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Determining Profitable Annual Forage Rotations

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Determining Profitable Annual Forage Rotations

Abstract

Producers are interested in growing annual forages, yet western Kansas lacks proven recommended crop rotations such as those for grain crops. Forage production 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 and may allow for increased cropping intensity and opportunistic cropping. A study was initiated in 2012 at the Southwest Research-Extension Center in Garden City, KS, comparing several 1-, 3-, and 4-year forage rotations with no-tillage and minimum-tillage (min-tillage). Data presented are from 2013 through 2016. Winter triticale yields were increased by tillage. Double-crop forage sorghum yielded 19% less than full-season forage sorghum across years. Oats failed to make a crop in 2013 and do not appear to be as drought tolerant as forage sorghum. Subsequent years will be used to compare forage rotations and profitability.

Keywords

forages, triticale, oat, forage sorghum, profit, soil water

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Summary

Producers are interested in growing annual forages, yet western Kansas lacks proven recommended crop rotations such as those for grain crops. Forage production 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 and may allow for increased cropping intensity and opportunistic cropping. A study was initiated in 2012 at the Southwest Research-Extension Center in Garden City, KS, comparing several 1-, 3-, and 4-year forage rotations with no-tillage and minimum-tillage (min-tillage). Data presented are from 2013 through 2016. Winter triticale yields were increased by tillage. Double-crop forage sorghum yielded 19% less than full-season forage sorghum across years. Oats failed to make a crop in 2013 and do not appear to be as drought tolerant as forage sorghum. Subsequent years will be used to compare forage rotations and profitability.

Introduction

To stabilize crop yields, dryland rotations in the southwest Kansas region have typically included fallow to accumulate moisture in the soil profile. Fallow is relatively inefficient at storing and utilizing precipitation when compared to storage and utilization of precipitation received during the growing season. Fallow periods increase soil erosion and organic matter loss (Blanco and Holman, 2012), representing a large economic cost to dryland producers.

Forage production may be considered 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 being potentially acceptable by producers, based on recent forage research and grower feedback. This study tests several forage rotations for water use efficiency, forage quality, and profitability.

Annual forage crops are grown for a shorter time and require less moisture than traditional grain crops. Additionally, annual forages in the cropping system might enable cropping intensity and increase opportunistic cropping. "Opportunistic cropping," or "flex cropping," is the planting of a crop when conditions (soil water and precipitation outlook) are favorable and fallowing when unfavorable. Forage producers in the region commonly grow continuous winter triticale (T), winter triticale or summer crop silage, or forage sorghum or sorghum/sudan hay (S), but they lack a proven rotation concept for forages such as that developed for grain crops (e.g. winter wheat-summer crop-fallow). Producers are interested in forage crop rotations that enable increased pest management control options, spread out equipment and labor resources over the year, reduce weather risk, and increase profitability. Growing forages throughout the year greatly reduces the risk of crop failure.

Double crop yields of winter triticale (WT) and forage sorghum (FS) were 70% of annual cropping at Garden City, KS ($P \leq 0.05$), between 2007 and 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 to annual cropping. An intermediate cropping intensity of three crops grown in two years or four crops in three years might be a successful crop rotation in western Kansas. Wheat yields following spring annual forages were similar to wheat yield following fallow in a wheat-fallow rotation in non-drought years, but wheat yields were reduced in drought years (Holman et al., 2012). Forages are valuable feedstuff to the cow/calf, stocker, cattle feeding, and dairy industries throughout the region (Hinkle et al., 2010).

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

Study Objectives

1. Improve precipitation use and fallow efficiency of dryland cropping systems by reducing fallow using forage crops.
2. Test a number of forage crop rotations and tillage practices (no-tillage and min-tillage) to identify sustainable forage cropping systems.

Experimental Procedures

An annual forage rotation experiment was initiated in 2012 at the Southwest Research-Extension Center in Garden City, Kansas. All crop phases were in place by 2013, with the exception of T-S-O, which had all crop phases in place by 2015. The study design was a randomized complete block design with four replications. Treatment was crop phase (with all crop phases present every year) and tillage (no-tillage or min-tillage). Plots were 30 ft wide and 30 ft long. Crop rotations were one-, three-, and four-year rotations (see treatment list below). Crops grown were winter triticale (×*Triticosecale* Wittm.), forage sorghum (*Sorghum 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 Included

