat was planted the beginning of March, and forage sorghum was planted the beginning of June. Crops were harvested at early heading to optimize forage yield and quality (Feekes 10.1) (Large 1954). Winter triticale was harvested approximately May 15, spring oat was harvested approximately June 1, and forage sorghum was harvested approximately the end of August. Forage yields were determined from a 3- × 30-ft area cut 3 in. high using a small plot Carter forage harvester from each plot. Forage yield and quality (protein, fiber, and digestibility) were measured at each harvest. Gravimetric soil moisture content was measured at planting and harvest to a depth of 6 ft using 1-ft increments. Precipitation storage efficiency (% of precipitation stored during the fallow period) was quantified for each fallow period, and crop water use efficiency (forage yield divided by soil water used plus precipitation) was determined for each crop harvest. Crop yield response to plant available water (PAW) at planting was used to develop a yield prediction model based on historical or expected weather conditions. Most producers use a soil probe rather than gravimetric sampling to determine soil moisture status, so soil penetration with a Paul Brown soil probe was used four times per plot at planting to estimate soil water availability. Previous studies found a soil moisture probe provided a practical, easy way to determine soil moisture level and crop yield potential. Profitable forage and tillage systems identified in this study will benefit producers in the High Plains region.

Results and Discussion

Rotation Yield

Annual rotation yield was determined by measuring total yield for the rotation and dividing by the number of years in the rotation. This method allowed for comparing rotations of different years to each other for annual forage production (Table 1 and Figure 1). A very dry year in 2013 resulted in low crop yields and no spring oat yield. In 2013, S-S produced the highest annual yield. In 2014, annual yield was comparable across treatments except for T/S-S-O (no-tillage), which had lower yield than T/S-S-S-O (min-tillage) and was comparable to all other treatments. The crop rotation of T-S-O was not in phase until 2015, so no comparison was made to that rotation until 2015. In 2015, T/S-S-O (no-tillage) yielded less than S-S, but more than T-S-O and comparable to all other treatments. The T-S-O annual yield was less than all other treatments in 2015. In 2016 and 2017, precipitation primarily occurred late spring and early summer, which favored forage sorghum yield. The highest yielding rotations in 2016 and 2017 were S-S, followed by T/S-S-S-O (no-tillage), and T-S-O yielded the least. Tillage generally increased the yield of triticale and thus the yield of T/S-S-O was improved with tillage, but yield improvement in the 4-yr rotation was not as evident due to triticale occurring less frequently in the rotation.

Forage yield per crop harvest was determined for each rotation since planting and harvesting expenses are the major expenses to growing a crop; yield and value per ton are the major income components. Crop rotations with greater yield per harvest are likely to be more profitable compared to rotations with low yield per harvest since some of the variable and fixed expenses are less. Although oat and triticale yield less than forage sorghum, they are also higher in crude protein and digestibility and are worth more per unit than forage sorghum. A full economic analysis of rotations will be completed at the conclusion of this study. In 2013, S-S had the greatest yield per harvest, and all other rotations had similar yields per harvest (Table 1 and Figure 2). In 2014, T/S-S-O (no-tillage) had lower average harvest yields than S-S or T/S-S-S-O (min-tillage) but was similar to T/S-S-O (min-tillage) and T/S-S-S-O (no-tillage). In 2015, S-S had the greatest yield per harvest, and T-S-O had the lowest yield per harvest, which was lower than S-S or T/S-S-S-O (no-tillage), but comparable to the other treatments. In 2016 and 2017, S-S had the greatest yield per harvest and T-S-O had the least. Sorghum has the greatest yield potential of the three crops investigated, but S-S does not allow for crop diversification, improved weed management, higher forage quality (oats and triticale), or the ability to reduce weather risk by growing a crop during different times of the year.

Crop Yield

Full-season sorghum yields either grown after T/S or S yielded similarly across rotations (Figure 3). Double-crop forage sorghum yielded less than full-season forage sorghum, but varied greatly from year to year based on precipitation during the growing season. Double crop forage sorghum yielded 70% less than full-season in 2013, 7% less in 2014, 12% less in 2015, 10% less in 2016, and 38% less in 2017. Across all years, double-crop (5,540 lb/a) averaged 22% less than full-season forage sorghum (7,103 lb/a). The lower yield of double-crop forage sorghum was due to less available soil moisture at planting. Sorghum yield was not affected by tillage or length of rotation, although there was a tendency for no-till forage sorghum yields to be greater than min-till yields.

Triticale yield was not affected by length of rotation but was affected by tillage. Averaged across years, triticale in min-tillage (3,321 lb/a) yielded 160% more than no-tillage (2,067 lb/a). The only tillage in this study occurred in the fallow period before triticale and, in this study, benefited the triticale crop. The exception was in 2017 when no-till (1869 lb/a) yielded more than min-till (1518 lb/a). Other studies and producers have found tillage ahead of a winter wheat crop has minimal impact on yield and can improve weed control, but tillage ahead of grain sorghum often reduced grain yield. For these reasons, tillage was only used ahead of triticale and, similar to winter wheat, did not reduce yields, but actually increased yields in the first 4 years of this study.

Oats failed to make a crop in 2013 due to drought conditions, and yields were similar among rotations in 2014 (400 lb/a), 2015 (4,900 lb/a), 2016 (2,300 lb/a), and 2017 (883 lb/a). Yields in 2015 were higher than other years due to very favorable spring precipitation. Oat yield was not affected by tillage or rotation.

Soil Water

Plant available water at planting was measured to a 6-foot soil depth, and soil water content varied by year and planting period. Soil water was greatest at full-season forage sorghum planting (6.3 in.), and was not different among the other planting periods, ranging from 3.42 to 4.43 in. (Figure 4). Double-crop forage sorghum averaged 4.43 in., which was 1.89 less in. of PAW at planting than full-season forage sorghum.

Water use efficiency (WUE) was greatest in forage sorghum, with full-season producing 628 lb/a/in. and double-crop producing 565 lb/a/in. Water use efficiency for winter triticale averaged 379 lb/a/in., and oat was 297 lb/a/in. The yield potential and thus water use efficiency was greater with forage sorghum than triticale or oat. However, when precipitation was favorable during a particular growing season, such as oat in 2015, the WUE of oat was comparable to forage sorghum. In years with moisture stress, WUE of double-crop forage sorghum was less than full-season, but in favorable moisture years WUE of double-crop was greater than full-season (Figure 5).

Precipitation storage efficiency (PSE) varied by fallow period and ranged from 14% ahead of winter triticale to 39% for double-cropped forage sorghum. Precipitation storage ahead of full-season forage sorghum was 37% and ahead of oat planting was 31% (Figure 6).

References

Blanco, H. and J. Holman. 2012. Cover crops reduce wind and water erosion. Kansas State University Agricultural Experiment Station and Cooperative Extension Service Report of Progress. SRP1070:7-11.

Hinkle, J.B., J.T. Vasconcelos, S.A. Furman, A.S. deMello, L.S. Senaratne, S. Pokharel, C.R. Calkins. 2010. Sensory attributes of beef from steers fed field peas. 2010 Nebraska Beef Report pg. 117-118. University of Nebraska-Lincoln, Dept. of Animal Science.

Holman, J.D., K. Arnet, J. Dille, S. Maxwell, A.K. Obour, T. Roberts, K. Roozeboom, and A. Schlegel. 2018. Can cover (or forage) crops replace fallow in the semiarid central Great Plains? Crop Sci. 58:1-13.

Holman, J., T., Dumler, T. Roberts, and S. Maxwell. 2012. Fallow replacement crop effects on wheat yield. Kansas State University Agricultural Experiment Station and Cooperative Extension Service Report of Progress. 1070:24-29.

Large, E.C. 1954. Growth stages in cereals illustration of the Feekes scale. Plant Pathology. 3 (4): 128–129. doi:10.1111/j.1365-3059.1954.tb00716.x

Table 1. Rotation treatment yields across years between 2013 and 2017

Crop rotation	2013	2014	2015	2016	2017	2015-17 Average†	2013-17 Average‡
	Total treatment yield (DM lb/a)						
S-S	4262	7426	10244	8025	5954	8074	7182
T/S-S-O (no-till)	3451	13322	25732	16067	13387	18395	14392
T/S-S-O (min-till)	4020	20130	28742	18404	11690	19612	16597
T/S-S-S-O (no-till)	7702	27260	38091	27320	19382	28264	23951
T/S-S-S-O (min-till)	8896	30266	36394	23831	17411	25879	23360
T-S-O§	*	*	18404	10060	9583	12682	12682
	Annualized treatment yield (DM lb/a)						
S-S	4262	7426	10244	8025	5954	8074	7182
T/S-S-O (no-till)	1150	4441	8577	5356	4462	6132	4797
T/S-S-O (min-till)	1340	6710	9581	6135	3897	6537	5532
T/S-S-S-O (no-till)	1926	6815	9523	6830	4845	7066	5988
T/S-S-S-O (min-till)	2224	7566	9099	5958	4353	6470	5840
T-S-O	*	*	6135	3353	3194	4227	4227
$LSD_{0.05}$¶	1508	3038	1488	801	1391	789	-
	Yield per harvest (DM lb/a)						
S-S	4262	7426	10244	8025	5954	8074	7182
T/S-S-O (no-till)	863	3331	6433	4017	4462	4971	3821
T/S-S-O (min-till)	1005	5032	7185	4601	3897	5228	4344
T/S-S-S-O (no-till)	1540	5452	7618	5464	4845	5976	4984
T/S-S-S-O (min-till)	1779	6053	12131	4766	4353	7083	5817
T-S-O	*	*	3681	3353	3194	3410	3410
$LSD_{0.05}$	1323	2566	1331	693	1248	663	---

†Average of years 2015-2017.
‡Average of years 2013-2017.
§T-S-O treatment started in 2015.
¶Means in columns separated by LSD in column are statistically different at $P \leq 0.05$.

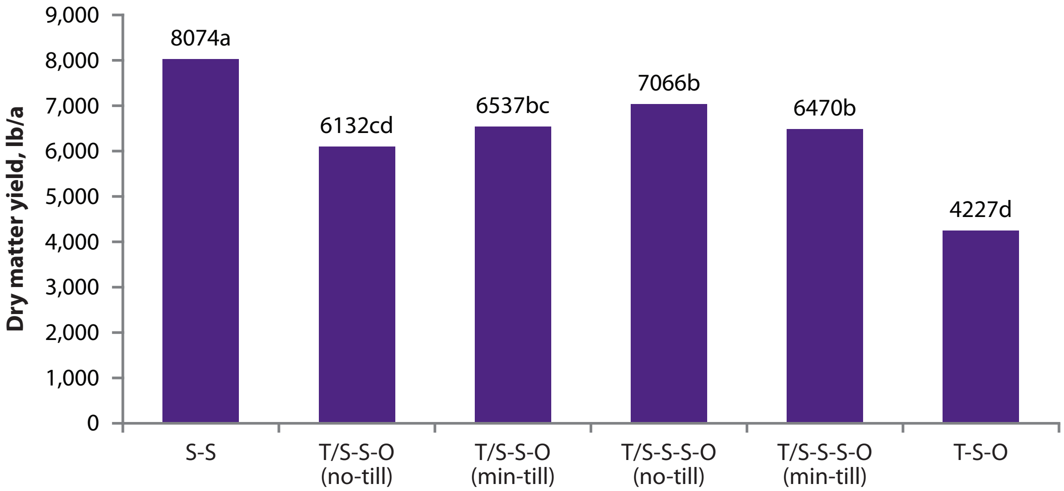

Figure 1. Forage dry matter annual yield for all crop rotations averaged across years from 2015 to 2017. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S: Forage sorghum. S-S: Continuous forage sorghum. T/S: Winter triticale/double crop forage sorghum. O: Spring oat.

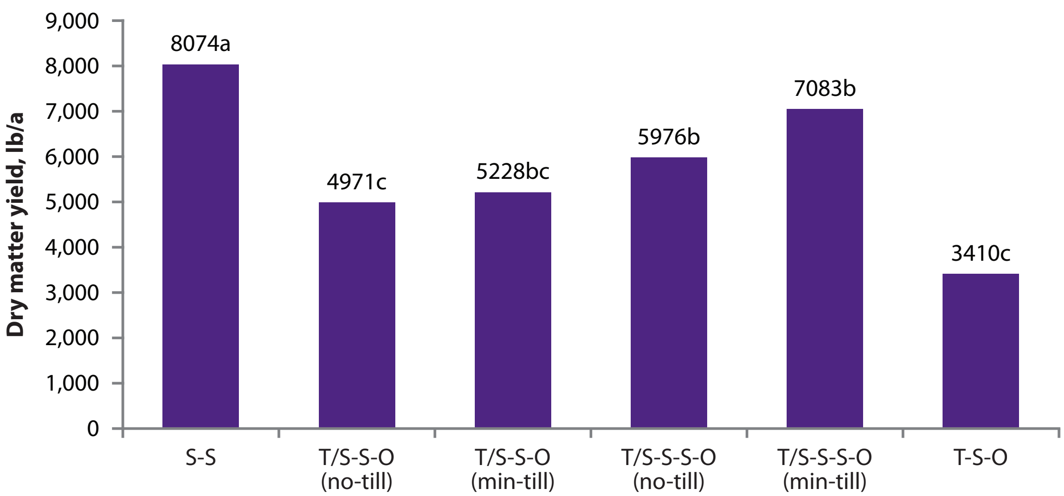

Figure 2. Forage dry matter yield per harvest for all crop rotations averaged across years from 2015 to 2017. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S: Forage sorghum. S-S: Continuous forage sorghum. T/S: Winter triticale/double crop forage sorghum. O: Spring oat.

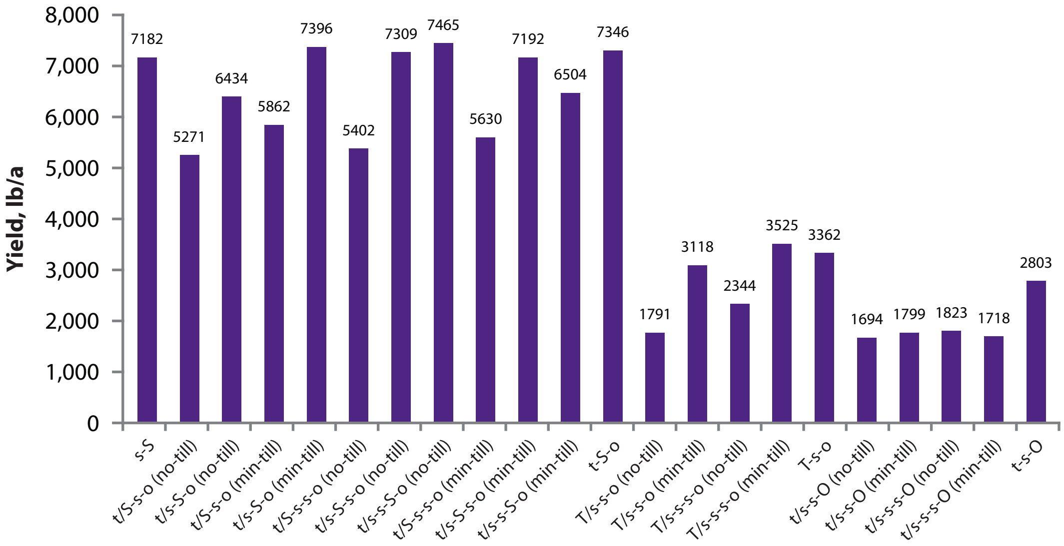

Figure 3. Forage dry matter yield for all crop rotations and phases averaged across years from 2013 to 2017. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S: Forage sorghum. S-S: Continuous forage sorghum. T/S: Winter triticale/double crop forage sorghum. O: Spring oat.

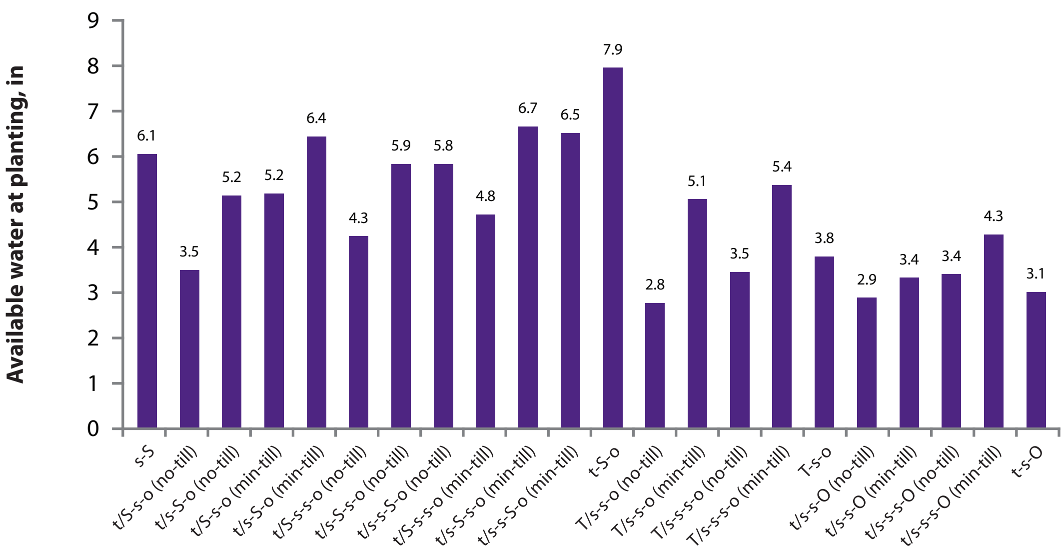

Figure 4. Plant available water in a 6-ft soil profile at planting for all crop rotations and phases averaged across years from 2013 to 2017. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

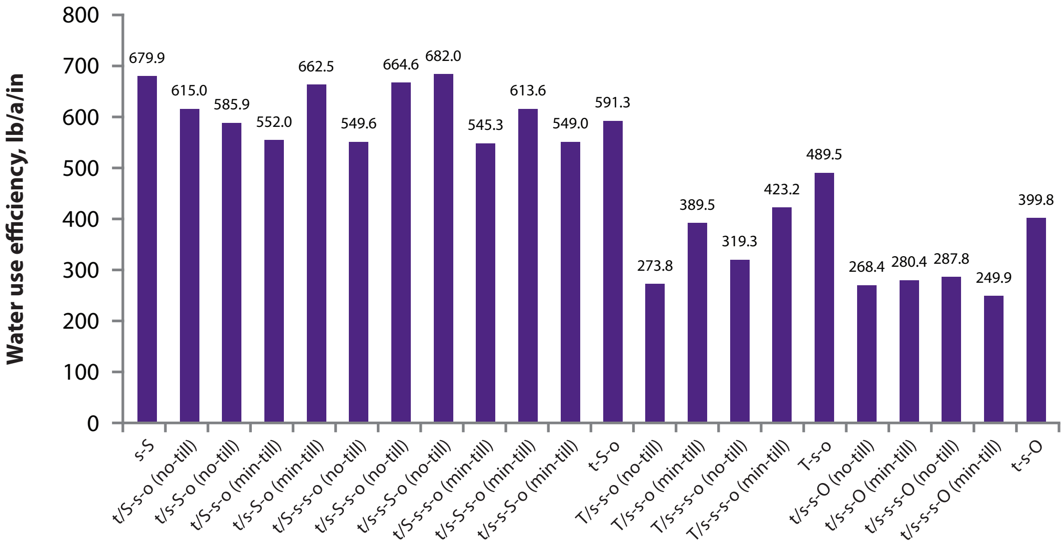

Figure 5. Water use efficiency (WUE) [forage dry matter yield/((ending-beginning soil water content) + growing season precipitation)] for all crop rotations and phases averaged across years from 2013 to 2017. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S: Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

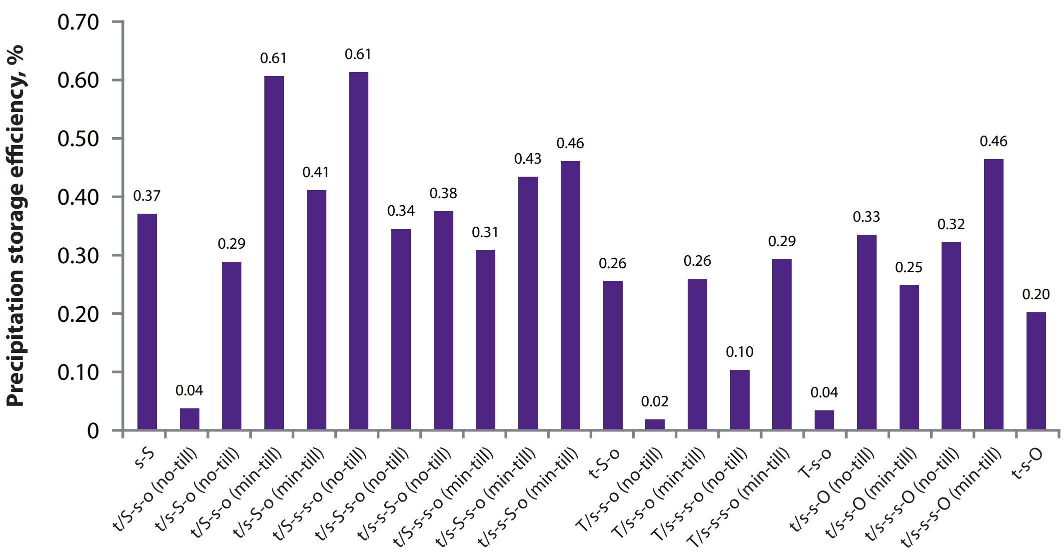

Figure 6. Precipitation storage efficiency (PSE) [precipitation/(ending-beginning soil water content)] for the fallow period preceding the crop for all crop rotations and phases averaged across years from 2013 to 2017. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

Estimating Annual Forage Yields with Plant Available Water and Growing Season Precipitation

J. Holman, A. Obour, A. Schlegel, T. Roberts, and S. Maxwell

Summary
Forage production is important for western Kansas region's livestock and dairy industries and has become increasingly important as irrigation-well capacity declines. Forages require less water than grain crops and may allow for increased cropping intensity and opportunistic cropping. Being able to estimate forage production is important for determining forage availability versus forage needs. Data from several studies were used to quantify annual forage yield response to plant available water (PAW) at planting and growing season precipitation (GSP). In addition, water use efficiency was quantified. Forages evaluated included winter triticale, spring triticale, and forage sorghum.

Introduction
Annual forage crops are grown for a shorter time and require less moisture than traditional grain crops. Including annual forages in the cropping system might enable increased cropping intensity and opportunistic cropping. "Opportunistic cropping," or "flex cropping," is the planting of a crop when conditions (soil water and precipitation outlook) are favorable and fallowing when unfavorable. Forage producers in the region commonly grow winter triticale, forage sorghum, or spring triticale/oat. Producers are interested in forage crop rotations that enable increased pest management control options, spread out equipment and labor resources over the year, reduce weather risk, and increase profitability. Growing forages throughout the year greatly reduces the risk of crop failure. Understanding the yield relationship to PAW and GSP would help producers better meet their forage needs.

Study Objectives
1. Quantify yield relationship of winter, spring, and summer forages with PAW and GSP.
2. Determine water use efficiency of winter, spring, and summer forages.

Experimental Procedures
Annual forages were grown as part of several different rotation experiments near Garden City, KS. Plant available water, growing season precipitation, and forage yield were measured annually. Data for winter triticale and forage sorghum were available from 2008 through 2017, and spring triticale from 2012 through 2017.

Annually, winter triticale was planted at the end of September, spring triticale was planted at the beginning of March, and forage sorghum was planted at the beginning of June. Crops were harvested at early heading to optimize forage yield and quality (Feekes 10.1) (Large 1954). Annually, winter triticale was harvested approximately May 15, spring oat was harvested approximately June 1, and forage sorghum was harvested approximately the end of August. Forage yields were determined from a 3- × 30-ft area cut 3 in. high using a small plot Carter forage harvester for each plot. Forage yield was measured at each harvest. Gravimetric soil moisture content was measured at planting and harvest to a depth of 6 ft using 1-ft increments. Precipitation storage efficiency (percent of precipitation stored during the fallow period) was quantified for each fallow period, and crop water use efficiency (forage yield divided by soil water used plus precipitation) was determined for each crop harvest. Crop yield response to plant available water at planting was regressed to estimate yield. These yield data will eventually be used to develop a yield prediction model based on historical or expected weather conditions when sufficient years of data are obtained.

Data produced by this study will be used to evaluate the economics of forage rotations and tillage. Production costs and returns will be calculated using typical values for the region. The implication of using forages on crop insurance dynamics and risk exposure is a critical component of a producer's decision-making process and will be evaluated at the conclusion of this study.

Results and Discussion

Winter Triticale

Winter triticale forage yield was correlated to PAW and GSP, although yield response was highly variable. Plant available water explained approximately 13% and GSP explained 5% of the variability in forage yield (Figures 1 and 2). Together, PAW and GSP explained 48% of the variability in forage yield (Figure 3). For every inch of water used (soil water plus GSP), yield was increased 640 lb/a. Averaged across the study period, yield was 3,500 lb/a.

Spring Triticale

Spring triticale forage yield was significantly correlated to PAW and GSP, but yield response was highly variable. Plant available water and GSP both explained approximately 5% of the variability in forage yield independently (Figures 4 and 5). Combining PAW and GSP explained only 10% of the yield variability; suggesting something other than moisture, most likely temperature greatly impacts yield (Figure 6). For every inch of water used (soil water plus GSP), yield was increased 187 lb/a. Averaged across the study period, yield was 1,450 lb/a.

Forage Sorghum

Forage sorghum forage yield was correlated to PAW but not GSP, and yield response was variable. Plant available water explained approximately 22% and GSP explained 3% of the variability in forage yield (Figures 7 and 8). Together, PAW and GSP explained 23% of the variability in forage yield (Figure 9). For every inch of water used (soil water plus GSP), yield was increased 410 lb/a. Averaged across the study period, yield was 5,400 lb/a.

References

Large, E.C. 1954. Growth stages in cereals illustration of the Feekes scale. Plant Pathology. 3 (4): 128–129. doi:10.1111/j.1365-3059.1954.tb00716.x

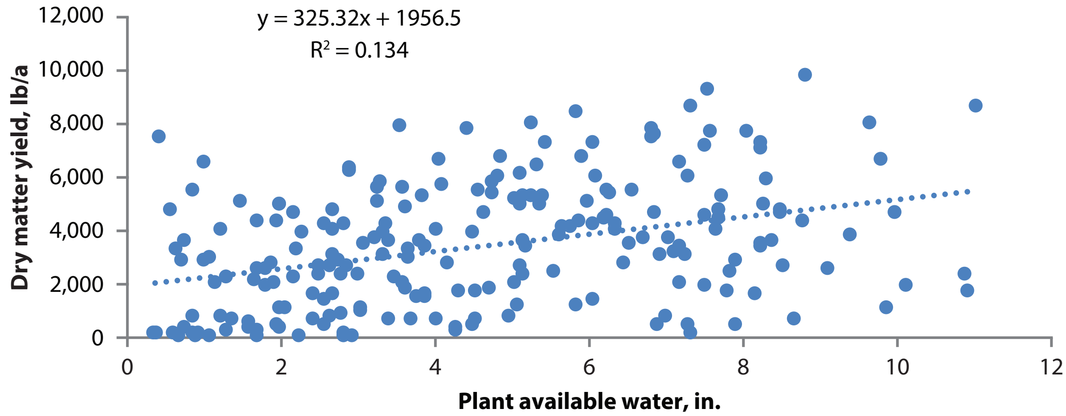

Figure 1. Winter triticale yield response to plant available water at planting.

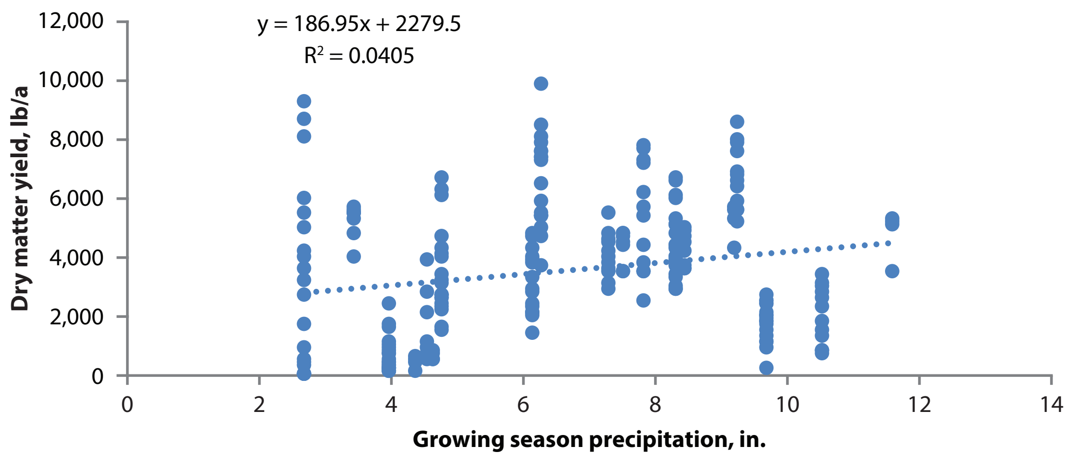

Figure 2. Winter triticale yield response to growing season precipitation.

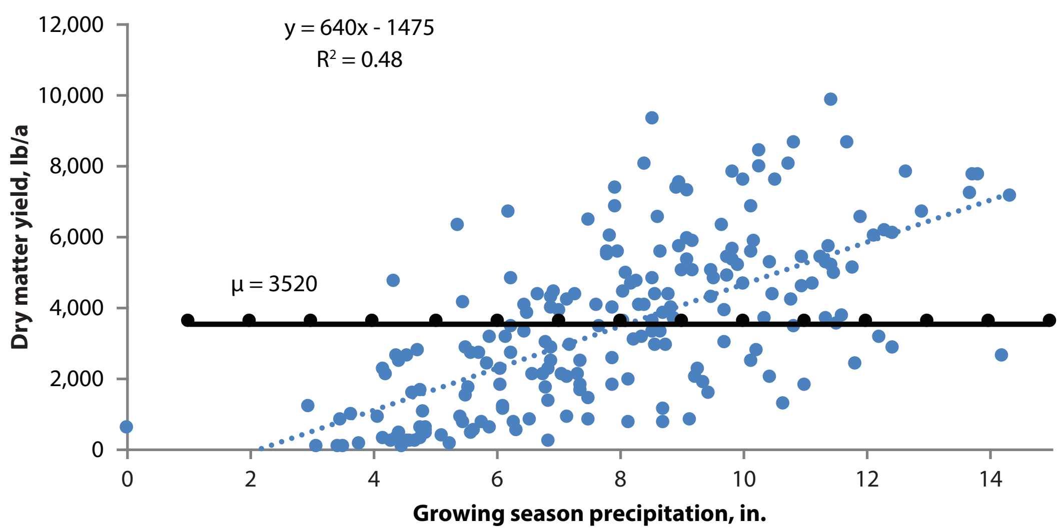

Figure 3. Winter triticale yield response to water use (soil water plus growing season precipitation) and average yield (bold line) across the study period.

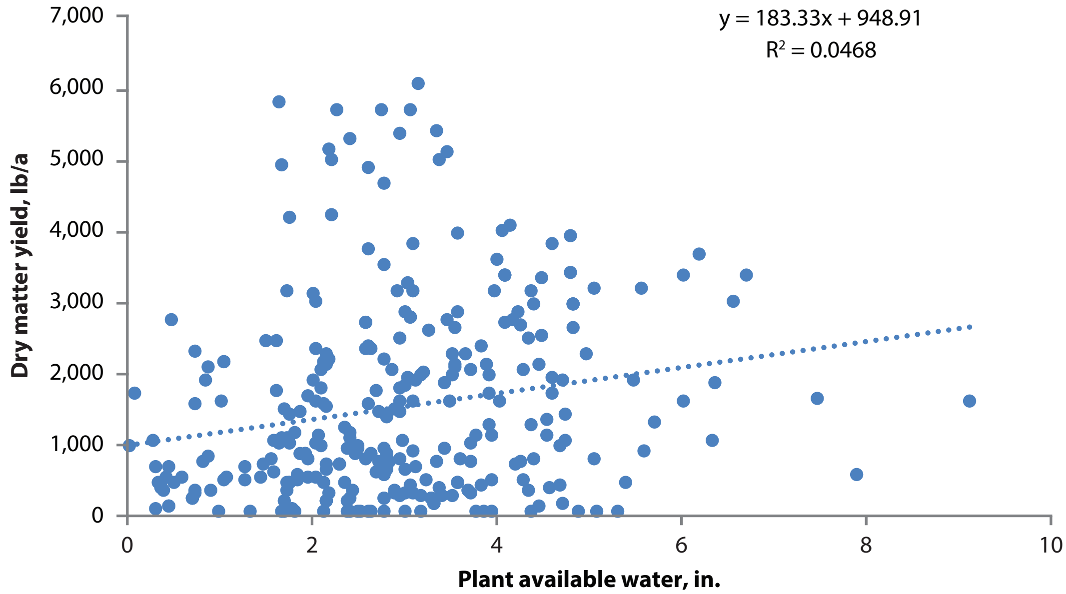

Figure 4. Spring triticale yield response to plant available water at planting.

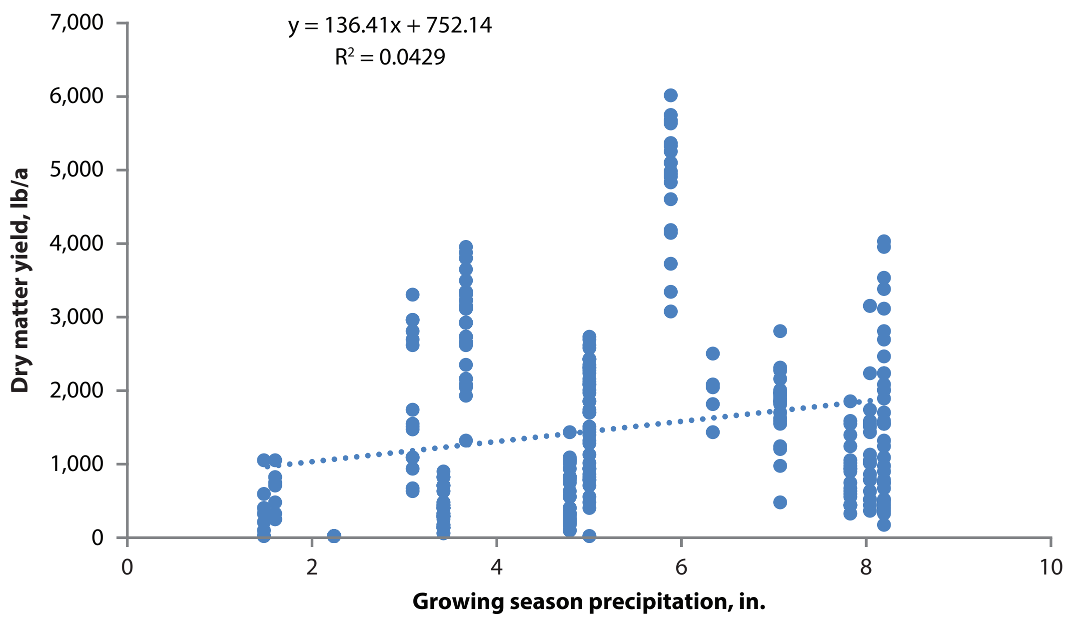

Figure 5. Spring triticale yield response to growing season precipitation.

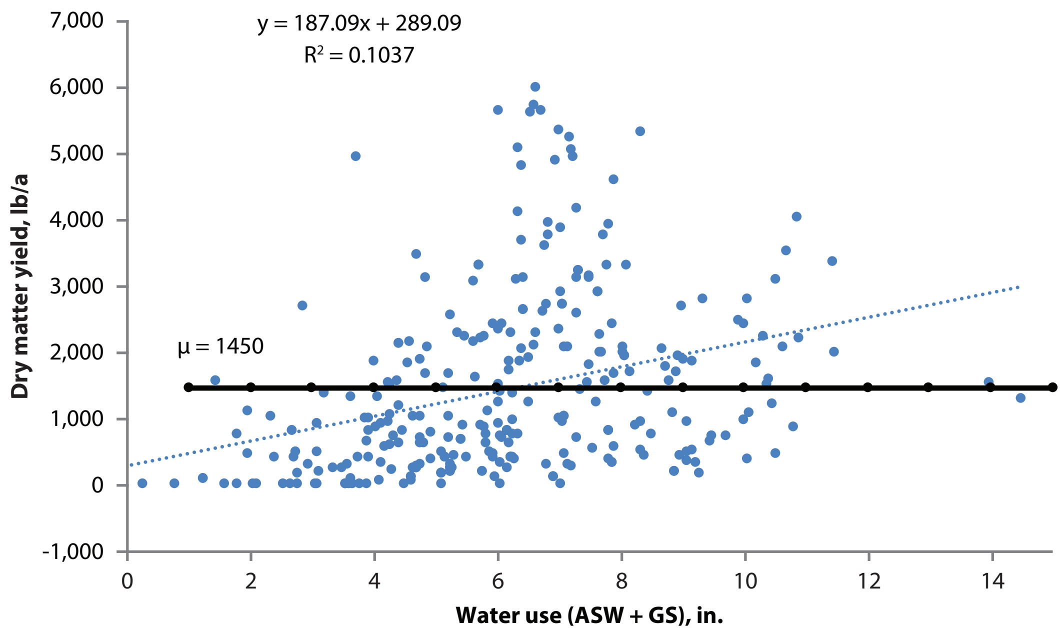

Figure 6. Spring triticale yield response to water use (soil water plus growing season precipitation) and average yield (bold line) across the study period.

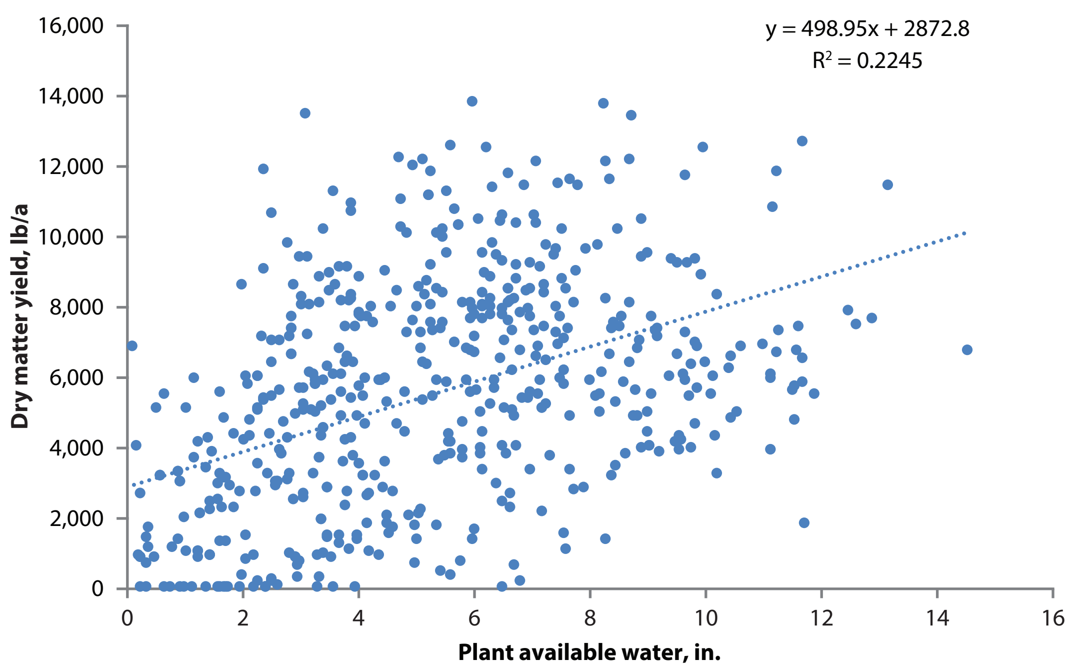

Figure 7. Forage sorghum yield response to plant available water at planting.

