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SOUTHWEST RESEARCH-EXTENSION CENTER

FIELD DAY 2014

Report of Progress 1106

K-STATE
Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

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Bob was appointed head of the Western Kansas Agricultural Research Centers (Colby, Garden City, Hays, and Tribune) in 2006. His research interests include grazing management systems, grassland ecology, and forage establishment.

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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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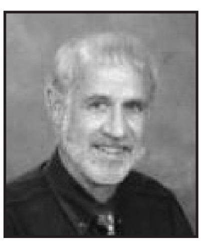
Debra works with county agents on various projects, program development, and training. Her research focuses on families in their environments, rural social systems, and community developmental processes.



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SOUTHWEST RESEARCH-EXTENSION CENTER

Field Day 2014

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Weather Information for Garden City

J. Elliott

Precipitation for 2013 totaled 17.29 in. This was 1.95 in. below the 30-year average of 19.24 in., and although still below average, it was welcome after two years with annual totals near 12 in. March and April were particularly dry, with precipitation totaling 13.4% of normal. August was abnormally wet, recording 6.09 in., which was 243% of normal. Pea-size hail and 70-mph wind observed on May 8 resulted in damage to windows and roll-up doors. The largest daily precipitation was 1.96 in. on August 1 and was accompanied by 50-cent size hail, resulting in considerable crop damage. Blowing dust was recorded on September 24.

Measurable snowfall occurred in each of the first four months of the year as well as October and November. Annual snowfall totaled 20.95 in. compared to an average of 19.7 in. The largest event was 5.0 in. recorded on February 21. Seasonal snowfall (2011–2012) was 20.45 in.

Average daily wind speed was 4.85 mph compared with the 30-year average of 5.10 mph. Open-pan evaporation was measured daily from April through October and totaled 82.90 in. This was 12.64 in. above the 30-year mean of 70.26 in.

Our mean annual temperature was 53.8°F, which was very near the 30-year average of 53.7°F. Triple-digit temperatures were observed on 22 days in 2013, with the highest being 110°F on June 28. This was two degrees from our all-time record high of 112°F on June 28 of 2012. Eight record-high temperatures were equaled or exceeded in 2013: 87°F on March 16, 89°F on April 29, 95°F on May 15, 107°F on June 11, 108°F on June 12, 102°F on September 8, 99°F on September 9, and 97°F on September 27.

Sub-zero temperatures occurred 3 times in 2013. The lowest temperature was -2°F, which was noted on December 10. Six record lows were equaled or set in 2013: 25°F on April 23, 19°F on April 24, 24°F on May 3, 25°F on May 4, 52°F on July 1, and 49°F on July 2.

The last spring freeze was 26°F on May 5, which was 6 days later than the 30-year average. The first fall freeze was 32°F on October 16, which was 4 days later than normal. This resulted in a 164 day frost-free period, which is one day shorter than the 30-year average.

The 2012 climate information for Garden City is summarized in Table 1.

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

	Precipitation		Monthly temperatures: 2013 avg.				Monthly temperatures: 2013 extreme		Wind		Evaporation	
Month	2013	avg.	Max	Min	Mean	30-year avg.	Max	Min	2013	30-year avg.	2013	30-year avg.
	---------- in. -----------		------------------------- °F -------------------------						-------- mph ---------		--------- in. ----------	
January	0.48	0.46	45.6	16.6	31.1	30.4	71		2.84	4.50	--	--
February	1.54	0.55	48.9	18.1	33.5	33.9	71		4.09	5.24	--	--
March	0.13	1.31	58.5	23.8	41.1	42.9	87	10	3.16	6.31	--	--
April	0.28	1.74	63.0	31.1	47.1	52.3	89	17	5.43	6.42	7.68	8.21
May	1.25	2.98	80.1	46.3	63.2	62.8	97	24	5.34	5.76	12.90	10.04
June	1.84	3.12	93.5	60.7	77.1	72.6	110	41	5.19	5.37	15.84	11.96
July	2.23	2.8	93.5	64.4	79.0	77.9	106	49	5.30	4.59	15.28	13.22
August	6.09	2.51	89.2	63.1	76.2	76.3	101	55	5.69	4.11	12.19	11.28
September	1.83	1.42	87.3	57.6	72.4	67.7	102	43	6.26	4.73	11.58	9.22
October	0.88	1.21	70.2	39.6	54.9	54.9	87	29	5.19	4.89	7.43	6.33
November	0.74	0.55	55.0	26.9	41.0	41.6	74	16	5.35	4.80	--	--
December	0	0.59	44.7	14.0	29.4	31.4	67	-2	4.40	4.45	--	--
Annual	17.29	19.24	69.1	38.5	53.8	53.7	110	-2	4.85	5.10	82.90	70.26

Normal latest spring freeze (32°F): April 29. In 2013: May 5.
Normal earliest fall freeze (32°F): Oct. 12. In 2013: Oct 16.
Normal frost-free period (>32°F): 165 days. In 2013: 164 days.
30-year averages are for the period 1981–2010. All recordings were taken at 8:00 a.m.

Weather Information for Tribune

D. Bond and R. Mai

In 2013, annual precipitation of 17.43 in. was recorded, which was 0.47 in. below normal. Nine months had below-normal precipitation. August (6.35 in.) was the wettest month. The largest single amount of precipitation was 1.69 in. on August 14. December, the driest month, recorded no precipitation. Snowfall for the year totaled 14.0 in.; January, February, March, April, May, and October had 1.6, 5.4, 2.5, 1.0, 2.5, and 1.0 in., respectively, for a total of 15 days of snow cover. The longest consecutive period of snow cover, 8 days, occurred February 21 through 28.

Record-high temperatures were recorded on 5 days: March 16 (83°F); May 15 (96°F); and June 4 (102°F), 11 (107°F), and 12 (111°F). Two record-high temperatures were tied on April 29 (88°F) and December 19 (66°F). Record-low temperatures were recorded on 6 days: April 11 (13°F), 19 (21°F), 24 (17°F), and 25 (24°F); and May 2 (22°F) and 3 (22°F). Two record-low temperatures were tied on May 5 (26°F) and July 2 (48°F). July was the warmest month, with a mean temperature of 76.4°F. The hottest days of the year (111°F) occurred on June 12. The coldest day of the year (-6°F) was December 9. December was the coldest month, with a mean temperature of 29.4°F.

Mean air temperature was below normal for 8 months. June had the greatest departure above normal (3.8°F), and April had the greatest departure below normal (-5.2°F). Temperatures were 100°F or higher on 18 days, which was 7 days above normal. Temperatures were 90°F or higher on 70 days, which was 7 days above normal. The latest spring freeze was May 5, which was 1 day earlier than normal; the earliest fall freeze was October 5, which was 2 days earlier than normal. This produced a frost-free period of 153 days, which was 1 day less than the normal 154 days.

Open-pan evaporation from April through September totaled 69.65 in., which was 1.75 in. below normal. Wind speed for this period averaged 5.2 mph, which was 0.1 mph less than normal.

Table 1. Climatic data, Southwest Research-Extension Center, Tribune, KS, 2013

	Precipitation (in.)		Monthly average temperatures (°F) 2013		Monthly average temperatures (°F) Normal		Monthly average temperatures (°F) 2013 extreme		Wind (mph)		Evaporation (in.)	
Month	2013	Normal	Max	Min	Max	Min	Max	Min	2013	Normal	2013	Normal
January	0.17	0.49	48.1	13.7	44.0	16.2	71	-2	---	---	---	---
February	0.61	0.52	48.5	16.3	47.5	19.4	68	0	---	---	---	---
March	0.47	1.22	56.3	21.8	56.3	26.8	83	7	---	---	---	---
April	0.15	1.45	61.5	28.8	65.7	34.9	88	13	5.5	6.0	6.92	8.27
May	1.93	2.38	78.8	45.2	75.1	46.4	99	22	5.8	5.6	12.72	11.75
June	1.82	2.94	92.7	57.2	85.7	56.6	111	40	5.7	5.2	16.73	14.04
July	2.02	2.85	91.6	61.1	91.8	61.7	102	48	4.7	5.2	12.71	15.58
August	6.35	2.33	87.6	61.3	89.4	60.4	100	52	4.2	4.7	10.55	12.16
September	2.79	1.18	84.1	54.7	81.5	50.6	98	40	5.1	5.0	10.02	9.60
October	1.11	1.49	68.4	35.8	68.9	37.1	88	26	4.4*	4.5*	6.76*	6.19*
November	0.01	0.55	55.4	23.3	54.9	25.7	80	11	---	---	---	---
December	0.00	0.50	45.7	13.2	44.7	17.0	66	-6	---	---	---	---
Annual	17.43	17.90	68.3	36.1	67.1	37.7	111	-6	5.2	5.3	69.65	71.40

Normal latest freeze (32°F) in spring: May 6. In 2013: May 5.
Normal earliest freeze (32°F) in fall: October 7. In 2013: October 5.
Normal frost-free (>32°F) period: 154 days. In 2013: 153 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.

Fallow Replacement Crop (Cover Crops, Annual Forages, and Short-Season Grain Crops) Effects on Wheat Yield

J. Holman, 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 have been 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 from 2007–2014 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, and in the second experiment (2012–2014), the rotation was no-till wheat-grain sorghum-fallow. Wheat yield was affected by the previous crop, but growing a previous crop as hay or cover did not affect wheat yield. Wheat yield following the previous crop was dependent on precipitation during fallow and the growing season. In dry years (2011–2013), growing a crop during the fallow period reduced wheat yields, whereas growing a crop during the fallow period had little impact on wheat yield in wet years (2008–2010). 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 continuous wheat, grain pea, or safflower were grown until grain harvest, which was approximately the first week of July. Cover crops did not improve wheat yield. Winter and spring lentil had the least negative impact on wheat yield, and yielded similar to fallow when averaged across years. Winter cover crop treatments tended to reduce yield more than spring cover crop treatments, which was due to less soil moisture available at wheat planting following winter cover crop compared with spring cover crop treatments. To be successful, the benefits of growing a cover crop during the fallow period must be greater than the expense of growing it; plus compensate for any negative yield impacts on the subsequent crop. Cover crops always resulted in less profit than fallow, whereas annual forages and grain peas often increased profit compared with fallow. The negative effects on wheat yields might be minimized with flex-fallow, which is the process of growing a crop in place of fallow only in years when soil moisture is ample 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 85 to 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 winter wheat yield. This study evaluated replacing part of the fallow period with a cover, annual forage, or short-season grain crop on plant-available water at wheat planting and winter wheat yield.

Procedures

A study from 2007–2014 evaluated cover crops, annual forages, and grain peas 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 to determine long-term treatment impacts. 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 only in monoculture. 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 (Table 1). 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 and 120 ft long, the split plot was 30 ft wide and 120 ft long, and the split-split plot was 15 ft wide and 120 ft long.

In experiment 2 (2012–2014), spring crops were grown the year following grain sorghum. Grain sorghum is harvested late in the year and in most years does 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 grown only in 2012, and that treatment was replaced with spring oat grown for grain beginning in 2013. Additional treatments initiated in 2013 were yellow sweetclover 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 sativas* L.) planted with winter wheat in a wheat-grain sorghum-fallow rotation, and spring oats planted in a "flex-fallow" system (Table 2). The flex-fallow treatment was planted using spring oats when a minimum of 1 ft (2013 only) and 1.5 ft (2014–subsequent years) of plant-available soil water (PAW) 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 safflower. Crops grown in place of fallow were compared with a wheat-grain sorghum-fallow rotation for a total of 16 treatments (Table 2). 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.

Winter crops were planted approximately October 1. Winter cover and forage crops were chemically terminated or forage-harvested approximately May 15. 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. Biomass yields for both cover crops and forage crops were determined from a 3-ft × 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-ft × 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

Winter Wheat Yield in Wheat-Fallow

In 2008, hail damaged the wheat crop 1 week before harvest; therefore, no statistical separation was made between treatments. In 2008, 9.49 in. of precipitation occurred during the growing season from October 1, 2007 through July 1, 2008, and 31.4 in. of precipitation occurred during fallow from July 1, 2006 through October 1, 2007. The normal precipitation during the growing season (October–July) was 12.51 in., and the normal precipitation during fallow (July–October) was 25.97 in. Winter wheat yield following a crop grown in place of fallow ranged from 21 to 26 bu/a, wheat yield following wheat was 13 bu/a, and wheat following fallow was 22 bu/a (Figure 1).

In 2009, 16.24 in. of precipitation occurred during the growing season from October 1, 2008 through July 1, 2009, and 20.34 in. of precipitation occurred during fallow from July 1, 2007 through October 1, 2008. Grain pea and winter clover/triticale yielded 7 and 9 bu/a less than fallow (83 bu/a), and spring pea yielded 7 bu/a more than fallow (Figure 2). Continuous wheat yielded least of all treatments (57 bu/a). All other treatments yielded similar to fallow.

In 2010, 14.15 in. of precipitation occurred during the growing season from October 1, 2009 through July 1, 2010, and 27.64 in. of precipitation occurred during fallow from July 1, 2008 through October 1, 2009. Winter pea/triticale and winter triticale yielded 5 and 7 bu/a less than fallow (70 bu/a), and spring lentil/triticale and spring pea/triticale yielded 4 and 6 bu/a less than fallow (Figure 3), respectively. Continuous wheat yielded least of all (43 bu/a). All other treatments yielded similar to fallow. Wheat

following cover crops yielded an average of 2.9 bu/a more than wheat following a hay crop.

In 2011, 6.77 in. of precipitation occurred during the growing season from October 1, 2010 through July 1, 2011, and 25.36 in. of precipitation occurred during fallow from July 1, 2009 through October 1, 2010. This drought resulted in low wheat yields and a greater impact of the preceding crop on wheat yield. Wheat grown following a winter cover or forage crop yielded less than fallow with the exception of winter lentil (22 bu/a), which yielded similar to fallow (23 bu/a) (Figure 4). Wheat yield following all other winter crops was reduced by 4 to 10 bu/a. Wheat yield following spring cover or forage crops was not affected as much as winter crops. Wheat yield following spring lentil, triticale, and lentil/triticale was similar to fallow, and wheat following spring pea and pea/triticale was reduced 7 and 3 bu/a, respectively. Wheat following spring grain pea was reduced 11 bu/a, and wheat following wheat was reduced 16 bu/a compared with fallow.

In 2012, 8.5 in. of precipitation occurred during the growing season from October 1, 2011 through July 1, 2012, and 14.37 in. of precipitation occurred during fallow from July 1, 2010 through October 1, 2011. The second year of drought conditions resulted in low wheat yields, and the preceding crop reduced wheat yield more than in previous years. Winter cover or forage crops reduced wheat yield 24 bu/a, and spring cover or forage crops reduced wheat yield 23 bu/a compared with fallow (Figure 5). Continuous wheat yielded 20 bu/a less than wheat-fallow. Wheat grown following grain peas yielded the least, with yields reduced to 3 bu/a following winter grain pea and 5 bu/a following spring grain pea.

Averaged from 2009 through 2012 (2008 was excluded due to hail damage), there was no difference in wheat yield whether the previous crop was grown as forage or cover ($P = 0.09$), although wheat yields following a cover crop did tend to yield more than a forage crop. This difference was due to slightly more soil moisture following a cover crop than a forage crop. With the exception of winter and spring lentil (53 bu/a), replacing fallow with a cover or grain crop reduced yield compared with fallow (56 bu/a) (Figure 6). Winter crop treatments tended to reduce wheat yields more than spring crop treatments. Winter triticale and triticale/legume mixtures yielded 9 to 12 bu/a less than fallow. Winter legume monocultures yielded more than triticale/legume mixtures. Winter pea and hairy vetch yielded 6 and 4 bu/a less than fallow, respectively. Spring triticale, triticale/legume mixtures, and spring pea yielded 6 to 8 bu/a less than fallow. Grain pea yielded 12 bu/a less than fallow, and continuous winter wheat yielded 23 bu/a less than fallow.

Winter Wheat Yield in Wheat-Grain Sorghum-Fallow

In 2013, 7.23 in. of precipitation occurred during the growing season from October 1, 2012 through July 1, 2013. This was 5.28 in. below normal (12.51 in.) for this time period, and was the third consecutive year of drought. The 30-year average precipitation during the fallow period (November–October) of a wheat-grain sorghum-fallow rotation averaged 18.03 in., and 12.88 in. of precipitation occurred during fallow from November 1, 2011 through October 1, 2012. 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 14 bu/a and all other treatments yielded between 2 to 7 bu/a (Figure 6).

In 2014, 16.4 in. of precipitation occurred during the fallow period from November 1, 2012 through October 1, 2013, which was 1.63 in. below normal. Little precipitation has occurred since wheat planting, and 2014 appears to be a fourth year of consecutive drought and below normal wheat yields.

Cover vs. Annual Forage

In experiment 1 (2009–2012) and experiment 2 (2012–2014), there was no difference in wheat yield whether the previous crop was left as cover or harvested for forage despite slightly more PAW following cover than forage harvest. This result indicates that the previous crop can be harvested for forage rather than left standing as a cover crop without negatively affecting wheat yield.

Conclusions

Fallow helps stabilize crops in dry years. Annual precipitation in this study ranged from 12.1 to 21.7 in. In the dry years (2011–2013), growing a crop during the fallow period reduced wheat yields, but in wet years (2008–2010), 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 continuous wheat, grain peas, or safflower were grown until grain harvest, which was approximately the first week of July.

In experiment 1, after the first year, winter lentil was grown in place of yellow sweet clover because the growth of yellow sweet clover was too slow to fit this cropping system. Winter peas and hairy vetch often winter-killed when grown in monoculture, but they survived the winter better when grown in combination with triticale. Winter lentil grown in monoculture or with triticale survived the winter well. Cover crops did not improve wheat yield. Winter and spring lentil had the least negative impact on wheat yield, and yielded similar to fallow when averaged across years. Winter cover crop treatments tended to reduce yield more than spring cover crop treatments, which was due to more available moisture at wheat planting following the spring cover crop treatments.

Forages can provide an economic return, whereas cover crops were an expense to grow. The cropping system can be intensified by replacing part of the fallow period with annual forages or spring grain pea to increase profit and improve soil quality; however, wheat yields will be reduced in semiarid environments, particularly in dry years. This yield reduction was compensated for by the value of a forage or grain crop in years with above-normal precipitation, but not with a cover crop. The negative impacts on wheat yields might be minimized with flex-fallow. Flex-fallow is the concept of planting forage or grain pea only when soil moisture levels are adequate and the precipitation outlook is favorable. Under drought conditions such as 2011–2013, a crop would have not been grown in place of fallow. Implementing flex-fallow may minimize the negative impacts of reduced fallow, but flex-fallow will not prevent reduced years in which growing season precipitation levels are below normal. Additional years of data from experiment 2 will help determine the effects of replacing fallow with forage or spring grain pea in a wheat-summer crop-fallow rotation.

Table 1. Fallow treatments, 2007–2011

		Year produced				
Season	Crop	2007	2008	2009	2010	2011
Winter	Yellow sweet clover	x	x			
	Yellow sweet clover/winter triticale		x			
	Hairy vetch	x	x	x	x	x
	Hairy vetch/winter triticale		x	x	x	x
	Winter lentil			x	x	x
	Winter lentil/winter triticale			x	x	x
	Winter pea	x	x	x	x	x
	Winter pea/winter triticale		x	x	x	x
	Winter triticale	x	x	x	x	x
	Winter pea (grain)		x	x		x
Spring	Spring lentil	x	x	x	x	x
	Spring lentil/spring triticale		x	x	x	x
	Spring pea	x	x	x	x	x
	Spring pea/spring triticale		x	x	x	x
	Spring triticale		x	x	x	x
	Spring pea (grain)				x	x
Other	Chem-fallow	x	x	x	x	x
	Continuous winter wheat	x	x	x	x	x

Table 2. Fallow treatments, 2012–2014

Season	Crop	Cover	Hay	Grain	Year produced 2012	2013	2014
Spring	Cocktail mix[1]	x	x		x	x	x
	Fallow				x	x	x
	Flex-fallow/spring oat (1.5 in. PAW[2] at planting)		x		-	x	No
	Safflower (grain)			x	x	-	-
	Spring oat		x		x	x	x
	Spring oat (grain)			x	-	x	x
	Spring pea	x	x		x	-	-
	Spring pea (grain)			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
Other	Daikon radish (planted with wheat)	x			-	x	x
	Shogoin turnip (planted with wheat)	x			-	x	x
	Yellow sweet clover (planted with sorghum)	x	x		-	x	x

[1] Oat, triticale, pea, buckwheat, forage brassica and forage radish.
[2] Plant-available soil water.