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

Winter triticale was planted at the end of September, spring oat was planted the beginning of March, and forage sorghum was planted the beginning of June. Crops were harvested at early heading to optimize forage yield and quality (Feekes 10.1) (Large, 1954). Winter triticale was harvested approximately May 15, spring oat was harvested approximately June 1, and forage sorghum was harvested approximately the end of August. Forage yields were determined from a 3- × 30-ft area cut 3 in. high using a small plot Carter forage harvester from each plot. Forage yield and quality (protein, fiber, and digestibility) were measured at each harvest. Gravimetric soil moisture content was measured at planting and harvest to a depth of 6 ft using 1-ft increments. Precipitation storage efficiency (% of precipitation stored during the fallow period) was quantified for each fallow period, and crop water use efficiency (forage yield divided by soil water used plus precipitation) was determined for each crop harvest. Crop yield response to plant available water (PAW) at planting was 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 a soil moisture probe provided a practical, 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 costs 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 and dividing by the number of years in the rotation. This method allows for comparing rotations of different years to each other for annual forage production (Table 1). A very dry year in 2013 resulted in low crop yields and no spring oat yield. In 2013, S-S produced the highest annual yield. In 2014, annual yield was comparable across treatments except for T/S-S-O (no-tillage), which had lower yield than T/S-S-S-O (min-tillage) and was comparable to all other treatments. The crop rotation of T-S-O was not in phase until 2015, so no comparison was made to that rotation until 2015. In 2015, T/S-S-O (no-tillage) yielded less than S-S, but more than T-S-O and comparable to all other treatments. The T-S-O annual yield was less than all other treatments in 2015. In 2016, precipitation primarily occurred June–August, which favored forage sorghum yield. The highest yielding rotation in 2016 was S-S, followed by T/S-S-S-O (no-tillage), and T-S-O yielded the least. Tillage increased the yield of triticale and thus the yield of T/S-S-O was improved with tillage, but yield improvement in the 4-yr rotation was not as evident due to triticale occurring less frequently in the rotation.

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

Crop Yield

Full-season sorghum yields either grown after T/S or S yielded similarly across rotations (Table 2 and Figure 1). Double-crop forage sorghum yielded less than full-season forage sorghum, but varied greatly from year to year based on precipitation during the growing season. Double crop forage sorghum yielded 70% less than full-season in 2013, 7% less in 2014, 12% less in 2015, and 10% less in 2016. Across all years, double-crop (5,970 lb/a) averaged 20% less than full-season forage sorghum (7,410 lb/a). The lower yield of double-crop forage sorghum was due to less available soil moisture at planting. Sorghum yield was not affected by tillage or length of rotation.

Triticale yield was not affected by length of rotation but was affected by tillage. Averaged across years, triticale in min-tillage (3,770 lb/a) yielded 178% more than no-tillage (2,110 lb/a). The only tillage in this study occurred in the fallow period before triticale and, in this study, benefitted the triticale crop. Other studies and producers have found tillage ahead of a winter wheat crop has minimal impact on yield and can improve weed control, but tillage ahead of grain sorghum often reduced grain yield. For these reasons, tillage was only used ahead of triticale and, similarly to winter wheat, did not reduce yields, but actually increased yields in the first 4 years of this study.

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

Soil Water

Plant available water at planting was measured to a 6-foot soil depth, and soil water content varied by year and planting period. On average, soil water was greatest at full-season forage sorghum planting (5.26 inches) and was not different among the other planting periods, ranging from 3.32 to 3.52 inches (Table 2 and Figure 2). Double-crop forage sorghum averaged 3.46 inches of PAW at planting.

Water use efficiency (WUE) was greatest in forage sorghum, with full-season producing 650 lb/a/in. and double-crop producing 601 lb/a/in. Water use efficiency for winter triticale averaged 428 lb/a/in., and oats was 350 lb/a/in. The yield potential and thus water use efficiency was greater with forage sorghum than triticale or oat. However, when precipitation was favorable during a particular growing season, such as oat in 2015, the WUE of oat was comparable to forage sorghum. In years with moisture stress, WUE of double-crop forage sorghum was less than full-season, but in favorable moisture years WUE of double-crop was greater than full-season (Table 2 and Figure 3).

Precipitation storage efficiency (PSE) varied by fallow period and ranged from 8% ahead of winter triticale to 56% for double-cropped forage sorghum. Precipitation storage ahead of full-season forage sorghum was 38% and ahead of oat planting was 42% (Table 2 and Figure 4).

