Kansas Agricultural Experiment Station Research Reports

Volume 4
Issue 8 *Southwest Research-Extension Center Reports* Article 5

2018

Integrated Grain and Forage Rotations

J. D. Holman
Kansas State University, jholman@ksu.edu

A. Obour
Kansas State University, aobour@ksu.edu

T. Roberts
Kansas State University, troberts@ksu.edu

See next page for additional authors

Follow this and additional works at: https://newprairiepress.org/kaesrr

Part of the Agronomy and Crop Sciences Commons

Recommended Citation

Holman, J. D.; Obour, A.; Roberts, T.; and Maxwell, S. (2018) "Integrated Grain and Forage Rotations," *Kansas Agricultural Experiment Station Research Reports*: Vol. 4: Iss. 8. https://doi.org/10.4148/2378-5977.7625

This report is brought to you for free and open access by New Prairie Press. It has been accepted for inclusion in Kansas Agricultural Experiment Station Research Reports by an authorized administrator of New Prairie Press. Copyright 2018 Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Contents of this publication may be freely reproduced for educational purposes. All other rights reserved. Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. K-State Research and Extension is an equal opportunity provider and employer.

Integrated Grain and Forage Rotations

Abstract

Interest in growing forages and reducing fallow has necessitated research on soil, water, and crop yields in intensified grain/forage rotations. Fallow stores moisture, which helps stabilize crop yields and reduces the risk of crop failure; however, only 25 to 30% of the precipitation received during the fallow period of a no-till wheat-sorghum-fallow rotation is stored. . The remaining 75 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 crop yields by using forage crops in the rotation. This study evaluated integrated grain/forage rotations compared to traditional grain-only crop rotations.

Keywords

grain, forage, crop rotations, soil water

Creative Commons License

This work is licensed under a Creative Commons Attribution 4.0 License.

Authors

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

This cropping and tillage systems is available in Kansas Agricultural Experiment Station Research Reports: https://newprairiepress.org/kaesrr/vol4/iss8/5

Integrated Grain and Forage Rotations

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

Summary

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

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

Introduction

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

Experimental Procedures

A study beginning in 2013 evaluated various integrated grain and forage rotations compared to a no-till wheat-grain sorghum-fallow rotation. All phases of the rotation were present every year and in-phase by 2014. A total of 11 crop rotations were evaluated. Beginning in 2013, the wheat/forage sorghum-grain sorghum-oat rotation was replaced with a wheat/forage sorghum-grain sorghum-fallow rotation since the no-fallow rotation tended to be too intensively cropped during dry years. The study design was a split-plot randomized complete block design with four replications; crop phase (wheat-sorghum-fallow) was the main plot and alternative crop choices were the split-plot. Each split-plot was 30-ft wide and 120-ft long.

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

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

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

Results and Discussion

Winter Wheat

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

Grain Sorghum

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

Forage Sorghum

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

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

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

Spring Oat

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

Conclusions

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

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

Table 1. Grain and forage crop rotation treatments

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

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

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

continued

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

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

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

‡ $P \le 0.05$

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

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

\# Data not available.

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

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

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

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

continued

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

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

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

‡ $P \leq 0.05$

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

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

Data not available.

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

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

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

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

continued

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

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

continued

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

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

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

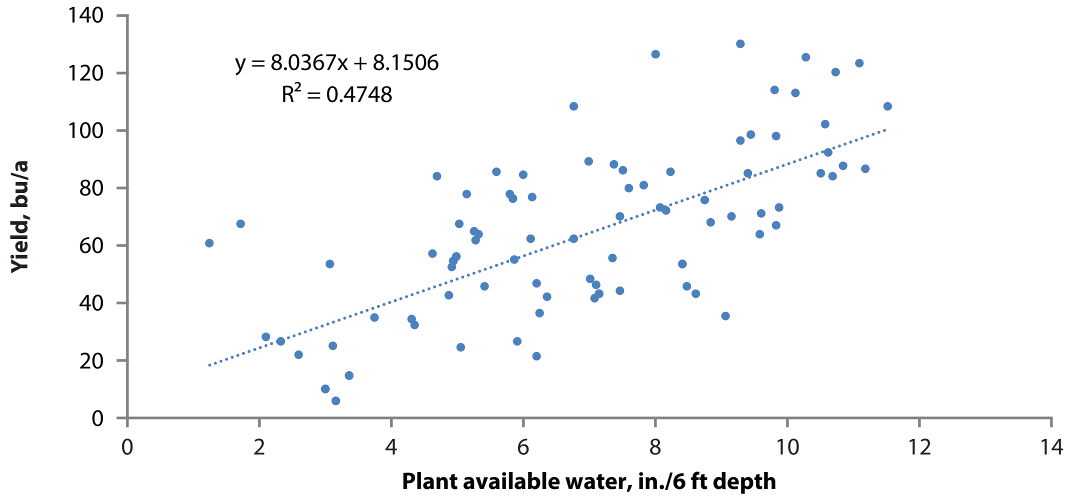

Figure 1. Grain sorghum yield response to plant available water at planting near Garden City, KS, between 2014 and 2017.

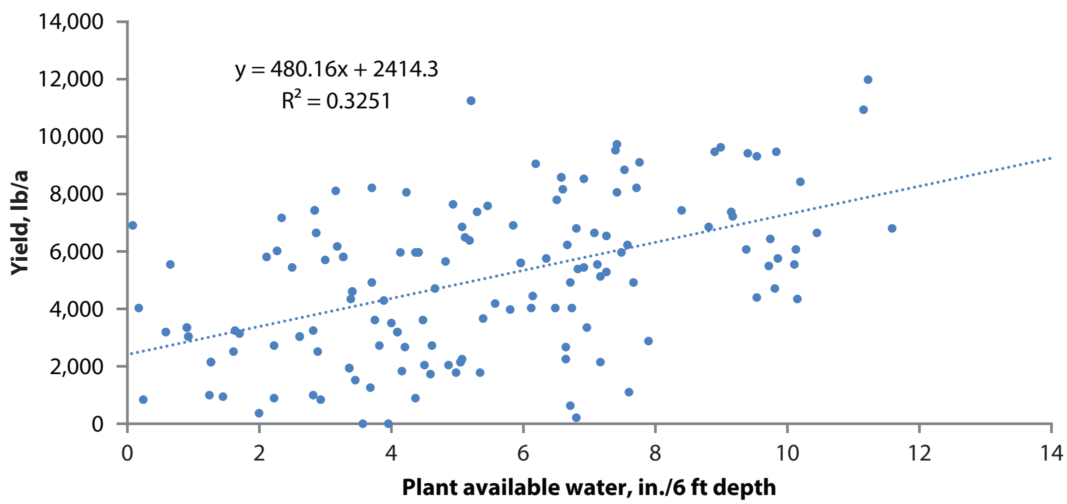

Figure 2. Forage sorghum yield response to plant available water at planting near Garden City, KS, between 2014 and 2017.