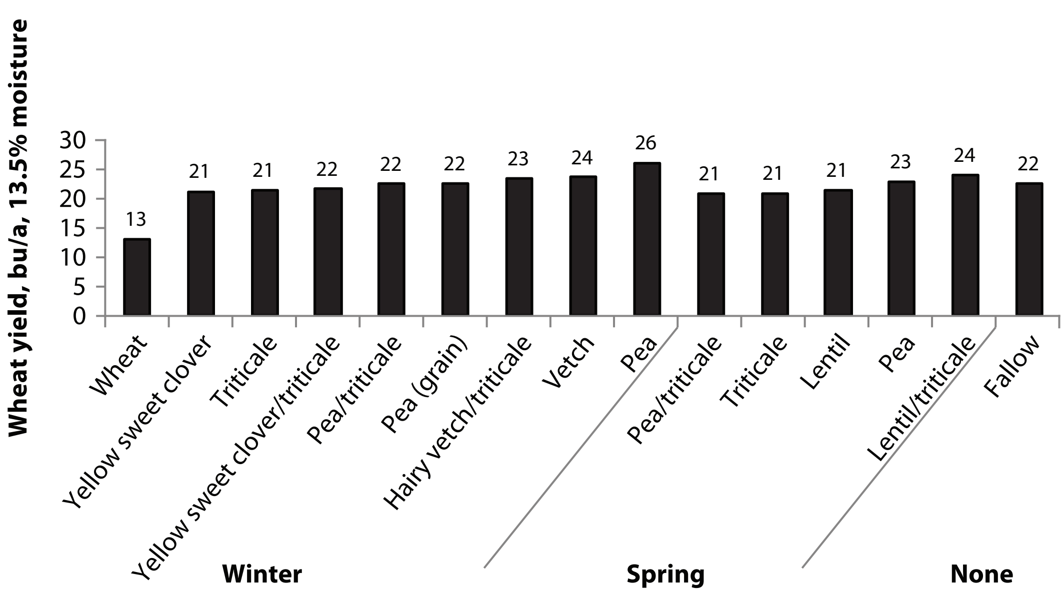

Figure 1. 2008 winter wheat yield following 2007 cover crops.

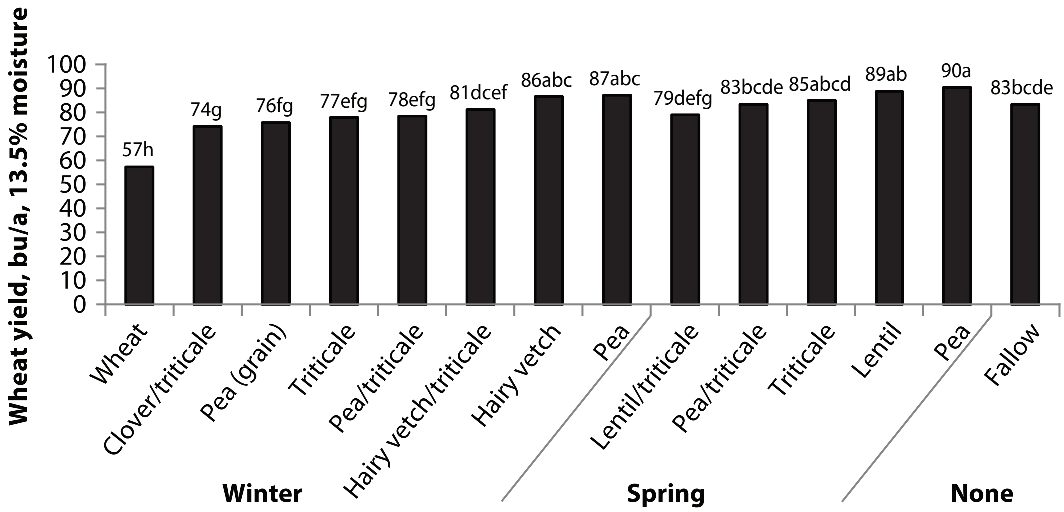

Figure 2. 2009 winter wheat yield following 2008 cover crops.
Values with different letters are significantly different at $P \leq 0.05$.

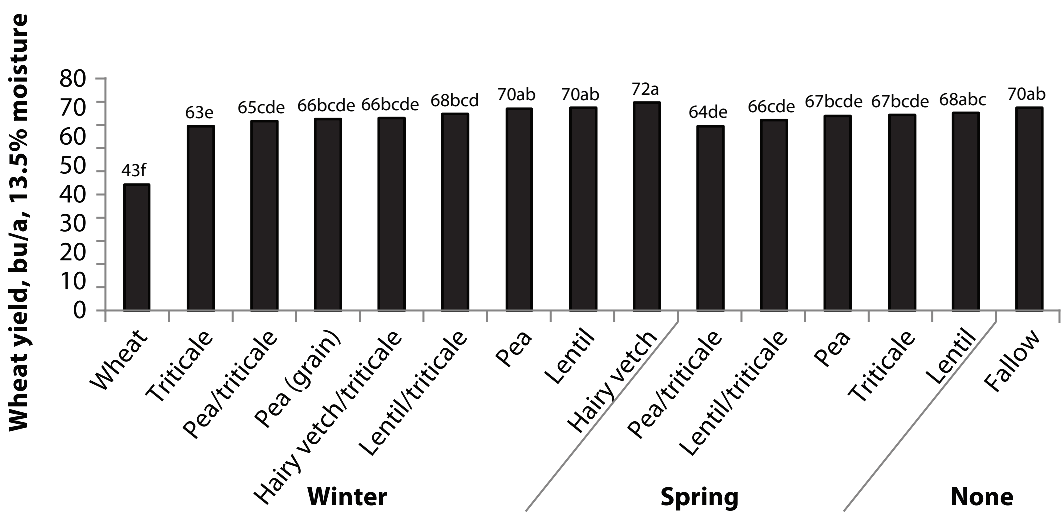

Figure 3. 2010 winter wheat yield following 2009 cover crops.
Values with different letters are significantly different at $P \leq 0.05$.

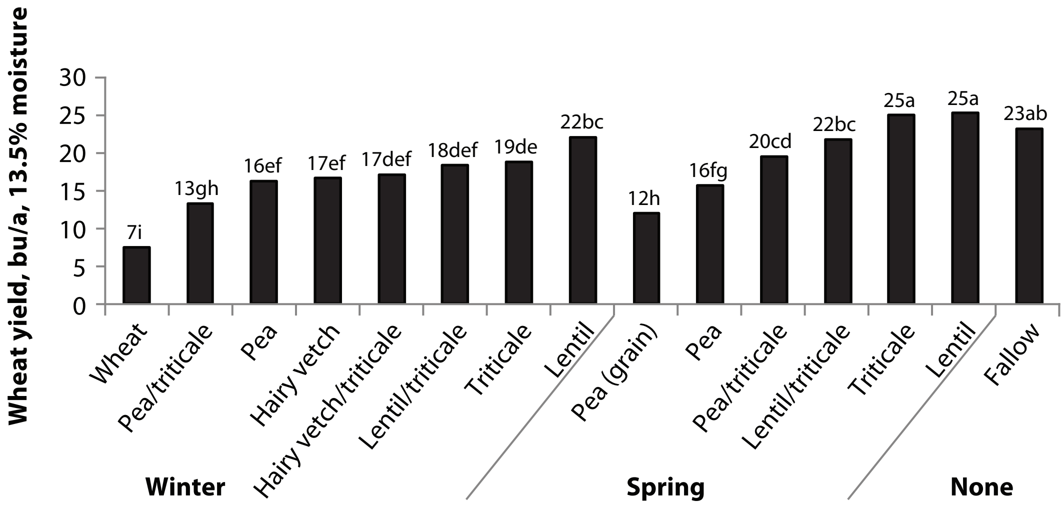

Figure 4. 2011 winter wheat yield following 2010 cover crops.
Values with different letters are significantly different at $P \leq 0.05$.

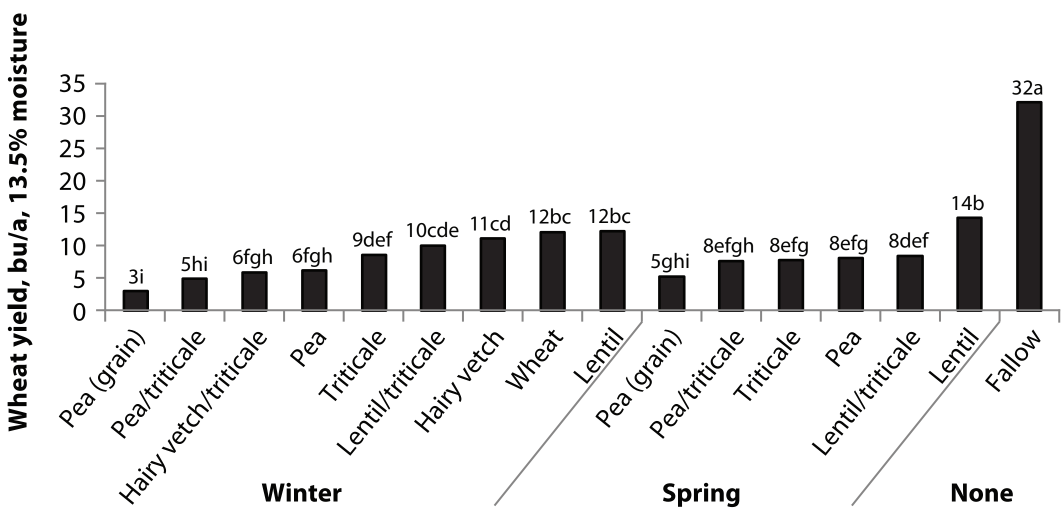

Figure 5. 2012 winter wheat yield following 2011 cover crops.
Values with different letters are significantly different at $P \leq 0.05$.

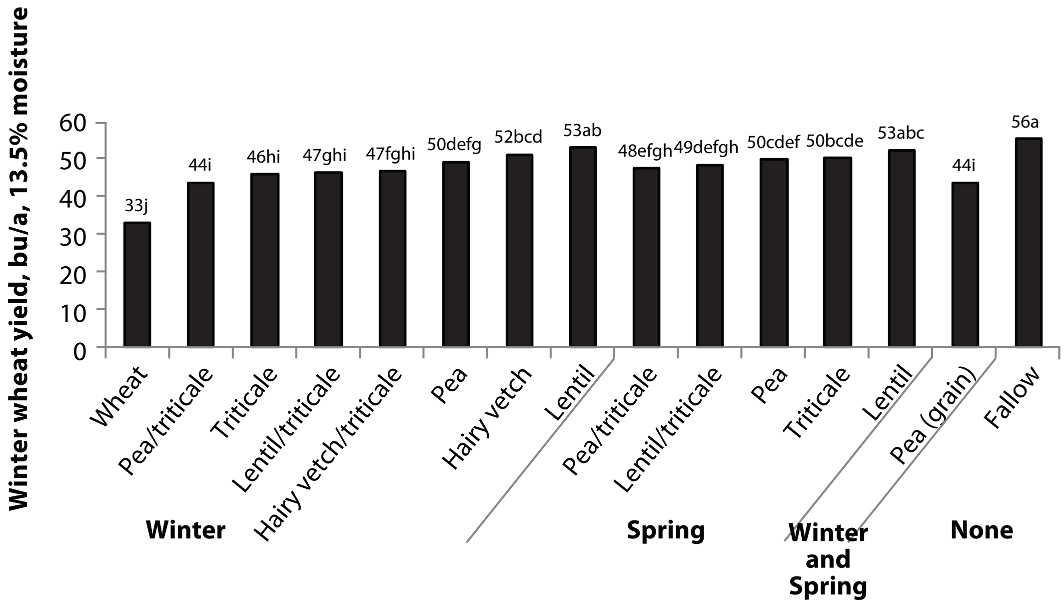

Figure 6. 2009–2012 winter wheat yields following cover crops. Values with different letters are significantly different at $P \le 0.05$.

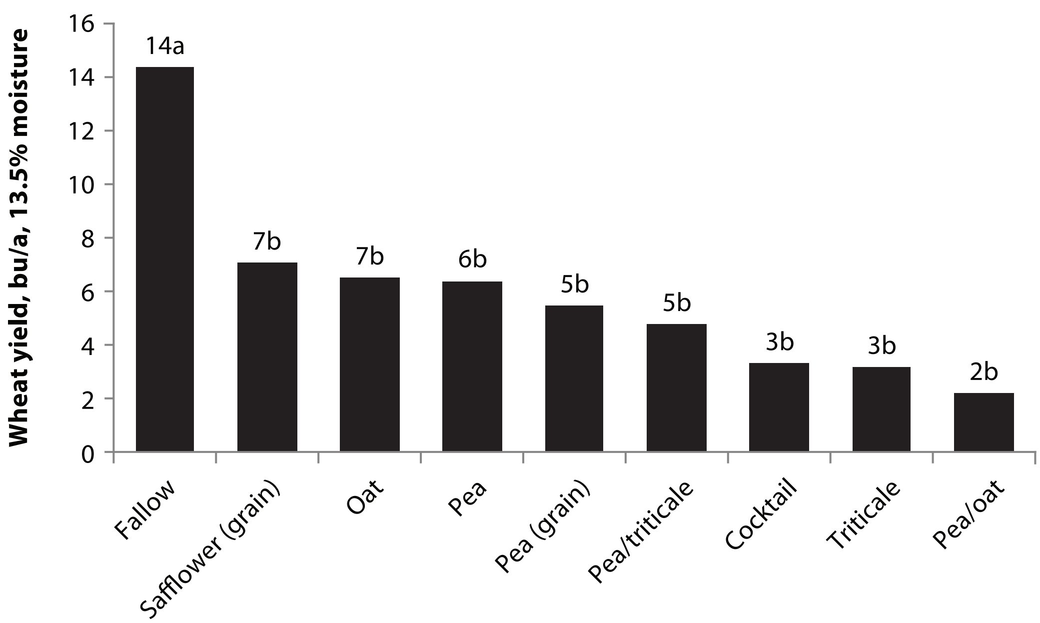

Figure 7. 2013 winter wheat yield following 2012 cover crops. Values with different letters are significantly different at $P \le 0.05$.

Fallow Replacement Crop (Cover Crops, Annual Forages, and Short-Season Grain Crops) Effects on Available Soil Water

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

Summary
Producers are interested in growing cover crops and reducing fallow. Limited information is available on growing crops in place of fallow in the semiarid Great Plains. Between 2007 and 2012, winter and spring cover, annual forage, and grain crops were grown in place of fallow in a no-till wheat-fallow (WF) rotation. A second study was initiated beginning in 2012, with spring cover, annual forage, and grain crops grown in place of fallow in a no-till wheat-sorghum-fallow (WSF) rotation. Growing a cover, hay, or grain crop in place of fallow reduced the amount of stored soil moisture at wheat planting. On average, cover crops stored slightly more moisture than hay crops, but this soil moisture difference did not affect wheat yields. Soil moisture following grain crops was less than cover or hay crops, and this difference resulted in reduced wheat yields. Stored soil moisture at wheat planting was lowest among spring grain crops and winter crops that produced a lot of biomass. Low-biomass spring crops had the least negative effect on stored soil moisture. These results do not support the claims that cover crops increase soil moisture compared with fallow. Soil moisture storage from fallow crop termination to wheat planting was greatest among those treatments that were most dry at termination and produced the most aboveground biomass. On average, cover crops had +6% precipitation storage efficiency (PSE), whereas hay crops had a -1% PSE between termination and wheat planting. Crops grown in place of fallow must compensate for the expense of growing the crop plus the reduction in soil moisture for the following crop.

Introduction
Interest in replacing fallow with a cash crop or cover crop has necessitated research on soil water storage 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 70 to 75% precipitation is lost, primarily 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 on plant-available water at wheat planting and winter wheat yield.

Procedures
See "Fallow Replacement Crop (Cover Crops, Annual Forages, and Short-Season Grain Crops) Effects on Wheat Yield" (page 5) for treatments (Tables 1 and 2) and study methods for wheat-fallow and wheat-sorghum-fallow.

Results and Discussion

Wheat-Fallow (2007–2012)

Year

Fallow and growing-season precipitation varied greatly during the course of this study. Average precipitation during the fallow period (July–December plus January–September) was 25.97 in., and growing season precipitation (October–June) was 12.51 in. Fallow precipitation was above average preceding the 2008–09 growing season (27.64 in.), about average preceding the 2009–10 growing season (25.36 in.), and below average preceding the 2007–08 (20.3 in.), 2010–11 (14.42 in.), and 2011–12 (16.66 in.) growing seasons. Growing-season precipitation was above average in 2008–09 (16.24 in.) and 2009–10 (14.1 in.) and below average in 2007–08 (9.46 in.), 2010–11 (6.77 in.), and 2011–12 (8.5 in.). These differences affected plant-available soil water at wheat planting and wheat yields (Table 1). Plant-available soil water in the 0–3-in. and 0–6-ft profile were greatest in 2008 and 2009 and least in 2010 and 2011.

Cover vs. Annual Forage

Plant-available soil water in the 0–3-in. soil depth averaged 0.03 in. greater among cover crop treatments (0.09 in.) than among hay treatments (0.06 in.) (Table 2). In the 0–6-ft profile, plant-available soil water averaged 0.8 in. more following cover crops (5.76 in.) than hay crops (4.96 in.). More surface residue in the cover crop treatments compared with hay treatments likely reduced evaporation near the soil surface and might have reduced water runoff.

Fallow Crop (0–3-in. soil depth)

Soil moisture in the top 0–3 in. is important for seed germination and seedling establishment. Plant-available soil water varied among treatments. Those treatments with winter triticale (hairy vetch/winter triticale, winter pea/winter triticale, winter lentil/winter triticale, and winter triticale) had the most soil moisture (Table 3). Legume monocultures, mixtures with spring triticale, spring triticale, and fallow had the second most amount of soil moisture. There was a tendency for more soil moisture with increased amounts of biomass (Figure 1), and winter triticale produced the most biomass. Increased levels of biomass likely reduced soil water evaporation. Thus, those treatments with winter triticale had more soil moisture than lower biomass treatments. Continuous winter wheat and grain pea had the least amount of surface soil moisture. Continuous winter wheat and grain pea also had the least amount of soil moisture at deeper depths, which likely kept soil near the surface dry.

Fallow Crop (0–6-ft soil depth)

Moisture in the 0–6-ft soil profile is important for growing a crop, particularly in semi-arid climates. Fallow had the greatest amount of soil moisture, and all other treatments had less (Table 4). Those treatments that produced less biomass (hairy vetch, spring pea, winter lentil, spring lentil, spring triticale, and winter pea) had more available soil moisture than the other treatments. Also, winter triticale and winter triticale mixtures had less soil moisture than spring triticale and spring triticale mixtures. Soil moisture was affected by both the amount of biomass and length of the time the cover crop was grown. More soil water was used to grow cover crops that produced large amounts of biomass and had a long growing season. Grain pea and continuous wheat had the least

amount of soil moisture because of their longer growing season and shorter fallow period.

Precipitation Storage from Termination to Wheat Planting

Precipitation storage efficiency was measured between fallow crop termination and wheat planting from 2008–2010. Precipitation in 2008, 2009, and 2010 from June 1 through October 1 were 61%, 113%, and 80% of normal, respectively. Precipitation storage efficiency is the percentage of precipitation stored in the soil.

$$\text{Precipitation storage efficiency (PSE)} = \frac{\text{Soil water content at wheat planting} - \text{Soil water content at fallow crop termination}}{\text{Precipitation between fallow crop termination and wheat planting}}$$

During this part of the fallow period (cover crop termination to wheat planting), precipitation storage efficiency ranged from 20% in grain pea to -12% in vetch (Table 5). Soil water content was not quantified in fallow at the time of fallow crop termination, so PSE for this time period in fallow could not be quantified. However, vetch seldom survived and produced very little biomass, so the field conditions of vetch were similar to fallow. Thus, PSE of fallow likely would have been similar to vetch. Previous research has shown late-summer PSE prior to wheat planting is low.

Precipitation storage efficiency tended to be highest among those treatments that had drier soil conditions at fallow crop termination, with the exception of winter lentil/winter triticale. Winter lentil/winter triticale was the fourth driest treatment at cover crop termination (data not shown) but had lower PSE than winter triticale or grain pea, the driest and second driest treatments at termination, respectively. The third driest treatment at termination was vetch/winter triticale, which had PSE similar to grain pea, winter triticale, and winter lentil/winter triticale (Table 5). Those treatments that produced little biomass, such as vetch, winter lentil, winter pea, spring pea, and spring lentil, used less water, had more soil water at termination, and had lower PSE.

Wheat-Sorghum-Fallow (2012–2013)

Cover vs. Annual Forage

Plant-available soil water in the 0–3-in. soil depth was 0.09 in. greater among cover crop treatments (0.17 in.) than hay treatments (0.08 in.) at wheat planting in 2012, but no differences occurred in 2013. In 2013, 0.11 in. of available soil water followed cover crop treatments, and 0.09 in. followed hay treatments at the 0–3-in. soil depth at wheat planting. There was no difference in available soil water between cover and hay treatments in the 0–6-ft profile in 2012 or 2013. On average, however, soil water at wheat planting in the 0–6-ft profile was greater following cover crops compared with hay crops both years; in 2012, it was 0.44 in. higher (2.63 vs. 2.18), and in 2013 it was 1.02 in. higher (3.90 vs. 2.88). Although there was a tendency for more soil water in the profile following cover crops compared with hay crops, wheat yield was not affected. More surface residue in the cover crop treatments compared with hay treatments likely reduced evaporation near the soil surface and might have reduced water runoff.

Fallow Crop (0–3-in. soil depth)

No differences occurred between crop treatments at the 0–3-in. soil depth in 2012 or 2013.