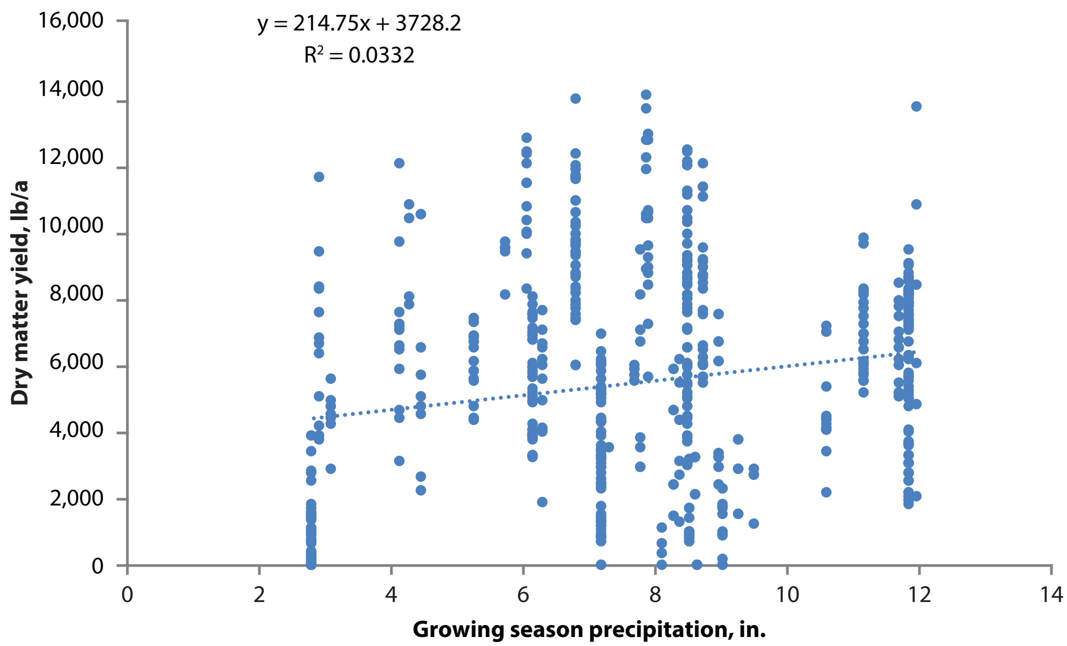

Figure 8. Forage sorghum yield response to growing season precipitation.

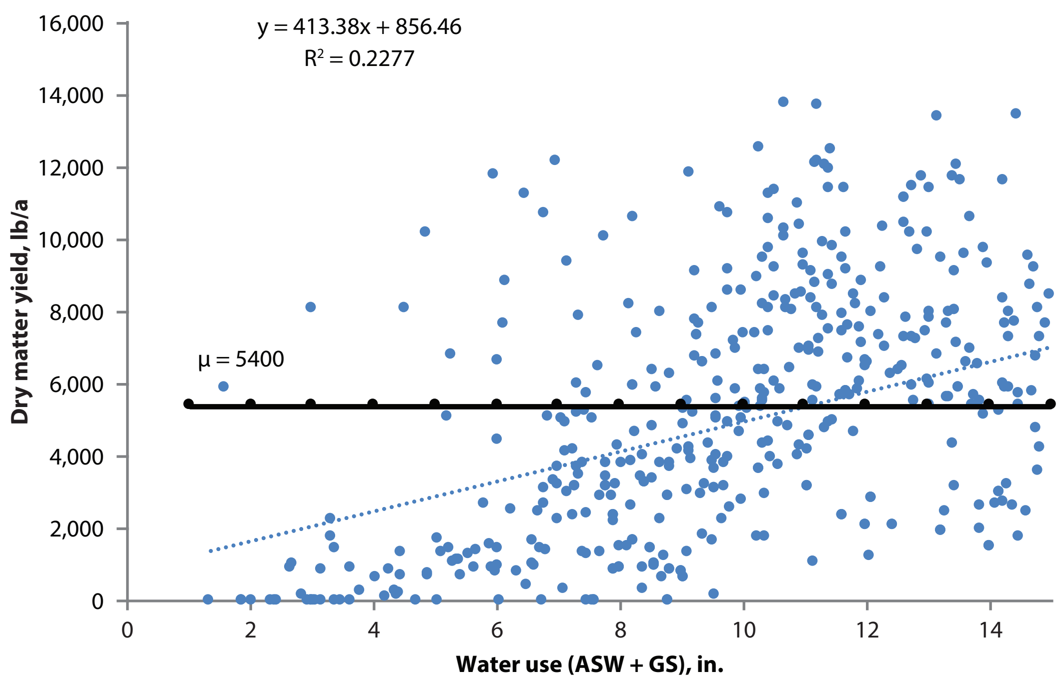

Figure 9. Forage sorghum yield response to water use (soil water plus growing season precipitation) and average yield (bold line) across the study period.

Integrated Grain and Forage Rotations

J. Holman, A. Obour, T. Roberts, and S. Maxwell

Summary
Producers are interested in growing forages in rotation with grain crops. Many producers are interested in diversifying their operations to include livestock or grow feed for the livestock industry. By integrating forages into the cropping system, producers can take advantage of more markets and reduce market risk. Forages require less water to make a crop than grain crops, so the potential may exist to reduce fallow by including forages in the crop rotation. Reducing fallow through intensified grain/forage rotations may increase profitability and sustainability compared to existing crop rotations.

This study was started in 2013, with crops grown in-phase beginning in 2014. Grain crops were more sensitive to moisture stress than forage crops. Growing a double-crop forage sorghum after wheat reduced grain sorghum yield the second year, but never reduced second-year forage sorghum yield in the years of this study. If double-crop forage sorghum is profitable, it appears the cropping system can be intensified by growing second-year forage sorghum. Since other research has found cropping intensity should be reduced in dry years, caution should be used when planting double-crop forage sorghum by evaluating the soil moisture conditions and precipitation outlook. The "flex-fallow" concept could be used to make a decision on whether to plant double-crop forage sorghum to increase the chance of improving cropping system profitability. Importantly, this research showed forages are more tolerant to moisture stress than grain crops and the potential exists to increase cropping intensity by integrating forages into the rotation.

Introduction
Interest in growing forages and reducing fallow has necessitated research on soil, water, and crop yields in intensified grain/forage rotations. Fallow stores moisture, which helps stabilize crop yields and reduces the risk of crop failure; however, only 25 to 30% of the precipitation received during the fallow period of a no-till wheat-sorghum-fallow rotation is stored. The remaining 75–70% precipitation is lost, primarily due to evaporation. Moisture storage in fallow is more efficient earlier in the fallow period, when the soil is dry, and during the winter months when the evaporation rate is lower. It may be possible to increase cropping intensity without reducing crop yields by using forage crops in the rotation. This study evaluated integrated grain/forage rotations compared to traditional grain-only crop rotations.

Experimental Procedures
A study beginning in 2013 evaluated various integrated grain and forage rotations compared to a no-till wheat-grain sorghum-fallow rotation. All phases of the rotation were present every year and in-phase by 2014. A total of 11 crop rotations were evaluated. Beginning in 2013, the wheat/forage sorghum-grain sorghum-oat rotation was replaced with a wheat/forage sorghum-grain sorghum-fallow rotation since the no-fallow rotation tended to be too intensively cropped during dry years. The study design was a split-plot randomized complete block design with four replications; crop phase

(wheat-sorghum-fallow) was the main plot and alternative crop choices were the split-plot. Each split-plot was 30-ft wide and 120-ft long.

"Flex-fallow" is a spring planting decision based on current soil moisture condition and seasonal outlook. Spring oats were planted when 14 inches or more of plant available water (PAW) was determined available by using a Paul Brown moisture probe, and seasonal precipitation forecasted outlook was neutral or favorable; otherwise the treatment was left fallow. The flex-fallow treatment was intended to take advantage of growing a crop during the fallow period in wet years and fallowing in dry years. A flex-fallow crop was planted in 2013 and 2016, but not in 2014, 2015, 2017, or 2018.

Each year, winter triticale was planted approximately October 1. Spring crops were planted as early as soil conditions allowed, ranging from the end of February through the middle of March. Spring forage crops were harvested approximately June 1. Forage sorghum was either planted around June 1st for full-season or following wheat harvest around July 1st for double-crop. Forage biomass yields were determined from a 3- × 120-ft area cut 3 in. high using a small plot Carter forage harvester. Winter wheat and grain sorghum were harvested with a small plot Wintersteiger combine from a 6.5- × 120-ft area at grain maturity.

Volumetric soil moisture content was measured at planting and harvest of winter wheat, grain sorghum, forage sorghum, spring oat, or fallow using a Giddings soil probe by 1-ft increments to a 6-ft soil depth. In addition, volumetric soil content was measured in the 0–3 in. soil depth at wheat planting to quantify moisture in the seed planting depth. Grain yield was corrected for moisture content, and test weight was measured using a grain analysis computer (GAC 2100, Dickey-John). Seed weight was determined from a 1,000-seed count using a seed counter computer (801, Seedburo). Grain samples were analyzed for nitrogen content.

Results and Discussion

Winter Wheat

Winter wheat yield, plant available moisture at planting, water use efficiency, and precipitation storage efficiency prior to planting were not affected by whether forage sorghum or grain sorghum were grown in place of one another in the rotation (Table 2). Wheat yields were reduced when oat was grown in place of fallow. Previous research found growing oats in place of fallow reduced wheat yields when wheat yield potential was less than 50 bu/a. A flex-crop was grown in 2013 and 2016, but not 2014, 2015, 2017, or 2018. Dry conditions developed soon after planting a flex-crop in 2013, and growing a flex-crop in place of fallow reduced wheat yield 67% in 2014 and did not affect 2017 yield. Dry fall conditions and rabbit feeding killed the wheat crop in 2016 and there was no yield that year. Soil moisture was dry in the fall of 2017 and some of the wheat did not emerge until spring. Conditions were again very dry during the winter and spring of 2018.

Grain Sorghum

Grain sorghum yield was highly correlated with plant available moisture at planting, which explained 47% of the variability in grain yield (Figure 1). Approximately 8 bushels were grown for every acre-inch of plant available water at planting. Plant available moisture was highest when forage sorghum was not double-cropped between wheat and grain sorghum (Table 3) and tended to be higher when nothing was grown in the fallow phase ahead of winter wheat. Higher wheat yields and residue levels improved the WUE of grain sorghum. Growing double-crop forage sorghum ahead of grain sorghum reduced grain sorghum yield 61% in 2014, 38% in 2015, 20% in 2016, and 56% in 2017. Growing a forage sorghum crop after wheat reduced the amount of plant available water at planting and water use efficiency of the subsequent grain sorghum crop each year, but did not affect precipitation storage efficiency in the fallow period ahead of grain sorghum. Growing a forage sorghum crop reduced the test weight and seed weight of grain sorghum in 2015 and seed weight in 2017.

Forage Sorghum

Forage sorghum yield was also correlated with plant available moisture at planting, but not as much as grain sorghum. Plant available moisture at planting explained approximately 33% of the variability in forage yield (Figure 2). Approximately 480 lb of forage was grown for every inch of plant available water (PAW) at planting.

Forage sorghum yields were not different across treatments in 2014, except double-crop FS in winter wheat/forage sorghum-forage sorghum-spring oat (ww/FS-fs-o) yielded 2,200 lb/a less than full-season forage sorghum in the same rotation of winter wheat/forage sorghum-forage sorghum-spring oat (ww/fs-FS-o) (Table 4). This lower yield was most likely due to less plant available water at planting, 1.3 versus 2.1 inches. In 2014, plant available water averaged 1.0 inch ahead of double-crop forage sorghum and 4.1 inches ahead of full season forage sorghum. In 2014 most of the annual precipitation occurred later in the year (June–September), which likely helped improve the yield of double-crop forage sorghum relative to full-season forage sorghum. In 2014, double-crop forage sorghum yielded, on average, 17% less than full-season forage sorghum (3,300 versus 3,900 lb/a). In 2015, most of the precipitation occurred earlier in the year (May–August) than 2014, which helped increase wheat yields but also resulted in comparatively less moisture at planting time of double-crop forage sorghum, 1.6 versus 7.2 inches. As a result, in 2015 double-crop forage sorghum yields were reduced 70% compared to full-season forage sorghum (2,400 versus 8,000 lb/a). In 2016, moisture conditions were favorable during the growing season (June–August), resulting in good forage yields across all treatments. There were 0.8 inches more PAW at planting of the full-season compared to double-crop forage sorghum. Double crop yields were reduced on average 43% compared to full-season forage sorghum (3,900 vs. 6,900 lb/a). In 2017, most of the precipitation occurred during the spring of the year, which increased moisture storage during the fallow period but little moisture during the growing season, resulting in low yields in the double-crop forage sorghum crop. Full season forage sorghum averaged 6,700 lb/a and double-crop averaged 1,000 lb/a.

Surprisingly, second-year forage sorghum yields following double-crop forage sorghum were similar to full-season forage sorghum following wheat with fallow between wheat harvest and sorghum planting (Table 4). Yet forage sorghum planted after double-crop forage sorghum had an average of 3 inches less soil moisture compared to forage sorghum planted after wheat with a fallow period between crops. In dry years this difference in plant available soil water may result in yield differences, but it did not affect yield in this study. The yield plateau of a forage crop is lower than a grain crop, which might explain why there was no yield penalty for second-year forage sorghum grown after either fallow or double-crop forage sorghum. These results suggest that as long as the benefits of growing a double-crop forage sorghum crop exceeded costs, an extra forage sorghum crop could be grown in the rotation. A partial enterprise analysis of this phase of the rotation only, indicated double-crop forage sorghum yield needs to be at least 30% of full-season forage sorghum, or at least 2,000 lb/a, for a double-crop forage sorghum crop that is grazed to be profitable. The additional variable expenses of growing double-crop forage sorghum would be around $25.00/a.

Spring Oat

Spring oat yield was not affected by rotation treatment and yielded 564 lb/a in 2014, 1,927 lb/a in 2015, 1,877 lb/a in 2016, and 1456 lb/a in 2017.

Conclusions

Wheat and spring oat yields were not affected whether grain or forage sorghum were grown in place of each other in the crop rotation. Oats were grown in place of fallow in those years that indicated favorable moisture conditions. Wheat yields were reduced when oats were grown in place of fallow. Our previous fallow replacement research found wheat yield potential needed to be greater than 50 bushels for wheat yields to not be reduced by growing a crop in place of fallow. Wheat yield potential was very low in all years at 6 bu/a in 2014, 15 bu/a in 2015, failed to make grain in 2016, and 8 bu/a in 2017.

Grain sorghum yield was more sensitive to moisture stress than forage sorghum. Growing a double-crop forage sorghum after wheat reduced grain yield 20 to 60% the second year but never reduced forage sorghum yield in the years of this study. However, in low precipitation years, full-season forage sorghum yields might be more negatively impacted than they were in this study. Double-crop forage sorghum yields were more sensitive than full-season forage sorghum. Double-crop forage sorghum yields averaged 47% less than full-season, and in the driest growing season (2017) yields were reduced 85%. As long as double-crop forage sorghum is profitable, which we identified to be around 2,000 lb/a yield when grazed, it appears the cropping system can be intensified without negatively affecting second-year forage sorghum yield. Caution should be used when planting double-crop forage sorghum, by evaluating soil moisture condition and precipitation outlook, since other research has found cropping intensity should be reduced in dry years. The “flex-fallow” concept could be used to make a decision on whether or not to plant double-crop forage sorghum to increase the chance of success. Importantly, this research showed forages are more tolerant to moisture stress than grain crops, and the potential exists to increase cropping intensity by integrating forages into the rotation.

Table 1. Grain and forage crop rotation treatments

No.	Crop rotation	Abbreviation
1	Wheat-grain sorghum-flex-fallow	ww-gs-fx
2	Wheat-grain sorghum-fallow	ww-gs-fl
3	Wheat/forage sorghum-forage sorghum-oat	ww/fs-fs-o
4	Wheat-forage sorghum-oat	ww-fs-o
5[†]	Wheat/forage sorghum-grain sorghum-oat	ww/fs-gs-o
6	Wheat-grain sorghum-oat	ww-gs-o
7	Wheat-forage sorghum-oat (tilled)	ww-fs-o(T)
8	Wheat-forage sorghum-fallow	ww-fs-fl
9	Wheat-forage sorghum-flex-fallow	ww-fs-fx
10	Wheat/forage sorghum-forage sorghum-flex-fallow	ww/fs-fs-fx
11	Wheat/forage sorghum-grain sorghum-flex-fallow	ww/fs-gs-fx
12	Wheat/forage sorghum-grain sorghum-fallow	ww/fs-gs-fl

Table 2. Winter wheat yield, plant available water at planting (PAW), water use efficiency (WUE), and precipitation storage efficiency (PSE) near Garden City from 2014 to 2017 and averaged across years

		Yield		PAW		WUE		PSE	
Rotation†	Crop	bu/a	P‡	in.§	P	bu/a/in.¶	P	%	P
		2014							
WW-gs-fx††	WW	2.0	bc††	2.4	ab	0.13	bc	0.27	ab
WW-gs-fl	WW	6.0	a	3.8	ab	0.38	a	0.19	b
WW/fs-fs-o	WW	1.0	c	3.0	ab	0.05	c	0.30	ab
WW-fs-sg	WW	0.1	c	2.9	ab	0.01	c	0.27	ab
WW/fs-gs-o	WW	0.4	c	1.4	b	0.03	c	0.21	b
WW-gs-o	WW	0.2	c	2.5	ab	0.01	c	0.24	b
WW-fs-o(T)	WW	2.3	bc	4.1	ab	0.13	bc	0.43	a
WW-fs-fl	WW	5.1	ab	3.7	ab	0.27	ab	0.22	b
WW-fs-fx	WW	*	*	*	*	*	*	*	*
WW/fs-fs-fx	WW	*	*	*	*	*	*	*	*
WW/fs-gs-fx	WW	*	*	*	*	*	*	*	*
WW/fs-fs-fl	WW	*	*	*	*	*	*	*	*
WW/fs-gs-fl	WW	*	*	*	*	*	*	*	*
LSD		3.1		2.6		0.20		0.18	
		2015							
WW-gs-fx††	WW	16.1	a	4.7	ab	1.11	a	*#	*
WW-gs-fl	WW	14.6	ab	5.4	a	0.98	ab	0.20	a
WW/fs-fs-o	WW	6.4	de	1.9	d	0.45	c	0.12	a
WW-fs-sg	WW	6.8	cde	2.8	bcd	0.58	bc	0.17	a
WW/fs-gs-o	WW	8.1	cde	1.6	d	0.64	bc	0.16	a
WW-gs-o	WW	8.0	cde	2.3	cd	0.59	bc	0.10	a
WW-fs-o(T)	WW	7.7	cde	2.4	cd	0.57	bc	0.12	a
WW-fs-fl	WW	10.3	bcd	4.6	ab	0.67	bc	*	*
WW-fs-fx	WW	11.8	abc	4.1	abc	0.93	ab	0.88	a
WW/fs-fs-fx	WW	4.8	e	2.7	bcd	0.34	c	0.12	a
WW/fs-gs-fx	WW	8.1	cde	1.6	d	0.64	bc	0.16	a
WW/fs-fs-fl	WW	*	*	*	*	*	*	*	*
WW/fs-gs-fl	WW	*	*	*	*	*	*	*	*
LSD		5.4		2.1		0.44		0.15	

continued

Table 2. Winter wheat yield, plant available water at planting (PAW), water use efficiency (WUE), and precipitation storage efficiency (PSE) near Garden City from 2014 to 2017 and averaged across years

		Yield		PAW		WUE		PSE	
Rotation†	Crop	bu/a	P‡	in.§	P	bu/a/in.¶	P	%	P
		2017							
WW-gs-fx‡‡	WW	9.4	ab	2.5	bc	0.89	ab	0.02	ab
WW-gs-fl	WW	7.8	bc	6.7	a	0.55	abcd	0.05	ab
WW/fs-fs-o	WW	*	*	*	*	*	*	*	*
WW-fs-sg	WW	4.5	cd	4.1	abc	0.50	bcd	0.13	a
WW/fs-gs-o	WW	*	*	*	*	*	*	*	*
WW-gs-o	WW	9.3	ab	4.7	ab	0.82	abc	0.09	b
WW-fs-o(T)	WW	*	*	*	*	*	*	*	*
WW-fs-fl	WW	2.4	d	4.8	ab	0.21	d	0.04	ab
WW-fs-fx	WW	7.8	bc	1.3	c	0.84	abc	-0.08	b
WW/fs-fs-fx	WW	5.4	bcd	3.7	bc	0.55	abcd	0.13	a
WW/fs-gs-fx	WW	12.3	a	2.6	bc	1.01	a	0.10	ab
WW/fs-fs-fl	WW	3.5	d	5.1	ab	0.39	cd	0.07	ab
WW/fs-gs-fl	WW	6.4	bcd	5.0	ab	0.47	bcd	0.09	ab
LSD		4.2		2.9		0.46		0.21	
		Average across years							
WW-gs-fx‡‡	WW	9.2		3.2		0.71		0.15	
WW-gs-fl	WW	9.5		5.3		0.64		0.15	
WW/fs-fs-o	WW	3.7		2.5		0.25		0.21	
WW-fs-sg	WW	3.8		3.3		0.36		0.19	
WW/fs-gs-o	WW	4.2		1.5		0.33		0.18	
WW-gs-o	WW	5.8		3.1		0.48		0.15	
WW-fs-o(T)	WW	5.0		3.2		0.35		0.28	
WW-fs-fl	WW	7.7		3.2		0.59		0.07	
WW-fs-fx	WW	8.6		3.9		0.74		0.51	
WW/fs-fs-fx	WW	5.1		3.2		0.44		0.12	
WW/fs-gs-fx	WW	10.2		2.1		0.82		0.13	
WW/fs-fs-fl	WW	3.5		5.1		0.39		0.07	
WW/fs-gs-fl	WW	6.4		5.0		0.47		0.09	

† WW is winter wheat, FS is forage sorghum, GS is grain sorghum, FL is fallow, FX is flex-fallow, FX(T) is flex-fallow with summer tillage, and O is spring oat.
‡ $P \leq 0.05$
§ Inches of plant available water in a 6 ft soil profile
¶ Bushels per acre produced for every 1 inch plant available water
# Data not available.
†† Means in columns followed by different letters are statistically different at $P \leq 0.05$.
‡‡ Flex-fallow was planted in 2013 and 2016.

Table 3. Grain sorghum yield, plant available water at planting (PAW), water use efficiency (WUE), and precipitation storage efficiency (PSE) near Garden City from 2014 to 2017 and averaged across years

		Yield		Test weight		Seed weight		PAW		WUE		PSE	
Rotation[†]	Crop	bu/a	P[‡]	lb/bu	P	g/1,000 seed	P	in.[§]	P	bu/a/in.[¶]	P	%	P
						2014							
ww-GS-fx[¶]	GS	47.5	a[§]	58.0	a	21.3	a	4.5	a	3.0	a	0.22	a
ww-GS-fl	GS	49.5	a	59.1	a	22.6	a	4.4	a	3.0	a	0.18	a
ww/fs-GS-o[†]	GS	17.8	b	57.7	a	21.1	a	4.2	a	1.1	b	0.31	a
ww-GS-o	GS	39.4	ab	57.7	a	22.7	a	6.4	a	2.2	ab	0.36	a
ww/fs-GS-fx	GS	17.8	b	57.7	a	21.1	a	4.2	a	1.1	b	0.31	a
ww/fs-GS-fl	GS	*	*	*	*	*	*	*	*	*	*	*	*
LSD		23.2		2.2		2.0		3.4		1.3		0.28	
						2015							
ww-GS-fx[¶]	GS	96.4	ab	60.8	ab	26.3	a	7.3	ab	5.5	a	0.27	a
ww-GS-fl	GS	108.9	a	60.9	a	27.0	a	9.0	a	5.9	a	0.35	a
ww/fs-GS-o[†]	GS	59.4	c	59.8	b	21.6	b	6.0	b	3.7	b	0.25	a
ww-GS-o	GS	84.1	b	60.3	ab	25.8	a	7.9	ab	4.8	ab	0.34	a
ww/fs-GS-fx	GS	59.4	c	59.8	b	21.6	b	6.0	b	3.7	b	0.25	a
ww/fs-GS-fl	GS	*	*	*	*	*	*	*	*	*	*	*	*
LSD		19.2		1.0		3.5		2.4		1.2		0.10	
						2016							
ww-GS-fx[¶]	GS	58.4	ab	58.8	a	58.8	A	7.2	A	3.2	A	0.22	A
ww-GS-fl	GS	64.6	a	59.2	a	59.2	A	7.4	A	3.5	A	0.21	A
ww/fs-GS-o[†]	GS	*	*	*	*	*	*	*	*	*	*	*	*
ww-GS-o	GS	55.7	ab	59.6	a	59.6	A	6.2	A	3.1	A	0.18	A
ww/fs-GS-fx	GS	51.0	ab	59.1	a	59.1	A	3.9	B	3.1	A	0.22	A
ww/fs-GS-fl	GS	43.7	b	58.6	a	58.6	A	3.2	B	2.6	A	0.19	A
LSD		17.7		2.4		2.4		1.5		1.1		0.13	
						2017							
ww-GS-fx[¶]	GS	82.3	ab	59.6	a	27.4	a	9.5	ab	4.6	a	0.7	a
ww-GS-fl	GS	88.2	a	59.5	a	25.7	ab	9.3	ab	5.3	a	0.2	a
ww/fs-GS-o[†]	GS	*	*	*	*	*	*	*	*	*	*	*	*
ww-GS-o	GS	97.6	a	60.5	a	27.3	a	10.0	a	5.8	a	0.4	a
ww/fs-GS-fx	GS	52.1	bc	59.5	a	23.7	b	8.2	bc	3.5	a	0.3	a
ww/fs-GS-fl	GS	47.9	c	59.5	a	23.5	b	7.4	c	3.5	a	0.2	a
LSD		33.4		1.4		2.9		1.4		2.33		0.56	

continued

Table 3. Grain sorghum yield, plant available water at planting (PAW), water use efficiency (WUE), and precipitation storage efficiency (PSE) near Garden City from 2014 to 2017 and averaged across years

		Yield		Test weight		Seed weight		PAW		WUE		PSE	
Rotation†	Crop	bu/a	P‡	lb/bu	P	g/1,000 seed	P	in.§	P	bu/a/in.¶	P	%	P
		Average across years											
ww-GS-fx¶	GS	71.1		59.3		33.5		7.1		4.1		0.35	
ww-GS-fl	GS	77.8		59.7		33.6		7.5		4.4		0.24	
ww/fs-GS-o‡	GS	38.6		58.7		21.3		5.1		2.4		0.28	
ww-GS-o	GS	69.2		59.5		33.8		7.6		4.0		0.32	
ww/fs-GS-fx	GS	45.1		59.0		31.3		5.6		2.8		0.26	
ww/fs-GS-fl	GS	45.8		59.0		41.0		5.3		3.1		0.22	

† WW is winter wheat , FS is forage sorghum, GS is grain sorghum, FL is fallow, FX is flex-fallow, FX(T) is flex-fallow with summer tillage, and O is spring oat.

‡ $P \leq 0.05$

§ Inches of plant available water in a 6 ft soil profile

¶ Bushels per acre produced for every 1 inch plant available water

Data not available.

†† Means in columns followed by different letters are statistically different at $P \leq 0.05$.

‡‡ Flex-fallow was planted in 2013 and 2016.

Table 4. Forage sorghum yield, plant available water at planting (PAW), water use efficiency (WUE), and precipitation storage efficiency (PSE) near Garden City from 2014 to 2017 and average across years

		Yield		PAW		WUE		PSE	
Rotation[†]	Crop	lb/a	P[‡]	in.[§]	P	lb/a/in.[¶]	P	%	P
		2014							
ww/FS-fs-o	FS	4705	a	1.3	c	565.9	a	0.60	ab
ww/fs-FS-o	FS	2490	b	2.1	bc	179.9	b	0.20	b
ww-FS-sg	FS	3305	ab	5.7	a	201.2	b	*	*
ww/FS-gs-o	FS	3964	ab	0.6	c	452.3	a	0.75	a
ww-FS-fx(T)	FS	3917	ab	4.3	ab	257.2	b	*	*
ww-FS-fx	FS	3531	ab	4.0	ab	225.1	b	0.45	ab
ww-FS-fl	FS	4093	ab	4.7	a	268.2	b	0.30	ab
ww/FS-fs-fx	FS	4705	a	1.3	c	565.9	a	0.60	ab
ww/fs-FS-fx	FS	2490	b	2.1	bc	179.9	b	0.20	b
ww/FS-gs-fx	FS	3964	ab	0.6	c	452.3	a	0.75	a
ww/FS-fs-fl	FS	4705	a	1.3	c	565.9	a	0.60	ab
ww/fs-FS-fl	FS	2490	b	2.1	bc	179.9	b	0.20	b
ww/FS-gs-fl	FS	3964	ab	0.6	c	452.3	a	0.75	a
LSD		2034		2.3		174.5		0.54	
		2015							
ww/FS-fs-o	FS	2320	b	1.7	b	208.9	b	*	*
ww/fs-FS-o	FS	7750	a	5.6	a	567.5	a	0.18	b
ww-FS-sg	FS	7948	a	8.3	a	487.6	a	0.38	a
ww/FS-gs-o	FS	2497	b	1.6	b	223.3	b	*	*
ww-FS-fx(T)	FS	7103	a	7.8	a	443.4	a	0.35	ab
ww-FS-fx	FS	8697	a	7.4	a	533.0	a	0.20	ab
ww-FS-fl	FS	8333	a	6.9	a	537.0	a	0.28	ab
ww/FS-fs-fx	FS	2320	b	1.7	b	208.9	b	*	*
ww/fs-FS-fx	FS	7750	a	5.6	a	567.5	a	0.18	b
ww/FS-gs-fx	FS	2497	b	1.6	b	223.3	b	*	*
ww/FS-fs-fl	FS	*	*	*	*	*	*	*	*
ww/fs-FS-fl	FS	*	*	*	*	*	*	*	*
ww/FS-gs-fl	FS	*	*	*	*	*	*	*	*
LSD		2270		3.1		161.1		0.18	

continued

Table 4. Forage sorghum yield, plant available water at planting (PAW), water use efficiency (WUE), and precipitation storage efficiency (PSE) near Garden City from 2014 to 2017 and average across years

		Yield		PAW		WUE		PSE	
Rotation[†]	Crop	lb/a	P[‡]	in.[§]	P	lb/a/in.[¶]	P	%	P
		2016							
ww/FS-fs-o	FS	*	*	*	*	*	*	*	*
ww/fs-FS-o	FS	*	*	*	*	*	*	*	*
ww-FS-sg	FS	6450	a	5.4	bc	422.3	abc	0.12	b
ww/FS-gs-o	FS	*	*	*	*	*	*	*	*
ww-FS-fx(T)	FS	6793	a	5.1	bc	431.6	abc	0.16	b
ww-FS-fx	FS	7223	a	8.2	a	469.2	a	0.21	ab
ww-FS-fl	FS	7018	a	6.8	ab	437.5	abc	0.23	ab
ww/FS-fs-fx	FS	3233	c	6.0	abc	207.9	e	*	*
ww/fs-FS-fx	FS	6726	a	4.4	bc	433.9	abc	0.35	a
ww/FS-gs-fx	FS	4090	bc	3.5	c	318.3	cde	*	*
ww/FS-fs-fl	FS	3563	bc	5.2	bc	255.7	de	*	*
ww/fs-FS-fl	FS	6905	a	3.4	c	492.0	a	0.25	ab
ww/FS-gs-fl	FS	4816	b	4.4	bc	349.5	bcd	*	*
LSD		1512		2.9		119.2			
		2017							
ww/FS-fs-o	FS	*	*	*	*	*	*	*	*
ww/fs-FS-o	FS	*	*	*	*	*	*	*	*
ww-FS-sg	FS	7101	a	9.8	a	521.2	a	0.36	a
ww/FS-gs-o	FS	*	*	*	*	*	*	*	*
ww-FS-fx(T)	FS	*	*	*	*	*	*	*	*
ww-FS-fx	FS	6285	a	9.6	a	510.9	a	0.2	b
ww-FS-fl	FS	6292	a	8.9	ab	479.5	a	0.16	b
ww/FS-fs-fx	FS	1153	b	5.0	cd	125.2		*	
ww/fs-FS-fx	FS	7228	a	9.4	a	534.0	a	0.30	a
ww/FS-gs-fx	FS	639	b	2.5	d	104.6		*	
ww/FS-fs-fl	FS	1305	b	6.6	bc	128.3		*	
ww/fs-FS-fl	FS	6632	a	9.3	a	493.0	a	0.28	a
ww/FS-gs-fl	FS	907	b	3.2	d	128.9		*	
LSD		1490		2.5		128.8		0.09	

continued

Table 4. Forage sorghum yield, plant available water at planting (PAW), water use efficiency (WUE), and precipitation storage efficiency (PSE) near Garden City from 2014 to 2017 and average across years

		Yield		PAW		WUE		PSE	
Rotation[†]	Crop	lb/a	P[‡]	in.[§]	P	lb/a/in.[¶]	P	%	P
		Average across years							
ww/FS-fs-o	FS	3513		1.5		387.4		0.60	
ww/fs-FS-o	FS	5120		3.8		373.7		0.19	
ww-FS-sg	FS	6201		7.3		408.1		0.28	
ww/FS-gs-o	FS	3231		1.1		337.8		0.75	
ww-FS-fx(T)	FS	5938		5.7		377.4		0.25	
ww-FS-fx	FS	6434		7.3		434.5		0.26	
ww-FS-fl	FS	6434		6.8		430.5		0.24	
ww/FS-fs-fx	FS	2853		3.5		277.0		0.60	
ww/fs-FS-fx	FS	6048		5.3		428.8		0.25	
ww/FS-gs-fx	FS	2797		2.0		274.6		0.75	
ww/FS-fs-fl	FS	3191		4.4		316.6		0.60	
ww/fs-FS-fl	FS	5342		4.9		388.3		0.24	
ww/FS-gs-fl	FS	3229		2.7		310.2		0.75	

[†] WW is winter wheat , FS is forage sorghum, GS is grain sorghum, FL is fallow, FX is flex-fallow, FX(T) is flex-fallow with summer tillage, and O is spring oat.
[‡] $P \leq 0.05$
[§] Inches of plant available water in a 6 ft soil profile
[¶] DM lb per acre produced for every 1 inch plant available water
[#] Data not available.
[††] Means in columns followed by different letters are statistically different at $P \leq 0.05$.
[‡‡] Flex-fallow was planted in 2013 and 2016.

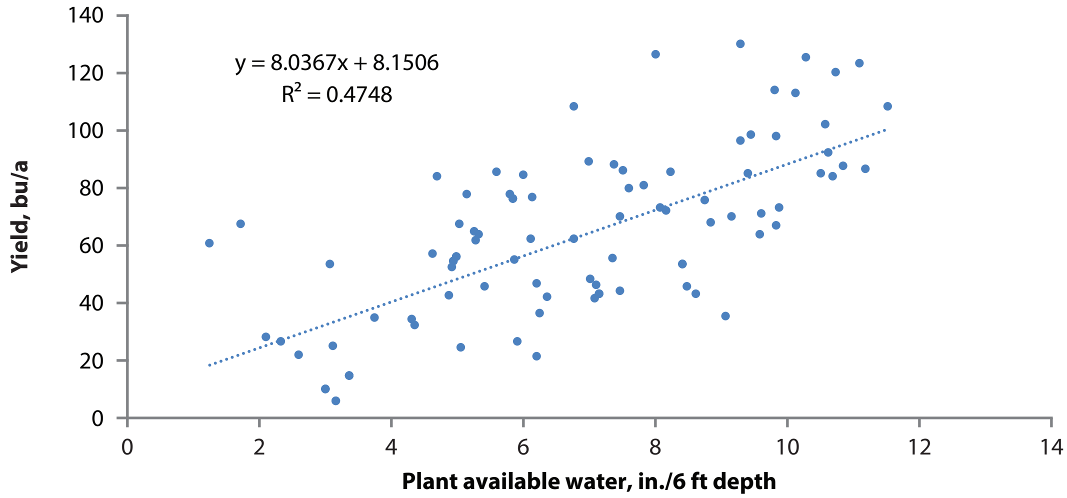

Figure 1. Grain sorghum yield response to plant available water at planting near Garden City, KS, between 2014 and 2017.

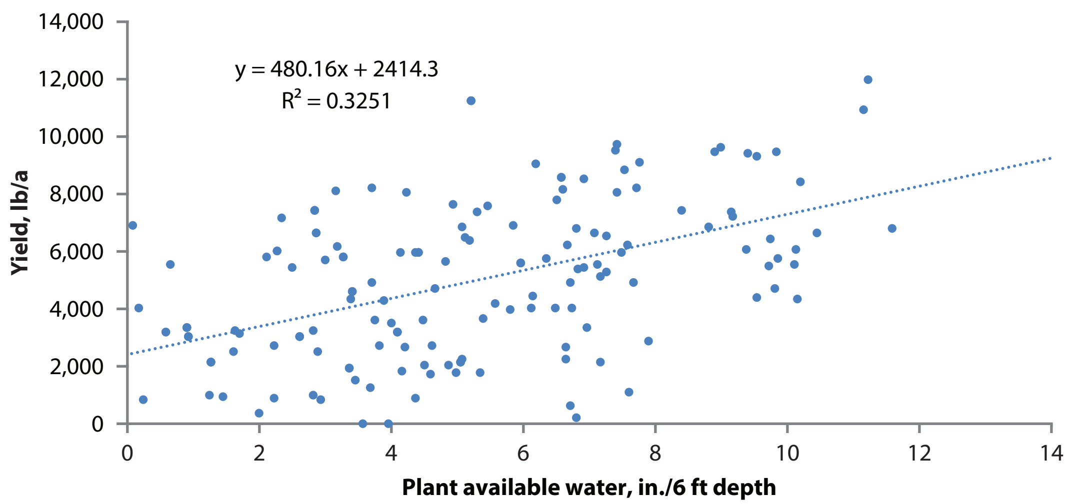

Figure 2. Forage sorghum yield response to plant available water at planting near Garden City, KS, between 2014 and 2017.