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Table 1. Rotation treatment yields across years between 2013 and 2016

	Total treatment yield (dry matter lb/a)				
Crop rotation	2013	2014	2015	2016	Average†
S-S	4,262	7,426	10,244	8,025	7,489
T/S-S-O (no-tillage)	3,451	13,322	25,732	16,067	14,643
T/S-S-O (min-tillage)	4,020	20,130	28,742	18,404	17,824
T/S-S-S-O (no-tillage)	7,702	27,260	38,091	27,320	25,093
T/S-S-S-O (min-tillage)	8,896	30,266	36,394	23,831	24,847
T-S-O‡	*	*	18,404	10,060	14,232
	Annualized treatment yield (dry matter lb/a)				
	2013	2014	2015	2016	Average†
S-S	4,262	7,426	10,244	8,025	7,489
T/S-S-O (no-tillage)	1,150	4,441	8,577	5,356	4,881
T/S-S-O (min-tillage)	1,340	6,710	9,581	6,135	5941
T/S-S-S-O (no-tillage)	1,926	6,815	9,523	6,830	6,273
T/S-S-S-O (min-tillage)	2,224	7,566	9,099	5,958	6,212
T-S-O	*	*	6,135	3,353	4,744
$LSD_{0.05}$§	1,508	3,038	1,488	801	938
	Yield per harvest (dry matter lb/a)				
	2013	2014	2015	2016	Average†
S-S	4,262	7,426	10,244	8,025	7,489
T/S-S-O (no-tillage)	863	3,331	6,433	4,017	3,661
T/S-S-O (min-tillage)	1,005	5,032	7,185	4,601	4,456
T/S-S-S-O (no-tillage)	1,540	5,452	7,618	5,464	5,019
T/S-S-S-O (min-tillage)	1,779	6,053	12,131	4,766	6,183
T-S-O	*	*	3,681	3,353	3,517
$LSD_{0.05}$§	1,323	2,566	1,331	693	791

† Average of years 2013-2016.
‡ T-S-O treatment started in 2015.
§ Forage sorghum (S), Continuous forage sorghum (S-S), Winter triticale/double crop forage sorghum (T/S), and spring oat (O).

Table 2. Forage dry matter yield, plant available water at planting, water use efficiency (WUE), and precipitation storage efficiency (PSE) for all crop rotations and phases between 2013 and 2017 at the Southwest Research-Experiment Station near Garden City, KS

			2013							
			Dry matter yield		Plant available water		WUE		PSE	
Rotation	Treatment	Crop	lb/a	*P* < 0.05	Inches in 6 ft depth	*P* < 0.05	lb/a inch^{-1}	*P* < 0.05	%	*P* < 0.05
s-S†‡	1	Sorghum	4,262.00	a¶	3.55	ab	591.60	a	0.38	ac
t/S-s-o (no-tillage)	2	Sorghum	1,385.40	cd	1.14	dg	319.00	bd	-0.19	bc
t/s-S-o (no-tillage)	2	Sorghum	2,612.70	bc	1.70	cg	356.30	bd	0.09	ac
t/S-s-o (min-tillage)	3	Sorghum	972.00	de	0.93	fg	188.80	ef	0.71	a
t/s-S-o (min-tillage)	3	Sorghum	3,875.90	ab	3.08	ac	523.50	ab	0.17	ac
t/S-s-s-o (no-tillage)	4	Sorghum	1,199.30	de	0.39	g	273.20	cd	0.48	ac
t/s-S-s-o (no-tillage)	4	Sorghum	3,086.50	ab	2.86	ad	401.40	ac	0.26	ac
t/s-s-S-o (no-tillage)	4	Sorghum	3,955.00	a	2.55	bf	484.50	ab	0.14	ac
t/S-s-s-o (min-tillage)	5	Sorghum	9,61.30	de	1.11	eg	209.10	ce	-0.35	c
t/s-S-s-o (min-tillage)	5	Sorghum	4,220.60	a	3.25	ac	602.20	a	0.16	ac
t/s-s-S-o (min-tillage)	5	Sorghum	3,989.50	a	2.89	ac	410.50	ac	0.25	ac
t-S-o	6	Sorghum	*§	*	*	*	*	*		
T/s-s-o (no-tillage)	2	Triticale	142.10	de	1.56	cg	31.50	ef	-0.21	bc
T/s-s-o (min-tillage)	3	Triticale	188.40	de	1.10	eg	40.70	ef	0.02	ac
T/s-s-s-o (no-tillage)	4	Triticale	310.70	de	0.81	g	61.80	ef	-0.03	ac
T/s-s-s-o (min-tillage)	5	Triticale	722.20	de	1.55	cg	163.20	ef	0.00	ac
T-s-o	6	Triticale	*	*	*	*	*	*		
t/s-s-O (no-tillage)	2	Oat	0.00	e	2.68	be	0.00	f	-0.06	ac
t/s-s-O (min-tillage)	3	Oat	0.00	e	3.16	ac	0.00	f	0.11	ac
t/s-s-s-O (no-tillage)	4	Oat	0.00	e	3.46	ab	0.00	f	0.48	ac
t/s-s-s-O (min-tillage)	5	Oat	0.00	e	4.49	a	0.00	f	0.61	ab
t-s-O	6	Oat	*	*	*	*	*	*	*	*
LSD $_{0.05}$§			1,321.70		1.73		206.83		0.83	