Fallow Crop (0–6-ft soil depth)

Treatments changed slightly between 2012 and 2013. Safflower and spring forage pea were grown only in 2012; beginning in 2013, spring oats were grown for grain and yellow sweet clover was planted with grain sorghum and allowed to grow into the fallow year. In 2012, fallow had 6.38 in. of plant-available soil water in the 0–6-ft profile at wheat planting, which was greater than all other treatments (Table 6). Of the fallow replacement crops, grain pea (3.26 in.) and forage pea (3.04 in.) had more plant-available soil water than safflower (1.11 in.). All other fallow replacement treatments had plant-available soil water similar to pea or safflower. Of all the cover or hay treatments, the cocktail had the least amount of stored soil water (1.95 in.). The combination of species in the cocktail had different rooting architecture and maturities, which likely helped to increase soil water use more than a single- or two-species crop. Compared with previous years in the WF study, grain pea had more soil moisture at wheat planting than expected. The drought and heat in 2012 resulted in low grain pea yield (12.4 bu/a) and an early harvest. The early harvest resulted in a longer fallow period and more time for moisture storage than normal. Safflower matures later than grain pea and had the shortest fallow period of any treatments. The short fallow period resulted in less soil moisture storage ahead of wheat planting.

In 2013, spring oat (grain) and spring pea (grain) had 2.3 and 3.4 in. less soil water than fallow, respectively, at wheat planting, and all other treatments were comparable to fallow (Table 7). There was a slight tendency for the cocktail treatment to have more soil water than other treatments, which was very different than 2012. In 2013, little precipitation occurred early in the year, and most precipitation occurred late in the summer. It is possible that no early season moisture and more crop residue from growing a spring crop improved precipitation storage late in the season. Wheat yields in 2014 following these crops would be lower if the previous trend continues; otherwise, wheat yields might be greater in 2014 if spring crops improved moisture storage.

Conclusions

Fallow is important for storing precipitation and stabilizing crop yields, particularly in semiarid climates such as the central Great Plains. Growing a cover, hay, or grain crop in place of fallow reduced the amount of stored soil moisture at wheat planting. On average, cover crops grown in a wheat-cover crop rotation stored 0.8 in. more moisture than hay crops, but this soil moisture difference did not affect wheat yield. Soil moisture following grain crops was lower than following cover or hay crops, and this difference resulted in reduced wheat yields. Increasing surface residue tended to increase the amount of soil moisture in the soil surface (0–3 in.), which could help improve stand establishment in dry years. However, variability in soil moisture stored at this depth was large, and soil residue does not guarantee moist soil to plant into. Total stored soil moisture was lowest among spring grain crops and winter crops that produced a lot of biomass. Stored soil water was low following a crop cocktail (six-species mixture) in 2012, but not in 2013. More years of data are needed to compare cocktail mixtures to fallow. Low-biomass spring crops such as spring lentil had the least negative effect

on stored soil moisture. Soil moisture storage from fallow crop termination to wheat planting was greatest among those treatments that were most dry at termination and produced the most aboveground biomass. Precipitation storage efficiency (PSE) ranged from 20% to -12%. On average, cover crops had a +6% PSE, whereas hay crops had a -1% PSE between termination and wheat planting. Crops grown in place of fallow must compensate for the expense of growing the crop, plus the reduction in soil moisture for the following crop.

Table 1. Plant-available soil water in the 0–3-in. and 0–6-ft soil depth at wheat planting in a wheat-fallow rotation, growing season precipitation, and fallow precipitation at Garden City, KS, 2007–2012

Growing season	Plant-available water (0–3 in.)			Plant-available water (0–6 ft)			Growing season precipitation (October–June)		Fallow precipitation (July–September)	
	---------- mm (in.) ----------									
2007–08	-	-	-	-	-	-	240.28	(9.46)	515.62	(20.30)
2008–09	0.91	(0.04)	b[1]	111.28	(4.38)	c	412.50	(16.24)	702.06	(27.64)
2009–10	7.02	(0.28)	a	192.52	(7.58)	a	358.14	(14.10)	644.14	(25.36)
2010–11	-1.53	(-0.06)	d	148.37	(5.84)	b	171.96	(6.77)	366.27	(14.42)
2011–12	0.12	(0.00)	c	72.05	(2.84)	d	215.90	(8.50)	423.16	(16.66)
	ANOVA P>F									
Source of variation										
	<0.0001			<0.0001						
LSD 0.05	0.66	(0.03)		11.72	(0.46)					

[1] Different letters within a column represent differences at LSD 0.05.

Table 2. Cover crop method (cover crop or hay harvest) effects on plant-available soil water in the 0–3-in. and 0–6-ft soil depth at wheat planting in a wheat-fallow rotation from 2008–2012

Cover crop method	Plant-available water (0–3 in.)			Plant-available water (0–6 ft)		
	---------- mm (in.) ----------					
Cover	2.37	(0.09)	a[1]	146.36	(5.76)	a
Hay	1.49	(0.06)	b	126.06	(4.96)	b
	ANOVA P>F					
Source of variation						
	<0.001			<0.0001		
LSD 0.05	0.70	(0.03)		11.48	(0.45)	

[1] Different letters within a column represent differences at LSD 0.05.

Table 3. Fallow, cover crop, and grain crop effects on plant-available soil water in the 0–3-in. soil depth at wheat planting in a wheat-fallow rotation from 2008–2012

Fallow method	Plant-available water (0–3 in.)		
	---------------------- mm (in.) ----------------------		
Hairy vetch/winter triticale	3.44	(0.14)	a[1]
Winter pea/winter triticale	2.97	(0.12)	ab
Winter lentil/winter triticale	2.43	(0.10)	abc
Winter triticale	2.34	(0.09)	abcd
Spring triticale	1.80	(0.07)	bcde
Winter pea	1.72	(0.07)	bcde
Hairy vetch	1.63	(0.06)	cde
Spring pea/spring triticale	1.63	(0.06)	cde
Spring lentil/spring triticale	1.61	(0.06)	cde
Fallow	1.54	(0.06)	cde
Spring pea	1.37	(0.05)	cde
Spring lentil	1.09	(0.04)	de
Winter lentil	0.97	(0.04)	ef
Winter wheat	-0.28	(-0.01)	fg
Pea (grain)	-0.54	(-0.02)	g
		ANOVA P>F	
Source of variation			
		<0.001	
LSD 0.05	1.33	(0.05)	

[1] Different letters within a column represent differences at LSD 0.05.

Table 4. Fallow, cover crop, and grain crop effects on plant-available soil water in the 0–6-ft soil depth profile and the difference in soil moisture compared with fallow at wheat planting in a wheat-fallow rotation from 2008–2012

Fallow method	Plant-available water (0–6 ft)			Difference in fallow plant-available water (0–6 ft)	
	------------------------------- mm (in.) -------------------------------				
Fallow	201.00	(7.91)	a[1]	0.00	(0.00)
Hairy vetch	158.38	(6.24)	b	-42.62	(-1.68)
Spring pea	156.55	(6.16)	b	-44.44	(-1.75)
Winter lentil	153.90	(6.06)	bc	-47.10	(-1.85)
Spring lentil	144.17	(5.68)	bcd	-56.82	(-2.24)
Spring triticale	139.36	(5.49)	bcd	-61.64	(-2.43)
Winter pea	137.16	(5.40)	bcd	-63.84	(-2.51)
Spring pea/spring triticale	133.00	(5.24)	cde	-68.00	(-2.68)
Spring lentil/spring triticale	131.22	(5.17)	cdef	-69.78	(-2.75)
Hairy vetch/winter triticale	130.91	(5.15)	def	-70.09	(-2.76)
Winter pea/winter triticale	125.67	(4.95)	defg	-75.32	(-2.97)
Winter lentil/winter triticale	114.06	(4.49)	efg	-86.94	(-3.42)
Winter triticale	109.03	(4.29)	fg	-91.97	(-3.62)
Pea (grain)	103.96	(4.09)	gh	-97.04	(-3.82)
Winter wheat	83.24	(3.28)	h	-117.76	(-4.64)
	ANOVA P>F				
Source of variation					
		<0.0001			
LSD 0.05	22.94	(0.90)			

[1] Different letters within a column represent differences at LSD 0.05.

Table 5. Precipitation storage efficiency between fallow crop termination and wheat planting in the 0–6-ft soil depth profile in a wheat-fallow rotation from 2008–2012

Fallow method	Precipitation storage efficiency (0–6 ft)	
	(%)	
Pea (grain)	19.21	a[1]
Winter triticale	16.44	ab
Spring lentil/spring triticale	11.89	abc
Hairy vetch/winter triticale	11.63	abc
Winter pea/winter triticale	10.72	abc
Spring pea/spring triticale	7.92	bcd
Spring triticale	5.67	bcd
Winter lentil/winter triticale	3.68	cd
Spring lentil	-0.83	de
Spring pea	-7.38	ef
Winter pea	-9.19	ef
Winter lentil	-9.63	ef
Hairy vetch	-12.32	f
	ANOVA P>F	
Source of variation		
	<0.001	
LSD 0.05	0.11	
Cover	5.74	a
Hay	-0.95	b
	ANOVA P>F	
Source of variation		
	<0.01	
LSD 0.05	0.04	

[1] Letters within a column represent differences at LSD 0.05.

Table 6. Fallow, cover crop, and grain crop effects on plant-available soil water in the 0–6-ft soil profile and the difference in soil moisture compared with fallow at wheat planting in a wheat-sorghum-fallow rotation in 2012

Fallow method	Plant-available water (0–6 ft)			Difference in fallow plant-available water (0–6 ft)	
	mm (in.)				
Fallow	161.93	(6.38)	a[1]	0.00	(0.00)
Spring pea (grain)	82.68	(3.26)	b	-79.25	(-3.12)
Spring pea	77.17	(3.04)	b	-84.75	(-3.34)
Spring oat	70.31	(2.77)	bc	-91.61	(-3.61)
Spring pea/triticale	66.25	(2.61)	bc	-95.67	(-3.77)
Spring triticale	51.86	(2.04)	bc	-110.07	(-4.33)
Spring peat/oat	51.44	(2.03)	bc	-110.49	(-4.35)
Cocktail[2]	49.57	(1.95)	bc	-112.35	(-4.42)
Safflower (grain)	28.07	(1.11)	c	-133.86	(-5.27)
	ANOVA P>F				
Source of variation					
		<0.001			
LSD 0.05	48.15	(1.90)			

[1] Different letters within a column represent differences at LSD 0.05.
[2] Cocktail: oat, triticale, pea, buckwheat, forage brassica, and forage radish.

Table 7. Fallow, cover crop, and grain crop effects on plant-available soil water in the 0–6-ft soil profile and the difference in soil moisture compared with fallow at wheat planting in a wheat-sorghum-fallow rotation in 2013

Fallow method	Plant-available water (0-6 ft)		Difference from fallow
	(in.)		
Cocktail[1]	4.31	a[2]	0.00
Spring pea/oat	3.65	ab	-0.66
Fallow	3.62	ab	-0.69
Spring pea/triticale	3.36	ab	-0.95
Spring triticale	2.74	abc	-1.56
Spring oat	2.45	abc	-1.86
Flex spring oat	2.41	abc	-1.90
Spring oat (grain)	2.00	bc	-2.30
Spring pea (grain)	0.89	c	-3.42
LSD 0.05	2.07		

[1] Cocktail: oat, triticale, pea, buckwheat, forage brassica, and forage radish.
[2] Different letters within a column represent differences at LSD 0.05.

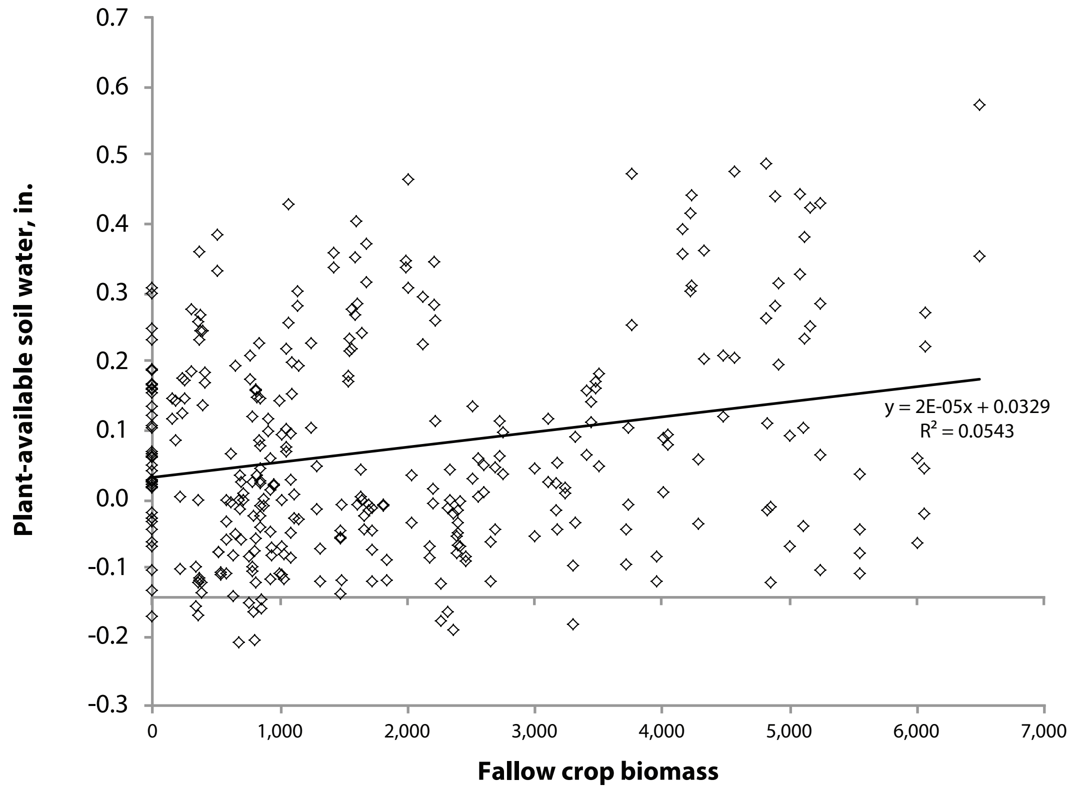

Figure 1. Plant-available soil water in the 0–3-in. soil depth correlated to cover and hay crop treatment biomass.

Cover Crop Forage Yield and Nutritive Values

J. Holman, D. Min, T. Roberts, and S. Maxwell

Summary
Producers are interested in growing cover crops or annual forages in place of fallow. Crops that produce the most biomass may be the best cover crop and forage crop. Cover crops that produce the most biomass also may have the least amount of soil wind and water erosion and greatest impact on soil carbon. Forage crops that produce the most biomass may also be the most profitable to grow. A study was conducted to evaluate the yield and nutritive values of several cover crops as forage grown in place of fallow in a no-till wheat-fallow system. Triticale produced more biomass than legumes, and binary mixtures with triticale yielded similar to triticale monocultures. Legume cover crops such as lentil, peas, and hairy vetch appeared to have higher nutritive values than monoculture triticale or binary mixtures with triticale. Overall, when averaged across years, lentil tended to have higher nutritive values than peas. Binary mixtures with spring triticale tended to improve crude protein (CP) and reduce acid detergent fiber (ADF) and neutral detergent fiber (NDF), whereas binary mixtures with winter triticale did not affect forage quality. The higher yield of winter triticale compared with spring triticale and the often-lower yield of winter legumes compared with spring legumes likely minimized the improvement in forage quality of winter binary mixtures.

Introduction
Interest in growing cover crops or replacing fallow with a cash crop has necessitated research on what species are adapted to southwest Kansas and their forage biomass potential. Cover crops by definition are grown only as cover; however, cover crops could be grown and harvested for forage. Fallow stores moisture, which helps stabilize crop yields and reduce the risk of crop failure, but only 25 to 30% of the precipitation received during the fallow period of a no-till wheat-fallow rotation is stored. The remaining 70 to 75% of precipitation is lost, primarily 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 compared with longer into the fallow period. It may be possible to increase cropping intensity without reducing winter wheat yield. Growing a cover crop that produces a lot of biomass may reduce evaporation; in contrast, evaporation may be greater following a cover crop harvested for forage. This study evaluated the forage nutritive values of several winter and spring cover crops.

Procedures
Fallow replacement crops (cover, annual forage, or short-season grain crops) have been grown during the fallow period of a no-till wheat-fallow cropping system every year since 2007. Crops were either grown as cover, harvested for forage (annual forage crop), or harvested for grain. Both winter and spring crop species were evaluated. Winter species included 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 only in monoculture. Winter lentil was grown in place of yellow sweet clover beginning in 2009.

Samples were weighed wet, dried at 50°C in a forced-air oven for 96 hours, weighed dry for dry matter yield, then sent to a commercial laboratory for determination of CP, ADF, and NDF.

Results and Discussion

Yield

Winter and spring triticale yielded more biomass than winter or spring legumes, respectively (Figure 1). Winter triticale yielded about double spring triticale. Binary mixtures with triticale yielded the same as triticale and more than legumes alone. Winter pea and hairy vetch yielded low, on average, due to frequent winter kill. Winter lentil always survived the winter but had low yield. Spring lentil produced about 30% of spring pea yield.

Crude protein

Crude protein contents varied year to year, and the highest and the lowest CP occurred in 2010 and 2011, respectively (Table 1). In 2008, hairy vetch and winter pea forage had the highest CP, and winter lentil + triticale had the lowest CP. Spring lentil and hairy vetch had the highest CP in 2009 and 2010, respectively. In 2011, the highest CP occurred in spring pea forage. When averaged across years, hairy vetch had the highest CP. Pure legume treatments such as hairy vetch, spring lentil, and winter pea appear to have significantly higher CP than non-legume plants such as triticale when averaged across years.

Acid detergent fiber

2010 and 2011 had significantly lower ADF than 2008 and 2009 (Table 2). Winter lentil had the lowest ADF when averaged across years, and spring triticale had the highest. Again, pure legumes had significantly lower ADF than non-legume or binary mixtures with triticale. This result indicates that legumes have higher digestibility potential than triticale.

Neutral detergent fiber

Cover crops from 2010 had the lowest average NDF contents (Table 3). Either spring or winter lentil had the lowest NDF contents, indicating that lentil has higher feed intake potential than other forage crops. Like ADF, legumes such as lentil and hairy vetch tended to have lower NDF than non-legumes such as triticale.

Total digestible nutrients

Cover crops from 2010 and 2011 had higher average total digestible nutrients (TDN) than those in 2008 and 2009 (Table 4). Lentil had significantly higher TDN than triticale. Both winter lentil and winter pea had significantly higher TDN than spring lentil and spring pea, respectively.

Relative feed value

2010 had significantly higher relative feed value (RFV) than other years when averaged across cover crops (Table 5). Both spring and winter lentil had significantly higher RFV than other cover crops.

Planting legumes with triticale resulted in lower forage quality than monoculture legumes, and for the most part was similar in quality to monoculture triticale. The only exception was the mixture of spring pea + triticale, which had higher RFV than spring triticale alone.

Table 1. Crude protein contents (%) of cover crops (2008–2011) in Garden City, KS

Crops	2008	2009	2010	2011	Average
SpLntl[1]	22.3b[2]	21.8 a	28.9 b	------	24.4 b
SpLntlTcl	15.9 de	19.5 b	17.0 e	15.9 c	17.0 e
SpPea (fo)	19.8 c	19.9 b	20.5 d	20.9 a	20.1 d
SpPeaTcl	16.2 d	19.9 b	18.5 e	17.0 b	17.9 e
SpTcl	14.4 ef	19.5 b	14.6 f	14.5 d	15.7 f
Vtch	26.1 a	-----	31.9 a	------	29.0 a
VtchTcl	14.5 de	16.6 c	12.6 g	16.6 bc	14.9 f
WtrLntl	-----	18.9 b	26.2 c	------	22.6 c
WtrLntlTcl	13.2 f	18.5 b	13.4 fg	17.2 b	15.6 f
WtrPea (fo)	25.0 a	21.6 a	27.4 b	------	24.6 b
WtrPeaTcl	13.9 f	15.6 c	13.5 fg	16.5 bc	14.7 f
WtrTcl	14.4 ef	16.8 c	12.7 g	16.8 bc	15.0 f
Average	17.8 c	19.0 b	19.8 a	16.5 d	

[1] SpLntl: spring lentil; Tcl: triticale; fo: forage; Vtch: hairy vetch; Wtr: winter.
[2] Different lowercase letters indicate significant difference at $\alpha = 0.05$ level within same year.

Table 2. Acid detergent fiber contents (%) of cover crops (2008–2011) in Garden City, KS

Crops	2008	2009	2010	2011	Average
SpLntl[1]	26.3 f[2]	31.4 d	21.9 ef	------	26.5 f
SpLntlTcl	36.0 ab	36.5 a	38.9 ab	30.4 b	35.8 b
SpPea (fo)	34.4 bcd	35.6 a	36.2 bc	29.6 b	34.3 bcd
SpPeaTcl	35.6 b	35.6 a	37.5 b	30.5 b	35.2 bc
SpTcl	38.2 a	35.4 a	40.9 a	35.5 a	37.7 a
Vtch	32.5 cde	-----	23.3 e	------	27.9 ef
VtchTcl	34.0 bcd	36.3 a	34.2 ed	30.8 b	34.1 bcd
WtrLntl	-----	29.2 d	20.1 f	------	24.6 g
WtrLntlTcl	34.8 bcd	34.7 a	33.5 d	30.2 b	33.6 cd
WtrPea (fo)	31.1 e	32.1 bc	22.0 ef	------	28.4 e
WtrPeaTcl	32.7 cde	36.6 a	32.6 d	30.0b	33.2 d
WtrTcl	34.2 bcd	36.4 a	33.5 d	30.6 b	33.9 cd
Average	33.6 a	34.5 a	31.2 b	31.3 b	

[1] SpLntl: spring lentil; Tcl: triticale; fo: forage; Vtch: hairy vetch; Wtr: winter.
[2] Different lower case letters indicate significant difference at α=0.05 level within same year.