Value of Fungicide Application in Wheat Production in Southwest Kansas, 2017 Report

A.J. Foster, R. Lollato, M. Vandeveer, E.D. De Wolf, and R.S. Currie

Summary

During the past several years, applying fungicide to wheat has become a more common practice. The availability of cost-effective generic fungicides, as well as the positive yield responses often reported, seem to be the potential drivers for the adoption of such practices by producers. A wheat fungicide trial was conducted in Garden City, KS, to answer the following questions: 1) Are fungicide applications profitable? and 2) Can remote sensing technology be used to quantify the efficacy of different fungicide products? The study consisted of two wheat varieties sown on September 30, 2016 (Oakley CL, highly resistant to stripe rust; and TAM 111, highly susceptible to stripe rust) and treated with different fungicide products. Stripe and leaf rust were the major fungal diseases impacting wheat yield in southwest Kansas in 2017. Wheat production in 2017 was impacted by dry planting conditions in late 2016, a winter ice storm in January, and a late snow storm on April 30, and severe wheat streak mosaic virus infestation. There were significant differences in grain yield among fungicide products for both TAM 111 and Oakley CL. The large changes in normalized difference vegetation index (NDVI) values suggest that multiple environmental factors were interacting to impact the wheat plant health. The benefit of fungicide application observed on yield was minimal under the environmental conditions of 2017.

Introduction

In recent years, producers are becoming interested in protecting wheat grain yield from major fungal diseases due to the availability of more affordable generic fungicides. However, it is important for producers to be aware that application of fungicides protects yield potential that is present at the time of application. Fungicides serve as yield protectors by enhancing the plant health. Therefore, it is common for producers to often associate delayed harvest with fungicide application. Fungicides allow plants to stay green and maintain their leaves longer, using more nutrients during the late development stages.

Previous research has reported variable results regarding the value of fungicide application in the Great Plains. In Kansas, several years of research have indicated that a single fungicide application to a susceptible variety, on average, could provide a 10% yield increase, relative to the untreated control (De Wolf, 2013). To maximize the benefit of a fungicide application, producers should know the vulnerability of the variety to be treated. Susceptible varieties are more likely to benefit from foliar fungicides as compared to varieties with moderate to high levels of resistance. It is also important to pay attention to weather conditions and scouting reports within a field, region, and even surrounding states to the south.

Rating the effectiveness of a foliar fungicide application on disease control is often tedious and very subjective. With the onset of remote sensing technology, there are great opportunities to develop more objective approaches for rating varietal resistance to diseases and the efficacy of fungicides. Measurements such as the normalized difference vegetative index (NDVI)–which combines wavebands in the red region of the spectrum that is controlled by the leaf pigment content, and wavebands in the near-infrared region of the spectrum that is controlled by the internal leaf structures–are strongly correlated with plant health. Application of fungicide is reported to enhance plant health that results in the plant staying green longer. Therefore, differences in NDVI before and after fungicide application relative to the control could be used to develop a more objective scale for rating fungicide efficacy.

The objectives of this study were to evaluate the value of variety selection and application of a foliar fungicide as part of an economically optimal disease management plan and to assess the potential for using remote sensing measurements such as NDVI as a tool for rating fungicide efficacy.

Experimental Procedures

An experiment was established at the Southwest Research-Extension Center in Garden City, KS, in fall 2016. The design of the experiment was a randomized complete block design with three replications consisting of eleven fungicide application treatments and two wheat varieties: Oakley CL (highly resistant to stripe rust) and TAM 111 (highly susceptible to stripe rust). The experimental treatments are summarized in Table 1. Experimental plots were sown on September 30, 2016, at a seeding rate of 120 lb/a, and were 7.5-ft wide × 30-ft long. The entire experimental area was fertilized with 100 lb of N/a at green-up in March of 2017, and plots were sprayed with a mixture of 0.4 pints of Starane, 0.375 quarts of MCPA, and 0.1 oz of Ally the first week of April for weed control. Fungicides were applied at a volume of 15 GPA with a CO_2 backpack sprayer when the flag leaf fully emerged and the ligule was visible (Feekes GS 9). A plot combine 7.5-ft wide was used to harvest 25 ft from each plot for yield. A subsample was collected from each plot to determine the test weight and moisture content. The yield was adjusted to 13% moisture.

NDVI was collected before and 15 and 30 days after the flag leaf fungicide application. A handheld Greenseeker sensor (Ntech Industries, Inc, Ukiah, CA) was used to measure the NDVI. The difference between the before and after NDVI values were used to assess the efficacy of the fungicide. The smaller the difference between the before and after application NDVI values of the treated compared to the control was indicative of the efficacy of the fungicide.

Results and Discussion

The 2017 wheat crop overcame many challenges, including a late winter snowstorm that covered the wheat in more than 20 inches of snow for three days, mild leaf and stripe rust, wetter than normal conditions in March and April, and warmer temperatures were the main environmental conditions for the 2016–2017 wheat crop.

The results of this study showed that the effect of fungicide on yield differed significantly among products and across both resistant and susceptible varieties. The variability in response to the fungicide applications may be attributed to the impact of environmental stress on wheat as well as the later application of the fungicide at Feekes 10 compared to Feekes 9 in 2016. Compared to the results of 2016, TAM 111 (the susceptible variety) once again out-yielded the resistant variety Oakley CL. Similar to 2016, lodging was again a problem for the Oakley CL variety (Table 3). The generic fungicide was the most consistent in producing a net return, with a net benefit of $3.45 for TAM 111 and $9.64 for Oakley CL. Oakley CL is not resistant to leaf rust, so a mild infestation of this fungus likely justified justifying the greater net returns as compared to TAM 111.

In 2016, Foster et al. (2017) reported differences of 0.07 in NDVI 30 days after application in the check TAM 111 plot, but in 2017 differences in NDVI for the check TAM 111 plot were 0.07 15 days after application, and 0.32 30 days after application (Table 3). Contrary to 2016, the changes in NDVI indicated significant differences in efficacy among the different fungicides 15 and 30 days after application for both TAM 111 and Oakley CL. The large changes in NDVI and the significant difference in efficacy among the fungicides in 2017 may be attributed to the later application timing, the impact of the April 30 snowstorm, other diseases (mild infestation of leaf rust), lodging, warmer temperatures in May and June, and the effect of the crop approaching physiological maturity at the time of the 30 day NDVI sampling.

Conclusion

The results of 2017 demonstrate the complexity of environmental conditions on wheat management. Therefore, it is important for producers to manage each crop independently, taking into consideration the environmental condition of that year in making decisions on fungicide application. Scouting the crop and gathering information about the condition of the crop is vital to making an optimal decision. Clearly, in 2017 the challenge of getting fungicide applied on time was a factor. In these situations, a good decision is to go with the generic products to minimize the potential for economic losses. The results observed in 2017 in no way should be interpreted outside of context of the particular growing season from which data were collected–that is, without considering the environmental conditions under which the wheat was grown. Fungicide decisions should take into consideration the current crop growing condition and yield potential, inoculum present in the field or neighboring fields, and weather conditions during that particular growing season. Remote sensing technology shows potential in quantifying the efficacy of different fungicides. However, the result was most beneficial when compared to the control, which might offer some challenges in real-world application.

References

De Wolf, E. D. (2013). Foliar fungicide efficacy ratings for wheat disease management 2013.

Foster, A., R. Lollato, M. Vandeveer, & E. De Wolf. (2017). Value of Fungicide Application in Wheat Production in Southwest Kansas. Kansas Agricultural Experiment Station Research Reports, 3(5), 3.

Chemical Disclaimer

Fungicide pricing used in this report maybe higher or lower. Brand names appearing in this report are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Person using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

Table 1. Fungicide rate, time and growth stage of application for each treatment in the 2016–2017 growing season at the Southwest Research–Extension Center, Garden City, KS

Treatment	Product	Time of application	Product rate	Stage of application	Date applied	Growth stage (GS)
			fl oz			
1	Control	NA	NA	NA	NA	NA
2	Aproach Prima	Spring	6.8	Flag leaf	May 9	Feekes, GS 10
3	Tebustar	Spring	4	Flag leaf	May 9	Feekes, GS 10
4	Absolute Maxx	Spring	4	Flag leaf	May 9	Feekes, GS 10
5	Prosaro	Spring	5	Flag leaf	May 9	Feekes, GS 10
5	Nexicor	Spring	7	Flag leaf	May 9	Feekes, GS 10
6	Absolute Maxx	Spring	5	Flag leaf	May 9	Feekes, GS 10
6	Twinline	Spring	9	Flag leaf	May 9	Feekes, GS 10
7	Trivapro	Spring	2	Flag leaf	May 9	Feekes, GS 10
8	Alto	Spring	2	Flag leaf	May 9	Feekes, GS 10
9	Aproach	Spring	3	Jointing	May 9	Feekes, GS 10
9	Aproach Prima	Spring	6.8	Flag leaf	April 11	Feekes, GS 7
10	Priaxor	Spring	2	Flag leaf	May 9	Feekes, GS 10

NA = Not applicable.

Table 2. Precipitation and temperature data for the 2016–2017 wheat growing season at the Southwest Research–Extension Center, Garden City, KS

	Average temperature (°F)		Rainfall (in.)	
Month	2016–2017	30-year average	2016–2017	30-year average
September	71	68	0.14	1.42
October	61	55	0	1.21
November	47	42	0.06	0.55
December	27	31	0.23	0.59
January	31	30	1.53	0.46
February	41	34	0	0.55
March	47	43	2.75	1.31
April	54	52	4.37	1.74
May	60	63	1.08	2.98
June	75	73	1.14	3.12
July	79	78	2.08	2.8
Annual	54	52	13.38	16.73

[1] 30-year averages are for the period 1985-2014.

Table 3. Wheat yield, test weight, and normalized difference vegetative index (NDVI) measured before and after fungicide application, and the difference in NDVI based on the fungicide treatments and wheat variety for the 2016–2017 wheat growing season at the Southwest Research–Extension Center, Garden City, KS

	Yield		Test weight		Lodging		NDVI_Diff @ 15DAA		NDVI_Diff @ 30DAA	
Treatments	TAM	OAK	TAM	OAK	TAM	OAK	TAM	OAK	TAM	OAK
	------ bu/a ------		----- lb/bu -----		-------- % --------					
Control	74	53	56	55	44	98	0.07	0.07	0.32	0.19
Aproach Prima	79	61	59	56	58	98	0.05	0.07	0.17	0.14
Tebustar	78	59	59	57	34	99	0.05	0.07	0.19	0.16
Absolute Maxx	85	59	59	56	55	83	0.05	0.06	0.15	0.12
Prosaro	86	57	58	55	31	85	0.05	0.07	0.17	0.14
Nexicor	80	56	58	56	63	100	0.05	0.06	0.15	0.14
Absolute Maxx	80	56	58	56	36	89	0.05	0.06	0.16	0.14
Twinline	76	55	59	57	63	100	0.04	0.06	0.16	0.14
Trivapro	80	53	58	57	26	99	0.05	0.07	0.18	0.16
Alto	76	53	58	57	40	90	0.05	0.06	0.17	0.15
Aproach/Aproach Prima	85	53	58	56	23	90	0.05	0.07	0.15	0.13
Priaxor	79	49	59	56	30	95	0.04	0.06	0.15	0.14
LSD (0.05)	10	9	1.4	2			0.05	0.01	0.02	0.02
CV	9	11	1.6	2			8	6	8	7
ANOVA (P >F)	0.5	0.08	0.15	0.59			<0.001	0.002	<0.001	<0.001

DAA = days after application.
TAM = TAM 11. OAK = Oakley CL.

Table 4. Net return on investment for different fungicide treatments on Oakley CL (OAK) and TAM 111 (TAM) wheat varieties for the 2016–2017 growing season Southwest Research–Extension Center, Garden City, KS

Treatments	Cost of fungicide[1]	Cost of application	Total cost of treatment	Yield		Value of production		Added return to treatment		Net return to treatment		Value of production treatment cost	
				TAM	OAK	TAM	OAK	TAM	OAK	TAM	OAK	TAM	OAK
	$/gal	$/pass	$/a	------- bu/a -------		-- $/a --							
Control	0.00	0.00	0.00	74	53	222.78	159.00	0.00	0.00	0.00	0.00	222.78	159.00
Aproach Prima	15.41	6.50	21.91	79	61	236.97	183.71	14.19	24.71	(7.72)	2.80	215.06	161.80
Tebustar	1.56	6.50	8.06	78	59	234.30	176.71	11.52	17.71	3.45	9.64	226.24	168.64
Absolute Maxx	9.69	6.50	16.19	85	59	226.24	176.57	30.94	17.57	14.75	1.38	237.54	160.38
Prosaro	11.33	6.50	17.83	86	57	253.72	171.75	35.23	12.75	17.40	(5.08)	240.19	153.92
Nexicor	11.48	6.50	17.98	80	56	240.71	168.07	17.92	9.07	(0.06)	(8.92)	222.72	150.08
Absolute Maxx	12.11	6.50	18.61	80	56	241.42	167.80	18.64	8.80	0.03	(9.81)	222.81	149.19
Twinline	11.60	6.50	18.10	76	55	229.16	164.31	6.38	5.31	(11.72)	(12.79)	211.06	146.21
Trivapro	2.73	6.50	9.23	80	53	239.10	159.74	16.32	0.74	7.08	(8.49)	229.87	150.51
Alto	2.34	6.50	8.84	76	53	227.66	159.22	4.88	0.22	(3.96)	(8.63)	218.82	150.37
Aproach/ Aproach Prima	23.53	13.00	36.53	85	53	254.04	158.14	31.26	(0.86)	(5.27)	(37.39)	217.51	121.61
Priaxor	8.98	6.50	15.48	79	49	236.06	147.25	13.28	(11.75)	(2.21)	(27.23)	220.58	131.77

(), negative return to treatment.

[1]Actual cost of fungicide may vary from those used in table.

Effects of Fallow Replacement Crops on Wheat and Grain Sorghum Yields

J. Holman, A. Obour, T. Roberts, and S. Maxwell

Summary

Producers are interested in growing cover crops and reducing fallow. Growing a crop during the fallow period would increase profitability if crop benefits exceeded expenses. Benefits of growing a cover crop were shown in high rainfall areas, but limited information is available on growing cover crops in place of fallow in the semiarid Great Plains. A study was conducted from 2007–2018 that evaluated cover crops, annual forages, and short season grain crops grown in place of fallow. In the first experiment (2007–2012), the rotation was no-till wheat-fallow. The second experiment (2012–2018) rotation was no-till wheat-grain sorghum-fallow. This report presents results from the second experiment. Wheat yield was affected by growing a crop in place of fallow, but managing the crop as either cover or hay did not affect wheat yield. Wheat yield following the previous crop was dependent on precipitation during fallow and the growing season. In dry years growing a crop during fallow reduced wheat yields, while growing a crop during fallow had little impact on wheat yield in wet years. Grain sorghum yield was only reduced one year by growing a crop in place of fallow, other years there was no yield difference. The length of the fallow period affected subsequent wheat yield. Growing a cover or hay crop in place of fallow had a less negative impact on wheat yield compared to growing a spring grain crop due to a shorter fallow period. Cover crops did not improve wheat or grain sorghum yields compared to fallow. To be successful, the benefits of growing a cover crop during the fallow period must be greater than the expense of growing it; and must compensate for any negative yield impacts on the subsequent crop. Cover crops always resulted in less profit than fallow, while annual forages often increased profit compared to fallow. The negative effects on wheat yields might be minimized with flex-fallow, which is the concept of only growing a crop in place of fallow in years when soil moisture at planting and precipitation outlook are favorable at the time of making the decision to plant.

Introduction

Interest in replacing fallow with a cash crop or cover crop has necessitated research on soil, water, and wheat yields following a shortened fallow period. Fallow stores moisture, which helps stabilize crop yields and reduces the risk of crop failure; however, only 25 to 30% of the precipitation received during the fallow period of a no-till wheat-fallow rotation is stored. The remaining 75 to 70% of precipitation is lost, primarily due to evaporation. Moisture storage in fallow is more efficient earlier in the fallow period, when the soil is dry, and during the winter months when the evaporation rate is lower. It may be possible to increase cropping intensity without reducing winter wheat yield. This study evaluated replacing part of the fallow period with a cover, annual forage, or short-season grain crop. Plant available water at wheat and grain sorghum planting and winter wheat and grain sorghum yields were measured.

Experimental Procedures

A study from 2007–2014 evaluated cover crops, annual forages, and spring grain crops (peas, oat, or triticale) grown in place of fallow in a no-till wheat-fallow rotation. This first experiment was modified beginning in 2012 to a wheat-grain sorghum-fallow rotation. Treatments that stayed the same between experiments 1 and 2 were maintained in the same plots so that long-term treatment impacts could be determined. Fallow replacement crops (cover crop, annual forage, or short-season grain crop) were either grown as standing cover, harvested for forage (annual forage crop), or harvested for grain.

In experiment 1 (2007–2012), both winter and spring crop species were evaluated. Winter species included yellow sweet clover (*Melilotus officinalis* (L.) Lam.), hairy vetch (*Vicia villosa* Roth ssp.), lentil (*Lens culinaris* Medik.), Austrian winter forage pea (*Pisum sativum* L. ssp.), Austrian winter grain pea (*Pisum sativum* L. ssp.), and triticale (×*Triticosecale* Wittm.). Spring species included lentil (*Lens culinaris* Medik.), forage pea (*Pisum sativum* L. ssp.), grain pea (*Pisum sativum* L. ssp.), and triticale (×*Triticosecale* Wittm.). Crops were grown in monoculture and in two-species mixtures of each legume plus triticale. Crops grown for grain were grown in monoculture only. Winter lentil was grown in place of yellow sweet clover beginning in 2008. Crops grown in place of fallow were compared with a wheat-fallow and continuous wheat rotation for a total of 16 treatments. The study design was a split-split-plot randomized complete block design with four replications; crop phase (wheat-fallow) was the main plot, fallow replacement was the split-plot, and fallow replacement method (forage, grain, or cover) was the split-split-plot. The main plot was 480-ft wide × 120-ft long, the split-plot was 30-ft wide × 120-ft long, and the split-split plot was 15-ft wide × 120-ft long.

In experiment 2 (2012–2018) spring crops were grown the year following grain sorghum. Grain sorghum is harvested late in the year and most years do not allow growing a winter crop during the fallow period. Spring planted treatments included spring grain pea, spring pea plus spring oat (*Avena sativa* L.), spring pea plus spring triticale, spring oat, spring triticale, and a six species "cocktail" mixture of spring oat, spring triticale, spring pea, buckwheat var. Mancan (*Fagopyrum esculentum* Moench), purple top turnip (*Brassica campestris* L.), and forage radish (*Raphanus sativus* L.). In addition, spring grain pea, spring oat, and safflower (*Carthamus tinctorius* L.) were grown for grain. Safflower was only grown in 2012, and that treatment was replaced with spring oat grown for grain beginning in 2013. Additional treatments initiated in 2013 were yellow sweet clover planted with grain sorghum and allowed to grow into the fallow year, daikon radish (*Brassica rapa* L.) planted with winter wheat in a wheat-grain sorghum-fallow rotation, shogoin turnip (*Raphanus sativus* L.) planted with winter wheat in a wheat-grain sorghum-fallow rotation, and spring oats or a cocktail planted in a "flex-fallow" system (Table 1). The flex-fallow treatment was planted when a minimum of 12 inches of PAW (2013 and 2016) was determined using a Paul Brown moisture probe at spring planting; otherwise, the treatment was left fallow. The flex-fallow treatment was intended to take advantage of growing a crop during the fallow period in wet years and fallowing in dry years. Crops grown for grain were grain peas, spring oat, and triticale. Crops grown in place of fallow were compared with a wheat-grain sorghum-fallow rotation for a total of 16 treatments (Table 1). The study design was a split-split-plot randomized complete block design with four replications; crop phase (wheat-grain sorghum-fallow) was the main plot, fallow replacement was the split-plot, and fallow replacement method (forage, grain, or cover) was the split-split-plot. The main plot was 330-ft wide × 120-ft long, the split-plot was 30-ft wide × 120-ft long, and the split-split plot was 15-ft wide × 120-ft long.

Annually, winter wheat was planted on approximately October 1. Spring crops were planted as early as soil conditions allowed, ranging from the end of February through the middle of March. Spring cover and forage crops were chemically terminated or forage-harvested approximately June 1 at early heading (Feekes 10.1) (Large, 1954). Biomass yields for both cover crops and forage crops were determined from a 3- × 120-ft area cut 3 in. high using a small plot Carter forage harvester from within the split-split-plot managed for forage. Winter and spring grain peas and winter wheat were harvested with a small plot Wintersteiger combine from a 6.5- × 120-ft area at grain maturity, which occurred approximately the first week of July.

Volumetric soil moisture content was measured at planting and harvest of winter wheat, grain sorghum, and fallow using a Giddings soil probe by 1-ft increments to a 6-ft soil depth. In addition, volumetric soil content was measured in the 0-3-in. soil depth at wheat planting to quantify moisture in the seed planting depth. Grain yield was adjusted to 13.5% moisture content, and test weight was measured using a grain analysis computer. Grain samples were analyzed for nitrogen content.

Results and Discussion

Fallow and Growing Season Precipitation

Fallow and growing season precipitation varied greatly during the course of this study (Table 2). Historical 30-yr (1984-2014) average precipitation during the fallow period between grain sorghum harvest and wheat planting (November-December plus January-September) was 18.03 in., and precipitation during the fallow period between wheat harvest and grain sorghum planting (July-December plus January-May) was 16.12 in. Long-term average growing-season precipitation for wheat (October-June) averaged 12.51 in., and growing-season precipitation for grain sorghum (June-October) averaged 11.06 in. Precipitation during the fallow period ahead of wheat planting was below normal in 2012 and 2013, average in 2017, and above average in 2014, 2015, and 2016. Growing-season precipitation for wheat was below normal in 2012, 2013, and 2017; near average in 2015; and above average in 2014 and 2016. Precipitation preceding grain sorghum planting was below average in 2012, 2013, and 2014, and above average in 2015, 2016, and 2017. Growing-season precipitation for grain sorghum was below normal in 2012, near normal in 2016 and 2017, and above average in 2013, 2014, and 2015. These differences in precipitation amount and timing affected plant-available soil water at wheat and grain sorghum planting and subsequently affected crop yields.

Precipitation storage efficiency averaged 28% with cover and 22% with hay, and stored soil water in the 0–6-ft profile averaged 3.5 inches with cover and 2.8 in. with hay at wheat planting. Plant-available soil water in the top 0-3-in. soil depth was not different between cover and hay treatments. Although more soil water tended to be available in the profile following cover crops compared to hay crops, this effect was not large enough to affect wheat yields. The greater average plant-available soil water and precipitation storage with cover crop is likely due to more surface residue in the cover crop treatments compared with hay treatments, which likely helps reduce water runoff and evaporation near the soil surface.

Winter Wheat Yield in Wheat-Grain Sorghum-Fallow

In 2013, 6.25 inches of precipitation occurred during the winter wheat growing season between planting and harvest. This was 50% of normal (12.5 inches) for this time period, and was the third consecutive year of drought. Below-normal precipitation during fallow and the winter wheat growing season resulted in any treatment other than fallow significantly reducing wheat yield 50% or more. The cover crop cocktail treatment yielded 79% less than fallow. Wheat following fallow yielded 19 bu/a and all other treatments yielded between 3 to 9 bu/a (Figure 1).

In 2014, 14.57 inches of precipitation occurred during the winter wheat growing season between planting and harvest. This was above average, but most of the rain came in June (10.5 inches), which was too late to benefit the wheat crop. Therefore, wheat yields were significantly reduced by 40-80% by any treatment other than fallow, and fallow only yielded 6 bu/a (Figure 2).

In 2015, 12.18 inches of precipitation occurred during the winter wheat growing season between planting and harvest, with most of this occurring in May (6.38 inches). Were it not for the rainfall received in May, yields likely would have been less than 10 bu/a in fallow. Precipitation received in the previous fallow period (between grain sorghum harvest and wheat planting) from November 2014 to October 2015 was 18.87 inches and the 30-yr average for this period was 18.03 in. The early season moisture stress and late season precipitation minimized yield differences between treatments and fallow (Figure 3). Only oats for grain, oat, and pea/triticale yielded less than fallow (15 bu/a).

In 2016, a large infestation of rabbits and feeding damage resulted in a failed crop and no grain production.

In 2017, 11.09 inches of precipitation occurred during the winter wheat growing season between planting and harvest. Most of the precipitation occurred in the spring of 2017 and soil conditions were dry at planting through winter. Precipitation received in the previous fallow period (between grain sorghum harvest and wheat planting) from November 2013 to October 2015 was 18.69. The early season moisture stress reduced yield potential and all treatments yielded less than 16 bu/a (Figure 4). Spring grain treatments yielded (16 bu/a) more than fallow (8 bu/a), which might have been due to more residue from the grain treatments improving water use efficiency.

Grain Sorghum Yield in Wheat-Grain Sorghum-Fallow

The first grain sorghum crop grown in-phase following cover crop treatments was in 2015. The above normal rainfall in 2015, particularly early in the growing season (5.36 inches in July and 3.24 inches in August), resulted in above normal sorghum yields, ranging from 84–109 bu/a (Figure 5). Despite the above-normal rainfall and yields, there was still a correlation with 2015 grain sorghum and 2014 winter wheat yields; thus, the impact of growing a cover crop was evident two years later.

In 2016, sorghum yield was similar among treatments. The difference in sorghum yield response to treatment between years was likely due to greater wheat yields and more residue following the 2015 wheat crop compared to the 2014 wheat crop. The poor wheat crop in 2014 resulted in low soil residue cover, and the effect of this was shown by differences in sorghum water use efficiency (WUE) among treatments in 2015. In 2016, there were no differences in sorghum yield or WUE across treatments. Additionally, sufficient precipitation during the preceding fallow period and growing season resulted in an average sorghum yield of 63 bu/a, which helped negate any antecedent differences in soil water.

Grain sorghum in 2017 was affected by previous cover crop treatments in 2015. Wheat yields were too low to harvest in 2016, so no comparisons could be made between 2017 grain sorghum and 2016 wheat yields. However, grain sorghum WUE in 2017 matched closely to grain yields. The results in 2017 suggest a similar response to grain sorghum in 2015, that those wheat plots that grew more biomass (data not available) improved grain sorghum WUE and yield (Figure 6). Fallow yield was similar to the other treatments, while pea (grain) yielded less than oat/triticale/pea, triticale (grain), cocktail, oat/triticale, and oat (grain). The lower yield following pea (grain) was most likely due to more weeds present in that treatment.

Cover vs. Annual Forage

Similar to the first experiment, there was no difference in wheat or grain sorghum yields whether the previous crop was left as cover or harvested for forage, despite slightly more plant available water following cover than forage harvest. This indicates the previous crop can be harvested for forage rather than left standing as a cover crop without negatively affecting wheat or grain sorghum yields.

Conclusions

Fallow helps stabilize crop yields in dry years. Annual precipitation in this study ranged from 12.1 to 23.3 inches. The 30-year average precipitation was 19.24 inches. In dry years, growing a crop during the fallow period reduced wheat yields, but previous research showed that in wet years, growing a crop during the fallow period had little impact on wheat yield. The length of the fallow period also affected yields of the following wheat crop. Growing a cover or hay crop until June 1 affected wheat less than if spring grain crops were grown in place of fallow until July 1. When wheat yields were very low there was a carryover effect onto grain sorghum, reducing WUE and grain yield.

Forages can be profitable to grow in place of fallow in favorable moisture years. However, cover crops were always an expense to grow. The cropping system can be intensified by replacing part of the fallow period with annual forages to increase profit and improve soil quality; however, in semiarid environments, wheat yields will be reduced in years with below-normal precipitation. Across all years (2007–2018) there was a tendency for wheat yields to not be affected by growing a crop in place of fallow when wheat yield potential was 50 bu/a or greater. The negative effect on yield was greater when wheat yield potential was least and the drought period lasted for more than a year. Some of the reduction in grain yield can be offset by growing a cover crop for forage or grain. Negative impacts on grain yields might also be minimized over time with "flex-fallow." Flex-fallow is the concept of only planting a crop in place of fallow when soil moisture levels and precipitation outlook are favorable. Under drought conditions such as 2011–2014, using flex-fallow, a crop would not have been grown in place of fallow. Therefore, flex-fallow may help reduce the negative effects of reduced fallow. Conversely, flex-fallow will not prevent reduced yield in years when growing-season precipitation levels are below normal. Additional years of data are required to determine the feasibility of flex-fallow and the effects of replacing fallow in a wheat-summer crop-fallow rotation.

References

Large, E.C. 1954. Growth stages in cereals illustration of the Feekes scale. Plant Pathology. 3 (4): 128–129. doi:10.1111/j.1365-3059.1954.tb00716.x

Table 1. Fallow treatments 2007–2018 at the Southwest Research-Extension Center near Garden City, KS, 2012–2017

				Year produced											
Crop	Cover	Hay	Grain	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Fallow				x	x	x	x	x	x	x	x	x	x	x	x
Cocktail mix[†]	x	x		-	-	-	-	-	x	x	x	x	x	x	x
Cocktail mix[†] (flex)[††]		x		-	-	-	-	-	-	-	-	N	Y	N	N
Spring oat (flex)		x		-	-	-	-	-	-	Y	N	N	Y	N	N
Spring oat		x		-	-	-	-	-	x	x	x	x	x	x	x
Spring oat (grain)			x	-	-	-	-	-	-	x	x	x	x	x	x
Spring pea	x	x		x	x	x	x	x	x	-	-	-	-	-	-
Spring pea (grain)			x	-	-	-	x	x	x	x	x	x	x	x	x
Spring pea/spring oat	x	x		-	-	-	-	-	x	x	x	-	-	-	-
Spring pea/spring triticale	x	x		-	-	-	-	-	x	x	x	-	-	-	-
Spring triticale	x	x		-	-	-	-	-	x	x	x	-	-	-	-
Spring triticale		x		-	x	x	x	x	x	x	x	x	x	x	x
Spring triticale (grain)			x	-	-	-	-	-	-	-	-	x	x	x	x
Spring oat/triticale/pea	x	x		-	-	-	-	-	-	-	-	x	x	x	x
Spring triticale/oat	x	x		-	-	-	-	-	-	-	-	x	x	x	x
Spring triticale/pea		x		-	x	x	x	x	x	x	x	-	-	-	-
Spring triticale/lentil				-	x	x	x	x	-	-	-	-	-	-	-
Spring lentil				x	x	x	x	x	-	-	-	-	-	-	-

[†]Oat, triticale, pea, buckwheat, forage brassica, and forage radish.

[††]Flex: Plant when soil moisture is 14 in. (12 in. in 2013) or > and precipitation outlook is neutral or favorable.

Table 2. Annual and 30-year monthly, growing season, and fallow precipitation at the Southwest Research-Extension Center near Garden City, KS, 2012–2017

Year	Month	Precipitation	30-year precipitation average†
		------------------- in.	-------------------
2012	January	0.00	0.46
	February	0.59	0.55
	March	1.92	1.31
	April	1.77	1.74
	May	0.30	2.98
	June	1.03	3.12
	July	2.41	2.80
	August	1.22	2.51
	September	1.19	1.42
	October	0.98	1.21
	November	0.00	0.55
	December	0.73	0.59
	Total	12.14	19.24
	Wheat growing season (October-June)	8.50	12.51
	Grain sorghum growing season (June-October)	6.83	11.06
	Fallow preceding wheat (November-September)	16.17	18.03
	Fallow preceding grain sorghum (July-May)	10.81	16.12
2013	January	0.48	0.46
	February	1.54	0.55
	March	0.13	1.31
	April	0.28	1.74
	May	1.25	2.98
	June	1.84	3.12
	July	2.23	2.80
	August	6.09	2.51
	September	1.83	1.42
	October	0.88	1.21
	November	0.74	0.55
	December	0.00	0.59
	Total	17.29	19.24
	Wheat growing season (October-June)	7.23	12.51
	Grain sorghum growing season (June-October)	12.87	11.06
	Fallow preceding wheat (November-September)	16.40	18.03
	Fallow preceding grain sorghum (July-May)	10.21	16.12

continued

Table 2. Annual and 30-year monthly, growing season, and fallow precipitation at the Southwest Research-Extension Center near Garden City, KS, 2012–2017

Year	Month	Precipitation	30-year precipitation average†
		------------------- in. -------------------	
2014	January	0.12	0.46
	February	0.38	0.55
	March	0.25	1.31
	April	0.69	1.74
	May	0.63	2.98
	June	10.50	3.12
	July	3.81	2.80
	August	1.99	2.51
	September	2.71	1.42
	October	1.78	1.21
	November	0.03	0.55
	December	0.40	0.59
	Total	23.29	19.24
	Wheat growing season (October-June)	14.19	12.51
	Grain sorghum growing season (June-October)	20.79	11.06
	Fallow preceding wheat (November-September)	21.82	18.03
	Fallow preceding grain sorghum (July-May)	13.84	16.12
2015	January	0.30	0.46
	February	1.21	0.55
	March	0.32	1.31
	April	0.37	1.74
	May	6.38	2.98
	June	1.39	3.12
	July	5.36	2.80
	August	3.24	2.51
	September	0.04	1.42
	October	2.87	1.21
	November	0.98	0.55
	December	0.81	0.59
	Total	23.27	19.24
	Wheat growing season (October-June)	12.18	12.51
	Grain sorghum growing season (June-October)	12.90	11.06
	Fallow preceding wheat (November-September)	19.04	18.03
	Fallow preceding grain sorghum (July-May)	19.30	16.12

continued

Table 2. Annual and 30-year monthly, growing season, and fallow precipitation at the Southwest Research-Extension Center near Garden City, KS, 2012–2017

Year	Month	Precipitation	30-year precipitation average[†]
		------------------- in.	-------------------
2016	January	0.04	0.46
	February	0.22	0.55
	March	0.06	1.31
	April	4.59	1.74
	May	0.92	2.98
	June	3.61	3.12
	July	5.97	2.80
	August	1.85	2.51
	September	0.17	1.42
	October	0.00	1.21
	November	0.08	0.55
	December	0.22	0.59
	Total	17.73	19.24
	Wheat growing season (October-June)	14.10	12.51
	Grain sorghum growing season (June-October)	11.60	11.06
	Fallow preceding wheat (November-September)	19.22	18.03
	Fallow preceding grain sorghum (July-May)	19.13	16.12
2017	January	1.54	0.46
	February	0	0.55
	March	2.55	1.31
	April	4.03	1.74
	May	1.47	2.98
	June	1.25	3.12
	July	2.02	2.80
	August	2.46	2.51
	September	3.29	1.42
	October	1.75	1.21
	November	0.01	0.55
	December	0	0.59
	Total	20.37	19.24
	Wheat growing season (October-June)	11.09	12.51
	Grain sorghum growing season (June-October)	10.77	11.06
	Fallow preceding wheat (November-September)	18.69	18.65
	Fallow preceding grain sorghum (July-May)	21.27	18.65

[†]30–year average (1984–2014).

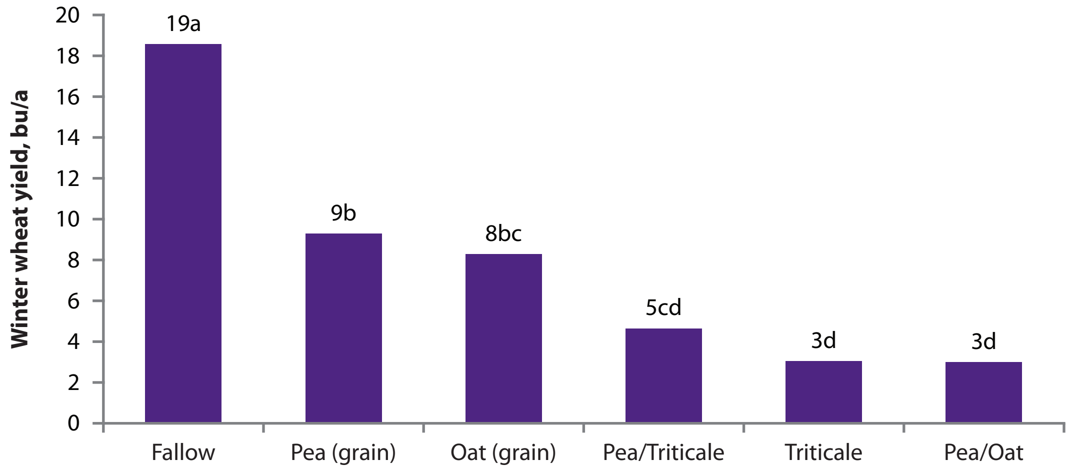

Figure 1. Winter wheat yield (bu/a) in 2013 following various cover crop treatments. Means followed by same letter are statistically similar at *P* ≤ 0.05.

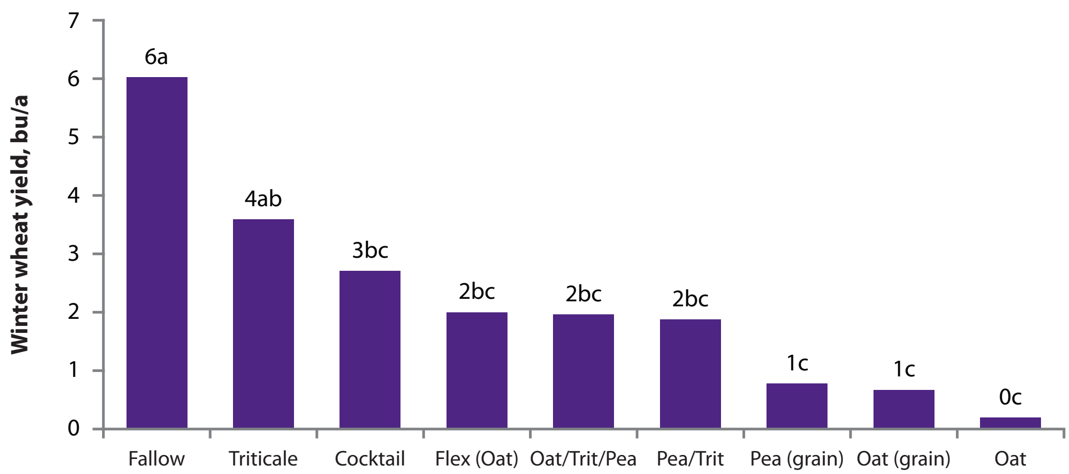

Figure 2. Winter wheat yield (bu/a) in 2014 following various cover crop treatments. Means followed by same letter are statistically similar at *P* ≤ 0.05.

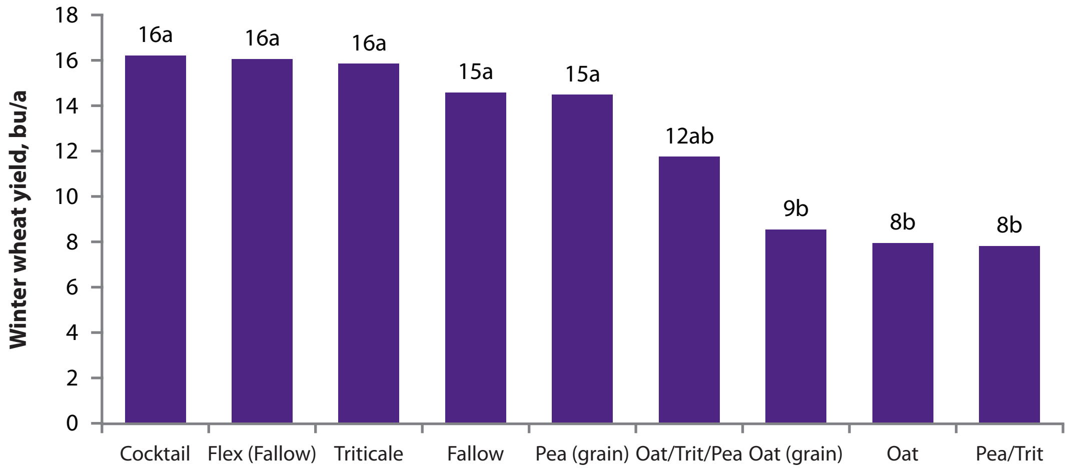

Figure 3. Winter wheat yield (bu/a) in 2015 following various cover crop treatments. Means followed by same letter are statistically similar at *P* ≤ 0.05.

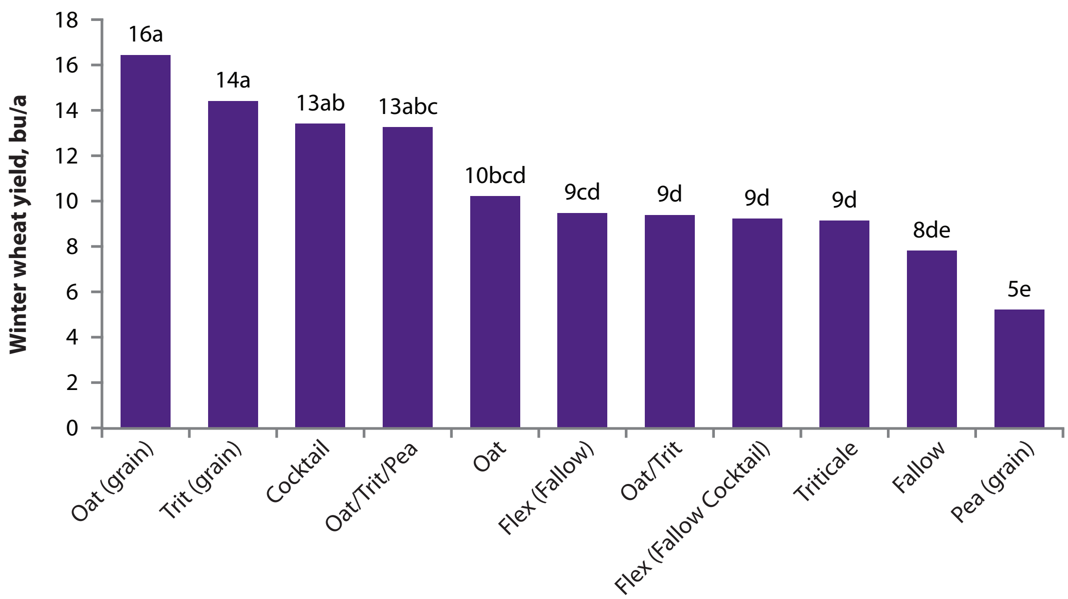

Figure 4. Winter wheat yield (bu/a) in 2017 following various cover crop treatments. Means followed by same letter are statistically similar at *P* ≤ 0.05.

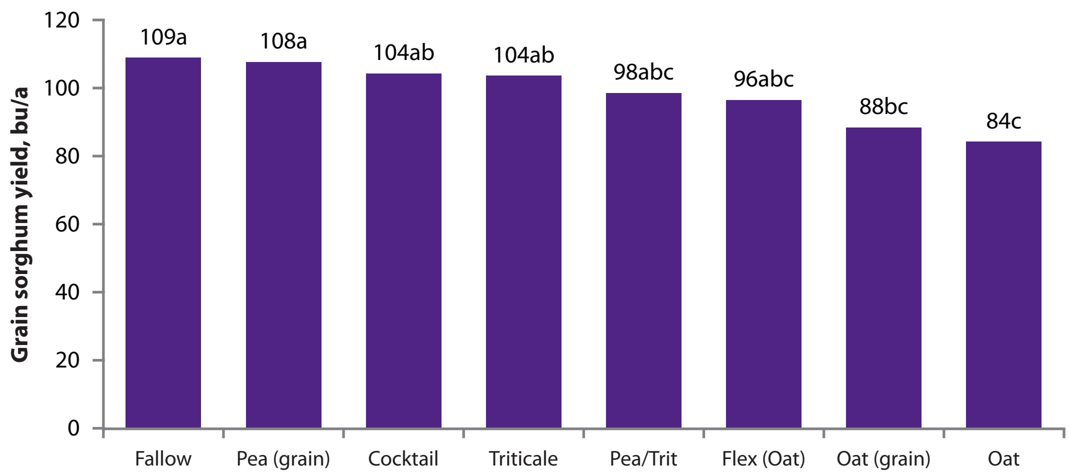

Figure 5. Grain sorghum yield in 2015 following various cover crop treatments. Means followed by same letter are statistically similar at *P* ≤ 0.05.

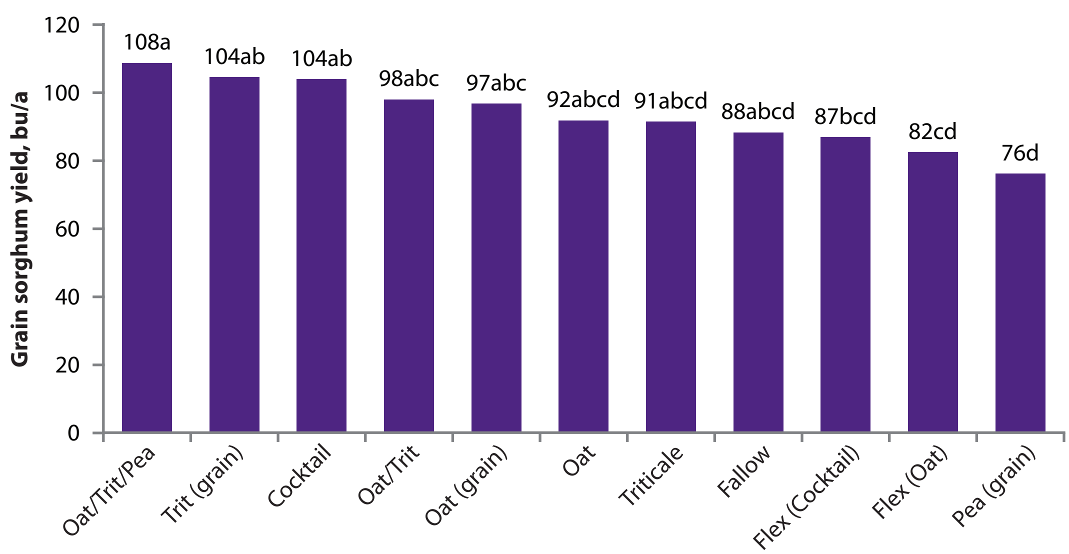

Figure 6. Grain sorghum yield in 2017 following various cover crop treatments. Means followed by same letter are statistically similar at *P* ≤ 0.05.

Alternative Cropping Systems with Limited Irrigation

A. Schlegel

Summary
A limited irrigation study involving four cropping systems and evaluating four crop rotations was initiated at the Southwest Research-Extension Center near Tribune, KS, in 2012. The cropping systems were two annual systems (continuous corn [C-C] and continuous grain sorghum [GS-GS]) and two 2-year systems (corn- grain sorghum [C-GS]) and corn-winter wheat [C-W]). In 2017, corn yields were greatest in the corn-wheat rotation and least with continuous corn. Grain sorghum yields were greater following sorghum than following corn. The wheat was destroyed by a severe infestation of wheat streak mosaic virus and not harvested.

Experimental Procedures
A crop rotation study under sprinkler irrigation at the Kansas State University Southwest Research-Extension Center near Tribune, KS, was initiated in the spring of 2012. The study evaluates four different crop rotations with a limited irrigation allocation. The rotations include 1- and 2-year rotations. The crop rotations are 1) continuous corn; 2) corn-winter wheat; 3) corn-grain sorghum; and 4) continuous grain sorghum (a total of 6 treatments). All rotations are limited to 10 inches of irrigation water annually. All crops are grown no-till, while other cultural practices (hybrid selection, fertility practices, weed control, etc.) are selected to optimize production. All phases of each rotation are present each year and replicated four times. Irrigations are scheduled to supply water at the most critical stress periods for the specific crops and limited to 1.5 inches/week. Soil water is measured at planting, during the growing season, and at harvest in 1-ft increments to a depth of 8 ft. Grain yields are determined by machine harvest. Nitrogen fertilizer (UAN) was surface applied (stream) in March to all crops (240 lb N/a for corn, 160 lb N/a for sorghum, and 120 lb N/a for wheat). Corn was planted on April 27, 2017, and harvested on October 12, 2017. Grain sorghum was planted on June 2, 2017, and harvested on October 30, 2017. Wheat was planted on September 24, 2016, and abandoned on June 22, 2017.

Results and Discussion
Wheat yields were zero in 2017 because of a severe infestation of wheat streak mosaic virus (Table 1). Weather conditions for summer crops were good in 2017. Precipitation was above normal for April, May, July, August, and September. Corn yields in 2017 were greatest with corn-wheat (211 bu/a) and least with continuous corn (154 bu/a). Grain sorghum yields were greater following corn than following grain sorghum. Despite the favorable precipitation, grain sorghum yields were less in 2017 than the multi-year average (Table 2).

Available soil water at corn planting and harvest was similar for all rotations in 2017 (Table 3). Fallow efficiency was less following corn than following either wheat or grain sorghum. For wheat, available soil water at planting and harvest was greater than the 4-yr average (Table 4). The only difference observed with grain sorghum was more fallow accumulation for grain sorghum following grain sorghum than following corn. This was consistent with the average fallow accumulation for the past 4 years. Average crop water use was much greater for corn (~6 inch) in 2017 because of the greater than normal precipitation (>22 inch growing season precipitation) while grain sorghum water use was about 2 inch above the long-term average. There were no differences in crop water use due to rotation for either crop.

Acknowledgment
The project was funded in part by Western Kansas Groundwater Management District No. 1.

Table 1. Grain yield of three crops under limited irrigation as affected by rotation in 2017

Rotation	Corn	Wheat	Sorghum
	------------------	bu/a	------------------
Continuous corn	154	---	---
Continuous sorghum	---	---	124
Corn-wheat	211	0	---
Corn-sorghum	173	---	108
Least significant difference$_{(0.05)}$	44	---	7

Table 2. Grain yields of three crops under limited irrigation as affected by rotation across years 2013–2017

Rotation	Corn	Wheat	Sorghum
	------------------	bu/a	------------------
Continuous corn	167b	---	---
Continuous sorghum	---	---	134b
Corn-wheat	189a	51	---
Corn-sorghum	181ab	---	143a
Least significant difference$_{(0.05)}$	16	---	6

Table 3. Profile available soil water, crop water use, and fallow accumulation for crop rotations under limited irrigation, Tribune, KS, 2017

		Available water					
Crop	Rotation	Previous harvest	Planting	Harvest	Crop water use	Fallow accumulation	Fallow efficiency
		------------	------------	in.	------------	------------	%
Corn	C-C	14.85	14.66	14.42	33.08	-0.19	-4c
	C-W	12.69	14.58	13.61	33.81	1.90	16b
	C-GS	11.37	13.03	13.03	32.84	1.66	39a
$LSD_{0.05}$		3.05	2.05	1.35	0.89	1.78	20
ANOVA (P > F)							
System		0.080	0.169	0.113	0.083	0.055	0.006
Wheat	C-W	15.94	15.94	14.02	20.44	0	---
ANOVA (P > F)							
System		---	---	---	---	---	---
Sorghum	C-GS	15.27	16.16	14.50	25.89	0.89	7
	GS-GS	11.32	15.49	13.42	26.30	4.17	35
$LSD_{0.05}$		4.29	2.56	3.13	0.65	1.80	15
ANOVA (P > F)							
System		0.061	0.465	0.351	0.138	0.010	0.010

Note: All crops received ~10 inches of irrigation.
In season rainfall for corn (4/27/17–10/09/17) = 22.83 inches; sorghum (6/06/17–10/31/17) = 15.13 inches; and wheat (9/15/16–6/22/17) = 13.90 inches.
C = corn.
W = wheat.
GS = grain sorghum.
LSD = least significant difference.
ANOVA = analysis of variance.

Table 4. Profile available soil water, crop water use, and fallow accumulation for crop rotations under limited irrigation across years, Tribune, KS, 2013-2017

		Available water					
Crop	Rotation	Previous harvest	Planting	Harvest	Crop water use	Fallow accumulation	Fallow efficiency
		------------	------------	in.	------------	------------	%
Corn	C-C	11.38a	13.87a	12.50a	26.74	2.50b	28b
	C-W	10.61ab	13.89a	12.43a	26.82	3.27a	22b
	C-GS	9.64b	12.11b	10.76b	26.72	2.47b	50a
$LSD_{(0.05)}$		1.06	0.82	0.94	0.77	0.52	7
ANOVA (P > F)							
System		0.008	0.001	0.001	0.958	0.005	0.001
Year		0.001	0.001	0.001	0.001	0.001	0.001
System × year		0.001	0.006	0.016	0.001	0.001	0.001
Wheat	C-W	11.52	11.52	11.41	20.09	0	-
ANOVA (P > F)							
System		---	---	---	---	---	---
Year		0.001	0.001	0.001	0.001	---	---
System × year		---	---	---	---	---	---
Sorghum	C-GS	9.52	13.28	11.41	23.83	3.76	32
	GS-GS	9.53	12.84	11.16	23.64	3.31	37
$LSD_{(0.05)}$		0.99	0.85	0.87	0.53	0.63	9
ANOVA (P > F)							
System		0.979	0.304	0.559	0.480	0.158	0.294
Year		0.001	0.001	0.001	0.001	0.001	0.001
System × year		0.001	0.009	0.369	0.082	0.001	0.019

Note: All crops received ~10 inches of irrigation each year.
C = corn.
W = wheat.
GS = grain sorghum.
LSD = least significant difference.
ANOVA = analysis of variance.

Occasional Tillage in a Wheat-Sorghum-Fallow Rotation

A. Schlegel and J. Holman

Summary

Beginning in 2012, research was conducted in Garden City and Tribune, KS, to determine the effect of a single tillage operation every 3 years on grain yields in a wheat-sorghum-fallow (WSF) rotation. Grain yields of wheat and grain sorghum were not affected by a single tillage operation every 3 years in a WSF rotation. Grain yield varied greatly by year from 2014 to 2017. Wheat yields ranged across years from mid-20s to 80 bu/a at Tribune and about 10 (hail damage) to near 60 bu/a at Garden City. Grain sorghum yields ranged from less than 60 to greater than 140 bu/a, depending upon year and location. In no year or location, were grain yields significantly affected by a single tillage operation. This indicates that if a single tillage operation is needed to control troublesome weeds, that grain yields will not be significantly affected. Furthermore, if weed populations were high enough to cause yield reductions, then tillage might improve yields.

Introduction

Previous research has shown lower dryland wheat and grain sorghum yields with reduced tillage compared with no-tillage in a wheat-sorghum-fallow (WSF) rotation. The reduced tillage systems generally used four or more tillage operations in the 3-yr rotation. With increased incidence of herbicide resistant weeds, the use of a complete no-tillage system may not be economical and tillage may be needed for effective control. The objective of the research project is to determine the effect of a single tillage operation every 3 years on grain yields in a WSF rotation.

Procedures

Research on occasional tillage intensities in a predominantly no-tillage WSF rotation at the Kansas State University Southwest Research-Extension Center research stations at Garden City and Tribune was initiated in 2012. The three tillage treatment intensities in this study are a single tillage in May or June during fallow, a single tillage after wheat harvest, and a complete no-tillage system. A sweep plow was used for all tillage operations. When needed, herbicides were used to control weeds during fallow for all treatments. All treatments used herbicides for in-crop weed control. All other cultural practices (variety/hybrid, seeding rate, fertilization, etc.) were the same for all treatments.

Results and Discussion

Weeds were effectively controlled in all treatments and there were no visual differences in weed population across treatments.

At Tribune, wheat yields were 27 to 30 bu/a in 2017 compared with 75 to 80 bu/a in 2016 (Table 1). Yields were reduced by wheat streak mosaic in 2017. There were no significant yield differences among tillage treatments in any year or across years. Grain sorghum yields were greater in 2017 than in any previous years ranging from 141 to

147 bu/a (Table 2). Similar to wheat, there were no significant yield differences among tillage treatments in any year or averaged across years.

At Garden City, wheat yields in 2017 were 19–23 bu/a (Table 3), and wheat yields were reduced in the fall of 2016 by wheat streak mosaic and dry conditions. Wheat yields in 2014 were severely reduced by hail. There were no significant yield differences among tillage treatments in any year or averaged across years. Grain sorghum yields in 2017 were less than half the yield of 2016 (Table 4), due to dry conditions late in the growing season. Similar to wheat, there were no significant yield differences among tillage treatments in any year or averaged across years.

In other research (Schlegel et al., 2018), reduced tillage systems produced lower yields than a complete no-tillage system in a WSF rotation. However, in this study, a single tillage operation in a 3-yr WSF rotation did not affect wheat or grain sorghum yields from 2014 to 2017 at Garden City or Tribune, KS.

Acknowledgment
This research was supported in part by the Ogallala Aquifer Program, a consortium between USDA Agricultural Research Service, Kansas State University, Texas AgriLife Research, Texas AgriLife Extension Service, Texas Tech University, and West Texas A&M University.

Table 1. Grain yield response of dryland wheat to a single tillage operation (sweep plow) in a 3 year wheat-sorghum-fallow rotation grown from 2014 to 2017 near Tribune, KS

	Year				
Tillage	2014	2015	2016	2017	Average
	bu/a				
No-tillage	28	24	75	30	39
June in fallow	26	25	80	27	39
July post-harvest	24	23	75	29	38
ANOVA (P > F)					
No-tillage vs. tillage	0.381	0.983	0.350	0.162	0.657
June vs. July	0.551	0.555	0.053	0.588	0.221
Year	---	---	---	---	0.001
Year × tillage	---	---	---	---	0.419

ANOVA = analysis of variance.

Table 2. Grain yield response of dryland grain sorghum to a single tillage operation (sweep plow) in a 3-year wheat-sorghum-fallow rotation grown from 2014 to 2017 near Tribune, KS

	Year				
Tillage	2014[a]	2015[a]	2016[a]	2017[b]	Average[b]
	bu/a				
No-tillage	77	133	129	147	122
June in fallow	84	124	131	145	118
July post-harvest	79	118	129	141	115
ANOVA (P > F)					
No-tillage vs. tillage	0.445	0.095	0.852	0.338	0.126
June vs. July	0.395	0.404	0.617	0.386	0.479
Year	---	---	---	---	0.001
Year × tillage	---	---	---	---	0.093

ANOVA = analysis of variance.

Note: Due to treatment change on August 31, 2016 (does not effect no-tillage):

[a] June in fallow and July post-harvest yields are two plots averaged together per block.

[b] June in fallow and July post-harvest yields are one plot per block.

Table 3. Grain yield response of dryland wheat to a single tillage operation (sweep plow) in a 3-year wheat-sorghum-fallow rotation grown from 2014 to 2017 near Garden City, KS

	Year				
Tillage	2014	2015	2016	2017	Average
	bu/a				
No-tillage	8	34	55	20	29
June in fallow	8	37	58	19	30
July post-harvest	10	33	56	23	30
ANOVA (P > F)					
No-tillage vs. tillage	0.767	0.686	0.460	0.604	0.642
June vs. July	0.222	0.101	0.200	0.239	0.715
Year	---	---	---	---	0.001
Year × tillage	---	---	---	---	0.287

ANOVA = analysis of variance.

Table 4. Grain yield response of dryland grain sorghum to a single tillage operation (sweep plow) in a 3-year wheat-sorghum-fallow rotation grown from 2014 to 2017 near Garden City, KS

	Year				
Tillage	2014	2015	2016	2017	Average
	bu/a				
No-tillage	58	63	116	51	72
June in fallow	57	64	123	46	71
July post-harvest	53	71	121	44	70
ANOVA (P>F)					
No-tillage vs. tillage	0.602	0.478	0.115	0.345	0.720
June vs. July	0.485	0.204	0.362	0.713	0.735
Year	---	---	---	---	0.001
Year × tillage	---	---	---	---	0.255

ANOVA = analysis of variance.

Large-Scale Dryland Cropping Systems

A. Schlegel and L. Haag

Summary
This study was conducted from 2008 to 2017 at the Kansas State University Southwest Research-Extension Center near Tribune, KS. The purpose of the study was to identify whether more intensive cropping systems can enhance and stabilize production in rainfed cropping systems to optimize economic crop production, more efficiently capture and utilize scarce precipitation, and maintain or enhance soil resources and environmental quality. The crop rotations evaluated were continuous grain sorghum (SS), wheat-fallow (WF), wheat-corn-fallow (WCF), wheat-sorghum-fallow (WSF), wheat-corn-sorghum-fallow (WCSF), and wheat-sorghum-corn-fallow (WSCF). All rotations were grown using no-tillage practices except for WF, which was grown using reduced-tillage. The efficiency of precipitation capture was not greater with more intensive rotations. Length of rotation did not affect wheat yields. Corn and grain sorghum yields were about 50% greater when following wheat than when following corn or grain sorghum. Grain sorghum yields were about 40% greater than corn in similar rotations.

Introduction
The change from conventional tillage to no-tillage cropping systems has allowed for greater intensification of cropping in semi-arid regions. In the central High Plains, wheat-fallow (1 crop in 2 years) has been a popular cropping system for many decades. This system is being replaced by more intensive wheat-summer crop-fallow rotations (2 crops in 3 years). There has also been increased interest in further intensifying the cropping systems by growing 3 crops in 4 years or continuous cropping. This project evaluates several multi-crop rotations that are feasible for the region, along with alternative systems that are more intensive than 2- or 3-year rotations. The objectives are to 1) enhance and stabilize production of rainfed cropping systems using multiple crops and rotations, using best management practices to optimize capture and utilization of precipitation for economic crop production, and 2) enhance adoption of alternative rainfed cropping systems that provide optimal profitability.

Experimental Procedures
The crop rotations are 2-year (wheat-fallow [WF]); 3-year (wheat-grain sorghum-fallow [WSF] and wheat-corn-fallow [WCF]); 4-year rotations (wheat-corn-sorghum-fallow [WCSF] and wheat-sorghum-corn-fallow [WSCF]); and continuous sorghum [SS]). All rotations are grown using no-tillage (NT) practices except for WF, which is grown using reduced-tillage (RT). All phases of each rotation are present each year. Plot size is a minimum of 100 × 450 ft. In most instances, grain yields were determined by harvesting the center 60 ft (by entire length) of each plot with a commercial combine and determining grain weight with a weigh-wagon or combine yield monitor. Soil water was measured in 12-inch increments to 96 inches near planting and after harvest either gravimetrically (RT WF) or by neutron attenuation (NT plots).

Results and Discussion

Precipitation averaged 101% of normal (17.90 in.) across the 10-yr study period and was near normal (+/- 15%) in 6 out of 10 years with three wet years (>20% above normal) and one exceptionally dry year (42% of normal) (Figure 1). Fallow accumulation, fallow efficiency, and profile available water at wheat planting was greater with WF than all other wheat rotations (Table 1). The fallow efficiencies of the 3- and 4-yr NT rotations were only 50-68% of WF under RT. With more water available, crop water use was also greater with WF than with wheat in other rotations. There were no differences in available water at wheat planting or crop water use among the 3- and 4-yr rotations.

Fallow accumulation prior to corn planting and profile available soil water at planting was greater following wheat (WCF or WCSF) than following grain sorghum (WSCF) (Table 1). However, the fallow period following wheat was longer, resulting in low fallow efficiencies (~17%) following wheat and only 25% following sorghum. Similar to wheat, corn water use was greater with greater available soil water at planting. Grain sorghum responded similarly to corn, with greater fallow accumulation and soil water at planting (and greater crop water use) when following wheat than following corn or sorghum. Again, fallow efficiencies prior to grain sorghum were low (16-23%).

Wheat yields were lower than normal in 2017 because of damage from wheat streak mosaic virus (Figure 2). The effect of cropping systems was not consistent across years with WF sometimes in the highest yielding group and sometimes in the lowest yielding group. Averaged across the 10 years, cropping system had little effect on wheat yields.

Grain sorghum yields were very good in 2017 with all treatments producing yields of 135 bu/a or greater (Figure 3). In contrast to previous years, grain sorghum yields following corn or sorghum were not much lower than following wheat. However, average grain sorghum yields following wheat were about 50% greater than following corn or sorghum.

Corn yields were also very good in 2017 (Figure 4) with all rotations yielding 115 bu/a or more. Corn yields following wheat in either the 3- or 4-yr rotations were always greater than corn yields following grain sorghum, except in 2015 where corn yields following sorghum (wsCf) were greater than wCf. On average, corn yields following wheat were about 50% greater than following grain sorghum.

When examining grain yields across crops, the greatest yields were produced by grain sorghum following wheat (either wSf or wScf) of about 80 bu/a (Figure 5). These yields were about 40% greater than corn following wheat (wCf or wCsf). Sorghum yields following wheat were about 50% greater than sorghum following corn or sorghum (wcSf or SS) while corn yields following wheat (wCf or wCsf) were also about 50% greater than following sorghum.

Acknowledgments

This research project received support from the U.S. Department of Agriculture, Agricultural Research Service Ogallala Aquifer Program.

Table 1. Fallow accumulation, fallow efficiency, profile (8 ft) available soil water at planting, and crop water use by wheat, corn, and grain sorghum in several crop rotations, Tribune, KS, 2008-2017

Crop	Rotation	Fallow accumulation	Fallow efficiency	Profile ASW at planting[2]	Crop water use
		inch	%	----------------inch----------------	
Wheat	Wf[1]	6.90a	28a	9.80a	18.21a
	Wsf	2.91bc	18b	6.10b	13.89b
	Wcf	2.42c	14c	5.88b	13.77b
	Wscf	3.26b	19b	6.41b	14.13b
	Wcsf	3.00b	18b	6.17b	13.98b
$LSD_{0.05}$		0.54	3	0.64	0.56
Corn	wCf	2.62a	18b	5.82a	13.81a
	wCsf	2.49a	17b	5.77a	13.80a
	wsCf	1.70b	25a	4.84b	12.99b
$LSD_{0.05}$		0.39	3	0.59	0.39
Grain sorghum	wSf	2.43b	16c	5.80a	13.16b
	wScf	3.09a	19b	6.32a	13.56a
	wcSf	1.57c	18bc	5.02b	12.56c
	SS	2.09b	23a	5.22b	12.61c
$LSD_{0.05}$		0.36	3	0.56	0.37

[1]Wheat-fallow rotation is reduced-tillage; all other rotations are no-tillage. Means within a column with the same letter for the same crop are not statistically different at $P = 0.05$. The capital letter in the rotation denotes the crop phase of the rotation.
[2]Available soil water (ASW) in an 8 ft profile at planting.
W = wheat; F = fallow; S = sorghum; C = corn; SS = continuous grain sorghum.

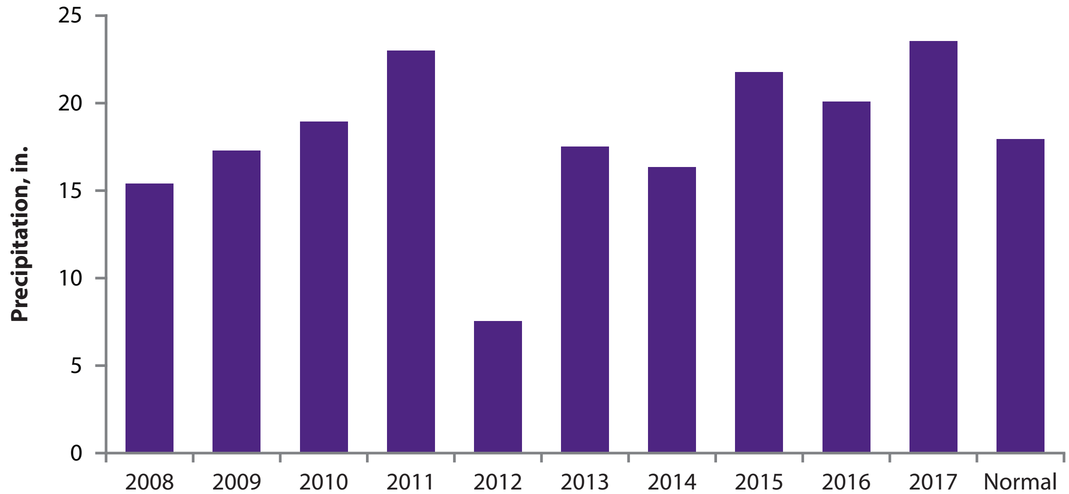

Figure 1. Annual (2008-2017) and normal precipitation (1981-2010, last bar), Tribune, KS.

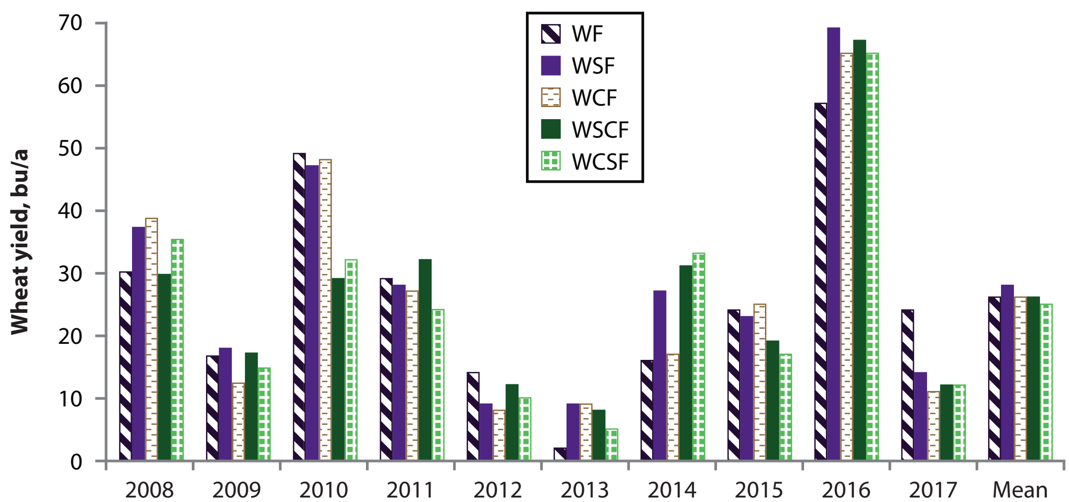

Figure 2. Wheat yields by cropping system, 2008-2017. Last set of columns are treatment means. Wheat-fallow (WF), wheat-sorghum-fallow (WSF), wheat-corn-fallow (WCF), wheat-corn-sorghum-fallow (WCSF), and wheat-sorghum-corn-fallow (WSCF).

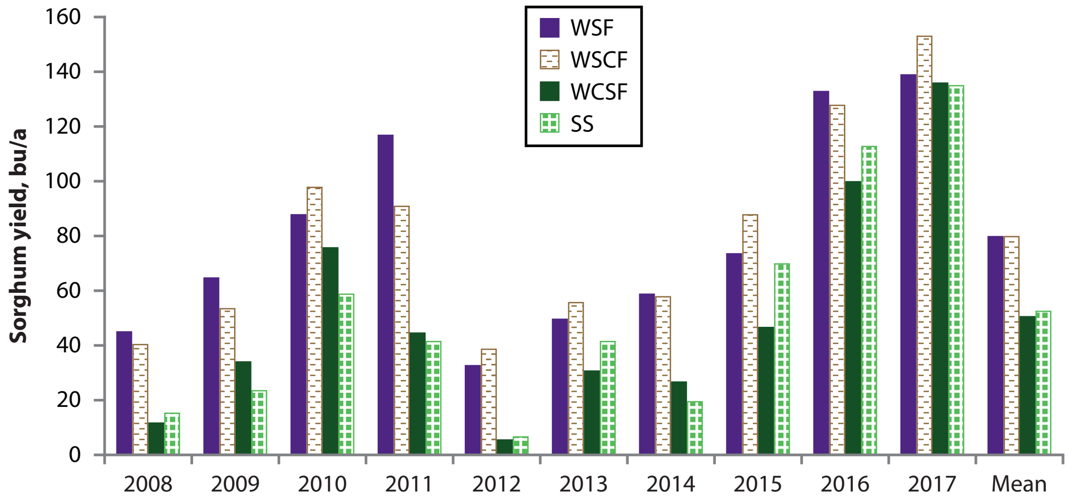

Figure 3. Grain sorghum yields by cropping system, 2008-2017. Last set of columns are treatment means. Wheat-sorghum-fallow (WSF), wheat-sorghum-corn-fallow (WSCF), wheat-corn-sorghum-fallow (WCSF), and continuous grain sorghum (SS).

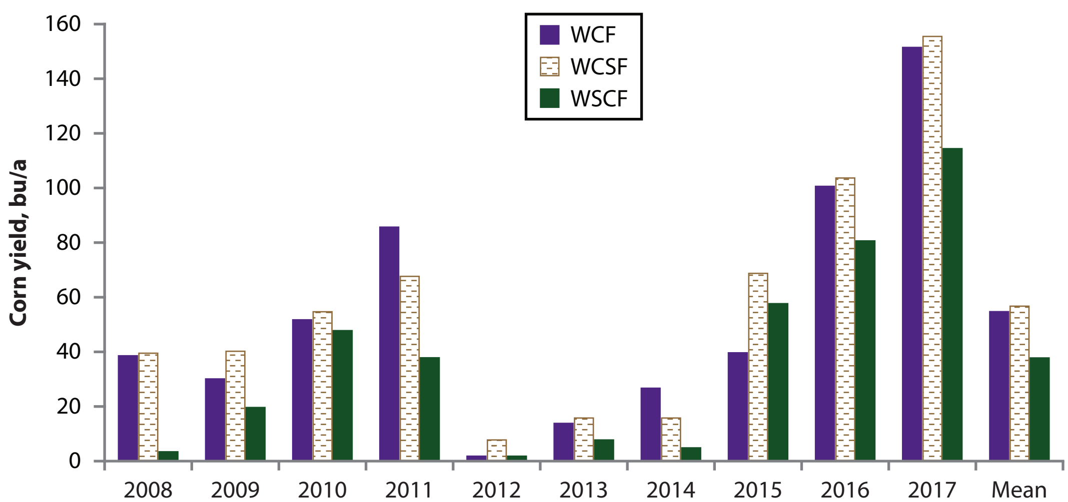

Figure 4. Corn yields by cropping system, 2008-2017. Last set of columns are treatment means. Wheat-corn-fallow (WCF), wheat-corn-sorghum-fallow (WCSF), and wheat-sorghum-corn-fallow (WSCF)

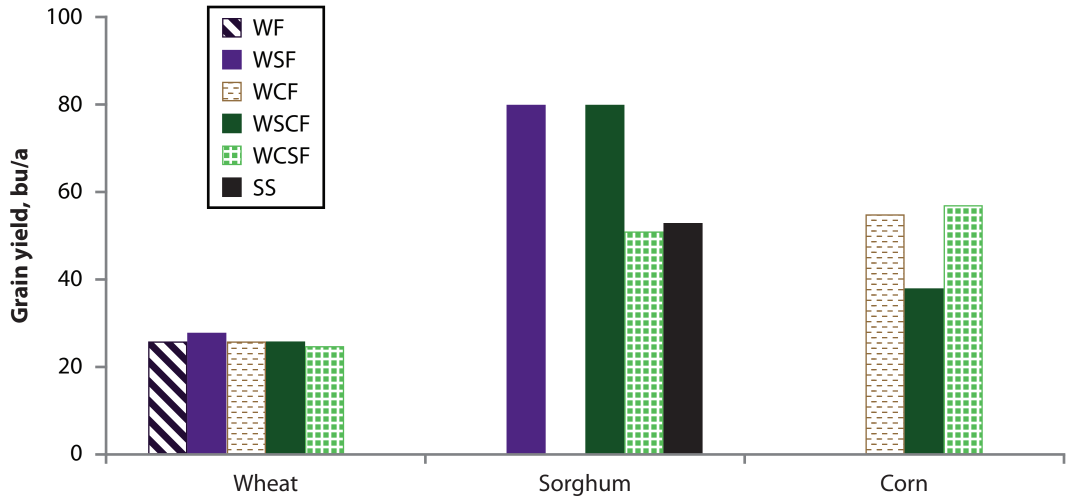

Figure 5. Average grain yields by cropping system, 2008-2017. Wheat-fallow (WF), wheat-sorghum-fallow (WSF), wheat-corn-fallow (WCF), wheat-sorghum-corn-fallow (WSCF), wheat-corn-sorghum-fallow (WCSF), and continuous grain sorghum (SS).

Tillage Intensity in a Long-Term Wheat-Sorghum-Fallow Rotation

A. Schlegel

Summary
This study was initiated in 1991 at the Kansas State University Southwest Research-Extension Center near Tribune, KS. The purpose of the study was to identify the effects of tillage intensity on precipitation capture, soil water storage, and grain yield in a wheat-sorghum-fallow rotation. Grain yields of wheat and grain sorghum increased with decreased tillage intensity in a wheat-sorghum-fallow (WSF) rotation. In 2017, available soil water at sorghum planting was greater for reduced tillage (RT) than no-tillage (NT) or conventional tillage (CT). For wheat there were no differences in available soil water at planting. Averaged across the 17-yr study, available soil water at wheat planting was similar for RT and NT and about 1 inch greater than CT. For sorghum, average available soil water at planting was greater in the order RT>NT>CT. Averaged across the past 17 years, NT wheat yields were 4 bu/a greater than RT and 6 bu/a greater than CT. Grain sorghum yields in 2017 were similar for long-term NT and short-term NT while greater than CT. Averaged across the past 17 years, sorghum yields with long-term NT have been 57% greater than with short-term NT (74 vs. 47 bu/a).

Experimental Procedures
Research on different tillage intensities in a WSF rotation at the Tribune, KS, unit of the Southwest Research-Extension Center was initiated in 1991. The three tillage intensities in this study are conventional (CT), reduced (RT), and no-tillage (NT). The CT system was tilled as needed to control weed growth during the fallow period. On average, this resulted in 4 to 5 tillage operations per year, usually with a blade plow or field cultivator. The RT system originally used a combination of herbicides (1 to 2 spray operations) and tillage (2 to 3 tillage operations) to control weed growth during the fallow period; however, in 2001, the RT system was changed to using NT from wheat harvest through sorghum planting (short-term NT) and CT from sorghum harvest through wheat planting. The NT system exclusively used herbicides to control weed growth during the fallow period. All tillage systems used herbicides for in-crop weed control.

Results and Discussion
Soil Water
The amount of available water in the soil profile (0 to 8 ft) at wheat planting varied greatly from year to year (Figure 1). In 2017, available soil water at wheat planting was greater with RT than NT and least with CT. Averaged across the 16-yr study, available soil water at wheat planting was similar for RT and NT (about 7 inches) and about 1 inch greater than CT.

Similar to wheat, the amount of available water in the soil profile at sorghum planting varied greatly from year to year (Figure 2). In 2017, available soil water at sorghum planting was greater with RT than NT and least with CT. On average, available soil water at sorghum planting was greater with RT than NT and NT was greater than CT.

Grain Yields

Wheat yields in 2017 were low because of severe infestation of wheat streak mosaic (Table 1). Since 2001, wheat yields have been depressed in 11 of 17 years, primarily because of lack of precipitation, while winterkill reduced yields in 2015 and disease in 2017. Reduced tillage and NT increased wheat yields. On average, wheat yields were 6 bu/a higher for NT (23 bu/a) than CT (17 bu/a). Wheat yields for RT were 2 bu/a greater than CT even though both systems had tillage prior to wheat. Yields of NT were significantly less than CT or RT in only 1 of the 17 years.