Table 3. Neutral detergent fiber contents (%) of cover crops (2008–2011) in Garden City, KS

Crops	2008	2009	2010	2011	Average
SpLntl[1]	34.4 g[2]	37.4 g	25.7 e	------	32.5 fg
SpLntlTcl	58.2 bc	55.1 c	58.1 a	59.2 ab	57.6 b
SpPea (fo)	41.7 e	45.4 e	42.3 d	38.5 d	42.3 d
SpPeaTcl	53.5 d	48.8 d	51.5 c	57.5 b	52.6 c
SpTcl	62.0 a	56.9 abc	61.4 a	61.5 a	60.4 a
Vtch	40.0 ef	-----	29.9 e	------	34.9 ef
VtchTcl	58.1 bc	58.7 a	57.4 ab	53.0 c	57.1 b
WtrLntl	-----	34.8 g	25.8 e	------	30.3 g
WtrLntlTcl	59.9 ab	55.4 bc	57.6 ab	53.2 c	56.8 b
WtrPea (fo)	37.4 f	40.6 f	29.7 e	------	35.9 e
WtrPeaTcl	56.6 c	59.1 a	56.5 bc	51.8 c	56.3 b
WtrTcl	57.6 bc	58.2 ab	56.4 bc	49.8 c	55.9 b
Average	50.8 b	50.0 b	46.0 c	53.5 a	

[1] SpLntl: spring lentil; Tcl: triticale; fo: forage; Vtch: hairy vetch; Wtr: winter.
[2] Different lower case letters indicate significant difference at α = 0.05 level within same year.

Table 4. Total digestible nutrient contents (%) of cover crops (2008–2011) in Garden City, KS

Crops	2008	2009	2010	2011	Average
SpLntl[1]	72.8 a[2]	67.3 ab	77.8 ab	------	72.6 b
SpLntlTcl	62.1 cd	61.7 d	59.0 ef	68.3 a	62.3 fg
SpPea (fo)	63.7 c	62.6 cd	61.9 cde	69.2 a	64.0 def
SpPeaTcl	62.6 cd	62.6 cd	60.3 def	68.4 a	63.1 ef
SpTcl	59.9 d	62.8 cd	56.5 f	63.0 b	60.3 g
Vtch	63.9 c	-----	75.3 b	------	69.6 c
VtchTcl	64.4 bc	61.7 d	63.9 cd	67.7 a	64.1 def
WtrLntl	-----	69.8 a	80.0 a	------	74.9 a
WtrLntlTcl	63.5 cd	63.9 bcd	64.8 c	68.6 a	64.9 de
WtrPea (fo)	67.5 b	66.4 abc	77.8 ab	------	70.6 bc
WtrPeaTcl	65.7 bc	61.5 d	66.2 c	68.9 a	65.3 d
WtrTcl	64.2 bc	61.9 d	65.1 c	68.0 a	64.5 de
Average	64.6 b	63.8 b	67.4 a	67.5 a	

[1] SpLntl: spring lentil; Tcl: triticale; fo: forage; Vtch: hairy vetch; Wtr: winter.
[2] Different lowercase letters indicate significant difference at $\alpha = 0.05$ level within same year.

Table 5. Relative feed value of cover crops (2008–2011) in Garden City, KS

Crops	2008	2009	2010	2011	Average
SpLntl[1]	185 a[2]	167 a	260 a	------	204 b
SpLntlTcl	98 c	102 de	94 de	103 cd	98 fg
SpPea (fo)	138 b	125 c	134 c	158 a	137 d
SpPeaTcl	106 c	117 ed	108 d	106 cd	109 e
SpTcl	89 c	100 de	86 e	93 d	91 g
Vtch	150 b	-----	220 b	------	184 c
VtchTcl	100 c	96 e	101 de	114 bc	101 efg
WtrLntl	-----	176 a	266 a	------	221 a
WtrLntlTcl	96 c	104 de	101 de	114 bc	103 ef
WtrPea (fo)	160 ab	147 b	225 b	------	177 c
WtrPeaTcl	104 c	95 e	104 de	124 b	105 ef
WtrTcl	101 c	96 e	103 de	124 b	104 ef
Average	120 b	120 b	150 a	115 b	

[1] SpLntl: spring lentil; Tcl: triticale; fo: forage; Vtch: hairy vetch; Wtr: winter.
[2] Different lowercase letters indicate significant difference at $\alpha = 0.05$ level within same year.

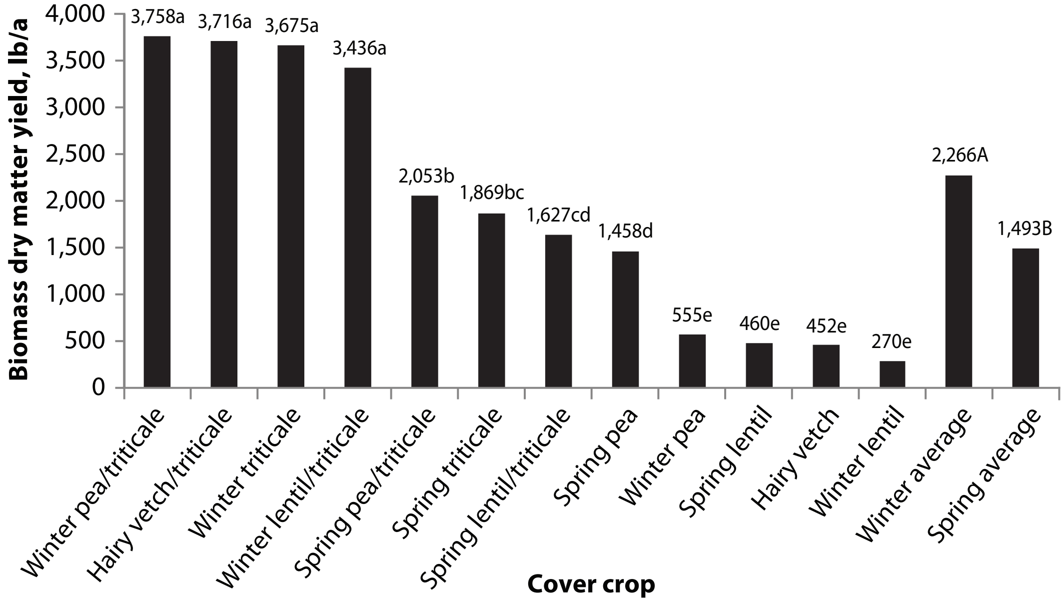

Figure 1. Dry matter biomass yield (lb/a) of cover crops averaged from 2008–2011.
Different lowercase letters indicate significant difference at $\alpha = 0.05$.
Different uppercase letters indicate significant difference between average of winter and spring crops at $\alpha = 0.05$.

Determining Profitable Annual Forage Rotations

J. Holman, D. Min, T. Roberts, and S. Maxwell

Summary
Producers are interested in growing forages, yet the region lacks proven recommended crop rotations like those for grain crops. Growing forages is important to the region's livestock and dairy industries and is becoming increasingly important as irrigation well capacity declines. Forages require less water than grain crops to make a crop and may allow for increasing cropping intensity and opportunistic cropping. A study was initiated in 2013 comparing several forage rotations of 2-, 3-, and 4-year rotations with minimum-till and no-till. First-year results found double-crop forage sorghum yielded only 30% of full-season forage sorghum in a drought year compared with average precipitation years, which found double-crop forage sorghum yielded 70% of full-season sorghum. Oats failed to make a crop during the drought year and do not appear to be as drought-tolerant as forage sorghum. Subsequent years will be used to compare forage rotations and profitability.

Introduction
Dryland rotations in the region have typically included fallow to accumulate precipitation in the soil profile and help stabilize crop yields. Fallow is relatively inefficient at storing and utilizing precipitation compared with precipitation received during the growing crop. Fallow periods increase soil erosion and organic matter loss (Blanco and Holman, 2012) and are a large economic cost to dryland producers.

Forage production may be a method to reduce the frequency of fallow in the region, increase precipitation use efficiency, improve soil quality, and increase profitability. Several annual forage rotations were identified as potentially acceptable by producers based on recent forage research and grower feedback. This study is testing several forage rotations for water use efficiency, forage quality, and profitability.

Annual forage crops are grown for a shorter time period and require less moisture than traditional grain crops. Thus, including annual forages in the cropping system might enable cropping intensity and opportunistic cropping to increase. "Opportunistic cropping," or "flex cropping," is the planting of a crop when conditions (soil water and precipitation outlook) are favorable and fallowing when conditions are not favorable. Forage producers in the region commonly grow continuous winter triticale (WT), triticale or summer crop silage, or forage sorghum/sudan hay (FS), but they lack a proven rotation concept for forages like that developed for grain crops (e.g., winter wheat-summer crop-fallow). Producers are interested in forage crop rotations that enable increased pest management control options, spread equipment and labor resources out over the year, and reduce weather risk. Growing forages throughout the year can greatly reduce the risk of crop failure. Double-crop yields of WT and FS were 70% of annual cropping at Garden City, KS ($P \leq 0.05$) from 2007 through 2010. Double-cropping resulted in about 44% more forage yield than annual cropping; however, crop establishment was more challenging, and crop growth was highly dependent on growing season precipitation in the double-crop rotation compared with annual cropping. An intermediate

cropping intensity of three crops grown in two years or four crops in three years might be successful in western Kansas. Wheat yields following spring annual forages were similar to wheat yield following fallow in a wheat-fallow rotation in non-drought years, and wheat yields were reduced only in drought years (Holman et al., 2012). Forages are valuable feedstuff to the cow/calf, stocker, cattle-feeding, and emerging dairy industries throughout the region (Hinkle et al., 2010).

Glyphosate-resistant kochia was recently identified in western Kansas along with several other already-tolerant grasses (e.g., tumble windmill grass and red threeawn). Although continuous no-till was shown to provide better water conservation and crop yields, this is contingent upon being able to control all weeds during fallow with herbicides. Only limited information is available on the impact of occasional tillage on forage yield. Yield of forage crops following tillage might not be affected as much as grain crops because forages require less water.

Objectives of this study were to (1) improve precipitation use and fallow efficiency of dryland cropping systems by reducing fallow through the use of forage crops; (2) test a number of forage crop rotations and tillage practices (no-till and min-till) to identify sustainable forage cropping systems; and (3) disseminate results to growers, crop advisors, and county extension agents through meetings and publications.

Procedures

An annual forage rotation experiment was initiated in 2012 at the Southwest Research-Extension Center in Garden City, KS. All crop phases were in place by 2013, with the exception of winter triticale-forage sorghum-spring oat, which had all crop phases in place by 2014. 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-till or min-till). Plots were 30 ft wide × 30 ft long. Crop rotations were 1-, 3-, and 4-year rotations (see treatment list below). Crops grown were winter triticale (×*Triticosecale* Wittm.), forage sorghum (*Sorghum bicolo*r 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 sweep plow with 6-ft blades and trailing rolling pickers.

Treatments were:

Continuous forage sorghum (no-till; S-S)

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

Winter triticale was planted at the end of September, spring oat was planted in the beginning of March, and forage sorghum was planted in the beginning of June. Crops were harvested at early heading to optimize forage yield and quality (Haun scale 9.5). 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-ft × 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 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 at planting is being used to estimate yield and 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 using a soil moisture probe provided an accurate and easy way to determine soil moisture level and crop yield potential.

Data produced by this study will be used to evaluate the economics of forage rotations and tillage. Production cost and returns will be calculated using typical values for the region. The implications 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

Rotation Yield

Annual rotation yield was determined by measuring total yield for the rotation within a year and dividing by the number of years in the rotation. This method allows for comparing rotations of different years to each other annually. In 2013, there was no difference in annual treatment yield (Figure 1), due in part to the dry conditions and low forage yield across all treatments. Tillage as a main effect between no-till and min-till treatments also was not significant.

Forage yield per crop harvest was determined because planting and harvest expenses are the major expenses to growing a crop. Crop rotations with higher yield per harvest are likely more profitable compared with rotations with low yield per harvest, because the expense per unit of yield is less. However, although oat and triticale yield less than sorghum, they are also higher in crude protein and digestibility and are worth more per unit than forage sorghum; thus, a full economic analysis of rotations will be completed at the conclusion of this study. In 2013, all rotations had similar yields per harvest (Figure 2). Sorghum has the highest 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

Winter triticale yield was not different across rotation treatments averaging 434 lb/a with a water use efficiency (WUE) of 29 lb/a per in. of soil water.

Full-season sorghum yields either grown after T/S or S yielded similar across rotations (Figure 3). Sorghum grown double-crop after triticale consisted yielded about 30% (1,130 lb/a) of full-season sorghum (3,870 lb/a). Sorghum grown after triticale had less available soil water and and was drought-stressed in the dry year of 2013. Previous research found that in normal to above-normal years, double-crop sorghum yield following triticale was 70% compared with full-season sorghum (Holman, unpublished data). Sorghum WUE was correlated to forage yield, with full-season sorghum having greater WUE (419 lb/a per in. soil water) than double-crop sorghum (97 lb/a per in. soil water) (Figure 4).

Oats failed to make a crop in any rotation treatment in 2013 due to drought conditions.

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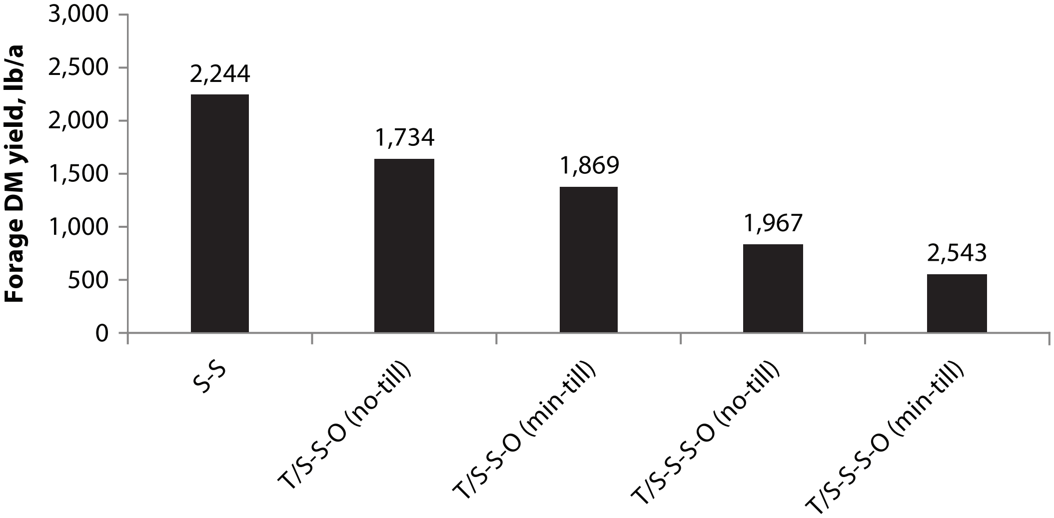

Figure 1. Annual treatment forage dry matter (DM) yield (total yield divided by number of years in the crop rotation) in 2013.

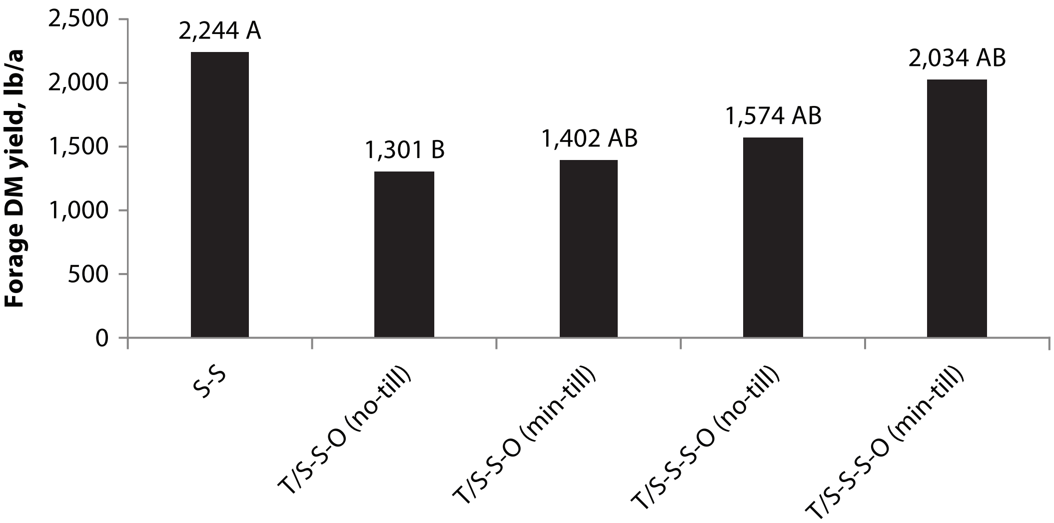

Figure 2. Forage dry matter (DM) yield per crop harvest (total annual yield divided by number of harvested crops in the rotation) in 2013.
Different uppercase letters indicate significant difference at $\alpha = 0.05$.

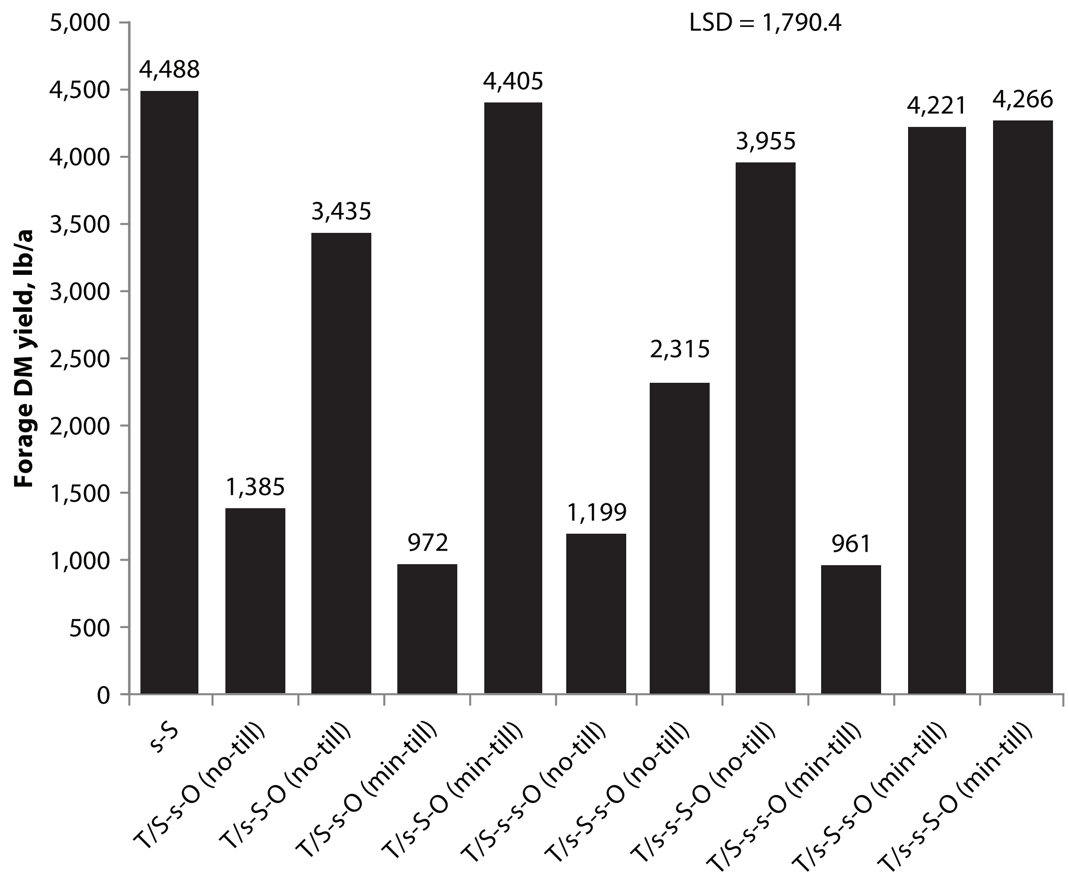

Figure 3. Forage sorghum (S) forage dry matter yield in all crop rotations and phases in 2013. Sorghum crop is identified by capitalization in X axis. LSD= 1,790 lb/a.