Grain sorghum yields in 2017 were more than twice as high as the long-term average (Table 2). Sorghum yields were similar for NT and RT with both being greater than CT. The yield benefit from reducing tillage is greater for grain sorghum than wheat. Grain sorghum yields for RT averaged 17 bu/a more than CT, whereas NT averaged 27 bu/a more than RT. For sorghum, both RT and NT used herbicides for weed control during fallow, so the difference in yield could be attributed to short-term compared with long-term NT. This yield benefit with long-term vs. short-term NT has been observed in most years since the RT system was changed in 2001. Averaged across the past 17 years, sorghum yields with long-term NT have been 57% greater than with short-term NT (74 vs. 47 bu/a).

Acknowledgment

The U.S. Department of Agriculture, Agricultural Research Service Ogallala Aquifer Program partially supported this research project.

Table 1. Wheat response to tillage in a wheat-sorghum-fallow rotation, Tribune, KS, 2001–2017

	Tillage				ANOVA (*P* > *F*)		
Year	Conventional	Reduced	No-tillage	LSD (0.05)	Tillage	Year	Tillage × year
	------------------------- bu/a -------------------------						
2001	17	40	31	8	0.002		
2002	0	0	0	---	---		
2003	22	15	30	7	0.007		
2004	1	2	4	2	0.001		
2005	32	32	39	12	0.360		
2006	0	2	16	6	0.001		
2007	26	36	51	15	0.017		
2008	21	19	9	14	0.142		
2009	8	10	22	9	0.018		
2010	29	35	50	8	0.002		
2011	22	20	20	7	0.649		
2012	0	1	5	1	0.001		
2013	0	0	0	---	---		
2014	10	11	18	12	0.336		
2015	10	9	9	9	0.966		
2016	72	85	82	18	0.239		
2017	13	12	12	9	0.970		
Mean	17c	19b	23a	2	0.001	0.001	0.001

ANOVA = analysis of variance.
LSD = least significant difference.

Table 2. Grain sorghum response to tillage in a wheat-sorghum-fallow rotation, Tribune, KS, 2001–2017

	Tillage				ANOVA ($P > F$)		
Year	Conventional	Reduced	No-tillage	LSD (0.05)	Tillage	Year	Tillage × year
	------------------------- bu/a -------------------------						
2001	6	43	64	7	0.001		
2002	0	0	0	---	---		
2003	7	7	37	8	0.001		
2004	44	67	118	14	0.001		
2005	28	38	61	35	0.130		
2006	4	3	29	10	0.001		
2007	26	43	62	42	0.196		
2008	16	25	40	20	0.071		
2009	19	5	72	31	0.004		
2010	10	26	84	9	0.001		
2011	37	78	113	10	0.001		
2012	0	0	0	---	---		
2013	37	51	78	32	0.053		
2014	38	72	94	28	0.008		
2015	56	60	102	55	0.153		
2016	55	124	139	47	0.010		
2017	121	163	159	33	0.038		
Mean	30c	47b	74a	5	0.001	0.001	0.001

ANOVA = analysis of variance.
LSD = least significant difference.

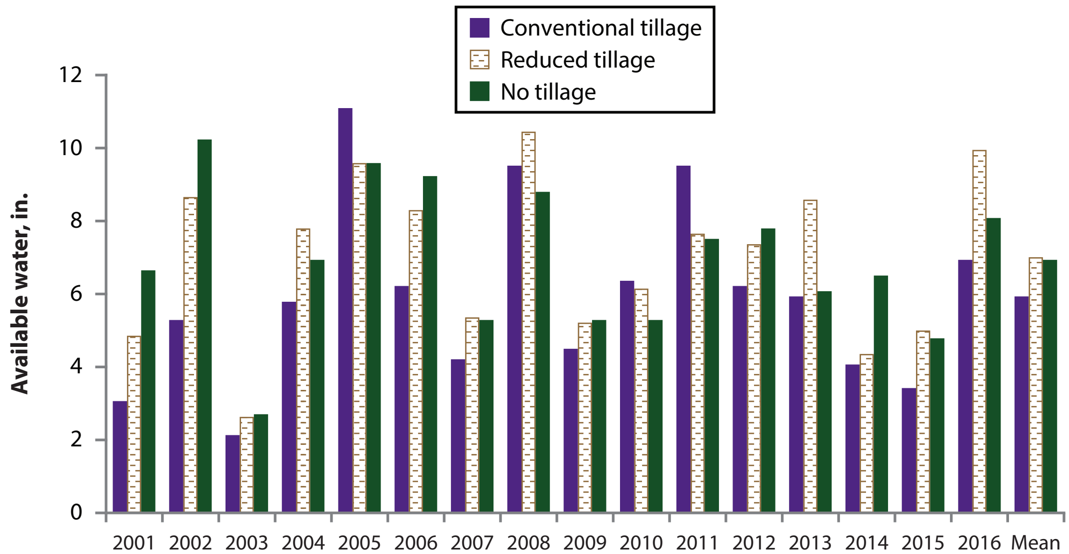

Figure 1. Available soil water in 8-ft profile at planting of wheat in a wheat-sorghum-fallow rotation as affected by tillage intensity, Tribune, KS, 2001–2017. The last set of bars (mean) is the average across years.

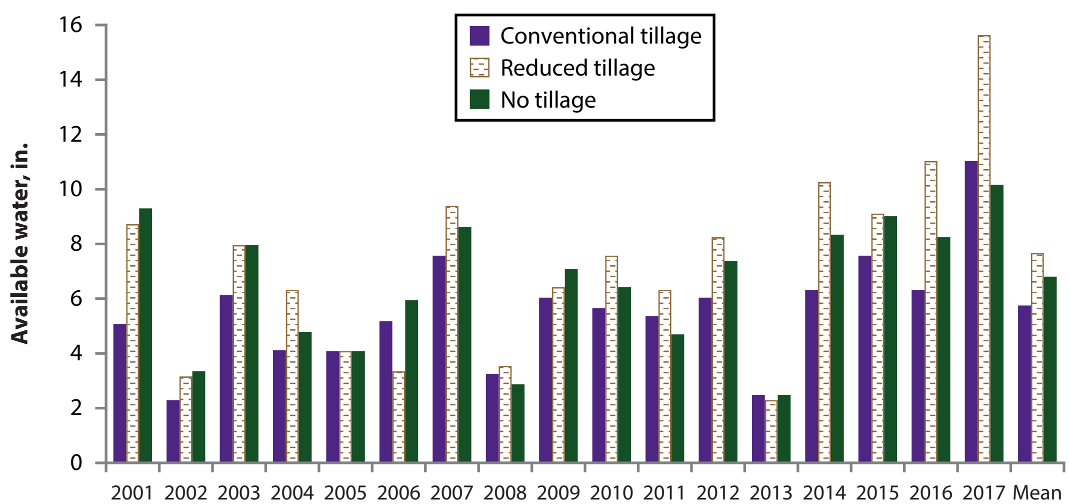

Figure 2. Available soil water in 8-ft profile at planting of grain sorghum in a wheat-sorghum-fallow rotation as affected by tillage intensity, Tribune, KS, 2001–2017. The last set of bars (mean) is the average across years.

Wheat and Grain Sorghum in Four-Year Rotations

A. Schlegel, J. Holman, and C. Thompson

Summary
In 1996, an effort began to quantify soil water storage, crop water use, and crop productivity on dryland systems in western Kansas. Research on 4-year crop rotations with wheat and grain sorghum was initiated at the Southwest Research-Extension Center near Tribune, KS. Rotations were wheat-wheat-sorghum-fallow (WWSF), wheat-sorghum-sorghum-fallow (WSSF), and continuous wheat (WW). Soil water at wheat planting averaged about 9 in. following sorghum, which is about 3 in. more than the average for the second wheat crop in a WWSF rotation. Soil water at sorghum planting was only about 1 in. less for the second sorghum crop compared with sorghum following wheat. Grain yield of recrop wheat averaged about 80% of the yield of wheat following sorghum. Grain yield of continuous wheat averaged about 60% of the yield of wheat grown in a 4-year rotation following sorghum. Generally, wheat yields were similar following one or two sorghum crops. Similarly, average sorghum yields were the same following one or two wheat crops. Yield of the second sorghum crop in a WSSF rotation averages ~65% of the yield of the first sorghum crop.

Introduction
In recent years, cropping intensity has increased in dryland systems in western Kansas. The traditional wheat-fallow system is being replaced by wheat-summer crop-fallow rotations. Research was conducted to better understand if more intensive cropping is feasible with concurrent increases in no-tillage. Objectives of this research were to quantify soil water storage, crop water use, and crop productivity of 4-year and continuous cropping systems.

Experimental Procedures
Research on 4-year crop rotations with wheat and grain sorghum was initiated in 1996 at the Tribune unit of the Southwest Research-Extension Center. Rotations were WWSF, WSSF, and WW. No-tillage was used for all rotations except for the first two years where reduced tillage was used for wheat following sorghum. Available water was measured in the soil profile (0 to 6 ft) at planting and harvest of each crop. The center of each plot was machine harvested after physiological maturity, and yields were adjusted to 12.5% moisture.

Results and Discussion
Soil Water
The amount of available water in the soil profile (0 to 6 ft) at wheat planting varied greatly from year to year (Figure 1). In 2017, available soil water was greater for wheat following sorghum and for wheat following wheat compared to the long-term average. Soil water was similar following fallow after either one or two sorghum crops and averaged about 9 in. across the 21-year study period. Water at planting of the second wheat crop in a WWSF rotation was generally less than at planting of the first wheat crop,

except in 1997 and 2003. Soil water for the second wheat crop averaged more than 3 in. (or about 40%) less than that for the first wheat crop in the rotation. Continuous wheat averaged about 0.8 in. less water at planting than the second wheat crop in a WWSF rotation.

Similar to wheat, the amount of available water in the soil profile at sorghum planting varied greatly from year to year (Figure 2) and available water at sorghum planting was greater than the long-term average. Soil water was similar following fallow after either one or two wheat crops and averaged about 8 in. over 22 years. Water at planting of the second sorghum crop in a WSSF rotation was generally less than that at planting of the first sorghum crop. Averaged across the entire study period, the first sorghum crop had about 1.3 in. more available water at planting than the second crop.

Grain Yields

In 2017, wheat yields were severely decreased by an infestation of wheat streak mosaic virus (Table 1). Averaged across 21 years, recrop wheat (the second wheat crop in a WWSF rotation) yielded about 80% of first-year wheat crop in WWSF. Before 2003, recrop wheat yielded about 70% of first-year wheat. Wheat yields following two sorghum crops are 2 bu/a greater than following one sorghum crop. In most years, continuous wheat yields have been similar to recrop wheat yields, but in several years (2003, 2007, 2009, and 2014), recrop wheat yields were considerably greater than continuous wheat yields.

Sorghum yields in 2017 for all rotations were the highest recorded in the study. Sorghum yields were 64 to 72 bu/a greater than the long-term average (Table 2). Sorghum yields were similar following one or two wheat crops, which is consistent with the long-term average. The second sorghum crop yields were 81% of the first sorghum crop in 2017, which is greater than the long-term average of about 65%.

Table 1. Wheat response to dryland crop rotation, Tribune, KS, 1997–2017

	Rotation					ANOVA (P > F)		
Year	Wssf[1]	Wwsf	wWsf	WW	LSD 0.05	Rotation	Year	Year × rotation
	------- bu/a -------							
1997	57	55	48	43	8	0.017		
1998	70	64	63	60	12	0.391		
1999	74	80	41	43	14	0.001		
2000	46	35	18	18	10	0.001		
2001	22	29	27	34	14	0.335		
2002	0	0	0	0	---	---		
2003	29	27	66	30	14	0.001		
2004	5.7	6.1	0.4	0.5	1.6	0.001		
2005	45	40	41	44	10	0.690		
2006	28	26	7	2	8	0.001		
2007	75	61	63	41	14	0.004		
2008	40	40	5	6	5	0.001		
2009	37	39	50	24	15	0.029		
2010	63	60	29	23	9	0.001		
2011	25	22	25	17	8	0.152		
2012	14	20	10	9	15	0.380		
2013	0	0	0	0	---	---		
2014	51	45	31	12	18	0.004		
2015	49	36	24	24	12	0.001		
2016	78	77	58	52	12	0.001		
2017	20	20	4	6	4	0.001		
Mean	39a	37b	29c	23d	2	0.001	0.001	0.001

[1]W = wheat; S = sorghum; capital letters denote current year's crop.
Wheat-sorghum-sorghum-fallow (WSSF), wheat-wheat-sorghum-fallow (WWSF), and continuous wheat (WW).
ANOVA = analysis of variance.
LSD = least significant difference.

Table 2. Grain sorghum response to crop rotation, Tribune, KS, 1996–2017

	Rotation				ANOVA (P>F)		
Year	wSsf[1]	wsSf	wwSf	LSD 0.05	Rotation	Year	Year × rotation
	---------------------- bu/a ----------------------						
1996	58	35	54	24	0.117		
1997	88	45	80	13	0.001		
1998	117	100	109	12	0.026		
1999	99	74	90	11	0.004		
2000	63	23	67	16	0.001		
2001	68	66	73	18	0.673		
2002	0	0	0	---	---		
2003	60	41	76	18	0.009		
2004	91	79	82	17	0.295		
2005	81	69	85	20	0.188		
2006	55	13	71	15	0.001		
2007	101	86	101	9	0.008		
2008	50	30	57	12	0.005		
2009	89	44	103	53	0.080		
2010	98	52	105	24	0.004		
2011	119	47	105	34	0.005		
2012	0	0	0	---	---		
2013	105	98	100	23	0.742		
2014	91	5	84	29	0.001		
2015	125	82	124	22	0.005		
2016	134	98	139	10	0.001		
2017	147	119	157	15	0.002		
Mean	84a	55b	85a	4	0.001	0.001	0.001

[1]W = wheat; S = sorghum; capital letters denote current year's crop.
Wheat-sorghum-sorghum-fallow (WSSF) and wheat-wheat-sorghum-fallow (WWSF).
ANOVA = analysis of variance.
LSD = least significant difference.

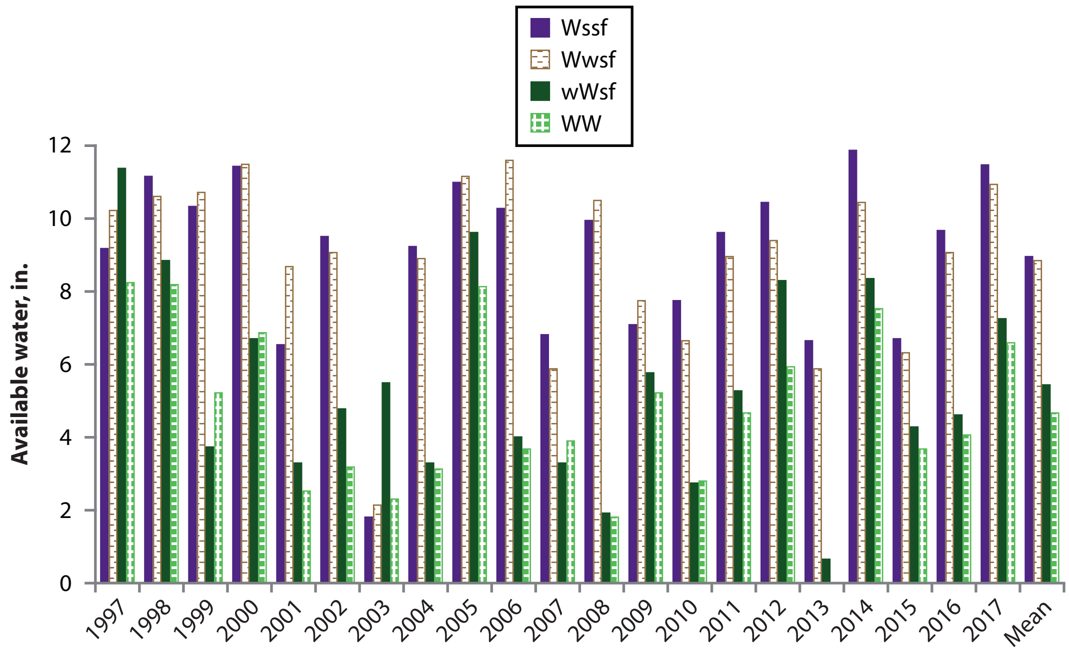

Figure 1. Available soil water in 6-ft profile at planting of wheat in several rotations at Tribune, KS, 1997–2017. Capital letter denotes current crop in rotation (W, wheat; S, sorghum). The last set of bars (Mean) is the average across years. Wheat-sorghum-sorghum-fallow (WSSF), wheat-wheat-sorghum-fallow (WWSF), and continuous wheat (WW).

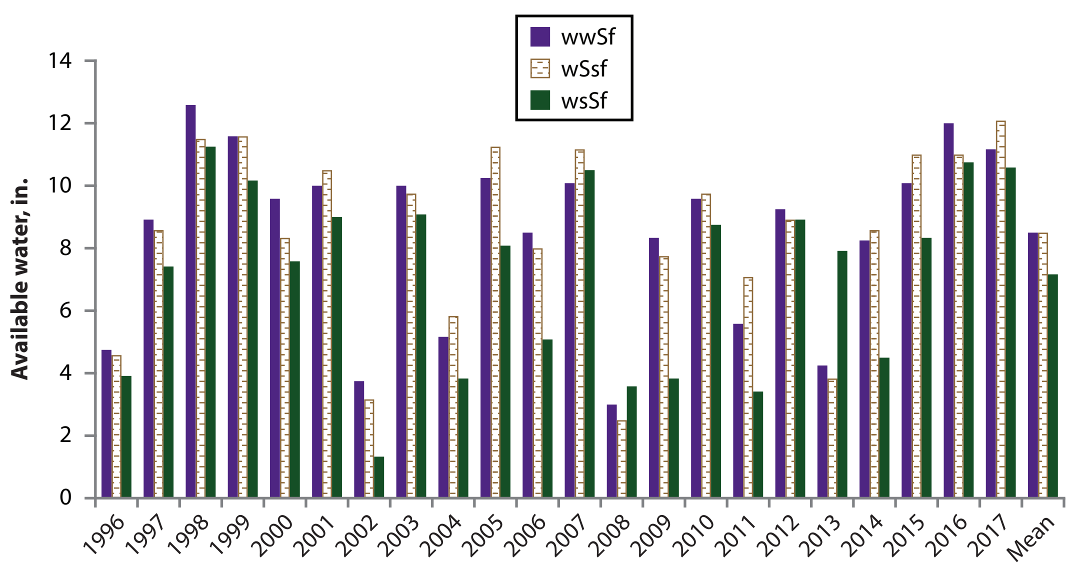

Figure 2. Available soil water in 6-ft profile at planting of sorghum in several rotations at Tribune, KS, 1996–2017. Capital letter denotes current crop in rotation (W, wheat; S, sorghum). The last set of bars (Mean) is the average across years. Wheat-sorghum-sorghum-fallow (WSSF) and wheat-wheat-sorghum-fallow (WWSF).

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Grain Sorghum

A. Schlegel and D. Bond

Summary
Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated grain sorghum in western Kansas. In 2017, N applied alone increased yields 53 bu/a, whereas N and P applied together increased yields up to 67 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields up to 77 bu/a. Application of 80 lb/a of N (with P) was sufficient to produce almost 90% of maximum yield in 2017, which is slightly less than the 10-yr average. Application of potassium (K) has had no effect on sorghum yield throughout the study period. Average grain N content reached a maximum of ~0.7 lb/bu while grain P content reached a maximum of 0.15 lb/bu (0.34 lb P_2O_5/bu) and grain K content reached a maximum of 0.19 lb/bu (0.23 lb K_2O/bu). At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 32% for N, 66% for P, and 39% for K.

Introduction
This study was initiated in 1961 to determine responses of continuous grain sorghum grown under flood irrigation to N, P, and K fertilization. The study is conducted on a Ulysses silt loam soil with an inherently high K content. The irrigation system was changed from flood to sprinkler in 2001.

Procedures
This field study is conducted at the Tribune, KS, unit of the Kansas State University Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a of N without P and K; with 40 lb/a of P_2O_5 and zero K; and with 40 lb/a of P_2O_5 and 40 lb/a of K_2O. All fertilizers are broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. Sorghum (Pioneer 85G46 in 2008–2011, Pioneer 84G62 in 2012-2014, Pioneer 86G32 in 2015, and Pioneer 84G62 in 2016 and 2017) was planted in late May or early June. Irrigation is used to minimize water stress. Sprinkler irrigation has been used since 2001. The center two rows of each plot are machine harvested after physiological maturity. Grain yields are adjusted to 12.5% moisture. Grain samples were collected at harvest, dried, ground and analyzed for N, P, and K concentrations. Grain N, P, and K content (lb/bu) and removal (lb/a) were calculated. Apparent fertilizer N recovery in the grain ($AFNR_g$) was calculated as N uptake in treatments receiving N fertilizer minus N uptake in the unfertilized control divided by N rate. The same approach was used to calculate apparent fertilizer P recovery in the grain ($AFPR_g$) and apparent fertilizer K recovery ($AFKR_g$). Aerial application for grasshoppers was applied on July 18 and hail damage occurred on August 18.

Results

Grain sorghum yields in 2017 were 8% lower than the 10-year average (Table 1). Nitrogen alone increased yields 53 bu/a while P alone increased yields less than 10 bu/a. However, N and P applied together increased yields up to 67 bu/a. Averaged across the past 10 years, N and P applied together increased yields up to 77 bu/a. In 2017, 40 lb/a of N (with P) produced about 88% of the maximum yield, which is greater than the 10-year average of 83%. The 10-year average for 80 lb/a of N (with P) and 120 lb/a of N (with P) was 93 and 95% of the maximum yield, respectively. Sorghum yields were not affected by K fertilization, which has been the case throughout the study period.

The 10-year average grain N concentration (%) increased with N rates but tended to decrease when P was also applied, presumably because of higher grain yields diluting N content (Table 2). Grain N content reached a maximum of ~0.7 lb/bu. Maximum N removal (lb/a) was obtained with 160 lb of N/a or greater with P. Similar to N, average P concentration increased with P application but decreased with higher N rates. Grain P content (lb/bu) of ~0.15 lb P/bu (0.34 lb P_2O_5/bu) was similar for all N rates when P was applied. Grain P removal was similar for all N rates of 40 lb/a or greater with P removal ranging from 18 to 22 lb/a. Average K concentration (%) and content (lb/bu) tended to decrease with increased N rates. Similar to P, K removal was similar for all N rates of 40 lb/a or greater plus K ranging from 22 to 26 lb/a. At the highest N, P, and K rate, apparent fertilizer recovery in the grain was 32% for N, 66% for P, and 39% for K.

Acknowledgment

The International Plant Nutrition Institute partially supported this research project.

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2008-2017

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
---------- lb/a ----------			---------- bu/a ----------										
0	0	0	66	64	51	75	78	62	90	89	80	70	73
0	40	0	60	70	51	83	90	77	94	102	91	79	80
0	40	40	65	76	55	88	93	72	96	97	91	80	81
40	0	0	92	84	66	106	115	94	115	122	106	87	99
40	40	0	111	118	77	121	140	114	144	160	142	120	125
40	40	40	105	109	73	125	132	110	142	155	137	118	121
80	0	0	114	115	73	117	132	102	120	133	120	104	113
80	40	0	128	136	86	140	163	136	151	173	154	123	139
80	40	40	126	108	84	138	161	133	164	178	160	129	138
120	0	0	106	113	70	116	130	100	116	127	108	93	108
120	40	0	131	130	88	145	172	137	162	177	164	121	143
120	40	40	136	136	90	147	175	142	170	178	170	131	147
160	0	0	105	108	74	124	149	117	139	150	135	120	122
160	40	0	138	128	92	152	178	146	171	181	173	137	150
160	40	40	133	140	88	151	174	143	176	179	161	131	147
200	0	0	120	110	78	128	147	119	139	155	151	123	127
200	40	0	137	139	84	141	171	136	165	177	167	131	145
200	40	40	135	129	87	152	175	138	170	179	170	131	147

continued

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2008-2017

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
---------- lb/a ----------			bu/a										
ANOVA (P>F)													
Nitrogen			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
P-K			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zero P vs. P			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
P vs. P-K			0.745	0.324	0.892	0.278	0.826	0.644	0.117	0.806	0.943	0.727	0.932
N × P-K			0.005	0.053	0.229	0.542	0.186	0.079	0.012	0.002	0.001	0.084	0.006
Means													
Nitrogen, lb/a													
0			64d	70c	52c	82d	87d	70d	94e	96d	87d	76d	78d
40			103c	104b	72b	117c	129c	106c	134d	146c	129c	108c	115c
80			123b	120a	81a	132b	152b	124b	145c	161b	145b	119b	130b
120			124ab	126a	82a	136ab	159ab	126b	149bc	161b	147b	115bc	133b
160			125ab	125a	84a	142a	167a	135a	162a	170a	156a	129a	140a
200			131a	126a	83a	141a	165a	131ab	158ab	170a	163a	129a	140a
$LSD_{(0.05)}$			7	11	5	8	9	8	9	8	8	9	6
P_2O_5-K_2O, lb/a													
0 - 0			101b	99b	68b	111b	125b	99b	120b	129b	117b	99b	107b
40 - 0			117a	120a	80a	130a	152a	124a	148a	162a	149a	119a	130a
40 - 40			117a	116a	79a	133a	152a	123a	153a	161a	148a	120a	130a
$LSD_{(0.05)}$			5	7	4	6	6	5	6	5	6	6	4

Table 2. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on grain N, P, and K content of irrigated grain sorghum, Tribune, KS, 2008-2017

Fertilizer			Grain						Grain removal					
N	P_2O_5	K_2O	N	P	K	N	P	K	N	P	K	*$AFNR_g$	*$AFPR_g$	*$AFKR_g$
---------- lb/a ----------			------------- % -------------			----------- lb/bu -----------			----------- lb/a ----------			------------- % -------------		
0	0	0	1.02	0.263	0.361	0.50	0.129	0.177	36	9	13	---	---	---
0	40	0	1.01	0.315	0.385	0.50	0.154	0.189	39	12	15	---	18	---
0	40	40	1.01	0.312	0.382	0.50	0.153	0.187	40	12	15	---	18	7
40	0	0	1.13	0.239	0.345	0.55	0.117	0.169	54	11	17	45	---	---
40	40	0	1.09	0.318	0.373	0.53	0.156	0.183	66	19	23	76	58	---
40	40	40	1.10	0.311	0.370	0.54	0.152	0.181	64	18	22	70	52	27
80	0	0	1.33	0.223	0.339	0.65	0.109	0.166	73	12	19	47	---	---
80	40	0	1.22	0.298	0.357	0.60	0.146	0.175	82	20	24	58	63	---
80	40	40	1.18	0.306	0.360	0.58	0.150	0.176	79	21	24	54	66	35
120	0	0	1.39	0.210	0.336	0.68	0.103	0.164	73	11	18	31	---	---
120	40	0	1.32	0.286	0.354	0.65	0.140	0.174	92	20	25	46	61	---
120	40	40	1.32	0.306	0.358	0.64	0.150	0.175	95	22	26	49	73	39
160	0	0	1.41	0.233	0.345	0.69	0.114	0.169	84	14	21	30	---	---
160	40	0	1.38	0.307	0.361	0.68	0.150	0.177	101	22	26	41	76	---
160	40	40	1.35	0.286	0.353	0.66	0.140	0.173	97	20	25	38	64	38
200	0	0	1.42	0.238	0.349	0.70	0.117	0.171	88	15	22	26	---	---
200	40	0	1.39	0.285	0.357	0.68	0.140	0.175	98	20	25	31	63	---
200	40	40	1.39	0.291	0.359	0.68	0.143	0.176	99	21	26	32	66	39

continued

Table 2. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers on grain N, P, and K content of irrigated grain sorghum, Tribune, KS, 2008-2017

Fertilizer	Grain						Grain removal					
N P_2O_5 K_2O	N	P	K	N	P	K	N	P	K	*$AFNR_g$	*$AFPR_g$	*$AFKR_g$
---------- lb/a ----------	------------- % -------------			----------- lb/bu -----------			----------- lb/a ----------			------------- % -------------		
ANOVA (P>F)												
Nitrogen	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic	0.001	0.005	0.001	0.001	0.005	0.001	0.001	0.001	0.001	0.094	0.001	0.001
P-K	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.911	---
Zero P vs. P	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	---	---	---
P vs. P-K	0.363	0.900	0.680	0.363	0.900	0.680	0.614	0.922	0.925	---	---	---
N × P-K	0.285	0.009	0.231	0.285	0.009	0.231	0.080	0.001	0.003	0.029	0.093	---
Means												
Nitrogen, lb/a												
0	1.01e	0.297a	0.376a	0.50e	0.146a	0.184a	38e	11d	14d	---	18c	7c
40	1.11d	0.289a	0.363b	0.54d	0.142a	0.178b	61d	16c	20c	64a	55b	27b
80	1.24c	0.276b	0.352c	0.61c	0.135b	0.172c	78c	18ab	22b	53b	64a	35a
120	1.34b	0.267b	0.349c	0.66b	0.131b	0.171c	86b	18bc	23b	42c	67a	39a
160	1.38ab	0.275b	0.353c	0.68ab	0.135b	0.173c	94a	19a	24a	36d	70a	38a
200	1.40a	0.272b	0.355c	0.68a	0.133b	0.174c	95a	19ab	24a	29e	64a	39a
$LSD_{(0.05)}$	0.04	0.012	0.006	0.02	0.006	0.003	4	1	1	6	8	5
P_2O_5-K_2O, lb/a												
0 - 0	1.28a	0.234b	0.346b	0.63a	0.115b	0.169b	68b	12b	18b	36b	---	---
40 - 0	1.24b	0.302a	0.365a	0.61b	0.148a	0.179a	80a	19a	23a	50a	56	---
40 - 40	1.22b	0.302a	0.364a	0.60b	0.148a	0.178a	79a	19a	23a	48a	56	---
$LSD_{(0.05)}$	0.03	0.008	0.004	0.01	0.004	0.002	3	1	1	5	5	---

*$AFNR_g$, $AFPR_g$, and $AFKR_g$ = Apparent Fertilizer N Recovery (grain), Apparent Fertilizer P Recovery (grain), and Apparent Fertilizer K Recovery (grain).

Seeding Rate for Dryland Wheat

A. Schlegel, J. Holman, and L. Haag

Summary
Four winter wheat varieties (PlainsGold Byrd, Limagrain T158, Syngenta TAM 111, and WestBred Winterhawk) were planted at five seeding rates (30, 45, 60, 75, and 90 lb/a) in the fall of 2014, 2015, and 2016 at Colby, Garden City, and Tribune, KS. The objective of the study is to identify appropriate seeding rates for dryland winter wheat in western Kansas. Averaged across varieties, a seeding rate of 60 lb/a seemed to be adequate at all locations in 2015. However, with higher yields in 2016, a higher seeding rate (75 lb/a) was beneficial. Although yields were less in 2017 than 2016, a seeding rate of 75 lb/a generally produced the highest yields. The wheat variety T158 was the highest yielding (or in the highest group) at all locations in 2015. Other varieties may have been affected by differential response to stripe rust and winter injury resulting in lower yields. In 2016, the highest yielding variety varied by location. TAM 114 was in the highest yielding variety at each location in 2017. Variety selection and growing season appears to have more effect on wheat yields than seeding rate.

Introduction
The purpose of this project is to determine appropriate seeding rates for dryland winter wheat in western Kansas. In recent years, there appears to be an increase in seeding rate without corresponding increase in grain yields. A preliminary study conducted in 2014 found no yield benefit from increasing seeding rates from 30 to 75 lb seed/a for 4 wheat varieties at Tribune, while a similar study at Garden City suffered severe hail damage causing yields to be less than 10 bu/a. The objective is to evaluate seeding rates on grain yield of several popular wheat varieties representing a range of genetic backgrounds and tillering ability under dryland conditions at three sites in western Kansas.

Experimental Procedures
Four winter wheat varieties (Byrd, T158, TAM111, and Winterhawk) were planted at five seeding rates (30, 45, 60, 75, and 90 lb/a) in the fall of 2014 to 2016 at Colby, Garden City, and Tribune, KS. The date of seeding was October 20, 2014, October 14, 2015, and October 10, 2016 at Colby; October 9, 2014, October 9, 2015, and October 14, 2016 at Garden City; and September 26, 2014, October 13, 2015, and October 5, 2016 at Tribune. Seed size in 2015 was 15,839, 15,479, 17,627, and 12,921 seed/lb for Byrd, T158, TAM 111, and Winterhawk, respectively. All plots were planted on no-till fallow land. Harvest was done on July 4, 2015, July 10, 2016, and July 1, 2017 at Colby, June 29, 2015, June 22, 2016, and July 6, 2017 at Garden City, and June 30, 2015, July 4, 2016, and June 28, 2017 at Tribune. Growing season precipitation (October through June) for 2015 wheat was 14.03 in. at Colby, 12.18 in. at Garden City, and 12.83 in. at Tribune. For 2016, growing season precipitation was 12.36 in. at Colby, 11.31 in. at Garden City, and 14.32 in. at Tribune. For 2017, growing season precipitation was 16.05 in. at Colby, 11.14 in. at Garden City, and 14.89 in. at Tribune. Starter fertilizer was applied (5.5-26-0 (nitrogen, N; phosphorus, P; and potassium, K)) at Garden City and (6-20-0) at Tribune each year. The wheat was topdressed with 90 lb N/a at Colby, 30 lb N/a at Garden City, and 60 lb N/a at Tribune in 2015. In 2016, wheat

was fertilized pre-plant with 90 lb N/a at Colby, and topdressed with 100 lb N/a at Garden City, and 80 lb N/a at Tribune. In 2017, wheat was fertilized pre-plant with 60 lb N/a at Colby, and topdressed with 80 lb N/a at Garden City, and 80 lb N/a at Tribune. Herbicides were applied in the spring for weed control: Ally Extra (0.5 oz/a) at Colby in 2015, Huskie (15 oz/a) + Dicamba (2 oz/a) + Zidua (2 oz/a) in 2016, and Rave (4 oz/a) in 2017; Starane Ultra (0.4 pt/a) + MCPA (0.75 pt/a) + Ally (0.1 oz/a) at Garden City in 2015 to 2017; and dicamba (4 oz/a) + Ally (0.1 oz/a) at Tribune in 2015 to 2017. Plot size was 7.5 × 30 ft at Garden City, and 5 or 6 × 40 ft at Colby and Tribune. Fungicide was applied for control of stripe rust at flag leaf emergence at Colby and Tribune in 2016 and Colby in 2017. All treatments were replicated four times. Grain yields were determined by harvesting with a plot combine with moisture corrected to 13%.

Results and Discussion

Growing season precipitation was below normal for Garden City all years, but normal to above normal for Tribune and Colby. In addition, precipitation was infrequent and variable across the growing seasons. In 2015, precipitation was high in May (6.38 in. in Garden City, 6.16 in. at Tribune, and 6.42 in. at Colby) making up for a dry winter and early spring. For 2016, rainfall was above normal for Tribune, slightly below normal for Garden City, and below normal at Colby. April was wet with 5.16 in. at Tribune, 4.59 in. at Garden City, and 5.64 in. at Colby. In 2017, precipitation was above average at Tribune for April (4.67 in.) and May (5.00 in.), however, wheat streak mosaic virus reduced grain yield. At Garden City conditions were very dry in the fall of 2016 (0.3 in. between October and January), and the majority of the precipitation (6.58 in.) occurred in March and April. At Colby, conditions were extremely dry at seeding time followed by above normal precipitation in the late spring. A blizzard event on April 30 to May 1, 2017 resulted in the wheat being completely laid flat at the boot stage at Tribune and Colby with 14-20 inches of snow on top.

In 2015, averaged across seeding rates at Tribune, T158 and Winterhawk produced the greatest yields with TAM 111 producing the lowest yields (Table 1). At Colby and Garden City in 2015, T158 produced significantly higher yields than all other varieties. Stripe rust was prevalent in the 2015 growing season. Resistance ratings from the Kansas State University Department of Plant Pathology (publication MF991, Wheat Variety Disease and Insect Ratings 2016, E.D. Dewolf, R. Lollato, and R.J. Whitworth.), with a scale of 1 being resistant to 10 being susceptible, were 8, 2, 8, and 6 for Byrd, T158, TAM111, and Winterhawk, respectively. Stripe rust infestation and associated yield reductions at Colby (and other locations) were consistent with these ratings.

At all sites averaged across varieties in 2015, there was a positive yield response to increased seeding rates with greatest response when increasing from 30–60 lb/a with minimal response above 60 lb/a.

Wheat yields were very good at all locations in 2016 (Table 2). The response to variety and seeding rate varied greatly across locations. Averaged across seeding rates, Byrd produced the greatest yields at Tribune while it produced the lowest yields at Garden City. Winterhawk and T158 were the lowest yielding at Tribune while they were the highest yielding at Garden City and Colby. There was a significant positive yield response to increased seeding rate at Tribune and Colby but no significant response to seeding rate at Garden City.

Wheat yields were increased by increased seeding rates at all locations in 2017 (Table 3). Wheat yields were the lowest at Tribune (significant wheat streak mosaic virus damage) and greatest at Colby. TAM 114 was in the highest yielding group at all locations. The ranking of the other varieties depended upon location. The dry fall conditions in 2016 at Garden City likely reduced tiller development, resulting in reduced wheat yields at seeding rates less than 60 lb/a. Relative differences in growth stage among varieties at the time of the late spring blizzard may have affected their yield potential, however this was very difficult to assess.

Averaged across years (2015–2017), T158 was the highest yielding variety at Garden City and Colby (Table 4). Byrd was the highest yielding variety at Tribune, but the lowest yielding at the other two locations. At all locations, grain yields were increased by increased seeding rate. When averaged across all locations and years, yields were increased 8 bu/a by increasing seeding rate from 30 to 60 lb/a and an additional 3 bu/a when seeding rate was increased to 90 lb/a. There was not a significant variety × seeding rate interaction as all varieties responded positively to increased seeding rate. These results support a previous Kansas State University recommendation that the economic optimum seeding rate for rainfed winter wheat production in western Kansas is 60 lb/a, while the highest yield can be obtained with a 75 lb/a seeding rate.

In 11 site-years of this study, the variety × seeding rate interaction has only been significant in 2 of 11 years. At those two site years (Garden City and Tribune, 2015), increasing seeding rates resulted in increased yield for stripe rust-susceptible varieties. We hypothesize that higher seeding rates in the stripe rust-susceptible varieties partially compensated for lower per plant grain yield due to stripe-rust reducing productive leaf area. In general, the data collected in this study would not support the need for variety-specific seeding rate recommendations.