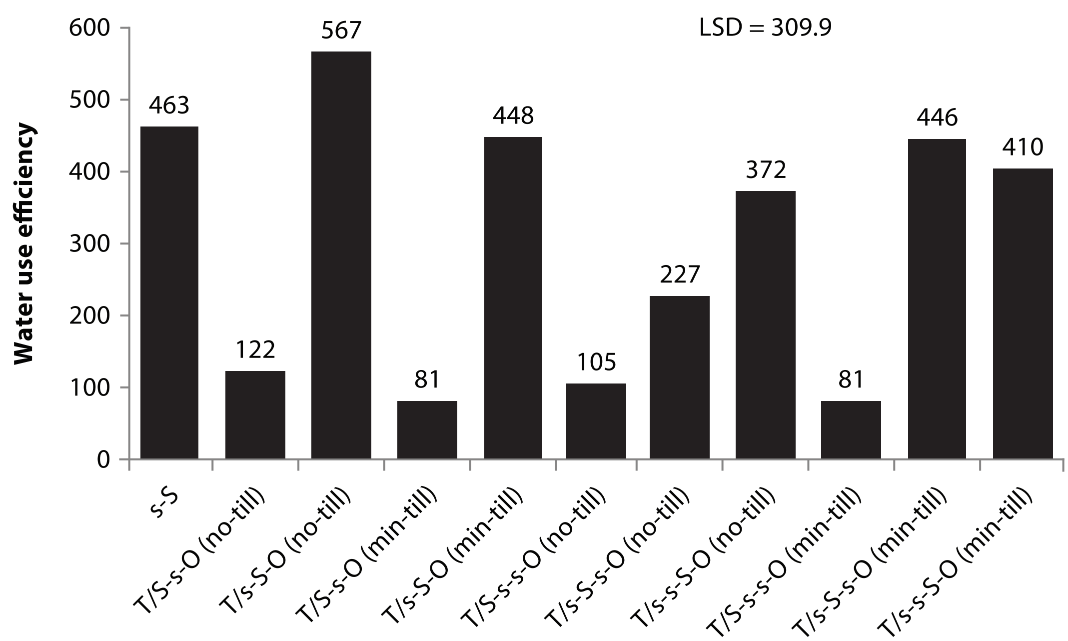

Figure 4. Forage sorghum (S) water use efficiency [forage dry matter yield/((ending-beginning soil water content) + growing season precipitation)] in all crop rotations and phases in 2013. Sorghum crop is identified by capitalization in X axis. LSD= 309 lb/a per in. of soil water.

2013 Grain Filling Rates of Irrigated and Dryland Corn in Southwest Kansas

J. Holman, T. Roberts, S. Maxwell, and M. Zarnstorff

Summary
The 2013 crop year started out with the continuation of the ongoing drought, then precipitation was average for the month of July and above average for the month in August. Irrigated corn received early season irrigation, and normal to above-normal late-season precipitation coupled with normal temperatures, which meant corn developed under fair conditions with the exception of some hail damage received at the end of July. This hail storm greatly reduced leaf area of the crop, which more than likely led to a reduction in final grain yield, which was 153 bu/a. A final moisture level for the grain at harvest was 7%, and cob moisture was 9%.

Primarily due to the drought but also due to hail, the dryland crop failed early in the growing season. The crop was stunted and set poorly developed ears. Although data were collected, little information could be obtained due to the lack of development and variability in the crop.

Introduction
A field experiment was conducted at the Kansas State University Southwest Research-Extension Center at Garden City, KS, to compare the grain fill rates of a corn hybrid under irrigated and dryland cropping conditions. Understanding the rate of grain yield development and changes in moisture content are important for making management decisions about when to plan and implement silage harvest and for determining grain yield potential. This experiment evaluated grain yield and moisture content throughout the reproductive growth stages of a corn crop grown under both irrigated and dryland conditions.

Procedures
A field with center-pivot irrigation was selected for the irrigated plot area, and a non-irrigated field adjacent to the irrigated field was selected for the dryland plot area. Both areas followed wheat. The soil type of both sites was a Ulysses Silt Loam.

On May 15, Dekalb DKC52-59 (102-day CRM) was planted in both the irrigated and dryland sites at seeding rates of 30,628 and 16,335 seeds/a, respectively, using 30-in. row spacing. An area consisting of 4 50-ft-long rows was marked out in the irrigated and dryland areas to be used for sample collection. Nitrogen was broadcast-applied as urea (46-0-0) at a rate of 100 lb/a product (46 lb N/a) to the irrigated site and 60 lb/a of product (28 lbs N/a) to the dryland site prior to planting corn.

On August 6, the irrigated corn was at early milk stage (R3), and the dryland corn was suffering from drought, with a few plants trying to set a few ears (R1 stage) (Table 1). Beginning at this time, five ears were hand-harvested weekly from the irrigated plots until grain harvest. The dryland corn had no ears at R3 until August 20, so sampling

started then and continued until the grain matured. Observations of husk greenness, crop canopy color, and intactness were recorded at each sampling (Table 2). At each sampling date, five ears were weighed and photographed, then broken in half to check the progression of the starch line, which was also photographed. The ears were then placed in a drying oven and dried at 104ºF for 4 or more days. Dried ears were then shelled and weights of the grain, cob, and 250 kernels were recorded. When the corn reached the R5 stage, the ears were shelled before drying so a wet weight could be recorded separately for the grain and cob.

2013 Growing Conditions

The ongoing drought continued into the 2013 growing season, but the soil profile moisture was sufficient in the irrigated site at planting because of pre-irrigation. The dryland field accumulated some moisture over the winter, but the crop was planted into soil with very little profile moisture. The dry weather conditions continued after planting from May through June, with precipitation levels at 60% of the long-term average (Table 3). Even with near-normal temperatures, the dryland crop suffered from the dry conditions, causing it to stress and affecting the development of the crop. A hail storm on July 31 caused severe tattering of the leaves on both the irrigated and dryland plants. Starting the first of August and through the month, precipitation was well above normal, 243% of the long-term average, and remained normal for the rest of the growing season.

Results

Irrigated corn grain developed in a linear pattern between early milk stage and mid R5 (August 6–September 11) (Figure 1). At the second to last sampling period, there was a decrease in grain yield, and upon viewing photographs of harvested ears, we determined the cause was shorter ears of corn sampled from that area of the plot. The irrigated plot reached physiological maturity on September 24, with a final yield of 153.1 bu/a and an accumulation of 2.4 bu/a per day. Dryland corn maturity and grain development varied widely due to the drought and hail damage. Most of the ears set on the dryland plants were small, around 4 in. long, with very few kernels (some ears had only 3 or 4 kernels). A spike in grain yield occurred in the dryland corn on August 27, which occurred due to the high variability in the crop; the ears sampled at this time happened to have better kernel set than any other sample period. In addition, dryland corn condition continued to worsen as the drought persisted into the growing season. Final grain yield in dryland was estimated to be around 5.5 bu/a.

Cob moisture in the irrigated corn started at 259.3 g/kg and decreased to 89.7 g/kg during the period of September 11 through September 25. Grain moisture went from 108.7 to 69.4 g/kg during this same period. Dryland corn had poor ear development and had a starting moisture content of 707.8 g/kg and remained at this level for the remainder of the season. Dryland grain moisture during the first sample period was 424.5 g/kg, then spiked to 674.7 g/kg on the second sample. This spike occurred because of the better ears sampled at this time. Grain moisture in the dryland then dropped to a final value of 329.7 g/kg.

Table 1. Crop growth stages

Stage	Reproductive stages description
R1	Silking: silks visible outside the husks
R2	Blister: kernels are white and resemble a blister in shape
R3	Milk: kernels are yellow on the outside and contain a milky inner fluid
R4	Dough: milky inner fluid thickens to pasty consistency
R5	Dent: nearly all kernels are denting
R6	Physiological maturity: the black abscission layer has formed

Table 2. Plant health observations

Date		Growth stage	Husk greenness	Canopy greenness	Canopy intactness
August 6	Dryland	--	--	--	--
August 6	Irrigated	R3	100%	100%	60%[1]
August 13	Dryland	--	--	--	--
August 13	Irrigated	R4	100%	95%	60%
August 20	Dryland	R3–R4[2]	100%	80%	50%
August 20	Irrigated	Early R5	95%	95%	60%
August 27	Dryland	Early R5	75%	75%	50%
August 27	Irrigated	Mid-R5	80%	80%	40%
September 11	Dryland	Early R5	50%	50%	40%
September 11	Irrigated	Mid-R5	0%	40%	40%
September 18	Dryland	Mid-R5	30%	40%	40%
September 18	Irrigated	Late R5	0%	20%	30%
September 25	Dryland	Late R5	0%	30%	30%
September 25	Irrigated	R6	0%	0%	30%

[1] Hail storm on July 31 caused severe leaf tattering.
[2] Maturity varied widely due to drought.

Table 3. Weather and irrigation data for the 2013 corn maturity study

Month	Precipitation	30-year avg. precipitation	Average air temperature	30-year avg. temperature	Irrigation
	--------------- in. ---------------		--------------- °F ---------------		in.
April	0.28	1.74	47.1	52.3	0.8
May	1.25	2.98	63.2	62.8	2.51
June	1.84	3.12	77.1	72.6	5.07
July	2.23	2.8	79.0	77.9	5.75
August	6.09	2.51	76.2	76.3	0
September	1.83	1.42	72.4	67.7	0
Total moisture	13.52	14.57	--	--	14.13
Avg. temperature	--	--	69.2	68.3	--

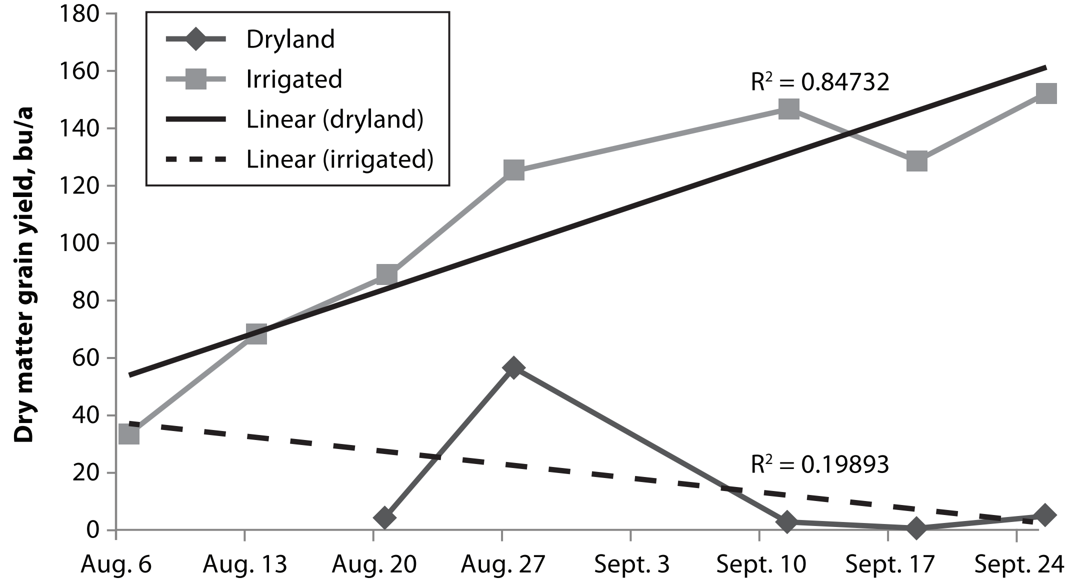

Figure 1. Accumulation of irrigated and dryland corn dry matter grain yield at Garden City, KS, 2013.

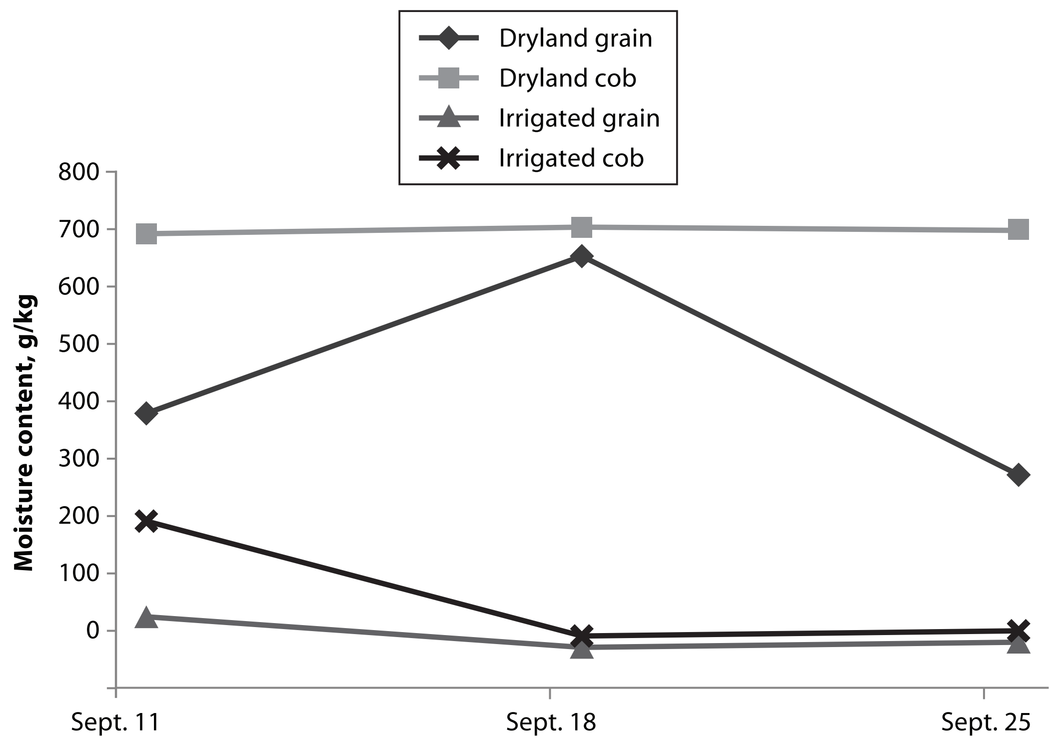

Figure 2. Grain and cob moisture content of irrigated and dryland corn at Garden City, KS, 2013.

Large-Scale Dryland Cropping Systems[1]

A. Schlegel

Summary
A large-scale rainfed cropping systems research and demonstration project evaluated two summer crops (corn and grain sorghum) along with winter wheat in crop rotations varying in length from 1 to 4 years. The crop rotations were continuous grain sorghum, wheat-fallow, wheat-corn-fallow, wheat-sorghum-fallow, wheat-corn-sorghum-fallow, and wheat-sorghum-corn-fallow. The objective of the study is to identify cropping systems that enhance and stabilize production in rainfed cropping systems to optimize economic crop production. Lack of precipitation during 2013 depressed grain yields of all crops. Averaged across the past six years, wheat yields ranged from 20 to 25 bu/a and were not affected by length of rotation. Corn and grain sorghum yields (6-year average) were about twice as great when following wheat than when following corn or grain sorghum.

Introduction
The purpose of this project is to research and demonstrate several multicrop rotations that are feasible for the region along with several 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 through the use of 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.

Procedures
The crop rotations are 2-year (wheat-fallow [WF]), 3-year (wheat-grain sorghum-fallow [WSF] and wheat-corn-fallow [WCF]), and 4-year rotations (wheat-corn-sorghum-fallow [WCSF] and wheat-sorghum-corn-fallow [WSCF]) and continuous sorghum (SS). All rotations are grown using no-till practices except for WF, which is grown using reduced-tillage. 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.

Results and Discussion
Grain yields of all crops were below average in 2013 because of lack of precipitation (Table 1). Precipitation during late July and August helped grain sorghum yields but was too late for wheat and corn. Wheat yields were less than 10 bu/a for all treatments, and corn yields were less than 20 bu/a for all rotations. Grain sorghum yields were quite variable and not significantly affected by rotation.

Wheat yields averaged across the past six years (2008–2013) ranged from 20 to 25 bu/a and were not affected by length of rotation (Table 2). Corn yields following wheat

[1] This research project received support from the Ogallala Aquifer Initiative.

averaged about twice as much than following sorghum. Similarly, sorghum yields following wheat were about twice as much than following corn or sorghum.

Table 1. Grain yield response to crop rotation in large-scale cropping systems study, Tribune, KS, 2013

Crop rotation	Wheat	Corn	Sorghum
	bu/a		
Wheat-fallow[1]	2c[2]		
Wheat-corn-fallow	9ab	14a	
Wheat-sorghum-fallow	9a		50a
Wheat-corn-sorghum-fallow	5bc	16a	31a
Wheat-sorghum-corn-fallow	8ab	8b	56a
Sorghum-sorghum			42a
$LSD_{0.05}$	4	6	31

[1] Wheat-fallow rotation is reduced-till; all other rotations are no-till.
[2] Means within a column with the same letter are not statistically different at $P = 0.05$.

Table 2. Grain yield response to crop rotation in large scale cropping systems study, Tribune, KS, 2008–2013

Crop rotation	Wheat	Corn	Sorghum
	bu/a		
Wheat-fallow[1]	24ab[2]		
Wheat-corn-fallow	24ab	37a	
Wheat-sorghum-fallow	25a		66a
Wheat-corn-sorghum-fallow	20b	38a	34b
Wheat-sorghum-corn-fallow	21ab	20b	63a
Sorghum-sorghum			32b
$LSD_{0.05}$	4	5	9

[1] Wheat-fallow rotation is reduced-till; all other rotations are no-till.
[2] Means within a column with the same letter are not statistically different at $P = 0.05$.

Effects of Wheat Stubble Height on Subsequent Corn and Grain Sorghum Crops

A. Schlegel

Summary
A field study initiated in 2006 was designed to evaluate the effects of three wheat stubble heights on subsequent grain yields of corn and grain sorghum. Yields in 2013 were substantially lower than the long-term average because of lack of precipitation, particularly through late July. No effect from stubble height was observed in 2013 for either corn or grain sorghum. When averaged across 2007–2013, corn grain yields were 10 bu/a greater when planted into either tall or strip-cut stubble than into low-cut stubble. This increase was primarily due to an increase in the number of kernels per ear. Average grain sorghum yields were not significantly affected by wheat stubble height. Harvesting the previous wheat crop shorter than necessary results in a yield penalty for the subsequent dryland corn crop.

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.

Procedures
This study was conducted at the Southwest Research-Extension Center dryland station near Tribune, KS. From 2007 through 2013, 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. In 2013, these heights were 9, 18, and 27 in., which were the same as the average heights from 2007–2013. In 2013, corn and grain sorghum were seeded at rates of 15,000 seeds/a and 35,000 seeds/a, respectively. Nitrogen was applied to all plots at a rate of 60 lb/a. Starter fertilizer (10-34-0 N-P-K) was surface dribble 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 measurements were

obtained with neutron attenuation to a depth of 6 ft in1-ft increments at seeding and harvest to determine water use and water use efficiency.

Results and Discussion

The 2013 growing season had below-normal precipitation through late July, which negatively affected grain yield. Corn grain yields were about 30 bu/a lower than the average yields from 2007–2013 (Tables 1 and 2). Stubble height did not affect grain yield or any of the other measured parameters in 2013; however, average corn yields from 2007–2013 were 10 bu/a greater when planted into high- or strip-cut stubble, primarily due to a greater number of kernels per ear. Biomass production and water use efficiency were also greater with the taller stubble.

Grain sorghum yields were about 50% greater than corn yields in 2013 and were not affected by stubble height (Table 3). When averaged across years from 2007–2013, 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 stubble height.

Table 1. Corn yield and yield components as affected by stubble height, Tribune, KS, 2013

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	40	13.7	13.7	7,800	5,900	10.5	250	163
High	45	13.8	13.7	7,400	5,300	10.7	274	196
Strip	47	14.0	13.9	7,100	4,800	10.9	277	219
$LSD_{0.05}$	8	0.8	0.7	900	1,000	0.5	38	51
ANOVA (P > F)								
Stubble height	0.178	0.751	0.697	0.194	0.095	0.259	0.261	0.096

[1] Water use efficiency (lb of grain/in. of water use).

Table 2. Corn yield and yield components as affected by stubble height, Tribune, KS, 2007–2013

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./head	lb/in.
Low	69	14.6	14.1	8,900	5,700	10.2	420	263
High	79	14.5	14.5	10,000	6,300	10.4	455	306
Strip	79	14.6	14.5	9,900	6,200	10.3	466	308
$LSD_{0.05}$	4	0.3	0.5	700	600	0.3	23	20
ANOVA (P > F)								
Year	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Stubble height	0.001	0.667	0.149	0.002	0.113	0.297	0.001	0.001
Year × stubble height	0.392	0.426	0.409	0.476	0.459	0.479	0.865	0.567

[1] Water use efficiency (lb of grain/in. of water use).

Table 3. Sorghum yield and yield components as affected by stubble height, Tribune, KS, 2013

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	62	67	8,600	5,500	0.68	1,250	251
High	67	68	8,300	5,000	0.72	1,240	266
Strip	64	71	8,400	5,300	0.69	1,180	247
LSD $_{0.05}$	6	10	1,500	1,400	0.06	180	23
ANOVA (P > F)							
Stubble height	0.187	0.638	0.899	0.679	0.310	0.672	0.180

[1] Water use efficiency (lb of grain/in. of water use).

Table 4. Sorghum yield and yield components as affected by stubble height, Tribune, KS, 2007–2013

Stubble height	Yield	Head population	Biomass	Residue	1,000-seed weight	Kernels	WUE[1]
	bu/a		---------- lb/a ----------		oz	no./head	lb/in.
Low	89	50	10,500	6,100	0.86	1960	353
High	94	52	11,000	6,400	0.87	2010	381
Strip	91	51	10,500	6,100	0.85	1920	371
LSD $_{0.05}$	5	3	700	600	0.02	170	25
ANOVA (P > F)							
Year	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Stubble height	0.163	0.411	0.278	0.573	0.137	0.552	0.089
Year × stubble height	0.969	0.453	0.991	0.969	0.598	0.043	0.842

[1] Water use efficiency (lb of grain/in. of water use).

Four-Year Rotations with Wheat and Grain Sorghum

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

Summary
Research on 4-year crop rotations with wheat and grain sorghum was initiated at the Southwest Research-Extension Center near Tribune, KS, in 1996. 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 that 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 65% of the yield of wheat grown in a 4-year rotation following sorghum. 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 was similar to the first sorghum crop in 2013, although the long-term average is about 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. With concurrent increases in no-till, is more intensive cropping feasible? Objectives of this research were to quantify soil water storage, crop water use, and crop productivity of 4-year and continuous cropping systems.