Table 1. Dryland wheat response to variety and seeding rate at three locations in 2015

Variety	Seeding rate	Grain yield			
		Tribune	Garden City	Colby	Average
	lb/a	----------------------------	bu/a	----------------------------	
Byrd	30	47	38	23	36
	45	52	42	25	40
	60	60	50	27	46
	75	53	51	29	45
	90	58	53	28	46
T158	30	58	72	45	59
	45	60	71	53	61
	60	64	79	56	67
	75	69	71	53	65
	90	71	65	55	64
TAM 111	30	39	34	20	31
	45	40	40	25	35
	60	43	44	28	39
	75	46	50	32	43
	90	44	52	34	43
Winterhawk	30	60	31	21	37
	45	66	41	25	44
	60	68	42	29	47
	75	64	51	34	50
	90	67	50	35	51

continued

Table 1. Dryland wheat response to variety and seeding rate at three locations in 2015

Variety	Seeding rate	Grain yield Tribune	Garden City	Colby	Average
	lb/a	bu/a			
ANOVA (P>F)					
Variety		0.001	0.001	0.001	0.001
Seeding rate		0.001	0.001	0.001	0.001
Variety × seeding rate		0.046	0.001	0.731	0.124
Location					0.001
Location × variety					0.001
Location × seeding rate					0.743
Location × variety × seeding rate					0.001
Means[1]					
Variety					
Byrd		54b	47b	26b	43c
T158		64a	72a	53a	63a
TAM 111		42c	44bc	28b	38d
Winterhawk		65a	43c	29b	46b
$LSD_{0.05}$		2	3	3	2
Seeding rate (lb/a)					
30		51c	44c	27c	41c
45		55b	49b	32b	45b
60		59a	54a	35ab	49a
75		58a	56a	37a	50a
90		60a	55a	38a	51a
$LSD_{0.05}$		3	4	4	2

[1] Means within a column with the same letter are not statistically different at $P = 0.05$.
ANOVA = analysis of variance.
LSD = least significant difference.

Table 2. Dryland wheat response to variety and seeding rate at three locations in 2016

		Grain yield			
Variety	Seeding rate	Tribune	Garden City	Colby	Average
	lb/a	bu/a			
Byrd	30	70	78	89	79
	45	76	79	100	85
	60	81	76	103	87
	75	86	79	116	94
	90	90	78	103	90
T158	30	60	107	102	90
	45	67	109	115	97
	60	69	110	107	95
	75	74	114	111	99
	90	73	115	115	101
TAM 111	30	63	89	95	82
	45	65	91	91	82
	60	72	90	106	89
	75	75	95	108	93
	90	77	96	110	94
Winterhawk	30	61	95	94	83
	45	65	99	100	88
	60	67	101	112	94
	75	70	105	111	95
	90	74	103	114	97

continued

Table 2. Dryland wheat response to variety and seeding rate at three locations in 2016

Variety	Seeding rate	Grain yield Tribune	Grain yield Garden City	Grain yield Colby	Average
	lb/a	bu/a			
ANOVA (P>F)					
Variety		0.001	0.001	0.029	0.001
Seeding rate		0.001	0.205	0.001	0.001
Variety × seeding rate		0.361	0.999	0.190	0.584
Location					0.015
Location × variety					0.001
Location × seeding rate					0.058
Location × variety × seeding rate					0.594
Means[1]					
Variety					
Byrd		81a	78d	102b	90c
T158		68c	111a	110a	96a
TAM 111		71b	92c	102b	88c
Winterhawk		68c	101b	106ab	91b
$LSD_{0.05}$		2	5	6	3
Seeding rate (lb/a)					
30		63d	92	95c	84d
45		68c	95	102b	88c
60		72b	94	107ab	91b
75		76a	98	112a	95a
90		78a	98	111a	96a
$LSD_{0.05}$		2	6	6	3

[1] Means within a column with the same letter are not statistically different at $P = 0.05$.
ANOVA = analysis of variance.
LSD = least significant difference.

Table 3. Dryland wheat response to variety and seeding rate at three locations in 2017

		Grain yield			
Variety	Seeding rate	Tribune	Garden City	Colby	Average
	lb/a	----------------------------	bu/a	----------------------------	
Byrd	30	26	25	47	33
	45	32	33	49	38
	60	29	36	53	40
	75	36	39	52	42
	90	38	35	56	43
T158	30	24	33	67	41
	45	29	40	71	47
	60	29	36	67	44
	75	34	43	75	51
	90	33	48	79	53
TAM 114	30	30	35	70	45
	45	30	41	72	48
	60	33	45	77	52
	75	37	47	72	52
	90	37	44	78	53
Winterhawk	30	24	26	62	37
	45	25	27	69	40
	60	31	38	65	45
	75	32	41	71	48
	90	34	41	74	50

continued

Table 3. Dryland wheat response to variety and seeding rate at three locations in 2017

Variety	Seeding rate	Grain yield: Tribune	Grain yield: Garden City	Grain yield: Colby	Average
	lb/a	bu/a			
ANOVA (P>F)					
Variety		0.014	0.001	0.001	0.001
Seeding rate		0.001	0.001	0.001	0.001
Variety × seeding rate		0.910	0.376	0.400	0.259
Location					0.001
Location × variety					0.001
Location × seeding rate					0.249
Location × variety × seeding rate					0.763
Means[1]					
Variety					
Byrd		32ab	34b	51c	39d
T158		30bc	40a	72a	47b
TAM 111		33a	42a	74a	50a
Winterhawk		29c	34b	68b	44c
$LSD_{0.05}$		3	4	3	2
Seeding rate (lb/a)					
30		26c	30c	61c	39c
45		29bc	35b	65b	43b
60		31b	39ab	66b	45b
75		35a	42a	67b	48a
90		36a	43a	72a	50a
$LSD_{0.05}$		3	4	4	2

[1] Means within a column with the same letter are not statistically different at $P = 0.05$.
ANOVA = analysis of variance.
LSD = least significant difference.

Table 4. Dryland wheat response to variety and seeding rate at three locations from 2015–2017

		Grain yield			
Variety	Seeding rate	Tribune	Garden City	Colby	Average
	lb/a	----------	bu/a	----------	----------
Byrd	30	47	47	53	49
	45	54	51	58	54
	60	57	54	61	57
	75	58	57	66	60
	90	62	55	62	60
T158	30	47	71	71	63
	45	52	73	80	68
	60	54	75	76	69
	75	59	76	79	72
	90	59	76	83	73
TAM 111/114	30	44	53	62	53
	45	45	58	63	55
	60	49	60	70	60
	75	53	64	71	62
	90	53	64	74	64
Winterhawk	30	48	51	59	52
	45	52	56	64	57
	60	55	60	69	62
	75	55	65	72	64
	90	59	65	75	66

continued

Table 4. Dryland wheat response to variety and seeding rate at three locations from 2015–2017

Variety	Seeding rate	Grain yield: Tribune	Garden City	Colby	Average
	lb/a	bu/a			
ANOVA (P>F)					
Variety		0.001	0.001	0.001	0.001
Seeding rate		0.001	0.001	0.001	0.001
Variety × seeding rate		0.305	0.680	0.178	0.306
Year		0.001	0.001	0.001	0.001
Year × variety		0.001	0.001	0.001	0.001
Year × seeding rate		0.013	0.247	0.125	0.521
Year × variety × seeding rate		0.391	0.103	0.327	0.356
Location					0.001
Location × variety					0.001
Location × seeding rate					0.890
Location × variety × seeding rate					0.381
Year × location					0.001
Year × location × variety					0.001
Year × location × seeding rate					0.013
Year × location × variety × seeding rate					0.085
Means[1]					
Variety					
Byrd		56a	53c	60c	56d
T158		54b	74a	78a	69a
TAM 111/114		49c	60b	68b	59c
Winterhawk		54b	59b	68b	60b
$LSD_{0.05}$		1	2	2	1
Seeding rate (lb/a)					
30		47e	55d	61d	54d
45		51d	59c	66c	59c
60		54c	62b	69b	62b
75		56b	65a	72a	65a
90		58a	65ab	73a	66a
$LSD_{0.05}$		2	3	3	1

[1] Means within a column with the same letter are not statistically different at $P = 0.05$.
ANOVA = analysis of variance.
LSD = least significant difference.

Wheat Stubble Height on Subsequent Corn and Grain Sorghum Crops

A. Schlegel and L. Haag

Summary
A field study initiated in 2006 at the Southwest Research-Extension Center near Tribune, KS, was designed to evaluate the effects of three wheat stubble heights on subsequent grain yields of corn and grain sorghum. Corn and sorghum yields in 2017 were greater than the long-term average. When averaged from 2007 through 2017, corn grain yields were 9 bu/a greater when planted into either high or strip-cut stubble than into low-cut stubble. Average grain sorghum yields were 5 bu/a (but not significantly) greater in high-cut stubble than low-cut stubble. Similarly, water use efficiency was greater for high or strip-cut stubble for corn and high-cut stubble for grain sorghum than for low-cut stubble. Harvesting wheat shorter than necessary causes a yield penalty for the subsequent row crops, especially dryland corn.

Introduction
Seeding of summer row crops throughout the west-central Great Plains often occurs following wheat in a 3-year rotation (wheat-summer crop-fallow). Wheat residue provides numerous benefits, including evaporation suppression, delayed weed growth, improved capture of winter snowfall, and soil erosion reductions. Stubble height affects wind velocity profile, surface radiation interception, and surface temperatures, all of which affect evaporation suppression and winter snow catch. Taller wheat stubble is also beneficial to pheasants in postharvest and overwinter fallow periods. Using stripper headers increases harvest capacity and provides taller wheat stubble than previously attainable with conventional small-grains platforms. Increasing wheat cutting heights or using a stripper header should further improve the effectiveness of standing wheat stubble. The purpose of this study is to evaluate the effect of wheat stubble height on subsequent summer row crop yields.

Experimental Procedures
This study was conducted at the Southwest Research-Extension Center dryland station near Tribune, KS. From 2007 through 2017, corn and grain sorghum were planted into standing wheat stubble of three heights. Optimal (high) cutter-bar height is the height necessary to maximize both grain harvested and standing stubble remaining (typically around two-thirds of total plant height), the short cut treatment was half of optimal cutter-bar height, and the third treatment was stubble remaining after stripper header harvest. For 2017, these heights were 20, 10, and 30 in. (cut after 2016 wheat harvest). In 2017, corn and grain sorghum were seeded at rates of 15,000 seeds/a and 45,000 seeds/a, respectively. Nitrogen was applied to all plots at a rate of 80 lb/a. Starter fertilizer (10-34-0 nitrogen–phosphorus–potassium (N-P-K)) was surface-dribbled off-row at a rate of 7 gal/a. Plots were 40 × 60 ft, with treatments arranged in a randomized complete block design with six replications. Two rows from the center of each plot were harvested with a plot combine for yield and yield component analysis. Soil water mea-

surements were obtained with neutron attenuation to a depth of 6 ft in 1-ft increments at seeding and harvest to determine water use and water use efficiency.

Results and Discussion

The 2017 growing season was above normal for precipitation with more than 4 inches received in April, May, and July. This produced above average yields for both corn and sorghum (Tables 1–4). With the good growing conditions, stubble height had little effect on corn yield or other parameters. When averaged across 2007 to 2017, corn yields were 9 bu/a greater in high or strip-cut than low-cut wheat stubble (Table 2). Biomass production and water use efficiency were also greater with the taller stubble.

Grain sorghum yields in 2017 were not affected by stubble height (Table 3). When averaged across years from 2007 through 2017, the highest yields were obtained in the high-cut stubble but were not significantly greater than the other stubble heights (Table 4). None of the other measured parameters for grain sorghum were affected by wheat stubble height except for greater water use efficiency in high-cut vs. low-cut stubble.

Table 1. Corn yield, biomass, and yield components as affected by stubble height, Tribune, KS, 2017

Stubble height	Yield	Plant population	Ear population	Biomass	Residue	1,000-seed weight	Kernels	WUE[1]
	bu/a	----------- 10^3/a -----------		--------- lb/a ---------		oz	no./ear	lb/in.
Low	129	14.0	17.6	16620	10505	13.31b	494	452
High	133	14.5	17.4	15751	9451	13.81ab	498	456
Strip	136	14.3	17.7	17526	11105	14.06a	490	456
$LSD_{0.05}$	8	0.9	0.9	2053	2050	0.54	33	33
ANOVA (P > F)								
Stubble height	0.242	0.411	0.644	0.207	0.239	0.033	0.094	0.957

[1] Water use efficiency (lb of grain/inch of water use).
LSD = least significant difference.
ANOVA = analysis of variance.

Table 2. Corn yield, biomass, and yield components as affected by stubble height, Tribune, KS, 2007–2017

Stubble height	Yield	Plant population	Ear population	Biomass	Residue	1,000-seed weight	Kernels	WUE[1]
	bu/a	----------- 10^3/a -----------		--------- lb/a ---------		oz	no./ear	lb/in.
Low	81b	13.9	13.8	9830b	6001	10.81	518	300b
High	90a	14.0	14.2	10713a	6445	11.11	508	336a
Strip	90a	14.0	14.2	10873a	6591	11.04	539	336a
$LSD_{0.05}$	5	0.4	0.6	626	551	0.28	78	19
ANOVA (P > F)								
Year	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Stubble height	0.001	0.966	0.334	0.002	0.092	0.087	0.731	0.001
Year × stubble height	0.986	0.995	0.978	0.337	0.102	0.830	0.944	0.953

[1] Water use efficiency (lb of grain/inch of water use).
LSD = least significant difference.
ANOVA = analysis of variance.

Table 3. Sorghum yield and yield components as affected by stubble height, Tribune, KS, 2017

Stubble height	Yield	Head population	Biomass	Residue	1,000-seed weight	Kernels	WUE[1]
	bu/a	10^3/a	---------- lb/a ----------		oz	no./head	lb/in
Low	157	79.6	14325b	6613	0.98	1822	548
High	158	81.0	15040a	7321	0.97	1795	571
Strip	156	79.6	14439ab	6807	0.98	1784	559
$LSD_{0.05}$	9	6.2	636	874	0.04	64	46
ANOVA (P > F)							
Stubble height	0.888	0.836	0.066	0.225	0.765	0.496	0.557

[1] Water use efficiency (lb of grain/inch of water use).
LSD = least significant difference.
ANOVA = analysis of variance.

Table 4. Sorghum yield, biomass, and yield components as affected by stubble height, Tribune, KS, 2007–2017

Stubble height	Yield	Head population	Biomass[2]	Residue[2]	1,000-seed weight	Kernels	WUE[1]
	bu/a	10^3/a	---------- lb/a ----------		oz	no./head	lb/in.
Low	102	55.2	11015	6056	0.89	1911	395b
High	107	56.9	11615	6419	0.90	1971	423a
Strip	103	56.2	11197	6135	0.88	1895	408ab
$LSD_{0.05}$	5	2.3	540	485	0.02	110	19
ANOVA (P > F)							
Year	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Stubble height	0.063	0.355	0.082	0.300	0.145	0.358	0.020
Year × stubble height	0.996	0.902	0.998	0.993	0.679	0.020	0.954

[1] Water use efficiency (lb of grain/inch of water use).
[2] 2015 values not included in average - no samples collected.
LSD = least significant difference.
ANOVA = analysis of variance.

Effect of Drilled Seeding and Nitrogen Rate on Grain Sorghum Yield in Southwest Kansas

A.J. Foster, A. Schlegel, I.B. Cuvaca, J. Holman, I.A. Ciampitti, C. Thompson, D. Ruiz Diaz, and R.S. Currie

Summary
This study compared drilled planted sorghum at four seeding rates to planted sorghum at three different nitrogen (N) fertility levels at two locations in southwest Kansas (Garden City and Tribune). In 2017, at the Garden City location using a John Deere experimental sorghum drill and at Tribune using a regular John Deere drill, higher yields were produced with drilled seeded sorghum with 60,000 and 80,000 seeds/a at both locations. Likewise, at both locations, there was no difference in yield between the planted and drilled sorghum at the same seeding rate. Nitrogen fertilizer did not interact with seeding rate to affect yield in Garden City, but significantly increased yield with an increased rate of application at the Tribune location. In general, the effect of nitrogen rates and seeding rates on sorghum yield was observed to be influenced by other management and environmental factors. The results of this study suggested that there was no yield penalty for drilling or planting sorghum at the same seeding rate.

Introduction
Drilled sorghum is normally done at the super-high population at row spacing between 7.5 and 10 inches, compared to rows planted at the spacing between 15 and 30 inches. Thompson (1983) growing super-thick sorghum at the Hays Research Station from 1974–1977, found that sorghum planted in narrow rows (12–18 in.) often produced higher yields than when planted in wide rows (24–40 in.). Norwood (1982) in Garden City repeated Thompson's work also concluded that yield of high population narrow row sorghum could exceed that of the low population-wide row when subsoil moisture and precipitation were adequate. The conclusion from the work of Thompson and Norwood was that subsoil moisture and precipitation were big drivers for the high population, narrow row sorghum to equal or exceed the yield of the low population wide row. Since then, most researchers have found yield response to plant population to be variable depending on the environment. Overall, the consensus is that under conditions of adequate moisture, the yield of high population sorghum can continue to increase but can decrease under dry conditions. Moisture still remains the key for successful dryland sorghum production in southwest Kansas. Thus, the very familiar saying, "moisture and fertility are joined at the hip." Thompson's and Norwood's work did not evaluate narrow row at population under 25,000 seeds/a and at a spacing less than 10 in. We hypothesized that drilled sorghum at lower population could make better use of water resources and produce similar yields to drilled sorghum at higher populations, and planted sorghum at the same population. Thus, the objective of this study is to evaluate drilled sorghum at different populations ranging from 20,000 to 80,000 seeds/a at a row spacing of 10 in. or less at different nitrogen rates. Furthermore, most farmers in southwest Kansas own both a drill and a planter. Thus, it is not just an agronomic issue,

but it is also about getting better value from a single piece of equipment in an already economically challenging wheat-sorghum-fallow production system.

Procedures

Experiments were conducted under dryland conditions at two locations in western Kansas (Southwest Research-Extension Center in Garden City and Tribune) to determine the interaction of seeding rate and nitrogen rate under narrow row sorghum in southwest Kansas. At the Garden City location, a John Deere sorghum experimental drill was used, while at the Tribune location research plot-sized equipment was used. The experimental design was a split plot design with seeding rate as the main plot and nitrogen rate as the subplot. The main plot size in Garden City was 30-ft wide × 40-ft long and the subplots were 10-ft wide × 40-ft long. In Tribune, the main plot was 60-ft wide × 50-ft long and the subplots were 20-ft wide × 50-ft long.

Planting Dates and Plot Layout

Sorghum variety Dekalb 3707 was planted at both locations, on June 12, 2017, in Garden City and June 6, 2017, in Tribune. A randomized complete block design with a 5 × 3 factorial treatment arrangement with four replications was used at both locations. At Garden City, sorghum was planted on 15 in. row spacing using a 40-ft wide John Deere experimental sorghum no-till drill. The drilled seeding rates were 20,000, 40,000, 60,000, and 80,000 seeds/a and the planted sorghum was seeded at 20,000 seeds/a with a planter at 30 in. row spacing with a John Deere 7300 planter.

At Tribune, sorghum was planted on 7.5 in. row spacing with a John Deere 1590 no-till drill. The drilled seeding rates were 20,000, 40,000, 60,000, and 80,000 seeds/a and the planted sorghum was seeded at 40,000 seeds/a with a planter at 30 in. row spacing with a John Deere 1700 planter. The three factors were three nitrogen rates (0, 50, and 100 lb/a) at both locations.

At both locations, potassium (K) and phosphorus (P) were applied based on the soil test recommendations provided by the Kansas State University Department of Agronomy Soil and Plant Testing Laboratory, Manhattan, KS.

Herbicide management at Garden City was the application of glyphosate at 1.25 qt/a + Harness at 2.5 pt/a + Starane Ultra at 0.75pt/a applied pre-plant on June 1, 2017. At Tribune, Atrazine at 1 lb/a + Rifle at 16 oz /a was applied early on February 16, 2017, followed by 80 oz/a Lumax E2 + 48 oz/a Gramoxone + 0.50% v/v NIS and applied pre-emergence on June 10, 2017.

Data Collection and Analysis

The Garden City location was harvested using a 7.5-ft wide head plot combine and Tribune was were harvested with a 5-ft wide head. Crop weights were adjusted to 13% moisture.

Data were analyzed using PROC GLM with SAS 9.4 (SAS Institute, Inc., Cary, NC) and a model statement appropriate for a factorial design. Treatment means were separated by Fisher's projected least significant difference test.

Results

Garden City

Drilled sorghum at the higher populations produced the highest yield, but there was no difference in grain yield between the planted sorghum at 20,000 seeds/a and the drilled sorghum at the same seeding rate (Figure 1). Nitrogen rate did not interact with population or affect sorghum yield independently in the study.

Tribune

Similar to Garden City, higher yield was produced at the higher drilled seeding rate and there was no difference in grain yield between planted sorghum and drilled sorghum at the same seeding rate (Figure 2). Sorghum yield increased with the increased rate of nitrogen fertilizer (Figure 3).

Conclusion

The result observed in the study can be attributed to the influence of planting equipment, planting date, and environmental condition. At the Garden City location, the later planting date and the drier condition at and after planting might have attributed to the low yield obtained. At the Tribune location, the response to nitrogen fertilizer may be attributed to the influence of a hail storm on August 18. These results indicate the complexity of seeding rate with the management and environmental condition. Additionally, these results suggest that there is no yield penalty for drilling or planting sorghum at the same population.

References

Norwood, C. A. 1982. High population, narrow row dryland sorghum for southwest Kansas. Keeping up with Research, 62. Kansas Agricultural Experiment Station. http://krex.k-state.edu/dspace/handle/2097/16547

Thompson, C. 1983. Super-thick sorghum management. Kansas Agricultural Experiment Station Report of Progress, 437, 24.

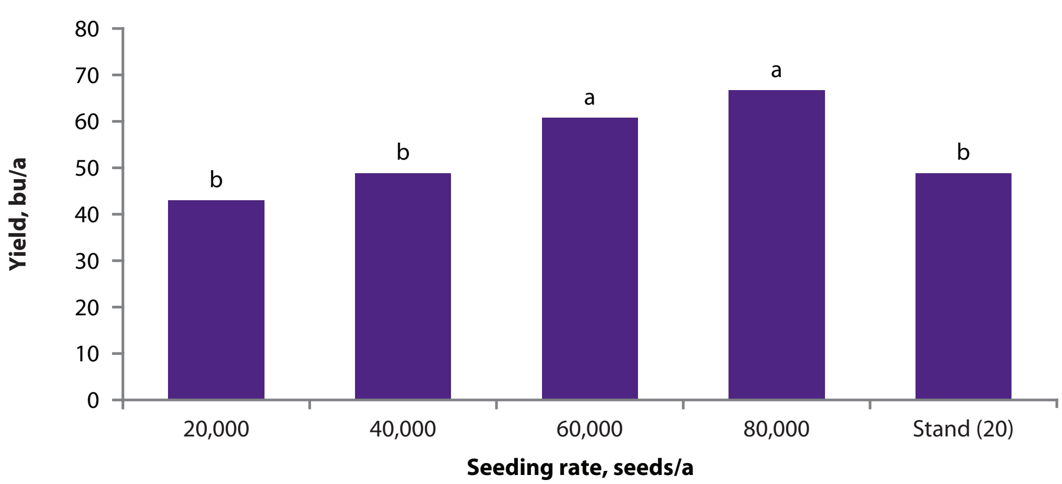

Figure 1. Grain sorghum yield affected by four drilled seeding rates and the standard planting rate (20,000 seeds/a) average across three different nitrogen rates at Garden City, KS.
[ab]Means followed by the same letter are not significantly different.

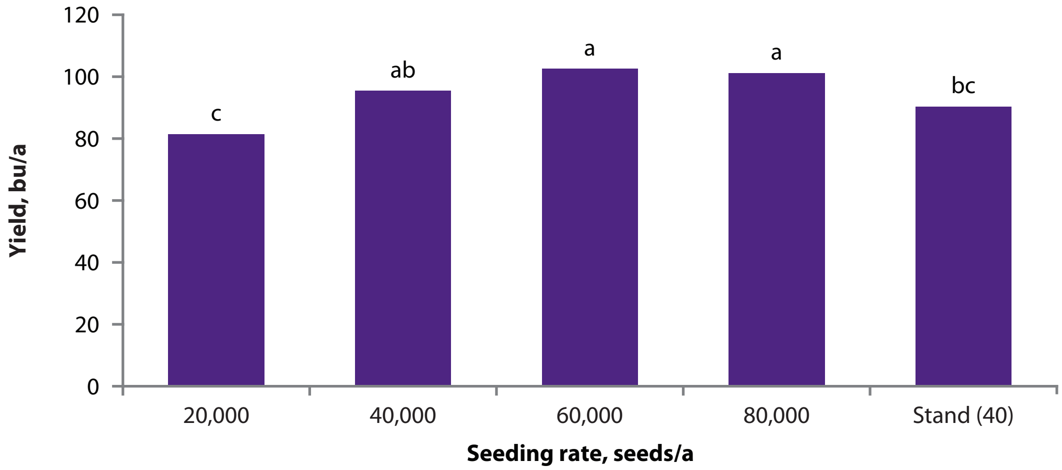

Figure 2. Grain sorghum yield affected by four drilled seeding rates and the standard planting rate (40,000 seeds/a) averaged across three different nitrogen rates at Tribune, KS.
[abc]Means followed by the same letter are not significantly different.

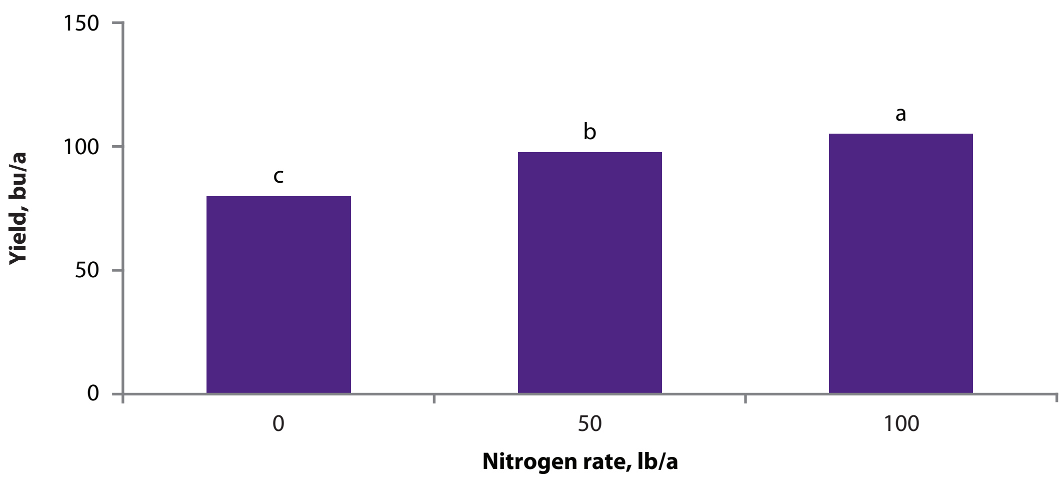

Figure 3. Grain sorghum yield affected by nitrogen rate under four drilled seeding rates and the standard planting rate in Tribune, KS.
[abc]Means followed by the same letter are not significantly different.

Forage Type and Maturity Effects on Yield and Nutritive Value

J. Holman, A. Obour, T. Roberts, and S. Maxwell

Summary
Forage sorghum (*Sorghum bicolor* L.) and sorghum × sudan (*Sorghum bicolor* sssp. Drummondii) are important annual forages in the High Plains. Advancements in brown mid-rib (BMR) cultivars will likely affect forage yield and nutritive values. A study was initiated in 2017 at the Southwest Research-Extension Center near Garden City, KS, comparing one variety each of BMR and non-BMR forage sorghum and sorghum × sudan cultivars. Forage type and growth stage affected yield and nutritive value, and occasionally there was an interaction between forage type and maturity.

Introduction
Forage variety testing has shown yield and nutritive value differences across forage sorghum and sorghum × sudan varieties (Holman et al. 2016, 2017, 2018). Growers commonly report differences in palatability of free-choice sorghum hay fed to cattle (Holman, unpublished data). The differences in palatability may be in part related to maturity of the forage and forage type. Therefore, one cultivar of each sorghum type was harvested at different maturities for yield and nutritive value to gain better insight into feed value differences.

Study Objectives
1. Compare yield and nutritive value differences of forage sorghum and sorghum × sudan BMR and non-BMR types.
2. Evaluate maturity differences (boot, heading, flowering, and soft dough) on forage yield and nutritive value.

Experimental Procedures
Annual forages were grown in 2017 at the Southwest Research-Extension Center near Garden City, KS. The study design was a randomized complete block design with four replications. Treatment was forage sorghum type (forage sorghum and sorghum × sudan) with and without the BMR trait, harvested at boot, heading, flowering, and soft dough for a total of 16 treatments. Plots were 15-ft wide × 60-ft long. Forage sorghum cultivars were non-BMR 'Canex' forage sorghum (FS), BMR 'Canex 210' forage sorghum (FSBMR), non-BMR 'Super Sugar' sorghum × sudan (SS), and BMR Sweet Six sorghum × sudan (SSBMR). Sorghum cultivars were planted on June 1, 2017, and harvested at boot, heading, flowering, and soft dough growth stages.

Forage nutrient components measured were dry matter yield, ash, lignin, acid detergent fiber (ADF), neutral detergent fiber (NDF), digestible neutral detergent fiber (NDFD), total digestible nutrients (TDN), crude protein (CP), relative feed quality (RFQ), milk $_{2000}$/ton, and milk $_{2000}$/a.

Results and Discussion

There was a significant interaction between forage type and growth stage for ADF and NDF (Table 1). Acid detergent fiber ranged from 34.4% (FS at boot) to 39.9% (SSBMR at heading), and NDF ranged from 50.4% (FS at dough) to 58.7% (SSBMR at flowering). Highly digestible forage grass would have an ADF < 35% and NDF < 50%. All of the fiber contents measured in this study would be considered lower-quality and less digestible regardless of forage type or maturity. The significant interaction was caused by SSBMR having greater ADF and NDF concentration at heading and dough than other forage types, and SSBMR having lesser ADF and NDF at boot. This suggests fiber content of SSBMR rapidly increased post-heading, resulting in forage with lower digestibility post-heading. It may be more critical to harvest SSBMR early than other forage types for best forage quality. Growth stage affected yield, ash, lignin, TDN, CP, milk/ton, and milk/a (Table 2). All forage attributes were affected by forage type (Table 3).

Growth Stage

Dry matter yield was greatest at dough and not different among other growth stages (Table 2). Harvesting at dough stage increases both forage and grain, thus increasing overall yield. These results also suggest a minimal yield penalty by harvesting early, yet harvesting early might increase overall forage quality and palatability. Ash content was highest at boot and lowest at dough. It is unclear why ash tended to be higher with earlier maturity, but might be due to less nutrient uptake as the plants mature. Lignin content was highest at dough and similar across the other growth stages. ADF was higher at boot than dough, while NDF was similar across growth stages. The grain (starch) component of the plant is more digestible and thus likely resulted in lower ADF at dough.

Neutral detergent fiber digestible (NDFD) and *in vitro* true dry matter digestibility (ITVD) were similar across growth stages. Crude protein decreased with maturity and was highest at boot. RFQ was similar across growth stages. TDN and milk/ton were highest at dough and lowest at boot, correlating with ADF content. The increased digestibility and improved energy at dough was likely due to the grain component of the forage. Milk/ton and milk/a were highest at dough and similar across the other growth stages.

Forage Type

Of the varieties evaluated, dry matter yield of forage sorghum (FSBMR and FS) tended to be greater than sorghum × sudan (SSBMR and SS) in a one-cut hay system (Table 3). Yield can vary greatly among varieties and environment (Holman et al. 2017a, 2017b, and 2018). Sorghum × sudan as a group tends to have greater regrowth than forage sorghum, and regrowth was not measured in this study. Ash content was highest in SSBMR and no different than the other forage types. It is unclear why ash content was higher in SSBMR.

Lignin content was highest in SS and FS, and lower in SSBMR and FSBMR, which coincides with the BMR trait having less lignin. Fiber content (ADF and NDF) tended to be higher in sorghum × sudan (SSBMR and SS), than forage sorghum (FSBMR and FS), but the differences between forage types was negligible. Fiber digestibility (NDFD and IVTD) tended to be greater among forage sorghum (FSBMR and FS) than sorghum × sudan (SSBMR and SS), although no difference was observed between FS and SSBMR. This indicates better fiber digestibility of SSBMR compared to SS. Crude protein content was greatest in SSBMR, and FSBMR was greater than FS, indicating BMR improved crude protein content.

Relative feed quality (RFQ) combines fiber digestibility and crude protein to provide a nutrient value index to compare similar forages, total digestible nutrients (TDN) is a measurement of digestibility energy, and milk per ton is a measurement of starch and fiber digestibility. FSBMR and FS had greater RFQ, TDN, and milk per ton than SSBMR or SS, largely caused by the differences in fiber content and fiber digestibility between the two forage types. Milk per acre combines the value of forage quality (milk per ton) and yield (dry matter yield/a) into one term. Milk per acre was greatest with FSBMR and lowest with FS and SSBMR, largely driven by yield/a since forage quality differences were minor among forage types.

Conclusion

Harvesting forage sorghum or sorghum × sudan at early maturity (boot) increased crude protein content, did not reduce yield compared to harvesting at heading or flowering, and would likely improve palatability when fed as free choice hay. However, if feeding as part of a total mixed ration where bunk sorting would be limited, harvesting forage sorghum later at soft dough increased fiber digestibility and yield. SSBMR in this study increased fiber concentration more with plant maturity than the other forage types.

In a one-cut system, forage sorghum will generally provide greater yield than sorghum × sudan, but sorghum × sudan typically has greater regrowth than forage sorghum. BMR forage types had less lignin and greater CP. Fiber content (ADF and NDF) was lower and forage digestibility (NDFD and IVTD) was greater among forage sorghum plots than sorghum × sudan. If regrowth is not required, then BMR forage sorghum can provide the most digestible forage.

References

Holman, J., J. Lingenfelser, A. Obour, A. Esser, J. Moyer, G. Cramer, T. Roberts, and S. Maxwell. 2017. Forage report 2015. *Kansas Agricultural Experiment Station Research Reports*: Vol. 3: Iss. 5. doi.org/10.4148/2378-5977.7397

Holman, J., G. Cramer, A. Esser, J. Lingenfelser, S. Maxwell, J. Moyer, A. Obour, and T. Roberts. 2017. Forage report 2016. *Kansas Agricultural Experiment Station Research Reports*: Vol. 3: Iss. 5. doi.org/10.4148/2378-5977.7398

Holman, J., A. Obour, A., Esser, J. Lingenfelser, S. Maxwell, T. Roberts, and G. Sassenrath. 2018. 2017 Kansas Summer Annual Forage Hay and Silage Variety Trial. *Kansas Agricultural Experiment Station Research Reports*: Vol. 4: Iss. 4. https://doi.org/10.4148/2378-5977.7580

Table 1. Analysis of variance summary of treatment effects on forage yield and nutritive value

	Yield	Ash	Lignin	ADF	NDF	NDFD	TDN	IVTD	CP	RFQ	Milk/ton	Milk/a
	Dry matter lb/a	----------------------	----------------------	----------------------	----------------------	%	----------------------	----------------------	----------------------			
Rep	0.006	0.98	0.12	0.04	0.29	0.25	0.60	0.30	<0.0001	0.24	0.63	0.03
Growth stage	<0.0001	<0.0001	0.02	0.16	0.24	0.52	0.01	0.88	<0.0001	0.50	0.01	<0.0001
Type	0.0014	<0.0001	<0.0001	0.01	0.01	<0.0001	<0.0001	<0.0001	<0.0001	0.00	<0.0001	0.00
Growth stage * type	0.734	0.34	0.49	0.05	0.04	0.39	0.34	0.11	0.23	0.42	0.31	0.70

ADF = acid detergent. NDF = neutral detergent fiber. NDFD = digestible neutral detergent fiber. TDN = total digestible nutrients. ITVD = *in vitro* true dry matter digestibility. CP = crude protein. RFQ = relative feed quality.
*ANOVA test of the significant interaction between growth stage and type.

Table 2. Growth stage effects on forage yield and nutritive value

	Yield	Ash	Lignin	ADF	NDF	NDFD	TDN	IVTD	CP	RFQ	Milk/ton	Milk/a
	Dry matter lb/a	----------------------	----------------------	----------------------	----------------------	%	----------------------	----------------------	----------------------			
Boot	5596.4	13.23	6.26	37.88	56.31	59.00	54.53	77.82	9.35	102.66	2396.50	6753.20
Heading	6122.0	11.83	6.06	37.54	56.24	59.59	56.14	77.91	8.88	107.91	2530.94	7813.30
Flowering	6627.1	10.98	6.08	37.19	55.97	57.92	56.51	77.22	8.33	107.34	2572.69	8545.90
Dough	9161.5	9.99	6.64	36.39	54.61	58.09	58.09	77.68	7.04	107.91	2709.13	12491.10
LSD[1]	1141.7	0.97	0.38	1.34	1.87	2.37	1.94	1.76	0.75	7.68	160.35	1830.00

[1]LSD = least significant difference at $P \leq 0.05$.
ADF = acid detergent. NDF = neutral detergent fiber. NDFD = digestible neutral detergent fiber. TDN = total digestible nutrients. ITVD = *in vitro* true dry matter digestibility. CP = crude protein. RFQ = relative feed quality.

Table 3. Forage type effects on forage yield and nutritive value

	Yield	Ash	Lignin	ADF	NDF	NDFD	TDN	IVTD	CP	RFQ	Milk/ton	Milk/a
	Dry matter lb/a	----------------------	----------------------	----------------------	----------------------	%	----------------------	----------------------	----------------------			
Forage sorghum	6349.6	10.60	6.58	36.39	53.83	59.38	57.91	78.88	7.58	109.00	2689.88	8649.80
Forage sorghum BMR	7918	10.82	5.55	36.52	55.84	62.72	58.46	79.93	8.49	115.67	2709.88	10902.90
Sorghum sudan	7418.7	11.11	6.83	37.70	56.40	53.01	54.59	74.26	7.98	99.41	2436.07	9030.30
Sorghum sudan BMR	5789.5	13.53	6.17	38.46	57.09	58.89	54.07	77.19	9.51	100.74	2356.31	6903.40
LSD[1]	1142.8	0.97	0.38	1.34	1.87	2.37	1.94	1.76	0.75	7.69	160.51	1831.80

[1]LSD = least significant difference at $P \leq 0.05$.
ADF = acid detergent. NDF = neutral detergent fiber. NDFD = digestible neutral detergent fiber. TDN = total digestible nutrients. ITVD = *in vitro* true dry matter digestibility. CP = crude protein. RFQ = relative feed quality.

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Corn

A. Schlegel and D. Bond

Summary
Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated corn in western Kansas. In 2017, N applied alone increased yields by 70 bu/a, whereas P applied alone increased yields by less than 10 bu/a. Nitrogen and P applied together increased yields up to 130 bu/a. This is 10 bu/a less than the 10-year average, where N and P fertilization increased corn yields up to 140 bu/a. Application of 120 lb/a N (with highest P rate) produced 93% of maximum yield in 2017, which is similar to the 10-year average. Application of 80 instead of 40 lb P_2O_5/a increased average yields 10 bu/a. Average grain N content reached a maximum of 0.6 lb/bu while grain P content reached a maximum of 0.15 lb/bu (0.34 lb P_2O_5/bu). At the highest N and P rate, apparent fertilizer nitrogen recovery in the grain ($AFNR_g$) was 42% and apparent fertilizer phosphorus recovery in the grain ($AFPR_g$) was 61%.

Introduction
This study was initiated in 1961 to determine responses of continuous corn and grain sorghum grown under flood irrigation to N, P, and potassium (K) fertilization. The study is conducted on a Ulysses silt loam soil with an inherently high K content. No yield benefit to corn from K fertilization was observed in 30 years, and soil K levels remained high, so the K treatment was discontinued in 1992 and replaced with a higher P rate.