Procedures
Research on 4-year crop rotations with wheat and grain sorghum was initiated at the Tribune Unit of the Southwest Research-Extension Center in 1996. Rotations were WWSF, WSSF, and WW. No-till was used for all rotations. 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 2013, available soil water was less than 1 in. for wheat following wheat. Soil water was similar following fallow after either one or two sorghum crops and averaged about 9 in. across the 17-year study period. Water at planting of the second wheat crop in a WWSF rotation generally was less than that 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). Soil water was similar following fallow after either one or two wheat crops and averaged about 8 in. across 18 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 in. more available water at planting than the second crop.

Grain yields

In 2013, wheat was a complete failure because of a dry growing season (Table 1). Averaged across 17 years, recrop wheat (the second wheat crop in a WWSF rotation) yielded about 80% of the yield of first-year wheat in WWSF. Before 2003, recrop wheat yielded about 70% of the yield of first-year wheat. In 2003 and 2009, however, recrop wheat yields were much greater than the yield in all other rotations. For 2003 recrop wheat, this is possibly a result of failure of the first-year wheat in 2002, which resulted in a period from 2000 sorghum harvest to 2003 wheat planting without a harvested crop, but this was not the case for the 2009 recrop wheat. Generally, little difference has occurred in wheat yields following one or two sorghum crops. In most years, continuous wheat yields have been similar to recrop wheat yields, but in several years (2003, 2007, and 2009), recrop wheat yields were considerably greater than continuous wheat yields.

Sorghum yields in 2013 were greater than 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 typically averages about 65% of the yield of the first sorghum crop, but in 2013, recrop sorghum yields were similar to the first sorghum crop.

Table 1. Wheat response to dryland crop rotation, Tribune, KS, 1997–2013

	Rotation					ANOVA ($P>F$)		
Year	**W**ssf[1]	**W**wsf	w**W**sf	**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	--	--		
Mean[2]	37a	36a	29b	23c	2	0.001	0.001	0.001

[1] W, wheat; S, sorghum; capital letters denote current year's crop.

[2] Means within a row with the same letter are not statistically different at $P = 0.05$.

Table 2. Grain sorghum response to crop rotation, Tribune, KS, 1996–2013

	Rotation				ANOVA (*P*>*F*)		
Year	w**S**sf[1]	ws**S**f	ww**S**f	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		
Mean[2]	75a	50b	75a	4	0.001	0.001	0.001

[1] W, wheat; S, sorghum; capital letters denote current year's crop.

[2] Means within a row with the same letter are not statistically different at $P = 0.05$.

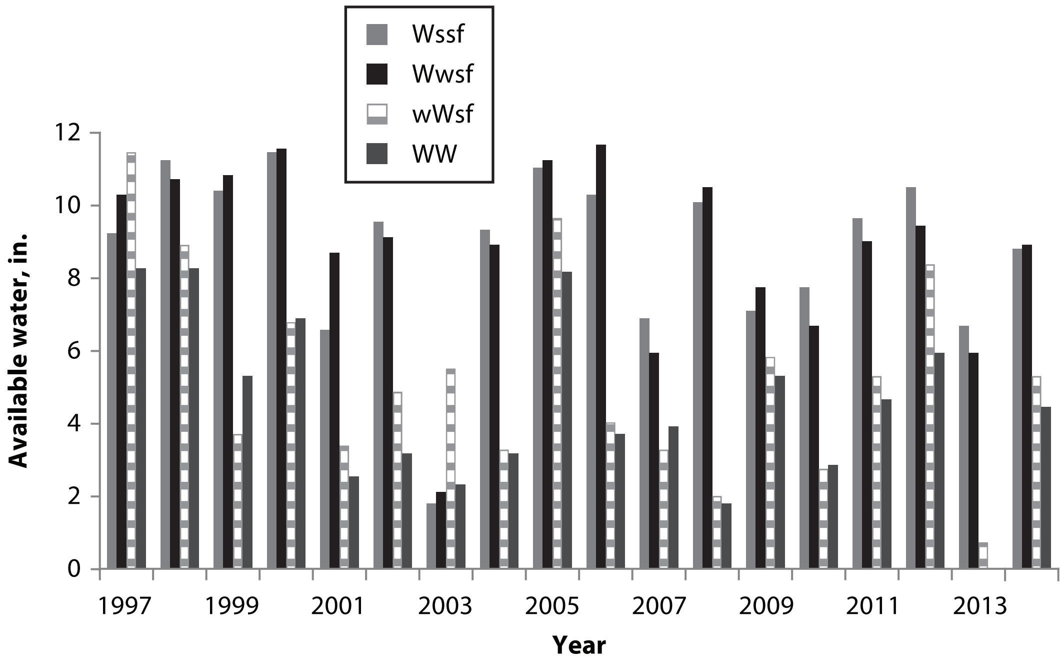

Figure 1. Available soil water in 6-ft profile at planting of wheat in several rotations, Tribune, 1997–2013.

Capital letter denotes current crop in rotation (W, wheat; S, sorghum). The last set of bars (Mean) is the average across years.

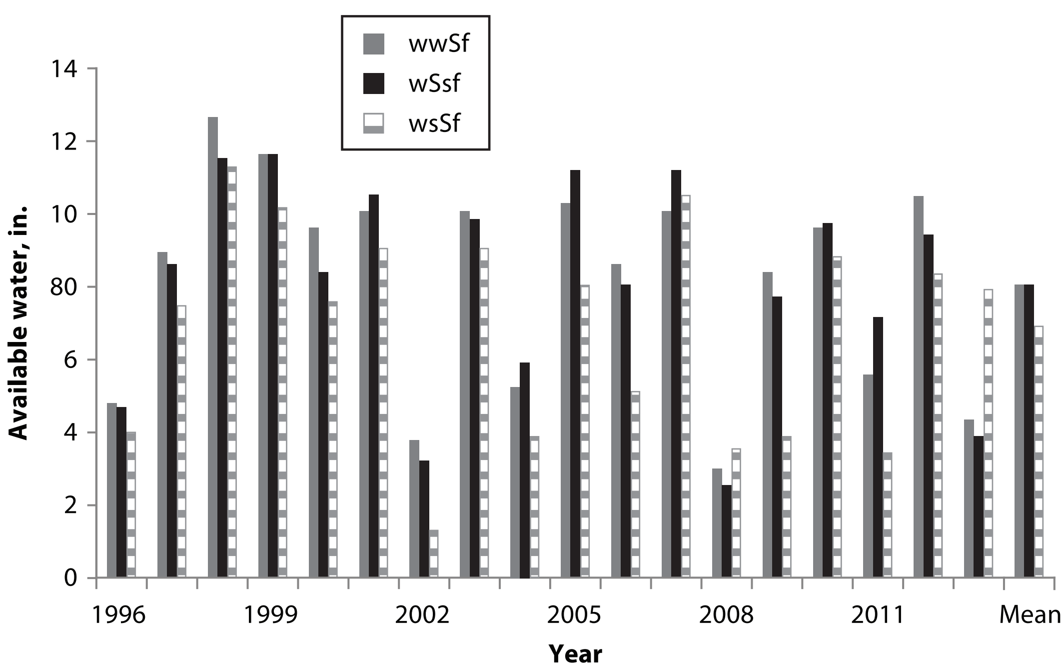

Figure 2. Available soil water in 6-ft profile at planting of sorghum in several rotations, Tribune, 1996–2013.

Capital letter denotes current crop in rotation (W, wheat; S, sorghum). The last set of bars (Mean) is the average across years.

Benefits of Long-Term No-Till in a Wheat-Sorghum-Fallow Rotation[1]

A. Schlegel and L. Stone[2]

Summary
Grain yields of wheat and grain sorghum increased with decreased tillage intensity in a wheat-sorghum-fallow (WSF) rotation. Averaged across the past 13 years, no-till (NT) wheat yields were 5 bu/a greater than reduced-tillage and 7 bu/a greater than conventional tillage. Grain sorghum yields in 2013 were 27 bu/a greater with long-term NT than short-term NT. Averaged across the past 13 years, sorghum yields with long-term NT have been nearly twice as great as short-term NT (58 vs. 30 bu/a).

Procedures
Research on different tillage intensities in a WSF rotation at the Tribune 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-till (NT). The CT system was tilled as needed to control weed growth during the fallow period. On average, this resulted in four to five tillage operations per year, usually with a blade plow or field cultivator. The RT system originally used a combination of herbicides (one to two spray operations) and tillage (two to three 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
Since 2001, wheat yields have been severely depressed in 8 of 13 years, primarily because of lack of precipitation. Reduced-tillage and NT increased wheat yields (Table 1). On average, wheat yields were 7 bu/a higher for NT (21 bu/a) than CT (14 bu/a). Wheat yields for RT were 2 bu/a greater than CT even though both systems had tillage prior to wheat. NT yields were significantly less than CT or RT in only 1 of the 13 years.

The yield benefit from RT was greater for grain sorghum than wheat. Grain sorghum yields for RT averaged 12 bu/a more than CT, whereas NT averaged 28 bu/a more than RT (Table 2). 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. In 2013, sorghum yields were 28 bu/a greater with long-term NT than short-term NT. This consistent yield benefit with long-term vs. short-term NT has been observed since the RT system was changed in 2001. Averaged across the past 13 years, sorghum yields with long-term NT have been nearly twice as great as short-term NT (58 vs. 30 bu/a).

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[1] This research project was partially supported by the Ogallala Aquifer Initiative.

[2] Kansas State University Department of Agronomy.

Table 1. Wheat response to tillage in a wheat-sorghum-fallow rotation, Tribune, KS, 2001–2013

	Tillage				ANOVA ($P > F$)		
Year	Conventional	Reduced	No-till	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	- - -	- - -		
Mean	14	16	21	2	0.001	0.001	0.001

Table 2. Grain sorghum response to tillage in a wheat-sorghum-fallow rotation, Tribune, KS, 2001–2013

	Tillage				ANOVA ($P > F$)		
Year	Conventional	Reduced	No-till	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		
Mean	18	30	58	5	0.001	0.001	0.001

Alfalfa Cutting Frequency Study

D. Min, A. Zukoff, S. Zukoff, J. Holman, J. Aguilar, C. Randall, S. Maxwell, J. Waggoner, and I. Kisekka

Summary
The objectives of this research are to: (1) assess how cutting frequency affects dry matter yield, forage quality, insect population, weed invasion, soil moisture, and stand persistence of alfalfa production in Southwest Kansas; and (2) determine the optimum cutting frequency that improves water use efficiency, reduces input costs (fuel, labor), and maintains alfalfa forage yield and forage quality. Based on one year of data in 2013, cutting alfalfa four times a year at mid-bloom stage appears to be better practice than cutting alfalfa three times, four times at early bloom stage, or five times a year in Garden City, KS.

Introduction
Alfalfa is one of the most important cash crops in Southwest Kansas: alfalfa hay provides vital feed for both dairy and beef cattle. Alfalfa is harvested five times a year in this area under irrigation, and proper harvest management is essential to profitable alfalfa production, particularly in manipulation of forage quality and yield. Within reason, fewer cuttings per season generally result in higher yield per season but at the expense of forage quality; however, determining the optimum cutting schedule is challenging due to ever-changing weather and price conditions. Forage quality is an important factor, but forage dry matter yield may be more important than forage quality under severe drought conditions in which forage supply is limited. Because high yield is more profitable in high price years and high quality is more important in low price years, producing more tonnage of alfalfa forage may be more important for producers' profitability than higher forage quality with lower alfalfa yield. The main objective of this study was to determine the cutting frequency that optimizes dry matter yield and forage quality in alfalfa production in Southwest Kansas. This study also may help reduce fuel costs by harvesting less frequently than the typical five cuttings per year, and less frequent cuttings may lengthen stand persistence, reduce insect damage and weed invasion, and increase water use efficiency, all of which relate to farm profitability.

Procedures
Alfalfa was seeded on August 20, 2012, on a cooperating producer's field in Garden City, KS. The experimental design is a randomized complete block design with four replications. Treatments are four different cutting schedules based on different stages of maturity: (1) late bud, (2) 10% bloom, (3) 50% bloom, and (4) 100% bloom, which are equivalent to harvesting every 30 (five cuttings per year), 35 (four cuttings per year), 42 (four cuttings per year), and 48 days (three cuttings per year), respectively. Treatments harvested at the late bud stage had more frequent cutting than the 100% bloom stage, possibly five rather than four cuttings. Fresh samples were collected from one PVC quadrant per plot. Samples were weighed wet and dried in an air-forced oven at 149°F for 72 hours. Dry samples were weighed for dry matter content, then ground and analyzed for forage quality [crude protein (CP), total digestible nutrients (TDN), and relative feed value (RFV)]. The alfalfa plots were irrigated by a central pivot system

every 10 days based on evapotranspiration (ET) demand of the bulk field, and the amount of irrigation each time was 580 gal/minute. Soil moisture levels were measured every 2–3 weeks using a neutron probe to determine the soil moisture level change in the different cutting frequency treatments of alfalfa.

Results and Discussion

Based on one year of data in 2013, the highest alfalfa yield (4.27 dry tons/a) occurred with cutting four times a year at mid-bloom stage, and this treatment had significantly higher dry matter yield than other cutting treatments (Table 1). Harvesting three times a year had no different dry matter yield than treatments such as four cuttings a year at the early bloom stage and five cuttings a year. Delaying alfalfa harvest from early to mid-bloom stage increased alfalfa yield by 0.7 dry matter tons/a.

In terms of alfalfa yield by cuttings, the biggest portion of dry matter yield came from the third harvest during three- and four-cutting treatments (Table 1). Dry matter yield at the third cutting from harvesting four times at mid-bloom stage was greater than those in other cutting treatments.

On average, harvesting more frequently (such as cutting alfalfa five times a year) had higher CP contents than other cutting treatments (Table 2), and no difference in CP was found between early and mid-bloom stages in the four-cutting treatment. As shown in Table 2, TDN and RFV increased as the cutting interval decreased; in other words, more frequent cutting resulted in higher TDN and RFV. No difference was found between the two stages of maturity when harvesting alfalfa four times a year.

In summary, cutting frequency affected dry matter yield and forage quality of alfalfa in Garden City, KS, based on 2013 data. When both dry matter yield and forage quality were considered, cutting alfalfa four times a year at mid-bloom stage appear to be a better practice than cutting alfalfa three times, four times at early bloom stage, or five times a year.

Table 1. Cutting (per year) frequency effects on dry matter yield (tons/a) of alfalfa, 2013

Cutting	3	4E[1]	4M[2]	5
1	0.60	0.65	0.58	0.75
2	0.95	0.64	0.77	0.40
3	1.49	1.47	1.77	0.35
4	-	0.76	1.14	0.58
5	-	-	-	0.94
Total	3.04ab[3]	3.52b	4.27c	3.02a

[1] Early bloom stage.
[2] Mid-bloom stage.
[3] Same letters within the same row are not significantly different at $\alpha = 0.05$ level.

Table 2. Cutting (per year) frequency effects on forage quality of alfalfa, 2013

	3	4E	4M	5
CP (%)[1]	25.9b[4]	25.9b	23.9c	29.7a
TDN (%)[2]	69.0c	73.0b	71.5b	75.6a
RFV[3]	183c	221b	205b	245a

[1] Crude protein.
[2] Total digestible nutrients.
[3] Relative feed value.
[4] Same letters within the same row are not significantly different at $\alpha = 0.05$ level.

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 2013, N applied alone increased yields 57 bu/a, whereas N and P applied together increased yields up to 84 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields up to 70 bu/a. Application of 40 lb/a N (with P) was sufficient to produce about 80% of maximum yield in 2013, which was slightly less than the 10-year average. Application of potassium (K) has had no effect on sorghum yield throughout the study period.

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 Unit of the Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a N 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. All fertilizers are broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. Sorghum (Pioneer 8500/8505 from 2003–2007, Pioneer 85G46 in 2008–2011, and Pioneer 84G62 in 2012–2013) 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.

Results
Grain sorghum yields in 2013 were similar to the 10-year average yields (Table 1). Nitrogen alone increased yields 57 bu/a, whereas P alone increased yields 15 bu/a; however, N and P applied together increased yields up to 84 bu/a. Averaged across the past 10 years, N and P applied together increased yields to 70 bu/a. In 2013, 40 lb/a N (with P) produced about 78% of maximum yield, which is slightly less than the 10-year average of 85%. Sorghum yields were not affected by K fertilization, which has been the case throughout the study period.

Table 1. Effects of nitrogen, phosphorus, and potassium fertilizers on irrigated grain sorghum yields, Tribune, KS, 2004–2013

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2004	2005[1]	2006	2007	2008	2009	2010	2011	2012	2013	Mean
---------------- lb/a ----------------			---------------- bu/a ----------------										
0	0	0	57	58	84	80	66	64	51	75	78	62	68
0	40	0	73	53	102	97	60	70	51	83	90	77	77
0	40	40	74	54	95	94	65	76	55	88	93	72	77
40	0	0	60	63	102	123	92	84	66	106	115	94	92
40	40	0	112	84	133	146	111	118	77	121	140	114	117
40	40	40	117	84	130	145	105	109	73	125	132	110	114
80	0	0	73	76	111	138	114	115	73	117	132	102	106
80	40	0	103	81	132	159	128	136	86	140	163	136	128
80	40	40	123	92	142	166	126	108	84	138	161	133	129
120	0	0	66	77	101	138	106	113	70	116	130	100	103
120	40	0	106	95	136	164	131	130	88	145	172	137	132
120	40	40	115	98	139	165	136	136	90	147	175	142	136
160	0	0	86	77	123	146	105	108	74	124	149	117	112
160	40	0	120	106	145	170	138	128	92	152	178	146	139
160	40	40	113	91	128	167	133	140	88	151	174	143	134
200	0	0	100	86	134	154	120	110	78	128	147	119	119
200	40	0	115	108	143	168	137	139	84	141	171	136	135
200	40	40	123	101	143	170	135	129	87	152	175	138	137

continued

Table 1. Effects of nitrogen, phosphorus, and potassium fertilizers on irrigated grain sorghum yields, Tribune, KS, 2004–2013

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2004	2005[1]	2006	2007	2008	2009	2010	2011	2012	2013	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			0.018	0.005	0.004	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			0.121	0.803	0.578	0.992	0.745	0.324	0.892	0.278	0.826	0.644	0.999
N × P-K			0.022	0.195	0.210	0.965	0.005	0.053	0.229	0.542	0.186	0.079	0.071
Means													
Nitrogen, lb/a													
0			68	55	93	91	64	70	52	82	87	70	74
40			96	77	121	138	103	104	72	117	129	106	108
80			100	83	128	155	123	120	81	132	152	124	121
120			96	90	125	156	124	126	82	136	159	126	123
160			107	92	132	161	125	125	83	142	167	135	129
200			113	98	140	164	131	126	84	141	165	131	130
LSD (0.05)			11	10	11	9	7	11	5	8	9	8	5
P_2O_5-K_2O, lb/a													
0			74	73	109	130	101	99	68	111	125	99	100
40-0			105	88	132	151	117	120	80	130	152	124	121
40-40			111	87	130	151	117	116	79	133	152	123	121
LSD (0.05)			7	7	7	6	5	7	4	6	6	5	4

[1] 2005 yields used only blocks 3, 4, and 5.

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Corn

A. Schlegel and H.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 2013, N applied alone increased yields 69 bu/a, whereas P applied alone increased yields 21 bu/a. Nitrogen and P applied together increased yields up to 150 bu/a. This is similar to the 10-year average, where N and P fertilization increased corn yields up to 147 bu/a. Application of 120 lb/a N (with P) produced about 92% of maximum yield in 2013, which was similar to the 10-year average. Application of 80 instead of 40 lb P_2O_5/a increased average yields 3 bu/a.

Introduction
This study was initiated in 1961 to determine the 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 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, when 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 34N45 (2004 and 2005), Pioneer 34N50 (2006), Pioneer 33B54 (2007), Pioneer 34B99 (2008), DeKalb 61-69 (2009), Pioneer 1173H (2010), Pioneer 1151XR (2011), and Pioneer 0832 (2012–2013)] were planted at about 32,000 seeds/a in late April or early May. Hail damaged the 2005 and 2010 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.

Results
Corn yields in 2013 were greater than the 10-year average (Table 1). Nitrogen alone increased yields 69 bu/a, and P alone increased yields 21 bu/a; however, N and P applied together increased corn yields up to 150 bu/a. Although maximum yield was obtained with the highest N and P rate, 160 lb/a N with 80 lb/a P_2O_5 caused less than a 2% yield reduction. Corn yields in 2013 (averaged across all N rates) were 3 bu/a greater with 80 than with 40 lb/a P_2O_5, which is less than the 10-year average of 6 bu/a.

Table 1. Effects of nitrogen and phosphorus fertilization on irrigated corn, Tribune, KS, 2004–2013

N	P_2O_5	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean
------------ lb/a ------------		------------ bu/a ------------										
0	0	67	49	42	49	36	85	20	92	86	70	60
0	40	97	60	68	50	57	110	21	111	85	80	74
0	80	98	51	72	51	52	106	28	105	94	91	75
40	0	92	63	56	77	62	108	23	114	109	97	80
40	40	154	101	129	112	105	148	67	195	138	125	127
40	80	148	100	123	116	104	159	61	194	135	126	127
80	0	118	75	79	107	78	123	34	136	128	112	99
80	40	209	141	162	163	129	179	85	212	197	170	165
80	80	205	147	171	167	139	181	90	220	194	149	166
120	0	103	66	68	106	65	117	28	119	134	114	92
120	40	228	162	176	194	136	202	90	222	213	204	183
120	80	234	170	202	213	151	215	105	225	211	194	192
160	0	136	83	84	132	84	139	49	157	158	122	114
160	40	231	170	180	220	150	210	95	229	227	199	191
160	80	240	172	200	227	146	223	95	226	239	217	199
200	0	162	109	115	159	99	155	65	179	170	139	135
200	40	234	169	181	224	152	207	97	218	225	198	191
200	80	239	191	204	232	157	236	104	231	260	220	207

continued

Table 1. Effects of nitrogen and phosphorus fertilization on irrigated corn, Tribune, KS, 2004–2013

N	P_2O_5	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	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		87	53	61	50	48	100	23	103	88	80	69
40		132	88	103	102	91	138	50	167	127	116	111
80		178	121	137	146	115	161	70	189	173	143	143
120		188	133	149	171	118	178	74	189	186	171	156
160		203	142	155	193	127	191	80	204	208	179	168
200		212	156	167	205	136	199	89	209	218	186	178
LSD (0.05)		11	10	15	11	9	12	9	13	10	10	8
P_2O_5, lb/a												
0		113	74	74	105	71	121	36	133	131	109	97
40		192	134	149	160	122	176	76	198	181	163	155
80		194	139	162	168	125	187	81	200	189	166	161
LSD (0.05)		8	7	11	8	6	9	7	9	7	7	6

Weed Control in Irrigated Glyphosate-Resistant Corn with Tank Mixes of Dual, Glyphosate, Cadet, Atrazine, and Anthem

R. Currie and J. Jester

Procedures

Broadleaf and grassy weed control was evaluated in Pioneer 33D49 corn at the Southwest Research-Extension Center near Garden City, KS. Corn was planted on May 16, 2013, with preemergence herbicides sprayed within 24 hours of planting. Preemergence application conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 71°F, 54°F, 8 mph, 49%, and adequate, respectively. Soil was Ulysses silt loam, and organic matter, soil pH, and cation exchange capacity (CEC) were 1.4%, 8, and 18.4, respectively. All herbicide treatments were applied with a tractor-mounted CO_2 pressurized windshield sprayer calibrated to deliver 20 gal/a at 30 psi and 4.1 mph. Adjuvant and ammonium sulfate (AMS) were added per manufacturer's recommendation. Postherbicide application was made on June 12, 2013. Postapplication conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 86°F, 79°F, 7 mph, 42%, and dry, respectively. The trial was established as a randomized complete block design with four replications, and plots were 10 × 25 ft. Crop injury and percentage weed control were visually rated.

Results

No crop injury was observed. Species rated were *Amaranthus palmeri* S. Watson, *Digitaria spp.* L., *Helianthus annuus L.*, *Kochia scoparia* L. Schrad., *Setaria viridis* L., and *Sorghum vulgare* Pers. Only *Amaranthus palmeri, Digitaria spp.,* and *Setaria viridis* had robust populations and were thus included in the data summary table. Corn yields were depressed by hail injury as the corn was tasseling. Treatments that yielded greater than 45 bu/a were not statistically better than the best-yielding plots. All treatments elevated yield over the control. Even the treatment with the poorest level of control increased yield more than 200%.

Table 1. Weed control in irrigated glyphosate-resistant corn with tank mixes of Dual, Glyphosate, Cadet, Atrazine, and Anthem

				% control						
				47 DAP[1]			91 DAP			
TRT	Herbicide	Rate	Timing[2]	DIGSS[3]	SETVI[4]	AMPA[5]	DIGSS	SETVI	AMPA	Yield[6]
1	Untreated check			0	0	0	0	0	0	16
2	Dual II Magnum Glyphosate+AMS[7]	1.3 pt/a 22 fl oz/a	A B	99	99	75	72	72	56	37
3	Harness Xtra Glyphosate+AMS	2 22 fl oz/a	A B	92	92	98	47	81	80	50
4	Anthem Balance Flexx Cadet Glyphosate+AMS	8 fl oz/a 3 fl oz/a 0.75 fl oz/a 22 fl oz/a	A A B B	99	99	100	97	321	92	52
5	Anthem ATZ Cadet Glyphosate+AMS +COC[8]	2 pt/a 0.75 fl oz/a 22 fl oz/a	A B B	96	96	100	96	96	93	55
6	Anthem ATZ Cadet Glyphosate+AMS+COC	2.5 pt/a 0.75 fl oz/a 22 fl oz/a	A B B	99	99	100	311	98	88	49
7	Anthem ATZ Balance Flexx F9387-1 AATrex Glyphosate+AMS+COC	2 pt/a 3 fl oz/a 2.5 fl oz/a 1 pt/a 22 fl oz/a	A A B B B	100	100	100	96	96	88	68
8	Anthem F9387-1 Atrazine Glyphosate+AMS+COC	8 fl oz/a 2.5 fl oz/a 1 pt/a 22 fl oz/a	A B B B	99	98	100	311	91	100	65

continued

Table 1. Weed control in irrigated glyphosate-resistant corn with tank mixes of Dual, Glyphosate, Cadet, Atrazine, and Anthem

				% control						
				47 DAP[1]			91 DAP			
TRT	Herbicide	Rate	Timing[2]	DIGSS[3]	SETVI[4]	AMPA[5]	DIGSS	SETVI	AMPA	Yield[6]
9	Anthem ATZ	2 pt/a	A	100	97	100	91	95	98	65
	F9387-1	2.5 fl oz/a	B							
	Atrazine	1 pt/a	B							
	Glyphosate+AMS + COC	22 fl oz/a	B							
10	Anthem	8 fl oz/a	A	98	98	100	71	60	98	44
	F9387-1	2.5 fl oz/a	B							
	Atrazine	2 pt/a	B							
	Glyphosate+AMS+COC	22 fl oz/a	B							
11	Anthem ATZ	2 pt/a	A	100	100	100	94	96	65	50
	Anthem	5 fl oz/a	B							
	F9387-1	2.5 fl oz/a	B							
	Glyphosate+AMS+COC	22 fl oz/a	B							
12	Anthem ATZ	2 pt/a	A	98	98	100	94	92	99	57
	Glyphosate+AMS +COC	22 fl oz/a	B							
13	Halex GT+AMS	3.6 pt/a	B	68	68	58	3	25	25	46
	LSD @ 10%=			11	12	27	33	30	30	23

[1] Days after planting.
[2] A is preplant, B is V2–V3 corn.
[3] Crabgrass.
[4] Green foxtail.
[5] Palmer amaranth.
[6] Bu/a.
[7] Ammonium sulfate added at 8.8 lb/100 gal.
[8] Crop oil concentrate added at 1% volume per volume.

Weed Control in Irrigated Glyphosate-Resistant Corn with Tank Mixes of Corvus, Atrazine, Balance, Anthem, Zidua, Capreno, Glyphosate, Dicamba, Laudis, Prequel, Keystone, and Surestart

R. Currie and J. Jester

Procedures

Broadleaf and grassy weed control was evaluated in Pioneer PO636HR corn at the Southwest Research-Extension Center near Garden City, KS. Corn was planted on May 14, 2013, with preemergence herbicides sprayed within 24 hours of planting. Preemergence application conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 70°F, 50°F, 5 mph, 38%, and adequate, respectively. Soil was Ulysses silt loam, and organic matter, soil pH, and cation exchange capacity (CEC) were 1.4%, 8, and 18.4, respectively. All herbicide treatments were applied with a tractor-mounted CO_2 pressurized windshield sprayer calibrated to deliver 20 gal/a at 30 psi at 4.1 mph. Adjuvant and ammonium sulfate (AMS) were added per manufacturer's recommendation. The first postherbicide application was made on June 12, 2013. Postapplication conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 87°F, 79°F, 7 mph, 42%, and dry, respectively. The second postherbicide application was made on June 24, 2013, with air temperature, soil temperature, wind speed, relative humidity, and soil moisture of 84°F, 63°F, 13 mph, 40%, and adequate, respectively. Trial was established as a randomized complete block design with four replications, and plots were 10 × 25 feet. Crop injury and percentage weed control were visually rated.

Results

No crop injury was observed. Species rated were *Amaranthus palmeri* S. Watson, *Digitaria spp.* L., *Helianthus annuus L., Kochia scoparia* L. Schrad., *Setaria viridis* L., and *Sorghum vulgare* Pers. Only *Amaranthus palmeri, Digitaria spp.,* and *Setaria viridis* had robust populations and were thus included in the data summary table. Hail injury caused a marked reduction in corn yields, which made conclusive differentiation difficult; however, all treatments elevated yield compared with untreated control plots. Treatments with yields above 53 bu/a were not statistically different from the highest yielding plots.

Table 1. Weed control in irrigated glyphosate-resistant corn with tank mixes of Corvus, Atrazine, Balance, Anthem, Zidua, Capreno, Glyphosate, Dicamba, Laudia, Prequel, Keystone, and Surestart

				% Control						
				48 DAP[1]			92 DAP			
TRT	Herbicide	Rate	Timing[2]	DIGSS[3]	SETVI[4]	AMPA[5]	DIGSS	SETVI	AMPA	Yield[6]
1	Untreated check			0	0	0	0	0	0	28
2	Corvus Atrazine	5.6 oz/a 1 qt/a	A A	72	72	75	69	70	75	47
3	Corvus Atrazine Clarity	5.6 oz/a 1 qt/a 1 pt/a	A A A	99	99	100	90	65	100	61
4	Bal Flexx Harness Xtra	4 oz/a 2.4 qt/a	A A	100	100	100	94	66	100	60
5	Bal Flexx Anthem ATZ	4 oz/a 32 oz/a	A A	100	100	10	97	63	100	71
6	Bal Flexx Zidua	4 oz/a 2.5 oz/a	A A	100	100	100	96	64	94	63
7	Capreno Atrazine Glyphosate+AMS[7]	3 oz/a 1 qt/a 32 oz/a	B B B	95	95	99	60	78	66	67
8	Capreno Atrazine Glyphosate+AMS Clarity	3 oz/a 1 qt/a 32 oz/a 0.5 pt/a	B B B B	91	91	100	55	68	88	70
9	Corvus Atrazine Laudis Atrazine Glyphosate+AMS	3.3 oz/a 1 qt/a 3 oz/a 0.5 qt/a 32 oz/a	A A C C C	100	100	100	97	99	88	56

continued

Table 1. Weed control in irrigated glyphosate-resistant corn with tank mixes of Corvus, Atrazine, Balance, Anthem, Zidua, Capreno, Glyphosate, Dicamba, Laudia, Prequel, Keystone, and Surestart

				% Control						
				48 DAP[1]			92 DAP			
TRT	Herbicide	Rate	Timing[2]	DIGSS[3]	SETVI[4]	AMPA[5]	DIGSS	SETVI	AMPA	Yield[6]
	Bal Flexx	3 oz/a	A							
	Atrazine	1 qt/a	C							
10	Capreno	3 oz/a	C	100	100	100	98	98	100	59
	Atrazine	1 qt/a	C							
	Glyphosate+AMS	32 oz/a	C							
	Prequel	1.66 oz/a	B							
12	Atrazine	1 qt/a	B	23	23	100	36	30	75	63
	2,4-D Ester	1	B							
	Prequel	1.66 oz/a	A							
13	Atrazine	1 qt/a	A	100	100	84	94	98	99	67
	Abundit S	32 oz/a	B							
14	Realm	4 oz/a	C	25	25	0	18	45	75	48
	Abundit S	32 oz/a	C							
15	Keystone	2.8 oz/a	A	35	35	100	0	13	75	68
	Hornet	3 oz/a	A							
16	SureStart	2 pt/a	A	100	100	100	87	96	100	63
	Durango+AMS	1.5 pt/a	C							
17	SureStart	2 pt/a	B	80	80	100	60	67	75	63
	Durango+AMS	1.5 pt/a	C							
	LSD @ 10%=			25.47	25.47	18.85	31.51	35.53	41.11	17.73

[1] Days after planting.
[2] A is preplant, B is V2–V3 corn.
[3] Crabgrass.
[4] Green foxtail.
[5] Palmer amaranth.
[6] Bu/a.
[7] Ammonium sulfate.

Weed Control in Irrigated ALS Herbicide-Resistant Milo with Tank Mixes of Atrazine, Nicosulfuron, Huskie, and Rimsulfuron

R. Currie and J. Jester

Introduction

Broadleaf and grassy weed control was evaluated in acetolactate synthase (ALS)-resistant sorghum. Conventional sorghum can be severely injured by herbicides with an ALS mode of action such as nicosulfuron and rimsulfuron. These herbicides are usually lethal to sorghum at the rates used in this study.

Procedures

The research was done the Southwest Research-Extension Center located near Garden City, Kansas. Sorghum was planted on July 2, 2013. Soil was Ulysses silt loam, and organic matter, soil pH, and cation exchange capacity (CEC) were 1.4%, 8, and 18.4, respectively. All herbicide treatments were applied with a tractor-mounted CO_2 pressurized windshield sprayer calibrated to deliver 20 gal/a at 30 psi and 4.1 mph. Adjuvant and ammonium sulfate (AMS) were added per manufacturer's recommendation. Postherbicide application was made on July 2, 2013. Postapplication conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 76°F, 58°F, 5 mph, 28%, and adequate, respectively. Trial was established as a randomized complete block design with four replications, and plots were 10 × 30 feet. Crop injury and percentage weed control were visually rated.

Results

No crop injury was observed. Species rated were *Amaranthus palmeri* S. Watson*, Digitaria spp.* L.*, Helianthus annuus L., Kochia scoparia* L. Schrad.*, Setaria viridis* L.*,* and *Sorghum vulgare* Pers. Only *Amaranthus palmeri, Digitaria spp.,* and *Setaria viridis* had robust populations and were thus included in the data summary table. Tank mixes of rimsulfuron and nicosulfuron provided adequate control 7 days after application. These products alone could not maintain an adequate level of control 45 days after application. The addition of Huskie and atrazine to these herbicides produced excellent levels of control for more than 45 days after application.

Table 1. Weed control in irrigated ALS herbicide-resistant milo with postemergence tank mixes of Atrazine, Nicosulfuron, Huskie, and Rimsulfuron

				% Control				
				7 DAP[1]		45 DAP		
TRT	Herbicide	Rate		SETVI[2]	AMPA[3]	DIGSS[4]	SETVI	AMPA
1	Untreated check			0	0	0	0	0
2	Nicosulfuron (dry) Crop oil concentrate	0.5 1	oz ai/a % v/v	99	68	99	99	18
3	Nicosulfuron (dry) Crop oil concentrate	0.75 1	oz a.i./a % v/v	97	58	95	95	0
4	Nicosulfuron (dry) Rimsulfuron Crop oil concentrate	0.375 0.1875 1	oz a.i./a oz a.i./a % v/v	97	97	97	96	3
5	Nicosulfuron (dry) Rimsulfuron Crop oil concentrate	0.5 0.25 1	oz a.i./a oz a.i./a % V/V	97	83	94	94	15
6	Nicosulfuron (dry) Rimsulfuron Huskie Atrazine Crop oil concentrate	0.375 0.1875 13 8 1	oz a.i./a oz a.i./a oz/a oz/a % V/V	100	100	88	87	95
7	Nicosulfuron (dry) Rimsulfuron Huskie Atrazine Crop oil concentrate	0.5 0.25 13 8 1	oz a.i./a oz a.i./a oz/a oz/a % V/V	100	95	100	100	95
8	Nicosulfuron (liquid) Crop oil concentrate	0.5 1	oz a.i./a % v/v	99	97	80	80	20
9	Nicosulfuron (liquid) Crop oil concentrate	0.75 1	oz a.i./a % V/V	97	73	72	72	20

continued

Table 1. Weed control in irrigated ALS herbicide-resistant milo with postemergence tank mixes of Atrazine, Nicosulfuron, Huskie, and Rimsulfuron

			% Control				
			7 DAP[1]		45 DAP		
TRT	Herbicide	Rate	SETVI[2]	AMPA[3]	DIGSS[4]	SETVI	AMPA
10	Nicosulfuron (liquid) Huskie Atrazine Crop oil concentrate	0.5 oz a.i./a 13 oz/a 8 oz/a 1 % V/V	100	100	96	96	97
11	Nicosulfuron (liquid) Huskie Atrazine 90DF Crop oil concentrate	0.75 oz a.i./a 13 oz/a 8 oz/a 1 % V/V	97	88	97	97	75
12	Nicosulfuron (liquid)	0.5 oz a.i./a	99	78	90	90	0
13	Nicosulfuron (liquid)	0.75 oz a.i./a	97	50	95	95	20
	LSD @ 10%=		4	4	21	21	34

[1] Days after planting.
[2] Green foxtail.
[3] Palmer amaranth.
[4] Crabgrass.

Weed Control in Irrigated Glyphosate-Resistant Corn with Tank Mixes of Atrazine, Verdict, Roundup, Status, Armezon, Sharpen, and Zidua

R. Currie and J. Jester

Procedures

Broadleaf and grassy weed control was evaluated in Pioneer PO636HR corn at the Southwest Research-Extension Center located near Garden City, KS. Corn was planted on May 8, 2013, with preemergence herbicides sprayed within 24 hours of planting. Preemergence application conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 76°F, 52°F, 7 mph, 40%, and adequate, respectively. Soil was Ulysses silt loam, and organic matter, soil pH, and cation exchange capacity (CEC) were 1.4%, 8, and 18.4, respectively. All herbicide treatments were applied with a tractor-mounted CO_2 pressurized windshield sprayer calibrated to deliver 20 gal/a at 30 psi and 4.1 mph. Adjuvant and ammonium sulfate (AMS) were added per manufacturer's recommendation. The first postherbicide application was made on June 12, 2013. Postapplication conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 86°F, 79°F, 7 mph, 40%, and dry. The second postherbicide application was made on June 24, 2013. Postapplication conditions of air temperature, soil temperature, wind speed, relative humidity, and soil moisture were 84°F, 63°F, 13 mph, 40%, and adequate. The trial was established as a randomized complete block design with four replications, and plots were 10 × 25 feet. Crop injury and percentage weed control were visually rated.

Results

No crop injury was observed. Species rated were *Amaranthus palmeri* S. Watson, *Digitaria spp.* L., *Helianthus annuus L.*, *Kochia scoparia* L. Schrad., *Setaria viridis* L., and *Sorghum vulgare* Pers. Only *Amaranthus palmeri, Digitaria spp.,* and *Setaria viridis* had robust populations and were thus included in the data summary table. Preemergence herbicide applications with residual weed control reduced population early in the season, which allowed for better spray coverage of later postemergence herbicide treatments. This style of application produced the best and most consistent weed control. Effects of weed control on crop yield were masked by hail injury sustained by the corn in the late reproductive stage.

Table 1. Weed control in irrigated glyphosate-resistant corn with tank mixes of Atrazine, Verdict, Glyphosate, Status, Armezon, Zidua, and Sharpen

				% Control						
				49 DAP[1]			99 DAP			
TRT	Herbicide	Rate	Timing[2]	DIGSS[3]	SETVI[4]	AMPA[5]	DIGSS	SETVI	AMPA	Yield[6]
	Verdict	15 fl oz/a	A							
	Glyphosate	22 fl oz/a	C							
1	Status	5 oz wt/a	C	93	93	98	85	89	95	49
	Methylated seed oil	1 % v/v	C							
	Ammonium sulfate	17 lb/100 gal	C							
	Verdict	15 fl oz/a	A							
	Glyphosate	22 fl oz/a	C							
	Armezon	0.75 fl oz/a	C							
2	Atrazine	16 fl oz/a	C	64	64	100	88	90	98	57
	Methylated seed oil	1 % v/v	C							
	Ammonium sulfate	17 lb/100 gal	C							
	Zidua	2.5 oz wt/a	A							
	Sharpen	2.5 fl oz/a	A							
	Glyphosate	22 fl oz/a	C							
3	Armezon	0.75 fl oz/a	C	71	71	100	97	97	100	56
	Atrazine	16 fl oz/a	C							
	Methylated seed oil	1 % v/v	C							
	Ammonium sulfate	17 lb/100 gal	C							

continued

Table 1. Weed control in irrigated glyphosate-resistant corn with tank mixes of Atrazine, Verdict, Glyphosate, Status, Armezon, Zidua, and Sharpen

				% Control						
				49 DAP[1]			99 DAP			
TRT	Herbicide	Rate	Timing[2]	DIGSS[3]	SETVI[4]	AMPA[5]	DIGSS	SETVI	AMPA	Yield[6]
4	Glyphosate	22 fl oz/a	B	0	0	75	13	3	98	48
	Outlook	18 fl oz/a	B							
	Armezon	0.75 fl oz/a	B							
	Atrazine	16 fl oz/a	B							
	Methylated seed oil	1 % v/v	B							
	Ammonium sulfate	17 lb/100 gal	B							
5	Glyphosate	22 fl oz/a	B	0	0	50	5	19	75	49
	Zidua	2.5 oz wt/a	B							
	Atrazine	16 fl oz/a	B							
	Methylated seed oil	1 % v/v	B							
	Ammonium sulfate	17 lb/100 gal	B							
6	Untreated check			0	0	0	0	0	0	39
	LSD			35	35	44	15	23	48	21

[1] Days after planting.
[2] A is preplant, B is early postemergence, C is V6–V8 corn.
[3] Crabgrass.
[4] Green foxtail.
[5] Palmer amaranth.
[6] Bu/a.