Procedures
This field study is conducted at the Tribune unit of the Kansas State University Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a without P and K; with 40 lb/a P_2O_5 and zero K; and with 40 lb/a P_2O_5 and 40 lb/a K_2O. The treatments were changed in 1992; the K variable was replaced by a higher rate of P (80 lb/a P_2O_5). All fertilizers were broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. The corn hybrids [Pioneer 34B99 (2008), DeKalb 61-69 (2009), Pioneer 1173H (2010), Pioneer 1151XR (2011), Pioneer 0832 (2012-2013), Pioneer 1186AM (2014), Pioneer 35F48 AM1 (2015), Pioneer 1197 (2016), and Pioneer 0801 (2017)] were planted at about 32,000 seeds/a in late April or early May. Hail damaged the 2008, 2010, and 2017 crops. The corn is irrigated to minimize water stress. Sprinkler irrigation has been used since 2001. The center two rows of each plot are machine harvested after physiological maturity. Grain yields are adjusted to 15.5% moisture. Grain samples were collected at harvest, dried, ground and analyzed for N and P concentrations. Grain N and P content (lb/bu) and removal (lb/a) were calculated. Apparent fertilizer N recovery in the grain ($AFNR_g$) was calculated as N uptake in treatments receiving N fertilizer minus N uptake in the unfertilized control divided by N rate. The same approach was

used to calculate apparent fertilizer P recovery in the grain ($AFPR_g$). Aerial application for grasshoppers was applied on July 18 and hail damage occurred on August 18.

Results

Corn yields in 2017 were 25% lower than the 10-year average (Table 1). Nitrogen alone increased yields 70 bu/a, whereas P alone increased yields less than 10 bu/a. However, N and P applied together increased corn yields up to 130 bu/a. Maximum yield was obtained with 200 lb/a N with 80 lb/a P_2O_5. Corn yields in 2017 (averaged across all N rates) were 10 bu/a greater with 80 than with 40 lb/a P_2O_5.

The 10-year average grain N concentration (%) increased with N rates but tended to decrease when P was also applied, presumably because of higher grain yields diluting N content (Table 2). Grain N content reached a maximum of 0.6 lb/bu. Maximum N removal (lb/a) was greatest at the highest yield levels, which were attained with 200 lb N and 80 lb P_2O_5/a. At the highest N and P rate, $AFNR_g$ was 42% and $AFPR_g$ was 61%. Similar to N, average P concentration increased with increased P rates but decreased with higher N rates. Grain P content (lb/bu) of about 0.15 lb P/bu (0.34 lb P_2O_5/bu) was greater at the highest P rate with low N rates. Grain P removal averaged 29 lb P/a at the highest yields.

Acknowledgment

The International Plant Nutrition Institute partially supported this research project.

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2008-2017

Fertilizer		Yield										
N	P_2O_5	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
------ lb/a ------		------ bu/a ------										
0	0	36	85	20	92	86	70	86	92	74	44	68
0	40	57	110	21	111	85	80	95	103	78	47	79
0	80	52	106	28	105	94	91	98	104	86	52	82
40	0	62	108	23	114	109	97	106	113	105	60	90
40	40	105	148	67	195	138	125	153	164	145	92	133
40	80	104	159	61	194	135	126	149	162	135	90	132
80	0	78	123	34	136	128	112	117	131	118	70	105
80	40	129	179	85	212	197	170	187	195	196	132	168
80	80	139	181	90	220	194	149	179	193	193	129	167
120	0	65	117	28	119	134	114	115	124	109	62	99
120	40	136	202	90	222	213	204	213	212	212	142	185
120	80	151	215	105	225	211	194	216	216	223	162	192
160	0	84	139	49	157	158	122	128	144	142	84	121
160	40	150	210	95	229	227	199	211	215	226	154	192
160	80	146	223	95	226	239	217	233	216	238	165	200
200	0	99	155	65	179	170	139	144	162	159	114	139
200	40	152	207	97	218	225	198	204	214	216	148	188
200	80	157	236	104	231	260	220	238	221	235	174	208

continued

Table 1. Nitrogen (N) and phosphorus (P) fertilization on irrigated corn yields, Tribune, KS, 2008-2017

Fertilizer		Yield										
N	P_2O_5	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
------ lb/a ------		------------------------					bu/a					------------------------
ANOVA (P>F)												
Nitrogen		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Phosphorus		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N × P		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Means												
Nitrogen, lb/a												
0		48e	100e	23e	103d	88f	80e	93e	100e	79e	48e	76e
40		91d	138d	50d	167c	127e	116d	136d	146d	129d	81d	118d
80		115c	161c	70c	189b	173d	143c	161c	173c	169c	110c	146c
120		118c	178b	74bc	189b	186c	171b	181b	184b	182b	122b	158b
160		127b	191a	80ab	204a	208b	179ab	190ab	192ab	202a	134a	171a
200		136a	199a	89a	209a	218a	186a	196a	199a	203a	145a	178a
$LSD_{(0.05)}$		9	12	9	13	10	10	10	9	10	11	7
P_2O_5, lb/a												
0		71b	121c	36b	133b	131c	109b	116c	128b	118b	72c	103c
40		122a	176b	76a	198a	181b	163a	177b	184a	179a	119b	157b
80		125a	187a	81a	200a	189a	166a	186a	185a	185a	129a	163a
$LSD_{(0.05)}$		6	9	7	9	7	7	7	6	7	8	5

*Note: Hail events on 7/23/10, 5/28/15, and 8/18/17.

Table 2. Nitrogen and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2008-2017

Fertilizer		Grain				Grain removal			
N	P_2O_5	N	P	N	P	N	P	*$AFNR_g$	*$AFPR_g$
------ lb/a ------		------- -% -------		----- lb/bu -----		------ lb/a ------		---------- % ----------	
0	0	0.98	0.232	0.47	0.110	31	7	---	---
0	40	0.95	0.313	0.45	0.148	34	12	---	25
0	80	0.95	0.322	0.45	0.152	36	12	---	15
40	0	1.17	0.184	0.55	0.087	49	8	45	---
40	40	0.97	0.304	0.46	0.144	60	19	73	67
40	80	0.98	0.324	0.46	0.153	60	20	73	36
80	0	1.26	0.181	0.60	0.085	62	9	38	---
80	40	1.05	0.259	0.50	0.122	83	20	65	73
80	80	1.02	0.312	0.48	0.148	79	25	61	49
120	0	1.26	0.175	0.60	0.083	58	8	23	---
120	40	1.13	0.230	0.54	0.109	98	20	56	70
120	80	1.10	0.299	0.52	0.141	99	27	57	55
160	0	1.25	0.179	0.59	0.085	71	10	25	---
160	40	1.18	0.245	0.56	0.116	106	22	47	82
160	80	1.17	0.283	0.55	0.134	110	27	49	54
200	0	1.24	0.188	0.59	0.089	80	12	25	---
200	40	1.19	0.241	0.56	0.114	105	21	37	78
200	80	1.18	0.297	0.56	0.140	115	29	42	61

continued

Table 2. Nitrogen and phosphorus (P) fertilization on grain N and P content of irrigated corn, Tribune, KS, 2008-2017

Fertilizer		Grain				Grain removal			
N	P_2O_5	N	P	N	P	N	P	*$AFNR_g$	*$AFPR_g$
------ lb/a ------		------- -% -------		----- lb/bu -----		------ lb/a ------		---------- % ----------	
ANOVA (P>F)									
Nitrogen		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	---	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	---	0.001
Phosphorus		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	---
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	---
N × P		0.001	0.001	0.001	0.001	0.001	0.001	0.035	0.088
Means									
Nitrogen, lb/a									
0		0.96e	0.289a	0.46e	0.137a	34f	10e	---	20d
40		1.04d	0.271b	0.49d	0.128b	56e	16d	64a	52c
80		1.11c	0.250c	0.53c	0.118c	75d	18c	55b	61b
120		1.16b	0.235d	0.55b	0.111d	85c	18bc	45c	63ab
160		1.20a	0.236d	0.57a	0.111d	96b	19b	40d	68ab
200		1.20a	0.242cd	0.57a	0.115cd	100a	21a	35e	70a
$LSD_{(0.05)}$		0.02	0.011	0.01	0.005	4	1	5	8
P_2O_5, lb/a									
0		1.19a	0.190c	0.56a	0.090c	59b	9c	31b	---
40		1.08b	0.265b	0.51b	0.126b	81a	19b	56a	66a
80		1.07b	0.306a	0.50b	0.145a	83a	23a	56a	45b
$LSD_{(0.05)}$		0.01	0.008	0.01	0.004	3	1	4	5

*$AFNR_g$ and $AFPR_g$ = Apparent fertilizer N recovery (grain) and Apparent fertilizer P recovery (grain).

Efficacy of Zest, Resolve, and Harmony Tank Mixes Used Sequentially in Irrigated Acetolactase Synthase (ALS)-Resistant Grain Sorghum

R.S. Currie and P.W. Geier

Summary
Palmer amaranth control was best when Cinch was applied preemergence (PRE) followed by Zest plus atrazine postemergence (POST) or when Cinch ATZ was applied early postemergence (EPOST) with Zest and atrazine. Most herbicides provided excellent crabgrass control. Shattercane control was excellent with all herbicides except Cinch ATZ applied PRE. Minor sorghum stunting was observed with some treatments three days after application, but sorghum had completely recovered within one week. Herbicide-treated grain sorghum yielded 48 to 93 bu/a more grain than untreated sorghum. Sorghum yields were best when Cinch or Cinch ATZ was applied PRE followed by Zest and atrazine POST, or when Cinch ATZ was applied with Zest and atrazine EPOST.

Introduction
Zest (nicosulfuron) and Resolve (rimsulfuron) are herbicides that have long been used in corn to control weedy sorghum species as well as other grasses. Using selections from weedy sorghum species that had developed resistance to the ALS mode of action, commercial sorghum hybrids have been developed. Although these compounds provide excellent control of weedy sorghum species they can be weak on many broadleaf weeds and some grassy species beyond a certain size. Harmony (thifensulfuron), another ALS herbicide long used for weed control in wheat, was also included. Therefore, it was the objective of this study to compare tank mixes of herbicides to augment the weed spectrum of Zest and Resolve.

Experimental Procedures
An experiment was conducted at the Kansas State University Southwest Research-Extension Center near Garden City, KS, to evaluate weed control and crop response with acetolactase-synthase (ALS) inhibiting herbicides Zest, Resolve, and Harmony in irrigated ALS-resistant grain sorghum. Atrazine and Cinch (*S*-metolachlor) were also included to augment weaknesses in these compounds. Herbicides were applied preemergence (PRE), early postemergence (EPOST), or PRE followed by postemergence (POST). The experimental area was overseeded with crabgrass and Rox Orange forage sorghum (to simulate shattercane) to supplement naturally occurring weed pressure prior to planting sorghum. Application, environmental, and weed information is shown in Table 1. A tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi was used to apply all herbicides. Plot size was 10 × 35 feet, arranged in a randomized complete block design with four replicates. Soil was a Beeler silt loam with 2.4% organic matter and pH of 7.6. Visual weed control was determined on July 17 and

August 30, 2017, which was 6 and 50 days after the POST treatment (DAPT), respectively. Grain yields were determined on November 1, 2017, by mechanically harvesting the center two rows of each plot and adjusting weights to 14% moisture.

Results and Discussion

Palmer amaranth control at 50 DAPT was best when Cinch was applied PRE followed by Zest plus atrazine POST or when Cinch ATZ was applied EPOST with Zest and atrazine (Table 2). Most herbicides provided 95 to 100% crabgrass control at 6 DAPT, and control was complete regardless of herbicide by 50 DAPT. Shattercane control at 50 DAPT was 95% or more with all herbicides except Cinch ATZ applied PRE (50%). Minor sorghum stunting and chlorosis (11 to 15%) was observed when Cinch ATZ was applied EPOST with Zest and atrazine at three days after application, but sorghum had completely recovered within seven days (data not shown). No other visible sorghum injury was observed. Herbicide-treated grain sorghum yielded 48 to 93 bu/a more grain than untreated sorghum. Sorghum yields were best (96 to 105 bu/a) when Cinch or Cinch ATZ was applied PRE followed by Zest and atrazine POST, or when Cinch ATZ was applied with Zest and atrazine EPOST.

Table 1. Application information

Application timing	Preemergence	Early postemergence	Postemergence
Application date	June 14, 2017	July 7, 2017	July 11, 2017
Air temperature (°F)	68	74	75
Relative humidity (%)	41	51	49
Soil temperature (°F)	72	71	71
Wind speed (mph)	5	4	4
Wind direction	North-northwest	East	South
Soil moisture	Good	Good	Excellent
Palmer amaranth			
Height (inch)	---	2	4
Density (plants/ft^2)	0	3.3	3.3
Crabgrass			
Height (inch)	---	1	2
Density (plants/ft^2)	0	2.3	1.4
Shattercane			
Height (inch)	---	3	3
Density (plants/ft^2)	0	0.5	0.5

Table 2. Efficacy of single and sequential herbicides in acetolactase synthase-resistant grain sorghum

Treatment[a]	Rate	Timing[b]	Palmer amaranth 6 DAPT[c]	Palmer amaranth 50 DAPT	Crabgrass 6 DAPT	Crabgrass 50 DAPT	Shattercane 6 DAPT	Shattercane 50 DAPT	Sorghum yield
			% Visual						bu/a
Untreated	---		0	0	0	0	0	0	11.8
Cinch ATZ	3.2 pt	PRE	93	85	95	100	60	50	80.8
Resolve	0.25 oz	PRE	98	55	73	100	85	95	66.1
Harmony SG	0.125 oz	PRE							
Atrazine	24 oz	PRE							
Zest	0.67 oz	POST							
Atrazine	24 oz	POST							
COC	2%	POST							
AMS	2 lb	POST							
Cinch	1.3 pt	PRE	73	58	100	100	100	100	60.0
Resolve	0.25 oz	PRE							
Harmony SG	0.125 oz	PRE							
Zest	0.67 oz	POST							
COC	2%	POST							
AMS	2 lb	POST							
Cinch ATZ	2.0 pt	PRE	78	86	95	100	85	100	97.2
Zest	0.67 oz	POST							
Atrazine	24 oz	POST							
COC	2%	POST							
AMS	2 lb	POST							
Cinch	1.0 pt	PRE	75	88	100	100	73	100	105.2
Zest	0.67 oz	POST							
Atrazine	24 oz	POST							
COC	2%	POST							
AMS	2 lb	POST							
Cinch ATZ	3.2 pt	EPOST	98	100	99	100	98	100	96.4
Zest	0.67 oz	EPOST							
Atrazine	24 oz	EPOST							
COC	2%	EPOST							
AMS	2 lb	EPOST							
LSD (0.05)			7	12	9	NS	10	12	22.2

[a]AMS = ammonium sulfate. COC = crop oil concentrate.
[b]PRE = preemergence. EPOST = early postemergence. POST = postemergence.
[c]DAPT = days after postemergence application. Evaluation dates were July 7 and August 30, 2017 and harvest date was November 1, 2017.

Dicamba-Tolerant Volunteer Soybean, Palmer Amaranth, and Green Foxtail Control in Irrigated Field Corn

R.S. Currie and P.W. Geier

Summary
Dicamba-tolerant soybean control was best when Armezon (topramezone) or Armezon Pro (topramezone + dimethenamid) was applied POST with atrazine and glyphosate, and when Status (dicamba + diflufenzopyr), atrazine, and glyphosate were applied POST. These treatments, along with PRE treatments of Armezon Pro and atrazine, completely controlled soybean. Similarly, control of Palmer amaranth and green foxtail was generally best with Armezon Pro and atrazine applied PRE or any herbicide combination applied POST. Corn receiving PRE treatments yielded 41 to 120 bu/a more grain than the weedy checks, whereas corn treated POST yielded 117 to 145 bu/a more grain than the untreated corn.

Introduction
With the advent of dicamba-tolerant soybean it has been postulated that they will be weeds in the subsequent corn crop. Dicamba has long been used as a foundation for postemergence broadleaf weed control in corn. If dicamba is not effective on dicamba-tolerant volunteer soybean, new tank mixes will be needed. Therefore, it was the objective of this study to test various other compounds to control dicamba-tolerant soybean and broadleaf weeds in corn.

Experimental Procedures
An experiment at the Kansas State University Southwest Research-Extension Center near Garden City, KS, evaluated preemergence (PRE) Armezon, Armezon Pro, and atrazine or these compounds applied postemergence (POST) with glyphosate for control of dicamba-tolerant soybean in field corn. Application, environmental, and weed information is given in Table 1. The experimental area was overseeded with dicamba-tolerant soybean seed prior to planting corn, whereas the Palmer amaranth and green foxtail populations were naturally occurring. Herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi. Plot size was 10 × 35 feet arranged in a randomized complete block design with four replications. Soil for the experiment was a Beeler silt loam with 2.4% organic matter and pH 7.6. Visual weed control ratings were determined on June 20 and September 5, 2017, which was 5 and 82 days after the POST treatments (DAPT), respectively. Grain yields were determined by mechanically harvesting the center two rows of each plot on October 20, 2017, and adjusting weights to 15.5% moisture.

Results and Discussion
Dicamba-tolerant soybean control at 5 DAPT was best when Armezon or Armezon Pro was applied POST with atrazine and glyphosate, or when with Status, atrazine, and glyphosate were applied POST (Table 2). These treatments, along with PRE treatments

of Armezon Pro and atrazine, completely controlled soybean at 82 DAPT. Similarly, control of Palmer amaranth and green foxtail was generally best with Armezon Pro and atrazine applied PRE or any herbicide combination applied POST regardless of evaluation date. Corn receiving PRE treatment of any herbicide yielded 41 to 120 bu/a more than the weedy checks; however, corn treated POST with any herbicide treatment yielded 117 to 145 bu/a more grain than the untreated controls.

Table 1. Application information

Application timing	Preemergence	Postemergence
Application date	May 16, 2017	June 15, 2017
Air temperature (°F)	93	77
Relative humidity (%)	22	58
Soil temperature (°F)	73	74
Wind speed (mph)	4	5
Wind direction	South	South-southeast
Soil moisture	Good	Good
Volunteer soybean		
Height (inch)	---	5
Density (plants/ft^2)	0	2.3
Palmer amaranth		
Height (inch)	---	5
Density (plants/ft^2)	0	2.3
Green foxtail		
Height (inch)	---	0.4
Density (plants/ft^2)	0	0.3

Table 2. Control of dicamba-tolerant soybean in corn

Treatment[a]	Rate	Timing[b]	Soybean 5 DAPT[c]	Soybean 82 DAPT	Palmer amaranth 5 DAPT	Palmer amaranth 82 DAPT	Green foxtail 5 DAPT	Green foxtail 82 DAPT	Corn yield
	oz/a		% Visual						bu/a
Untreated	---		0	0	0	0	0	0	48.3
Armezon	0.5	PRE	74	70	67	52	77	57	89.0
Atrazine	16	PRE							
Armezon	0.75	PRE	80	81	78	63	84	73	118.8
Atrazine	16	PRE							
Armezon Pro	16	PRE	70	100	93	85	100	98	168.5
Atrazine	16	PRE							
Armezon Pro	20	PRE	83	100	90	85	98	100	156.2
Atrazine	16	PRE							
Armezon	0.5	POST	95	100	91	88	95	98	187.1
Atrazine	16	POST							
Glyphosate	32	POST							
MSO	1%	POST							
AMS	2%	POST							
Armezon	0.75	POST	95	100	93	87	98	100	191.3
Atrazine	16	POST							
Glyphosate	32	POST							
MSO	1%	POST							
AMS	2%	POST							
Armezon Pro	16	POST	95	100	94	87	100	100	174.5
Atrazine	16	POST							
Glyphosate	32	POST							
Superb HC	0.5%	POST							
AMS	2%	POST							
Armezon Pro	20	POST	95	100	94	78	100	100	165.5
Atrazine	16	POST							
Glyphosate	32	POST							
Superb HC	0.5%	POST							
AMS	2%	POST							
Status	5	POST	95	100	93	89	100	100	192.9
Atrazine	16	POST							
Glyphosate	32	POST							
MSO	1%	POST							
AMS	2%	POST							
LSD (0.05)			7	6	9	11	5	5	25.0

[a]AMS = ammonium sulfate. MSO = methylated seed oil.
[b]PRE = preemergence. POST = postemergence.
[c]DAPT = days after postemergence application. Weed control was determined on June 20 and September 5, 2017, whereas yields were determined on October 20, 2017.

Efficacy of Mesotrione-Based Tank Mixtures and Application Timings Compared to Standards in Irrigated Corn

R.S. Currie and P. W. Geier

Summary

Kochia, Russian thistle, and quinoa control was excellent regardless of treatment or rating date. Sunflower control at 10 DAPT was very good when Anthem Maxx (pyroxasulfone + fluthiacet) + Solstice (fluthiacet + mesotrione) + atrazine and glyphosate were applied EPOST, while green foxtail control was 94% with the same treatment at 68 DAPT. Palmer amaranth and green foxtail control at 68 DAPT was 93 and 91%, respectively, when SureStart II (acetochlor + flumetsulam + clopyralid) + atrazine and glyphosate were applied PRE followed by glyphosate POST. All herbicide-treated corn yielded 34 to 69 bu/a more grain than the untreated control. Yields among herbicide-treated corn were lowest when no EPOST or POST application was included.

Introduction

Mesotrione has recently come off of patent and this has greatly reduced its price. This has allowed companies that previously did not have patent rights to include it to broaden the weed spectrum of their tank mixes. Many of these tank mixes, as well as other competitive chemistries have potent preemergence as well as postemergence activity so they may be applied prior to planting then reapplied after corn and escaped weeds have emerged. Therefore, it was the objective of this study to apply a broad array of these compounds at various timings to measure their relative weed control.

Experimental Procedures

An experiment at the Kansas State University Southwest Research-Extension Center near Garden City, KS, evaluated various herbicide premixes and tank mixtures for efficacy at various application timings. Naturally occurring weed populations were supplemented by overseeding the experimental area with quinoa, domesticated sunflower, and Rox Orange forage sorghum prior to corn planting. These species simulated common lambsquarters, common sunflower, and shattercane. Resicore (acetochlor + clopyralid + mesotrione), atrazine, glyphosate, and 2,4-D ester were applied 28 days early preplant (EPP). Preemergence (PRE) treatments included Anthem Maxx, atrazine, glyphosate, Solstice, Callisto (mesotrione), Balance Flexx (isoxaflutole), Keystone NXT (acetochlor + atrazine), Hornet WDG (flumetsulam + clopyralid), SureStart II, Acuron (*S*-metolachlor + atrazine +mesotrione + bicyclopyrone), and Resicore. Status (diflufenzopyr + dicamba) as well as many of the PRE herbicides were then reapplied as postemergence (POST) treatments. Application, environmental, crop, and weed information is given in Table 1. Herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi. Plot size was 10 × 35 feet, and the experiment was a randomized complete block with four replications. Soil was a Beeler silt loam with pH 7.6 and 2.4% organic matter. Weed control ratings for all species were visually determined on June 19 and August 16, 2017, which was 10 and 68 days after the POST treatments

(DAPT), respectively. Corn yields were determined October 18, 2017, by mechanically harvesting the two center rows of each plot and adjusting grain weights to 15.5% moisture.

Results and Discussion

Overall weed control was good with most herbicides, such that kochia, Russian thistle, and quinoa control was 98% or more regardless of treatment or rating date (data not shown). Sunflower control at 10 DAPT was 95% when Anthem Maxx + Solstice + atrazine and glyphosate were applied EPOST, while green foxtail control was 94% with the same treatment at 68 days after postemergence treatment (DAPT; Table 2). Palmer amaranth and green foxtail control at 68 DAPT was 93 and 91%, respectively, when SureStart II + atrazine and glyphosate were applied PRE followed by glyphosate POST. All herbicide-treated corn yielded 34 to 69 bu/a more grain than the untreated control. Yields among herbicide-treated corn plots were lowest when no EPOST or POST application was included.

Table 1. Application information

Application timing	Early preplant	Preemergence	Early postemergence	Postemergence
Application date	April 12, 2017	May 9, 2017	May 30, 2017	June 9, 2017
Air temperature (°F)	62	76	74	67
Relative humidity (%)	45	47	41	66
Soil temperature (°F)	52	46	72	67
Wind speed (mph)	10	3	5	7
Wind direction	South	Southeast	West	South
Soil moisture	Good	Good	Good	Good
Corn				
Height (inch)	---	---	4 to 7	7 to 10
Leaves (number)	0	0	2 to 3	4 to 5
Common sunflower				
Height (inch)	---	---	2 to 4	2 to 4
Density (plants/10 ft^2)	0	0	3	1
Palmer amaranth				
Height (inch)	---	---	1 to 3	2 to 4
Density (plants/10 ft^2)	0	0	1 to 5	1 to 5
Green foxtail				
Height (inch)	---	---	1 to 3	1 to 4
Density (plants/10 ft^2)	0	0	3	3
Kochia				
Height (inch)	---	---	4 to 8	2 to 4
Density (plants/10 ft^2)	0	0	3	1
Russian thistle				
Height (inch)	---	---	6 to 12	6 to 15
Density (plants/10 ft^2)	0	0	5	3
Quinoa				
Height (inch)	---	---	1 to 3	1 to 3
Density (plants/10 ft^2)	0	0	3	1

Table 2. Application timing and tank mixture evaluation in corn

Treatment[a]	Rate	Timing[b]	Sunflower 10 DA-D[c]	Sunflower 68 DA-D	Palmer amaranth 10 DA-D	Palmer amaranth 68 DA-D	Green foxtail 10 DA-D	Green foxtail 68 DA-D	Corn yield
	oz/a		% Visual						bu/a
Untreated	---		0	0	0	0	0	0	103.7
Anthem Maxx	4.0	PRE	100	100	100	100	100	99	172.6
Atrazine	32	PRE							
Glyphosate	22	PRE							
AMS	1%	PRE							
Solstice	2.5	POST							
Atrazine	16	POST							
Glyphosate	22	POST							
COC	1%	POST							
AMS	1%	POST							
Anthem Maxx	4.0	PRE	100	100	100	100	100	99	165.3
Callisto	4.0	PRE							
Atrazine	32	PRE							
Glyphosate	22	PRE							
AMS	1%	PRE							
Solstice	2.5	POST							
Atrazine	16	POST							
Glyphosate	22	POST							
COC	1%	POST							
AMS	1%	POST							
Anthem Maxx	4.0	PRE	100	100	100	100	100	98	161.9
Balance Flexx	3.0	PRE							
Atrazine	32	PRE							
Glyphosate	22	PRE							
AMS	1%	PRE							
Solstice	2.5	POST							
Atrazine	16	POST							
Glyphosate	22	POST							
COC	1%	POST							
AMS	1%	POST							
Anthem Maxx	4.0	PRE	100	100	100	99	100	100	166.1
Hornet WDG	4.0	PRE							
Atrazine	32	PRE							
Glyphosate	22	PRE							
AMS	1%	PRE							
Solstice	2.5	POST							
Atrazine	16	POST							
Glyphosate	22	POST							
COC	1%	POST							
AMS	1%	POST							

continued

Table 2. Application timing and tank mixture evaluation in corn

			Sunflower		Palmer amaranth		Green foxtail		
Treatment[a]	Rate	Timing[b]	10 DA-D[c]	68 DA-D	10 DA-D	68 DA-D	10 DA-D	68 DA-D	Corn yield
	oz/a		% Visual						bu/a
Anthem Maxx	2.0	EPOST	95	98	100	100	100	94	164.9
Solstice	2.5	EPOST							
Atrazine	32	EPOST							
Glyphosate	22	EPOST							
COC	1%	EPOST							
AMS	1%	EPOST							
Anthem Maxx	4.0	EPOST	100	100	100	100	100	98	151.0
Callisto	3.0	EPOST							
Atrazine	32	EPOST							
Glyphosate	22	EPOST							
COC	1%	EPOST							
AMS	1%	EPOST							
Acuron	1.25 qt	PRE	100	100	100	99	100	100	169.9
Atrazine	10	PRE							
Glyphosate	22	PRE							
AMS	1%	PRE							
Acuron	1.25 qt	POST							
Atrazine	10	POST							
Status	2.5	POST							
Glyphosate	28	POST							
AMS	1%	POST							
Acuron	2.5 qt	PRE	100	100	100	100	100	97	138.0
Atrazine	13	PRE							
Glyphosate	22	PRE							
AMS	1%	PRE							
Resicore	2.5 qt	EPP	100	100	100	98	98	96	161.3
Atrazine	32	EPP							
Glyphosate	32	EPP							
2,4-D ester	16	EPP							
AMS	2.5%	EPP							
Glyphosate	32	POST							
AMS	2.5%	POST							
Keystone NXT	2.1 qt	PRE	100	100	100	98	100	96	164.3
Hornet WDG	4.0	PRE							
Glyphosate	32	PRE							
AMS	2.5%	PRE							
Glyphosate	32	POST							
AMS	2.5%	POST							

continued

Table 2. Application timing and tank mixture evaluation in corn

			Sunflower		Palmer amaranth		Green foxtail		
Treatment[a]	Rate	Timing[b]	10 DA-D[c]	68 DA-D	10 DA-D	68 DA-D	10 DA-D	68 DA-D	Corn yield
	oz/a		------ % Visual ------						bu/a
SureStart II	2.0 pt	PRE	100	100	100	93	100	91	160.5
Atrazine	32	PRE							
Glyphosate	32	PRE							
AMS	2.5%	PRE							
Glyphosate	32	POST							
AMS	2.5%	POST							
Resicore	2.5 qt	PRE	100	100	100	100	100	97	167.1
Atrazine	32	PRE							
Glyphosate	32	PRE							
AMS	2.5%	PRE							
Glyphosate	32	POST							
AMS	2.5%	POST							
Resicore	1.25 qt	PRE	100	100	100	100	100	97	171.6
Atrazine	32	PRE							
Glyphosate	32	PRE							
AMS	2.5%	PRE							
Resicore	1.25 qt	POST							
Atrazine	32	POST							
Glyphosate	32	POST							
AMS	2.5%	POST							
LSD (0.05)			4	2	1	4	2	4	31.7

[a]AMS = ammonium sulfate. COC = crop oil concentrate.
[b]EPP = 28 days before planting, PRE = preemergence, EPOST = early postemergence, and POST = postemergence.
[c]DA-D = days after postemergence treatment. Weed control was determined on June 19 and August 16, 2017, whereas corn yields were determined on October 18, 2017.

Liberty Rates and Tank Mixes with Balance Flexx, Capreno, Diflexx, Halex GT, and Laudis for Weed Control in Irrigated Liberty-Resistant Corn

R.S. Currie and P.W. Geier

Summary
Control of common sunflower, quinoa, green foxtail, and kochia was excellent regardless of herbicide treatment or evaluation date. Palmer amaranth and crabgrass control was 95% or more regardless of herbicide treatment at 7 days after postemergence application (DAPT). Postemergence applications of Liberty (glufosinate) at any rate alone controlled Palmer amaranth greater than 85% 72 DAPT, whereas tank mixing any herbicide with Liberty increased control 7 to 15%. Crabgrass control was greater than 89% at 72 DAPT with all treatments except when Liberty at 22 oz/a was applied with Diflexx (dicamba). Corn yields did not differ among herbicide-treated plots, but all herbicide treatments increased yield 118 to 149 bu/a relative to the untreated controls.

Introduction
The active ingredient in Liberty, glufosinate, was first reported to have herbicidal activity in 1981. Although it has very broad spectrum capacity to burn most weed species, it does not translocate well in plants so it only kills very small weeds. Further, it could also cause severe damage to crops. With the advent of Liberty Link soybean and corn with excellent resistance to glufosinate, this compound has had renewed interest for weed control. Further as more weeds have developed resistance to glyphosate, Liberty–when used on small weeds–has been shown to provide a suitable substitute. However, like glyphosate it lacks any preemergence weed control. Unlike glyphosate it also needs some assistance when applied to weeds above certain sizes. Therefore, it was the objective of this study to explore tank mixes of atrazine, Capreno (tembotrione + thiencarbazone), Laudis (tembotrione), and Halex GT (*S*-metolachlor + glyphosate + mesotrione) to enhance weed control provided with Liberty.

Experimental Procedures
An experiment at the Kansas State University Southwest Research-Extension Center near Garden City, KS, evaluated Liberty rates and tank mix partners for postemergence weed control in corn. The experimental area was overseeded with a mixture of kochia, Palmer amaranth, crabgrass, quinoa, and domesticated sunflower seed prior to corn planting. Quinoa and domesticated sunflower were used as surrogates for common lambsquarters and common sunflower, respectively. All postemergence treatments were preceded by a preemergence application of Balance Flexx at 3.0 oz/a + atrazine at 32 oz/a. Herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi. Application, environmental, crop, and weed details are shown in Table 1. Plot size was 10 × 35 feet and arranged in a randomized complete block with four replicates. Soil for the experiment was a Beeler silt loam with pH 7.6 and

2.4% organic matter. Weed control was visually rated on June 12 and August 16, 2017, which was 7 and 72 DAPT, respectively. Corn yields were determined on October 18, 2017, by mechanically harvesting the center two rows of each plot and adjusting grain weights to 15.5% moisture.

Results and Discussion

Control of quinoa, green foxtail, and kochia was 98% or more regardless of herbicide treatment or evaluation date (data not shown) as was common sunflower control (Table 2). Palmer amaranth and crabgrass control was 95% or more regardless of herbicide treatment at 7 DAPT. Postemergence applications of Liberty at any rate alone controlled Palmer amaranth 85 to 88% at 72 DAPT, whereas tank mixing any herbicide with Liberty increased control 7 to 15%. Crabgrass control was 89 to 96% at 72 DAPT with all treatments except when Liberty at 22 oz/a was applied with Diflexx at 10 oz/a (84%). Corn yields did not differ among herbicide-treated plots, but each herbicide treatment increased yield 118 to 149 bu/a relative to the untreated controls.

Table 1. Application information

Application timing	Preemergence	Postemergence
Application date	April 20, 2017	June 5, 2017
Air temperature (°F)	54	90
Relative humidity (%)	56	29
Soil temperature (°F)	60	90
Wind speed (mph)	8	5
Wind direction	North-northwest	Southeast
Soil moisture	Good	Good
Corn		
Height (inch)	---	8 to 10
Leaves (no.)	0	3 to 4
Common sunflower		
Height (inch)	---	4 to 6
Density (plants/10 ft^2)	0	3
Palmer amaranth		
Height (inch)	---	3 to 7
Density (plants/10 ft^2)	0	3
Green foxtail		
Height (inch)	---	2 to 3
Density (plants/10 ft^2)	0	2
Kochia		
Height (inch)	---	3 to 7
Density (plants/10 ft^2)	0	15
Russian thistle		
Height (inch)	---	3 to 6
Density (plants/m^2)	0	2
Crabgrass		
Height (inch)	---	2 to 4
Density (plants/10 ft^2)	0	10

Table 2. Liberty rates and tank mixtures in corn

Treatment	Rate	Timing[a]	Palmer amaranth 7 DAPT[b]	Palmer amaranth 72 DAPT	Common sunflower 7 DAPT	Common sunflower 72 DAPT	Crabgrass 7 DAPT	Crabgrass 72 DAPT	Corn yield
	oz/a		% Visual						bu/a
Untreated	---		0	0	0	0	0	0	52.1
Balance Flexx	3.0	PRE	99	88	100	100	97	95	176.9
Atrazine	32	PRE							
Liberty	32	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	99	86	100	100	95	93	183.1
Atrazine	32	PRE							
Liberty	36	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	98	85	100	100	97	89	186.7
Atrazine	32	PRE							
Liberty	43	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	98	100	100	98	91	173.5
Atrazine	32	PRE							
Liberty	32	POST							
Atrazine	16	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	96	99	100	97	93	188.8
Atrazine	32	PRE							
Liberty	36	POST							
Atrazine	16	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	95	100	100	98	94	201.5
Atrazine	32	PRE							
Liberty	43	POST							
Atrazine	16	POST							
Ammonium sulfate	3.0 lb	POST							
Balance Flexx	3.0	PRE	100	100	100	100	97	90	170.4
Atrazine	32	PRE							
Liberty	22	POST							
Laudis	3.0	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	99	100	100	97	94	185.4
Atrazine	32	PRE							
Liberty	32	POST							
Laudis	3.0	POST							
AMS	3 lb	POST							

continued

Table 2. Liberty rates and tank mixtures in corn

Treatment	Rate	Timing[a]	Palmer amaranth 7 DAPT[b]	Palmer amaranth 72 DAPT	Common sunflower 7 DAPT	Common sunflower 72 DAPT	Crabgrass 7 DAPT	Crabgrass 72 DAPT	Corn yield
	oz/a		% Visual						bu/a
Balance Flexx	3.0	PRE	98	95	100	100	96	84	184.7
Atrazine	32	PRE							
Liberty	22	POST							
Diflexx	10	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	99	97	100	96	89	179.6
Atrazine	32	PRE							
Liberty	32	POST							
Diflexx	10	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	100	100	98	99	90	181.8
Atrazine	32	PRE							
Liberty	22	POST							
Capreno	3.0	POST							
Atrazine	16	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	98	99	100	99	94	188.8
Atrazine	32	PRE							
Liberty	22	POST							
Halex GT	3.6 pt	POST							
Ammonium sulfate	3 lb	POST							
Balance Flexx	3.0	PRE	100	100	100	100	99	96	198.3
Atrazine	32	PRE							
Halex GT	3.6 pt	POST							
Status	5.0	POST							
Nonionic surfactant	0.25%	POST							
Ammonium sulfate	1.7 lb	POST							
LSD (0.05)			2	6	3	2	3	7	32.9

[a] PRE = preemergence, POST = postemergence.
[b] DAPT = days after postemergence treatments. Weed control ratings determined on June 12 and August 16, 2017. Corn yields determined on October 18, 2017.

Preemergence and Early Postemergence Weed Control with Instigate, Glyphosate, Realm Q, Atrazine, Dicamba, Corvus, Acuron, and Resicore in Irrigated Corn

R.S. Currie and P.W. Geier

Summary
Palmer amaranth, kochia, quinoa, common sunflower, and green foxtail control was excellent with most treatments. Crabgrass control was also good with most treatments. Crabgrass control with Realm Q (rimsulfuron + mesotrione) + atrazine, dicamba, and glyphosate; and with Corvus (isoxaflutole + thiencarbazone) + atrazine, dicamba, and glyphosate was slightly less by 73 DAPT. The exceptional weed control with these herbicides resulted in grain yields that were 108 to 125 bu/a greater than in the untreated plots. However, there were no differences among herbicide treatments for corn yield.

Introduction
Mesotrione, a key component of Acuron (*S*-metolachlor + atrazine + mesotrione + bicyclopyrone), has recently come off patent, allowing it to be used in several novel premixes such as Instigate (rimsulfuron + mesotrione), Realm Q, and Resicore (acetochlor + clopyralid + mesotrione). Corvus has a different mode of action than these compounds and is commercially competitive with them. Many of these premixes can be augmented by adding Cinch ATZ (*S*-metolachlor + atrazine), glyphosate, atrazine, or dicamba. Therefore, it was the objective of this study to compare the weed control of these herbicides at preemergence and postemergence application timings.