Weed Control of Preemergence Verdict Herbicide with Three Postemergence Timings and Two Rates of Prowl in Irrigated Grain Sorghum

R. Currie and J. Jester

Introduction

Postemergence broadcast applications of Prowl herbicide in grain sorghum are currently not labeled for use on sorghum smaller than 4 in. on the High Plains. Work to expand the label was reported in 2010[1]. This work strongly suggested that Prowl applied at the spike stage greatly enhanced grass control of other herbicide tank mixes and increased grain yield. To expand on this work, 2013 studies were conducted at Garden City and Tribune, KS, to evaluate weed control and crop tolerance to 1X and 2X rates of Prowl applied at three postemergence timings.

Procedures

All treatments included preemergence applications of Verdict herbicide atrazine at 0.625 + 2 pt/a followed by postemergence applications of 2 or 4 pt/a Prowl pendimethalin applied to spike, 2- to 3-leaf, or 12-in. sorghum. This experiment was conducted near Garden City, with populations of crabgrass, green foxtail, and Palmer amaranth. It was repeated near Tribune under weed-free conditions. Experimental design was a randomized complete block with four replications. Within 6 days of any herbicide application, 1 in. of overhead irrigation was applied to ensure herbicide incorporation.

Results

Postemergence applications of Prowl to spike and 2- to 3-leaf sorghum proceeded by preemergence Verdict provided threefold better green foxtail and crabgrass control than the 12-in. timing, regardless of Prowl rate (Table 1). All treatments produced significant levels of Palmer amaranth control compared with the untreated control. Although herbicide treatments were not statistically different, Palmer amaranth control with treatments of Verdict followed by the highest rates of Prowl applied at spike and 2- to 3-leaf sorghum produced the highest levels of Palmer amaranth control. No visual aboveground sorghum injury was observed at any location. At Tribune, root ratings taken 8 weeks after the last postemergence treatment showed no injury from labeled rates of Prowl (Table 2). At twice the labeled rates of Prowl, the lowest level of root injury was seen with spike applications. The other application timings produced more than twofold higher levels of root injury. At Tribune, the highest Prowl rate resulted in significantly greater root injury ($P = 0.05$) when applied at 2- to 3-leaf and 12-in. sorghum, but not at spike. These root ratings did not translate into yield reductions. No statistical reductions in yield were detected at the 5% significance level; however, despite the lower levels of root ratings at the 10% significance level, the spike applications of Prowl at twice the labeled rate reduced sorghum yield 15%. Root ratings clearly

[1] Proceedings of North Central Weed Science Society, 65:120, 2010.

were not a good index of yield loss. Although possible injury from Prowl is confounded with weed control at the Garden City location, the highest yield was produced with the highest rate of Prowl applied at the 2- to 3-leaf stage. Furthermore, the lowest-yielding treatments were measured with the latest application of Prowl regardless of rate. These treatments also had the poorest level of weed control. Although no visual injury was noted in these trials, in the previous study reported in 2010, the greatest level of injury was observed with this latest Prowl application. As was concluded in work done in 2010, these data also indicate that Prowl labels should be expanded to include earlier postemergence applications.

Table 1. Weed control and percentage yield reduction at Garden City, KS

				% Control			
				64 DAP[1]			
TRT	Herbicide	Rate (pt/a)	Timing[2]	DIGSS[3]	SETVI[4]	AMPA[5]	Yield[6]
1	G-Max Lite	3	A	94	95	75	96
	Sharpen	0.3	A				
2	Verdict	0.625	A	96	97	73	68
	Atrazine	2	A				
	Prowl H_2O	2	B				
3	Verdict	0.625	A	93	92	85	97
	Atrazine	2	A				
	Prowl H_2O	2	C				
4	Verdict	10	A	16	28	72	54
	Atrazine	2	A				
	Prowl H_2O	2	D				
5	Verdict	0.625	A	94	98	98	102
	Atrazine	2	A				
	Prowl H_2O	4	B				
6	Verdict	10	A	97	99	98	121
	Atrazine	2	A				
	Prowl H_2O	4	C				
7	Verdict	0.625	A	17	32	80	52
	Atrazine	2	A				
	Prowl H_2O	4	D				
8	Untreated check			0	0	0	100
	LSD @ 10%=			19	30	32	

[1] Days after planting.
[2] A is preemergence, B is spike stage, C is 2- to 3-leaf, D is 12-in. sorghum.
[3] Crabgrass.
[4] Green foxtail.
[5] Palmer amaranth.
[6] Percentage yield reduction compared with control plots.

Table 2. Sorghum root rating injury and yield under weed-free conditions

TRT	Herbicide	Rate (pt/a)	Timing[1]	Root injury rating	Yield[2]
1	G-Max Lite	3	A	0	130
	Sharpen	0.3	A		
2	Verdict	0.625	A	0.3	127
	Atrazine	2	A		
	Prowl H_2O	2	B		
3	Verdict	0.625	A	0	130
	Atrazine	2	A		
	Prowl H_2O	2	C		
4	Verdict	10	A	0.5	130
	Atrazine	2	A		
	Prowl H_2O	2	D		
5	Verdict	0.625	A	1.8	111
	Atrazine	2	A		
	Prowl H_2O	4	B		
6	Verdict	10	A	4.5	129
	Atrazine	2	A		
	Prowl H_2O	4	C		
7	Verdict	0.625	A	3.5	128
	Atrazine	2	A		
	Prowl H_2O	4	D		
8	Untreated check			0	121
	LSD @ 10%=			1.01	10.9

[1] A is preemergence, B is spike stage, C is 2- to 3-leaf, D is 12-in. sorghum.
[2] Bu/a.

Advances in Sensing Crop Water Stress for Irrigation Management

I. Kisekka and J. Aguilar

Introduction

Producers have long recognized that factors affecting crop growth vary over time and space, but monitoring of these factors has proven challenging. With recent advances in sensor technology and wireless communication, integrating wireless sensor networks (WSN) into crop production operations can add value by acquiring the high-resolution temporal and spatial data needed for optimum management. These data could then be coupled with decision support tools to guide producers in using limited agricultural inputs such as water in the most economical and environmentally sustainable manner. The added value of adopting sensor technologies can be realized in the form of higher yields, improved quality of yields, decreased input costs, and reduction in production risks and labor costs (Thessler et al., 2011). Different types of sensors are used in crop production, such as soil water sensors, soil bulk electro conductivity sensors, micrometeorological sensors, multi-spectral sensors for monitoring vegetation cover, thermal infrared radiometers, and cameras for monitoring plant water stress. Here we focus on remote sensing of crop water stress using thermal infrared radiometers and thermal imaging cameras for guiding irrigation scheduling in row crop production.

Remote sensing of crop water stress involves acquiring information about the water status of the plant (canopy temperature) without making physical contact with it. The thermal infrared band (3–12 µm) of the electromagnetic spectrum provides the most useful information for detecting crop water stress. Canopy temperature measured by an infrared radiometer or contained in a thermal infrared image depends on the thermodynamic properties of the plant canopy, emissivity, and surrounding environmental conditions. Plant canopy temperature, a component of the soil-plant-atmosphere system, has long been shown as a useful variable for monitoring plant water status and for improving irrigation scheduling because it is related to the water status of the plant and soil (Idso et al., 1981; Jackson, 1982). As plants transpire, the evaporation of water from liquid to vapor via the stomata consumes heat energy; in addition, movement of water vapor away from the leaves also removes energy, which causes the plant canopy to cool. On the other hand, soil water depletion causes the rate of evapotranspiration to be reduced, leading to a reduction in heat removal and an increase in canopy temperature (Colaizzi et al., 2012).

Earlier work on remote sensing of plant water status was based on handheld thermometers that provided only a single average value of canopy temperature over a target. With recent advances in infrared radiometer sensors (e.g., Apogee Instruments, Inc., Logan, UT, and Exergen Corp., Watertown, MA) and miniaturization of thermal infrared cameras (e.g., FLIR Systems Inc., Boston, MA, and Thermoteknix Systems Ltd., Cambridge, UK), however, canopy temperature data can be monitored with high temporal-spatial resolution (Figure 1). In addition, advances in communication technology have been significant, especially the advent of wireless networks. Until recently, field monitoring of canopy temperature depended on offline sensors using data loggers

for manual download, but today many canopy temperature sensors can be configured to be online, with near real-time data transfer to the cloud, or directly connected to the irrigation system control panel to automate irrigation applications as shown in Figure 2 (O'Shaughnessy et al., 2013).

It is worth noting that because canopy temperature depends on meteorological conditions at the time of measurement, canopy temperature measurements alone are not an absolute indicator of water stress. Therefore, crop water stress indices that account for environmental conditions have been developed to allow for operational irrigation scheduling decision-making based on canopy temperature measurements.

Crop Water Stress Indices

The most common index used to provide guidance on irrigation management based on canopy temperature and environmental factors such as air temperature and vapor pressure deficit is the crop water stress index (CWSI). The CWSI, introduced by Idso et al. (1981) and Jackson (1982), is derived from an energy balance at the leaf surface and is expressed as equation (1):

$$(1) \qquad CWSI = \frac{(T_c - T_A)_M - (T_c - T_A)_{LL}}{(T_c - T_A)_{UL} - (T_c - T_A)_{LL}}$$

where T_c and T_A denote canopy and air temperature (°C), respectively, whereas the subscripts *M, UL,* and *LL* denote the measured canopy-air temperature difference, upper limit canopy-air temperature difference (non-transpiring plant), and lower limit canopy-air temperature difference (well watered transpiring plant) under a given set of meteorological conditions. Normalizing the CWSI with the upper and lower limits allows it to be scaled between zero, which indicates no water stress, and one, which indicates complete water stress. The canopy-air temperature difference for the well-watered transpiring plant and for the non-transpiring plant can be obtained analytically or empirically through field experiments. For limited irrigation management, a threshold CWSI needs to be determined for triggering irrigation to ensure acceptable economical yields.

Time Temperature Threshold (TTT)

Another approach to managing irrigation based on canopy temperature is to use the time temperature threshold. The TTT algorithm is developed from observations that plant enzymes are most productive under a very narrow range of temperatures called the thermal kinetic window (Burke, 1993). In the TTT approach, the accumulated time that canopy temperature exceeds the threshold temperature is used as criteria for irrigation. For example, the threshold temperature for corn in the south High Plains was determined by Evett (2006) as 28°C and threshold time is 240 minutes, implying that if corn canopy temperature exceeded 28°C for more than 4 hours, irrigation would be triggered. The TTT method is advantageous over the CWSI approach because it does not require measurements of canopy temperature at the lower and upper limits. Colaizzi et al. (2012) noted that the TTT algorithm appeared to be more responsive to a wide range of meteorological conditions because it is a time-integrating method rather than an algorithm based on measurements made at only one time of day.

Case Studies

Several studies have been conducted to evaluate the robustness of using canopy temperature for irrigation scheduling; a few examples are in Table 1, and they indicate that canopy temperature monitoring is an effective technique for scheduling irrigation. In the three studies in Table 1, grain yield and water applied by the scientific irrigation scheduling based on soil water monitoring with a neutron probe were not significantly different from irrigation scheduling treatments triggered by canopy temperature. Starting this summer (2014), a study will be initiated at the Southwest Research-Extension Center in Garden City, KS, to evaluate sensor-based irrigation scheduling methods in corn. The treatments will include irrigation scheduling based on canopy temperature, soil water sensors, evapotranspiration, and a combination of these methods. The goal will be to quantify differences in yield, and crop water productivity from the different irrigation scheduling methods.

Conclusion

Monitoring plant water status using canopy temperature provides a powerful tool to enhance irrigation scheduling, but this irrigation scheduling technology needs to be adapted to local irrigated crop production systems of the Central Plains to increase its acceptance by producers. Southwest Research-Extension Center scientists are working on ways to integrate canopy temperature, soil water sensing, and climatic data to develop robust irrigation scheduling tools for producers.

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Table 1. Comparison of grain yield and water applied by canopy temperature irrigation scheduling and soil water monitoring with a neutron probe

Irrigation scheduling method	Grain yield (bu/a)	Water applied (mm)	Crop	Reference	Location
Crop water stress indices (CWSI)	190	292	Corn	Steele et al. (1994)	North Dakota
Neutron probe	176	248			
Time temperature threshold (TTT)	170	585	Corn	Evett et al. (1996)	Texas
Neutron probe	164	589			
CWSI	92	332	Grain sorghum	O'Shaughnessy et al. (2012)	Texas
Neutron probe	89	324			

Figure 1. Ground-based remote sensing of canopy temperature using a thermal camera on a tractor crane (A), and ground-based remote sensing of corn canopy temperature using thermal infrared radiometers (B) at USDA ARS, Fort Collins, CO.

Figure 2. Canopy temperature sensors installed on a center pivot to automate irrigation scheduling of grain sorghum at USDA ARS, Bushland, TX (O'Shaughnessy et al., 2013).

The Influence of Irrigation Amount and Frequency on Alfalfa Forage Quality

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Summary

With the irrigation management used in this study in Southwest Kansas, irrigation affected alfalfa forage quality parameters such as crude protein (CP), neutral detergent fiber (NDF), total digestible nutrients (TDN), and relative feed value (RFV). In general, applying the highest amount of irrigation (i.e., 24 in. during the growing season) appears to lower forage quality in alfalfa compared with other irrigation treatments. No forage quality difference in alfalfa was found in timing under the same amount of irrigation (i.e., applying irrigation after greenup and between all cuttings vs. none between cuttings two and three). Total irrigation amounts of 8 in. or less during the growing season maximized forage quality of alfalfa in Southwest Kansas. One must, however, consider both yield and forage quality of alfalfa when making an irrigation management decision. Results from this study suggests forage quality can be improved using lower amounts of irrigation, but reducing irrigation will also result in lower alfalfa yields.

Introduction

Alfalfa (*Medicago sativa* L.) is an important forage crop in the Great Plains as well as many other parts of the world for dairy and beef cattle industries. Interest in irrigated alfalfa production is growing because of the increasing number of dairies in the semi-arid central Great Plains of the U.S.; however, water supplies are dwindling, particularly in the Ogallala Aquifer region, and irrigating many fields is becoming a challenge. Information on forage quality change in alfalfa under different irrigation levels is limited. Therefore, the objective of this field study was to evaluate the effects of different timings of irrigation using various irrigation rates on forage quality (i.e., crude protein [CP], acid detergent fiber [ADF], neutral detergent fiber [NDF], total digestible nutrients [TDN], and relative feed value [RFV]) of a long-term field study of alfalfa in Southwest Kansas.

Procedures

This research was conducted at the Kansas State University Southwest Research-Extension Center near Garden City, KS. The soil type was a deep, well drained Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustolls) with pH of 8.1–8.3. The protocol for irrigation timing and amount was intended to provide yield responses from irrigation and development of regressions of dry matter yield with respect to irrigation and crop evapotranspiration (ETc), within the context of best management practices for alfalfa production (Table 1). The alfalfa was seeded on August 17, 2006. Harvest dates were determined when alfalfa in the majority of treatments reached 10% bloom and when more than 50% of crown buds had regrowth of 0.5 in. Forage quality as measured by CP, NDF, TDN, and RFV was determined on herbage sampled on harvest dates in 2007–2011. Data from each irrigation treatment for each year were subjected to

an analysis of variance where treatment means were separated using Fisher's protected LSD at the 5% level (SAS Institute Inc., Cary, NC, 2006).

Results and Discussion

Crude Protein

As shown in Table 2, CP concentration in alfalfa ranged from 19.5 to 26.5% under six water treatments in 2008–2011. Overall, CP concentration was the highest in 2008 and lowest in 2010. When averaged across irrigation treatments, CP in alfalfa decreased from 2008 to 2010, then increased in 2011. Irrigation treatment 6 had higher CP concentration than other irrigation treatments in 2008. Irrigation had an effect similar to drought in that CP tended to decrease as irrigation level increased. This finding differed, however, in 2011, when the CP content in treatment 6 was likely less because weeds were more prevalent toward the end of the study, particularly in the low water treatments. Comparing irrigation between all cuttings or none between cuttings two and three showed no significant difference in CP concentration between the 8- and 15-in. irrigation treatments except in 2011.

NDF

The NDF contents of alfalfa in 2011 were lower than other years in each water treatment except for treatment 6 (Table 3). Treatment 1 in 2008, 2009, and 2010 had significantly higher NDF contents than other water treatments. Comparing the same water amount at different timings, such as treatments 2 and 3 and 4 and 5, shows that timing did not affect NDF contents in 2008 and 2009, respectively. Irrigation timing did affect NDF in 8-in. and 15-in. irrigation treatments in 2010, however, and in the 8-in. irrigation treatment in 2011. This result indicates that irrigating alfalfa after greenup and between all cuttings tended to lower NDF contents compared with not irrigating in midsummer in 2010 and 2011.

TDN

The TDN values of alfalfa in 2011 were significantly higher than in other years (Table 4). 2011 had much lower precipitation than other years. Total digestible nutrients tended to be lowest in 2009, a wet year. The lower precipitation might have resulted in higher TDN by increasing the leaf to stem ratio. Overall, TDN values from the highest amount of irrigation were lower than other irrigation treatments, and this result is consistent with NDF results.

RFV

2011 had the highest RFV (193) and the lowest precipitation (Table 5) compared with other years. This result indicates that RFV might be better during a dry year than during a wet year. The exception was treatment 6 (rainfed), which had the highest RFV in 2008 and was always under drought stress. This trend also seems to be related to irrigation treatments; the highest amount of irrigation had the lowest RFV when averaged across years.

Total irrigation amounts of 8 in. or less during the growing season appear to have maximized forage quality of alfalfa in southwest Kansas. One must, however, consider both yield and forage quality of alfalfa when making an irrigation management decision. Results from this study suggests forage quality can be improved using lower amounts of irrigation, but reducing irrigation will also result in lower alfalfa yields.

Table 1. Protocol for total irrigation during growing season

Irrigation treatment	Total irrigation (in.)	Timing
1	24	After greenup and between all cuttings
2	15	After greenup and between all cuttings
3	15	None between cuttings 2 and 3
4	8	None between cuttings 2 and 3
5	8	After greenup and between all cuttings
6	0	None

Table 2. Crude protein contents (%) affected by irrigation treatments, 2008–2011

Irrigation treatments	2008	2009	2010	2011
1	22.4 Ae[1,2]	21.7 ABc	19.9 Cc	20.7 BCc
2	23.3 ABde	22.7 Babc	20.9 Cbc	24.3 Aa
3	23.8 Acd	22.1 Cbc	20.6 Dbc	22.3 BCb
4	24.9 Abc	23.7 Ba	21.2 Cab	22.1 Cb
5	24.8 Abc	23.0 BCab	22.1 Ca	24.2 ABa
6	26.5 Aa	23.1 Bab	21.2 Cab	19.5 Dd

[1] Different uppercase letters: significantly different at $\alpha = 0.05$ level within same irrigation treatment.
[2] Different lowercase letters: significantly different at $\alpha = 0.05$ level within same year.

Table 3. Neutral detergent fiber contents (%) affected by irrigation treatments, 2008–2011

Irrigation treatments	2008	2009	2010	2011
1	42.5 Aa[1,2]	44.0 Aa	43.9 Aa	38.3 Ba
2	38.9 Ab	40.3 Abc	38.5 Ac	31.8 Bc
3	39.2 Ab	40.7 Ab	41.2 Ab	32.4 Bbc
4	36.2 ABc	37.3 Ac	38.0 Acd	34.5 Bb
5	36.3 ABc	38.4 Abc	35.8 Bd	31.5 Cc
6	31.9 Bd	37.5 Ac	38.8 Ac	39.9 Aa

[1] Different uppercase letters: significantly different at $\alpha = 0.05$ level within same irrigation treatment.
[2] Different lowercase letters: significantly different at $\alpha = 0.05$ level within same year.

Table 4. Total digestible nutrients (%) affected by irrigation treatments, 2008–2011

Irrigation treatments	2008	2009	2010	2011
1	64.6 Bd[1,2]	62.9 Bc	63.1 Bc	69.1 Ac
2	67.5 Bc	66.3 Bb	68.7 Bb	74.8 Ab
3	68.0 Bc	66.2 Bb	67.5 Bb	74.0 Ab
4	70.3 Bb	69.4 Ba	71.0 Ba	73.5 Ab
5	70.6 Bb	68.1 Cab	72.0 Ba	76.2 Aa
6	74.3 Aa	69.6 Ba	70.7 Ba	74.6 Aab

1 Different uppercase letters: significantly different at $\alpha = 0.05$ level within same irrigation treatment.
2 Different lowercase letters: significantly different at $\alpha = 0.05$ level within same year.

Table 5. Relative feed value affected by irrigation treatments, 2008–2011

Irrigation treatments	2008	2009	2010	2011
1	143 Bd[1,2]	134 Bc	135 Bd	166 Ac
2	163 Bc	155 Bab	167 Bb	212 Aa
3	163 Bc	152 Bb	152 Bc	205 Aab
4	180 ABb	174 Ba	170 Bb	193 Ab
5	181 Bb	167 Ca	188 Ba	215 Aa
6	209 Aa	169 Ba	165 Bbc	168 Bc

1 Different uppercase letters: significantly different at $\alpha = 0.05$ level within same irrigation treatment.
2 Different lowercase letters: significantly different at $\alpha = 0.05$ level within same year.

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