Experimental Procedures
An experiment at the Kansas State University Southwest Research-Extension Center near Garden City, KS, evaluated residual weed control with herbicides applied preemergence (PRE) or early postemergence (EPOST) when corn had one to two true leaves. The experimental area was overseeded with Palmer amaranth, kochia, crabgrass, quinoa, and domesticated sunflower seed prior to corn planting. Quinoa and domesticated sunflower were used as surrogates for common lambsquarters and common sunflower. All herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi. Application, environmental, crop, and weed information is shown in Table 1. Plot size was 10 × 35 feet and arranged in a randomized complete block with four replicates. Soil was a Beeler silt loam with pH 7.6 and 2.4% organic matter. Weed control was visually determined on June 16 and August 17, 2017, which was 11 and 73 days after the early postemergence treatments (DAPT), respectively. Corn yields were determined by mechanical harvest of the two center rows of each plot on October 19, 2017, and adjusting grain weights to 15.5% moisture.

Results and Discussion

Palmer amaranth, kochia, quinoa, common sunflower, and green foxtail control was 97% or more regardless of herbicide or evaluation date, and did not differ between any treatments (data not shown). Crabgrass was controlled 94% or more by all treatments except Realm Q + atrazine, dicamba, and glyphosate at 11 and 73 DAPT; and Corvus + atrazine, dicamba and glyphosate at 73 DAPT (Table 2). The exceptional weed control with these herbicides resulted in grain yields that were 108 to 125 bu/a greater than in the untreated plots. However, no differences occurred among herbicide treatments for corn yield.

Table 1. Application information

Application timing	Preemergence	Early postemergence
Application date	May 16, 2017	June 5, 2017
Air temperature (°F)	93	91
Relative humidity (%)	22	26
Soil temperature (°F)	73	83
Wind speed (mph)	4	5
Wind direction	South	East
Soil moisture	Good	Good
Corn		
Height (inch)	---	4 to 6
Leaves (number)	0	1 to 2
Common sunflower		
Height (inch)	---	1 to 2
Density (plants/10 ft^2)	0	1
Palmer amaranth		
Height (inch)	---	0.5 to 2
Density (plants/10 ft^2)	0	10
Green foxtail		
Height (inch)	---	0.25 to 1
Density (plants/10 ft^2)	0	2
Kochia		
Height (inch)	---	1 to 2
Density (plants/10 ft^2)	0	2
Quinoa		
Height (inch)	---	0.5 to 2
Density (plants/10 ft^2)	0	1
Crabgrass		
Height (inch)	---	0.25 to 1
Density (plants/10 ft^2)	0	2

Table 2. Preemergence and early postemergence weed control in corn

Treatment	Rate/a	Timing[a]	Crabgrass		Corn yield
			11 DAPT[b]	73 DAPT	
			------------- % Visual ------ -------		bu/a
Untreated	---		0	0	63.7
Instigate	6.0 oz	PRE	99	94	172.1
Cinch ATZ	2 qt	PRE			
Glyphosate	22 oz	PRE			
Nonionic surfactant	0.25%	PRE			
Ammonium sulfate	2%	PRE			
Realm Q	4.0 oz	EPOST	94	88	183.4
Atrazine	32 oz	EPOST			
Dicamba	4.0 oz	EPOST			
Glyphosate	22 oz	EPOST			
Crop oil concentrate	1%	EPOST			
Ammonium sulfate	2%	EPOST			
Corvus	5.6 oz	EPOST	98	91	188.7
Atrazine	32 oz	EPOST			
Dicamba	4.0 oz	EPOST			
Glyphosate	22 oz	EPOST			
Nonionic surfactant	0.25%	EPOST			
Ammonium sulfate	2%	EPOST			
Acuron	3.0 qt	EPOST	100	97	183.5
Glyphosate	22 oz	EPOST			
Nonionic surfactant	0.25%	EPOST			
Resicore	2.5 qt	EPOST	99	97	186.8
Atrazine	32 oz	EPOST			
Glyphosate	22 oz	EPOST			
Nonionic surfactant	0.5%	EPOST			
LSD (0.05)			3	6	29.2

[a] PRE = preemergence, EPOST = early postemergence when corn was in the two leaf stage.
[b] DAPT = days after early postemergence applications. Weed control ratings determined on June 16 and August 17, 2017. Corn grain yields determined on October 19, 2017.

Diflexx Duo Compared to Capreno, Halex GT, Armezon, Outlook, Status, Degree Xtra, and Bicep II Magnum for Weed Control in Irrigated Corn

R.S. Currie and P.W. Geier

Summary
Control of kochia, quinoa, and green foxtail was complete with all herbicides at 78 days after treatment (DAT). Palmer amaranth, common sunflower, and crabgrass was 97% at 8 DAT. By 78 DAT, common sunflower control was complete with all herbicides. Crabgrass control at 78 DAT was excellent except when Diflexx Duo (dicamba + tembotrione) at 24 oz/a + atrazine was mixed with glyphosate or Liberty. All herbicide-treated corn yielded 111 to 126 bu/a more grain than the untreated controls. The various additions to the premixes improved weed control to the point that no difference occurred among them for yield.

Introduction
Diflexx Duo is a very competitive herbicide package mix with Capreno, Halex GT (*S*-metolachlor + atrazine + mesotrione + glyphosate), Armezon (topramezone), Degree Xtra (acetochlor + atrazine), and Bicep II Magnum (*S*-metolachlor + atrazine). Each of these package mixes has different levels of preemergence and postemergence weed control. Adding other compounds–such as Liberty (glufosinate), Outlook (dimethenamid-*P*), and Status (dicamba + diflufenzopyr)–can often improve overall weed control. Therefore, it was the objective of this study to compare these compounds alone and with other products to measure their overall weed control.

Experimental Procedures
An experiment at the Kansas State University Southwest Research-Extension Center near Garden City, KS, evaluated the premix of Diflexx Duo with tank mixtures for postemergence efficacy compared to standards in corn. All herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi when corn was 5 to 8 inches tall. Application, environmental, crop, and weed information is shown in Table 1. Plot size was 10 × 35 feet and arranged in a randomized complete block with four replicates. Soil for the experiment was a Beeler silt loam with pH 7.6 and 2.4% organic matter. Visual weed control was evaluated on June 7 and August 16, 2017, which was 8 and 78 DAT, respectively. Corn yields were determined on October 18, 2017 by mechanically harvesting the center two rows of each plot and adjusting grain weights to 15.5% moisture.

Results and Discussion

Control of kochia, quinoa, and green foxtail was complete with all herbicides evaluated at 8 and 78 DAT (data not shown), and was 97% or more for Palmer amaranth, common sunflower, and crabgrass at 8 DAT (Table 2). By 78 DAT, common sunflower control was complete with all herbicides. On the same date, only Capreno + glyphosate and atrazine controlled Palmer amaranth less than 94%. Crabgrass control at 78 DAT was greatest with any herbicide treatment except when Diflexx Duo at 24 oz/a + atrazine was mixed with glyphosate or Liberty (85 to 86%). All herbicide-treated corn yielded 111 to 126 bu/a more grain than the untreated controls, but no difference occurred among herbicide treatments for yield.

Table 1. Application information

Application timing	Postemergence
Application date	May 30, 2017
Air temperature (°F)	71
Relative humidity (%)	54
Soil temperature (°F)	64
Wind speed (mph)	5
Wind direction	West
Soil moisture	Good
Corn	
Height (inch)	5 to 8
Leaves (number)	3 to 4
Common sunflower	
Height (inch)	6 to 10
Density (plants/ft^2)	0.3
Palmer amaranth	
Height (inch)	1 to 6
Density (plants/ft^2)	1.9
Green foxtail	
Height (inch)	3 to 6
Density (plants/ft^2)	0.5
Kochia	
Height (inch)	4 to 6
Density (plants/ft^2)	0.3
Quinoa	
Height (inch)	4 to 8
Density (plants/ft^2)	0.5
Crabgrass	
Height (inch)	3 to 5
Density (plants/ft^2)	1.9

Table 2. Diflexx Duo postemergence comparisons in corn.

Treatment	Rate	Palmer amaranth 8 DAT[a]	Palmer amaranth 78 DAT	Common sunflower 8 DAT	Common sunflower 78 DAT	Crabgrass 8 DAT	Crabgrass 78 DAT	Corn yield
	oz/a	% Visual						bu/a
Untreated	---	0	0	0	0	0	0	46.2
Diflexx Duo Glyphosate Atrazine Ammonium sulfate	32 32 16 1%	100	96	100	100	97	90	170.6
Diflexx Duo Atrazine Crop oil concentrate Ammonium sulfate	32 16 1% 1%	100	99	99	100	97	91	158.5
Diflexx Duo Glyphosate Atrazine Ammonium sulfate	24 32 16 1%	100	96	98	100	98	86	159.2
Diflexx Duo Liberty Atrazine Ammonium sulfate	24 32 16 1%	100	94	97	100	97	85	161.4
Capreno Glyphosate Atrazine Ammonium sulfate	3.0 32 16 1%	100	91	99	100	98	93	168.5
Halex GT Atrazine Nonionic surfactant Ammonium sulfate	3.6 pt 16 0.25% 1%	100	98	99	100	97	88	169.0
Armezon Outlook Glyphosate Atrazine Ammonium sulfate	0.57 14 32 16 1%	100	98	98	100	97	94	168.3
Armezon Status Glyphosate Atrazine Ammonium sulfate	0.57 3.0 32 16 1%	99	100	97	100	98	88	156.9
Degree Xtra Diflexx Duo Glyphosate Ammonium sulfate	3.0 qt 32 32 1%	100	100	100	100	98	93	164.8
Bicep II Magnum Diflexx Duo Glyphosate Ammonium sulfate	1.6 qt 32 32 1%	100	100	100	100	98	93	171.7
LSD (0.05)		NS	6	2	NS	NS	7	25.4

[a] DAT = days after herbicide treatment. Weed control determined on June 7 and August 16, 2017. Corn yields determined on October 18, 2017.

Split Applications of Acuron, Halex GT, Resicore, Balance Flexx, and Armezon Pro for Weed Control in Irrigated Corn

R.S. Currie and P.W. Geier

Summary

Control of kochia, green foxtail, quinoa, and Palmer amaranth was excellent and did not differ among treatments. Common sunflower control was slightly less effective with Acuron (*S*-metolachlor + atrazine + mesotrione + bicyclopyrone) + atrazine applied PRE compared to other treatments early in the season but later in the season no differences occurred. Crabgrass control was excellent regardless of treatment early in the season, and remained high with all herbicides except Balance Flexx (isoxaflutole) + atrazine PRE followed by Diflexx (dicamba) + atrazine and glyphosate POST, which provided less than 89% control. All herbicide treatments resulted in grain yields that were 67 to 101 bu/a greater than the untreated controls. The best herbicide treatment yielded 34 bu/a more than the lowest yielding herbicide combination.

Introduction

Acuron, Halex GT (*S*-metolachlor + mesotrione + glyphosate), Resicore (acetochlor + clopyralid + mesotrione), Balance Flexx, Diflexx, and Armezon Pro (topramezone + dimethenamid-*P*) are all competitive herbicides with different levels of preemergence and postemergence weed control. Because many of the preemergence components of these package mixes begin to decay as soon as they are applied to moist soil, it has long been known that applying part of the total load early and delaying application of the rest of the dose until later can extend control. Further, many of these premixes have postemergence activity as well, allowing for extended control with a second application. Zidua (pyroxasulfone) is a long residual herbicide with excellent preemergence control of grassy weeds and good activity on some small seeded broadleaf weeds. It was also included to augment weed control with atrazine applied preemergence alone. Postemergence glyphosate was included to help with any weeds that escaped the initial application. Therefore, it was the objective of this study to test these various compounds and their timings of application for weed control.

Experimental Procedures

An experiment at the Kansas State University Southwest Research-Extension Center near Garden City, KS, evaluated sequential applications of premix herbicides for efficacy in corn. The experimental area was overseeded with kochia, Palmer amaranth, crabgrass, quinoa, and domesticated sunflower prior to corn planting. Quinoa and domesticated sunflower were used as surrogates for common lambsquarters and common sunflower, respectively. Herbicides were applied either preemergence (PRE) alone or PRE followed by postemergence (POST). All herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi. Application, environmental, crop, and weed information is shown in Table 1. Plot size was 10 × 35 feet and arranged in a randomized complete block with four replicates. Soil for the experiment was a Beeler silt loam with pH 7.6 and 2.4% organic matter. Visual weed control was determined on June 23 and September 5, 2017, which was 7 and 81 days after the POST treatments (DAPT), respectively. Corn yields were determined on October 23, 2017, by mechanically harvesting the center two rows of each plot and adjusting grain weights to 15.5% moisture.

Results and Discussion

Control of kochia, green foxtail, quinoa, and Palmer amaranth was 96 to 100% regardless of herbicide or evaluation date, and did not differ among treatments (data not shown). Although common sunflower control was slightly less with Acuron + atrazine applied PRE compared to other treatments at 7 DAPT (Table 2), no differences for sunflower control occurred by 81 DAPT. Crabgrass control was 95 to 100% regardless of treatment early in the season, and remained high with all herbicides except Balance Flexx + atrazine PRE followed by Diflexx + atrazine and glyphosate POST (88%). All herbicide treatments resulted in grain yields that were 67 to 101 bu/a greater than the untreated controls. The best yields were achieved when Acuron + atrazine were applied alone PRE and when Resicore + atrazine PRE was followed by Resicore + atrazine and glyphosate POST (133 to 128 bu/a). These yields were better than yields from corn receiving Balance Flexx + atrazine PRE followed by Diflexx + atrazine and glyphosate POST (99 bu/a). The best herbicide treatment yielded 34 bu/a more than the lowest yielding herbicide combination.

Table 1. Application information

Application timing	Preemergence	Postemergence
Application date	May 24, 2017	June 16, 2017
Air temperature (°F)	66	77
Relative humidity (%)	30	56
Soil temperature (°F)	54	75
Wind speed (mph)	2	8
Wind direction	West	South
Soil moisture	Fair	Good
Corn		
Height (inch)	---	8 to 13
Leaves (number)	0	4 to 5
Common sunflower		
Height (inch)	---	4 to 8
Density (plants/10 ft^2)	0	1
Palmer amaranth		
Height (inch)	---	4 to 6
Density (plants/10 ft^2)	0	2
Green foxtail		
Height (inch)	---	8 to 12
Density (plants/10 ft^2)	0	2
Kochia		
Height (inch)	---	10 to 15
Density (plants/10 ft^2)	0	2
Quinoa		
Height (inch)	---	6 to 10
Density (plants/10 ft^2)	0	1
Crabgrass		
Height (inch)	---	2 to 4
Density (plants/10 ft^2)	0	3

Table 2. Split-application herbicide efficacy in corn

			Common sunflower		Crabgrass		
Treatment	Rate/a	Timing[a]	7 DAPT[b]	81 DAPT	7 DAPT	81 DAPT	Corn yield
			---------------------- % Visual	----------------------			bu/a
Untreated	---		0	0	0	0	31.5
Acuron	2.5 qt	PRE	96	100	98	97	132.9
Atrazine	0.4 qt	PRE					
Acuron	1.25 qt	PRE	100	100	100	99	124.2
Atrazine	0.3 qt	PRE					
Acuron	1.25 qt	POST					
Atrazine	0.3 qt	POST					
Status	2.5 oz	POST					
Glyphosate	31 oz	POST					
Ammonium sulfate	2.0%	POST					
Acuron	1.5 qt	PRE	100	100	100	100	125.0
Atrazine	0.3 qt	PRE					
Halex GT	4.0 pt	POST					
Atrazine	0.5 qt	POST					
Status	2.5 oz	POST					
Nonionic surfactant	0.5%	POST					
Ammonium sulfate	2.0%	POST					
Resicore	1.25 qt	PRE	100	100	95	100	127.6
Atrazine	0.5 qt	PRE					
Resicore	1.25 qt	POST					
Atrazine	0.5 qt	POST					
Glyphosate	31 oz	POST					
Ammonium sulfate	2%	POST					
Balance Flexx	3.0 oz	PRE	100	100	96	88	98.8
Atrazine	0.5 qt	PRE					
Diflexx	32 oz	POST					
Atrazine	0.5 qt	POST					
Glyphosate	31 oz	POST					
Ammonium sulfate	2%	POST					
Zidua	3.0 oz	PRE	100	100	100	100	120.2
Atrazine	0.5 qt	PRE					
Armezon Pro	16 oz	POST					
Atrazine	0.5 qt	POST					
Glyphosate	31 oz	POST					
Crop oil concentrate	1%	POST					
Ammonium sulfate	2%	POST					

continued

Table 2. Split-application herbicide efficacy in corn

			Common sunflower		Crabgrass		
Treatment	Rate/a	Timing[a]	7 DAPT[b]	81 DAPT	7 DAPT	81 DAPT	Corn yield
			---------------------- % Visual			----------------------	bu/a
Acuron	1.5 qt	PRE	100	100	99	100	121.5
Atrazine	0.3 qt	PRE					
Acuron	1.5 qt	POST					
Atrazine	0.3 qt	POST					
Status	2.5 oz	POST					
Glyphosate	31 oz	POST					
Ammonium sulfate	2%	POST					
LSD (0.05)			3	NS	4	3	28.0

[a]PRE = preemergence. POST = postemergence.
[b]DAPT = days after postemergence applications Weed control was determined on June 23 and September 5, 2017. Corn yields were determined on October 23, 2017.

Vida Alone and in Tank Mixtures for Spring Kochia Control in Fallow

R.S. Currie, P.W. Geier, G.W. Boyer, and P.W. Stahlman

Summary
No herbicide treatment provided more than 50% kochia control at Garden City, KS, or 80% kochia control at Hays the first week of application. At Garden City, KS, treatments of Vida (pyraflufen) plus glyphosate and 2,4-D or dicamba, glyphosate alone, or glyphosate plus 2,4-D or dicamba provided greater than 89% kochia control. At Hays, glyphosate alone or with 2,4-D, and Vida plus dicamba alone or with glyphosate had greater than 85% control of kochia.

Introduction
Vida is a protoporphyrinogen oxidase (PPO) inhibitor (Group 14) herbicide that includes compounds such as Cobra (lactofen), Flexstar (fomesafen), and Ultra Blazer (acifluorfin). This class of herbicides causes cell membranes to burst leading to rapid tissue death. Cell rupture happens so quickly that very little translocation to root or meristematic tissues occur. This can dramatically reduce the ability of this class of herbicides to kill weeds. Therefore, it was the objective of this study to tank mix Vida with herbicides that translocate better such as glyphosate, 2,4-D, and dicamba.

Experimental Procedures
Two experiments were conducted in western Kansas to evaluate Vida alone and in tank mixtures for early spring kochia control in fallow. Locations included the Kansas State University Agricultural Research Center near Hays, KS, and the Southwest Research-Extension Center near Garden City, KS. Application, environmental, and weed information are given in Table 1. Herbicides were applied using a tractor-mounted sprayer delivering 20 GPA at 30 psi at Garden City or a backpack sprayer at Hays delivering 15 GPA at 32 psi. Soil at Hays was a Roxbury silt loam with 2.7% organic matter and pH 7.9. Garden City soil was a Ulysses silt loam with 3.4% organic matter and pH 7.9. Plots were 10 × 32 feet (Hays) or 10 × 35 feet (Garden City) and arranged in randomized complete blocks with four replications. Visual kochia control was determined on May 17, June 2, and June 16, 2017, at Garden City; dates were 5, 21, and 35 days after treatment (DAT), respectively. At Hays, visual kochia control was determined on June 9, June 23, and July 7, 2017; dates were 7, 21, and 35 DAT, respectively.

Results and Discussion
By 7 DAT, no herbicide treatment provided more than 50% kochia control at Garden City or 80% kochia control at Hays (Table 2). At Garden City, treatments of Vida plus glyphosate and 2,4-D or dicamba, glyphosate alone, or glyphosate plus 2,4-D or dicamba provided the best kochia control at 21 and 35 DAT (89 to 97%). Glyphosate alone or with 2,4-D, and Vida plus dicamba alone or with glyphosate controlled kochia 85 to 91% at Hays by 21 DAT, and only Vida plus dicamba with or without glyphosate controlled kochia more than 80% by 35 DAT.

Table 1. Application and weed information

Location	Garden City, KS	Hays, KS
Application date	May 12, 2017	June 2, 2017
Air temperature (°F)	64	71
Relative humidity (%)	43	72
Soil temperature (°F)	55	70
Wind speed (mph)	5	5
Wind direction	North	South
Soil moisture	Good	Excellent
Kochia:		
Height (inch)	2 to 8	1 to 9
Density (plants/ft^2)	9.3	56

Table 2. Vida alone and in tank mixtures for spring kochia control in fallow at two Kansas locations

		Garden City			Hays		
Treatment[a]	Rate	5 DAT[b]	21 DAT	35 DAT	7 DAT[b]	21 DAT	35 DAT
	oz/a	% Visual					
Untreated	---	0	0	0	0	0	0
Vida COC AMS	2.0 1.0% 2.0%	33	53	45	70	60	40
Vida Glyphosate AMS	2.0 22 2%	33	94	83	63	73	48
Vida 2,4-D amine COC AMS	2.0 4.0 1.0% 2.0%	48	58	50	63	55	23
Vida Glyphosate 2,4-D amine AMS	2.0 22 4.0 2%	45	96	89	55	58	45
Glyphosate AMS	22 2.0%	19	97	90	48	85	68
Glyphosate 2,4-D amine AMS	22 4.0 2.0%	25	97	90	55	88	73
2,4-D amine AMS	4.0 2.0%	---[c]	---	---	3	0	0
Vida Dicamba COC AMS	2.0 4.0 1.0% 2.0%	50	91	93	80	90	83
Vida Glyphosate Dicamba AMS	2.0 22 4.0 2.0%	48	96	97	73	91	83
Dicamba AMS	4.0 2.0%	21	55	70	50	70	73
Dicamba Glyphosate AMS	4.0 22 2.0%	38	97	97	---[c]	---	---
LSD (0.05)		7	6	8	8	8	8

[a]AMS = ammonium sulfate. COC = crop oil concentrate.

[b]DAT = days after treatment. Dates for weed control determination were May 17, June 2, and June 16, 2017 at Garden City, and June 9, June 23, and July 7, 2017 at Hays.

[c]--- = treatment not included at that location.

Tank Mixtures of Vida for Late Summer Weed Control in Fallow

R.S. Currie and P.W. Geier

Summary

Kochia control at soon after application was best when Vida (pyraflufen) was tank mixed with glyphosate, 2,4-D amine, and/or dicamba. However, no Vida treatment controlled kochia more than 60% one month after treatment. Treatments containing glyphosate, 2,4-D, and/or dicamba without Vida did not control kochia more than 33% during the first month. Similarly, Russian thistle control was best regardless of evaluation date when Vida was applied alone or tank mixed with another herbicide. Vida treatments provided 90 to 94% Russian thistle control one month after treatment. Treatments without Vida controlled Russian thistle no more than 63%.

Introduction

Previous studies have shown that adding glyphosate, 2,4-D, or dicamba could ameliorate Vida's weakness of rapid tissue burn without significant translocation. It was unknown if such tank mixes could control older, larger weeds later in the season. Therefore, it was the objective of this study to compare tank mix Vida with glyphosate, 2,4-D, and/or dicamba for late season fallow weed control.

Experimental Procedures

An experiment at the Kansas State University Southwest Research-Extension Center near Garden City, KS, evaluated Vida alone and in tank mixtures for late summer weed control in fallow. All herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer calibrated to deliver 20 GPA at 30 psi and 4.2 mph. Application, environmental, and weed information is given in Table 1. The experiment was conducted on a Beeler silt loam soil with pH 7.6 and 2.4% organic matter. Plots were 10 × 35 feet and arranged in a randomized complete block with four replications. Visual control of kochia and Russian thistle was determined on September 15 and 29, and October 12, 2017, which corresponded to 8, 22, and 35 days after herbicide treatment (DAT), respectively.

Results and Discussion

Kochia control at 8 DAT was best when Vida was tank mixed with glyphosate, 2,4-D amine, and/or dicamba (Table 2), and this trend continued through 35 DAT. However, no Vida treatment controlled kochia more than 60% at 35 DAT. Treatments containing glyphosate, 2,4-D, and/or dicamba without Vida did not control kochia more than 33% at 35 DAT. Similarly, Russian thistle control was best regardless of evaluation date when Vida was applied alone or tank mixed with another herbicide, and Vida treatments provided 90 to 94% Russian thistle control at 35 DAT. Treatments without Vida controlled Russian thistle no more than 63%.

Table 1. Application and weed information

Application date	September 7, 2017
Air temperature (°F)	62
Relative humidity (%)	53
Soil temperature (°F)	64
Wind speed (mph)	5
Wind direction	South
Soil moisture	Very dry
Kochia:	
Height (inch)	8 to 15
Density (plants/ft^2)	3.2
Russian thistle:	
Height (inch)	8 to 14
Density (plants/ft^2)	4.6

Table 2. Vida alone and in tank mixtures for late summer weed control in fallow

		Kochia			Russian thistle		
Treatment[a]	Rate	8 DAT[b]	22 DAT	35 DAT	8 DAT	22 DAT	35 DAT
	oz/a	% Visual					
Untreated	---	0	0	0	0	0	0
Vida COC AMS	2.0 1.0% 2.0%	30	53	48	50	85	90
Vida Glyphosate AMS	2.0 22 2%	35	55	60	53	85	90
Vida 2,4-D amine COC AMS	2.0 4.0 1.0% 2.0%	35	50	55	48	91	91
Vida Glyphosate 2,4-D amine AMS	2.0 22 4.0 2%	33	58	58	50	91	94
Glyphosate AMS	22 2.0%	18	28	30	20	53	55
Glyphosate 2,4-D amine AMS	22 4.0 2.0%	23	33	33	28	55	63
2,4-D amine AMS	4.0 2.0%	18	28	25	23	33	30
Vida Dicamba COC AMS	2.0 4.0 1.0% 2.0%	33	53	58	50	95	94
Vida Glyphosate Dicamba AMS	2.0 22 4.0 2.0%	38	55	55	53	89	91
Dicamba AMS	4.0 2.0%	15	28	28	25	35	30
Dicamba Glyphosate AMS	4.0 22 2.0%	23	33	33	30	55	55
LSD (0.05)		7	9	10	7	7	8

[a] AMS = ammonium sulfate. COC = crop oil concentrate.
[b] DAT = days after treatment. Weed control rating were determined on September 15, September 29, and October 12, 2017.

Weed Control and Injury with Non-Labeled Herbicides in Grain Sorghum

R.S. Currie, P.W. Geier, W. Keeling, and B. Bean

Summary
Palmer amaranth control at Garden City, KS, was good with Acuron or Lumax EZ. At Lubbock, TX, Palmer amaranth control was excellent with all herbicides except Surestart II and Valor at 1 oz/a. Surestart II and Valor provided only fair control of kochia and Russian thistle late in the season at Garden City. No visible sorghum injury from any herbicide was observed at Garden City, and sorghum yields were not affected. Very dry conditions during the experiment at Garden City likely minimized sorghum injury and limited sorghum yields. At Lubbock, minor sorghum injury was observed early with Acuron and Valor. Later in the season only Surestart II showed sorghum injury at Lubbock that translated into some yield loss. However, all herbicide-treated sorghum at Lubbock yielded 28 to 65 bu/a more grain than nontreated sorghum.

Introduction
Acuron (*S*-metolachlor + atrazine + mesotrione + bicyclopyrone) and SureStart II (acetochlor + clopyralid + flumetsulam) are not currently labeled for use in grain sorghum, as their potential to injure grain sorghum is unknown. Currently, it is a violation of federal law to use them for weed control in sorghum. However, they show potential for further research. Valor (flumioxazin) is currently labeled for use 30 days before planting grain sorghum provided 1 inch of rain falls prior to planting. It is not known how much injury can occur from Valor when applied 2 weeks prior to planting without rainfall, or the effects of Acuron or Surestart II on grain sorghum. Lumax EZ (*S*-metolachlor + mesotrione + atrazine), Bicep Lite II Magnum (*S*-metolachlor + atrazine), and Degree Xtra (acetochlor + atrazine) have long been used for weed control in sorghum. Therefore, it was the objective of this study to compare Acuron, SureStart II, and Valor to the known standards Lumax EZ, Bicep Lite II Magnum, and Degree Xtra.

Experimental Procedures
An experiment was conducted at the Kansas State University Southwest Research-Extension Center near Garden City, KS, and at the Texas AgriLife Research Center near Lubbock, TX, to evaluate preplant, non-labeled herbicides for residual weed control and crop tolerance in grain sorghum. Herbicides were applied using a tractor-mounted, compressed-CO_2 sprayer delivering 20 GPA at 30 psi at Garden City and a backpack sprayer delivering 10 GPA at 32 psi at Lubbock. Application, environmental, crop, and weed information is shown in Table 1. Plot size was 10 × 35 feet at Garden City and 10 × 25 feet at Lubbock. Plots were arranged in randomized complete blocks replicated four times at both locations. Soils for the experiments were a Beeler silt loam with pH 7.6 and 2.4% organic matter at Garden City, and an Acuff loam with 0.8% organic matter and pH 7.8 at Lubbock. Weed control was visually rated on August 4 and 18, 2017, at Lubbock and Garden City and these dates were 53 and 67 days after planting (DAP), respectively. Visual sorghum injury was determined on June 13 and July 11, 2017, at Lubbock (14 and 42 DAP), and on June 29 and August 18, 2017 at Garden City (17

and 67 DAP). Sorghum yields were determined on October 19 and November 1, 2017, at Lubbock and Garden City, respectively.

Results and Discussion

Palmer amaranth control at Garden City was 90% or more with Acuron at 2.0 or 2.5 qt/a and Lumax EZ at 2.7 qt/a (Table 2). At Lubbock, Palmer amaranth control exceeded 96% with all herbicides except Surestart II at 1.5 qt/a and Valor at 1.0 oz/a. Surestart II at 1.5 qt/a and Valor at 1.0 oz/a controlled kochia 75 to 85% at Garden City, and these herbicides along with the 2 oz/a rate of Valor provided 70 to 73% Russian thistle control at Garden City. No visible sorghum injury was observed at Garden City, and sorghum yields did not differ between herbicide-treated and nontreated sorghum (Table 3). Very dry conditions during the experiment at Garden City likely minimized sorghum injury and limited sorghum yields. At Lubbock, minor sorghum injury was observed early with Acuron at either rate or Valor at 2 oz/a. By 42 DAP, only Surestart II showed sorghum injury at Lubbock. The injury with this treatment at Lubbock was also evident in sorghum yields. Sorghum receiving Surestart II yielded 36 bu/a less grain than sorghum treated with Bicep Lite II Magnum, which had the highest yield. However, all herbicide-treated sorghum at Lubbock yielded 28 to 65 bu/a more grain than nontreated sorghum. This research shows that injury from these non-labeled herbicides can vary a great deal from location to location, which suggests that it should also vary from season to season based on rainfall. Therefore, growers should avoid using these unregistered products until permitted by labeling changes.

Table 1. Application information

Application timing	Garden City, KS	Lubbock, TX
Application date	May 29, 2017	May 19, 2017
Sorghum planting date	June 12, 2017	May 30, 2017
Air temperature (°F)	53	78
Relative humidity (%)	66	50
Soil temperature (°F)	57	76
Wind speed (mph)	2	8
Wind direction	North	Southwest
Soil moisture	Fair	Good

Table 2. Weed control with preplant herbicides in grain sorghum

		Palmer amaranth		Kochia	Russian thistle
		Garden City	Lubbock	Garden City	
Treatment	Rate/a	67 DAP[a]	66 DAP	67 DAP	67 DAP
		---------------------------- % Visual ----------------------------			
Untreated	---	---	---	---	---
Acuron	2.0 qt	90	97	99	98
Acuron	2.5 qt	96	97	98	100
Lumax EZ	2.7 qt	90	100	100	93
Surestart II	1.5 qt	78	92	75	73
Valor	1.0 oz	79	59	85	70
Valor	2.0 oz	80	97	90	73
Bicep Lite II Magnum	1.5 qt	80	97	98	94
Degree Xtra	2.25 qt	83	99	94	95
LSD (0.05)		11	7	13	12

[a]DAP is days after planting. Weed control ratings were taken on August 4, 2017 at Lubbock and August 18, 2017 at Garden City.

Table 3. Sorghum injury and yield with preplant herbicides in grain sorghum

		Injury		Yield	
		Lubbock		Garden City	Lubbock
Treatment	Rate/a	14 DAP[a]	42 DAP	142 DAP	142 DAP
		--------- % Visual ---------		----------- bu/a -----------	
Untreated	---	0	0	14.8	16.3
Acuron	2.0 qt	5	0	23.7	72.0
Acuron	2.5 qt	5	0	23.7	62.2
Lumax EZ	2.7 qt	0	0	21.1	71.5
Surestart II	1.5 qt	0	33	22.3	44.7
Valor	1.0 oz	0	0	17.3	59.0
Valor	2.0 oz	8	0	18.9	80.5
Bicep Lite II Magnum	1.5 qt	0	0	21.1	80.9
Degree Xtra	2.25 qt	0	0	19.9	74.2
LSD (0.05)		2	2	NS	15.6

[a]DAP is days after planting. Sorghum injury was evaluated on June 13, 2017 at Lubbock and July 11, 2017 at Garden City. Yield data were determined on October 19, 2017 and November 1, 2017 at Lubbock and Garden City, respectively.

Integrating Half Rates of Dicamba and Atrazine with Increasing Sorghum Density and Nitrogen Rate for Palmer Amaranth Control

I.B. Cuvaca, A.J. Foster, and R.S. Currie

Summary
In-season weed control options for grain sorghum (*Sorghum bicolor*) are limited. Palmer amaranth (*Amaranthus palmeri*) can significantly reduce sorghum yield. Integrating half rates of dicamba and atrazine with increasing sorghum density and nitrogen rate could speed up canopy closure and therefore suppress Palmer amaranth (PA). A study was conducted at the Southwest Research-Extension Center near Garden City, KS from 2016 to 2017 to determine if PA could be suppressed with half-rates of dicamba and atrazine applied as preemergent (PRE) with increasing sorghum density (60,000, 90,000, and 120,000 seeds/a), and nitrogen rate (0, 100, and 200 lb/a). Sorghum grain yield was reduced by about 40% with the integration of increased sorghum density and nitrogen rate with half rates of dicamba and atrazine. Therefore, integrating half-rates of dicamba and atrazine applied as PRE with increasing sorghum density and nitrogen rate may not be an effective strategy for Palmer amaranth control.

Introduction
Sorghum is an important crop in Kansas. However, in-season weed control options for sorghum are limited. Season-long interference by Palmer amaranth exacerbates the limitation, due to PA's resistance to multiple herbicides that have different modes of action.

This 2-year study investigated the ability of a contrasting combination of cultural and chemical practices to control Palmer amaranth while maintaining or improving sorghum grain yield. Particular research emphasis was to evaluate the effect(s) of integrating half-rates of dicamba and atrazine applied as PRE with increasing sorghum density and nitrogen rate on PA control and grain yield in an irrigated environment.

Procedures
Experimental Site
Field experiments were conducted at the Southwest Research-Extension Center, near Garden City, KS, in 2016 and 2017. The soil at the site was predominantly Richfield silt loam (fine, montmorillonitic, mesic Aridic Argiustoll).

Experimental Design
Three planting densities (60,000, 90,000, and 120,000 seeds/a), three nitrogen rates (0, 100, and 200 lb/a), and two in-season weed control levels (weedy vs. weed free) were evaluated for their ability to control Palmer amaranth while maintaining grain yield of sorghum using a completely randomized block design with split-split plot arrangement

and four replicates. Planting density, nitrogen rate, and in-season weed control were treated as the main plot, sub-plot, and sub-sub plot factors, respectively.

Plot Establishment and Management

Experimental plots were established using a John Deere planter in a field with a natural infestation of Palmer amaranth. Each sub-sub plot was planted to 4 rows of sorghum at 22.5 ft (2016) or 35 ft (2017) long. The field was disked and field cultivated to assure a weed-free seedbed at planting. Sorghum, "DK 3707," was planted on June 20, 2016, and May 24, 2017, in rows 30 in. apart, and 0.5 lb/a dicamba tank-mixed with 2 lb/a atrazine + .25% v/v Induce (surfactant) was sprayed across all plots at the spike stage or after sorghum had sprouted, but prior to sorghum emergence to avoid potential injury from the herbicide. No other weed species but Palmer amaranth was allowed to grow within the plots to avoid unwanted sources of variation. Further, hand-pulling and hoeing were done as necessary in plots assigned for in-season weed control. Irrigation was supplied to meet 120% of crop evapotranspiration. Sorghum was harvested at physiological maturity and yields were adjusted to 13% grain moisture.

Data Collection

Yield and other parameters including sorghum height and headcount, and Palmer amaranth number, height, and biomass were estimated from the two central rows. Only grain yield will be presented in this report.

Data Analysis

Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, NC).

Results

Nitrogen rate and seeding rate did not affect sorghum yield independently or in combination. Controlling Palmer amaranth in plots increased sorghum yield by 50 bu/a (56%) in 2017 and 35 bu/a (32%) in 2016 (Figure 1).

Conclusion

In both years of the study, Palmer amaranth reduced sorghum yield by an average of about 40%. Clearly, integration of greater sorghum density (>60,000 seeds/a) in conjunction with increased N rate and half rates of dicamba and atrazine is not an effective strategy to control Palmer amaranth.

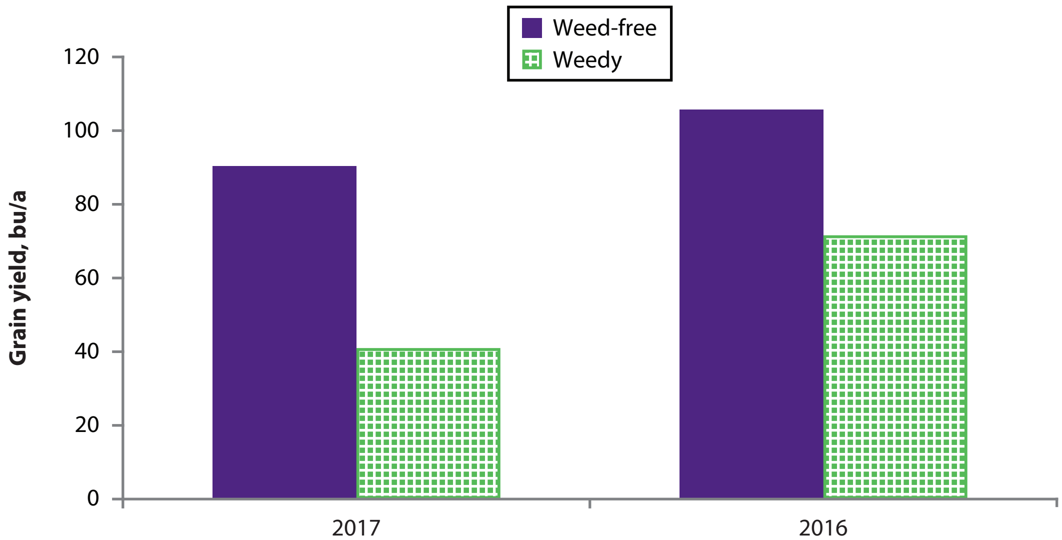

Figure 1. Sorghum grain yield as influenced by in-season weed control.

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Walter Moss Seed
Watley Seed
Winfield United
W-L Alfalfa

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SOUTHWEST RESEARCH-EXTENSION CENTER

Field Day 2018

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