continued

Table 2. Forage dry matter yield, plant available water at planting, water use efficiency (WUE), and precipitation storage efficiency (PSE) for all crop rotations and phases between 2013 and 2017 at the Southwest Research-Experiment Station near Garden City, KS

			2014							
			Dry matter yield		Plant available water		WUE		PSE	
Rotation	Treatment	Crop	lb/a	$P < 0.05$	Inches in 6 ft depth	$P < 0.05$	lb/a inch^{-1}	$P < 0.05$	%	$P < 0.05$
s-S[†‡]	1	Sorghum	7,426.00	ac	4.19	cf	679.20	ac	0.11	eg
t/S-s-o (no-tillage)	2	Sorghum	5,341.00	cd	2.22	f	536.20	bd	0.58	ac
t/s-S-o (no-tillage)	2	Sorghum	6,629.00	ac	3.67	df	600.70	ac	0.08	fg
t/S-s-o (min-tillage)	3	Sorghum	7,016.00	ac	3.58	df	666.60	ac	0.60	ac
t/s-S-o (min-tillage)	3	Sorghum	7,577.00	ac	3.75	df	794.50	ab	0.24	cg
t/S-s-s-o (no-tillage)	4	Sorghum	6,505.00	ac	3.60	df	624.40	ac	0.82	a
t/s-S-s-o (no-tillage)	4	Sorghum	8,415.00	ab	2.91	ef	855.00	a	-0.02	g
t/s-s-S-o (no-tillage)	4	Sorghum	9,107.00	a	4.41	ce	802.00	ab	0.37	bg
t/S-s-s-o (min-tillage)	5	Sorghum	9,122.00	a	3.93	cf	862.80	a	0.72	ab
t/s-S-s-o (min-tillage)	5	Sorghum	7,458.00	ac	4.32	ce	669.10	ac	0.17	eg
t/s-s-S-o (min-tillage)	5	Sorghum	5,894.00	bc	5.52	bd	494.50	cd	0.34	bg
t-S-o	6	Sorghum	*	*	*	*	*	*	*	*
T/s-s-o (no-tillage)	2	Triticale	695.00	e	3.21	ef	121.00	de	0.20	cg
T/s-s-o (min-tillage)	3	Triticale	4,650.00	cd	6.60	b	609.60	ac	0.58	ac
T/s-s-s-o (no-tillage)	4	Triticale	2,449.00	de	5.87	bc	301.30	de	0.53	ad
T/s-s-s-o (min-tillage)	5	Triticale	7,013.00	ac	8.92	a	724.10	ac	0.82	a
T-s-o	6	Triticale	*	*	*	*	*	*	*	*
t/s-s-O (no-tillage)	2	Oat	657.00	e	2.96	ef	80.20	e	0.51	ae
t/s-s-O (min-tillage)	3	Oat	887.00	e	3.79	df	126.40	e	0.43	af
t/s-s-s-O (no-tillage)	4	Oat	784.00	e	3.13	ef	101.50	e	0.57	ad
t/s-s-s-O (min-tillage)	5	Oat	779.00	e	4.07	cf	91.20	e	0.58	ac
t-s-O	6	Oat	*	*	*	*	*	*	*	*
$LSD_{0.05}$[§]			3,067.40		1.98		292.24		0.40	

continued

Table 2. Forage dry matter yield, plant available water at planting, water use efficiency (WUE), and precipitation storage efficiency (PSE) for all crop rotations and phases between 2013 and 2017 at the Southwest Research-Experiment Station near Garden City, KS

			2015							
			Dry matter yield		Plant available water		WUE		PSE	
Rotation	Treatment	Crop	lb/a	$P < 0.05$	Inches in 6 ft depth	$P < 0.05$	lb/a $inch^{-1}$	$P < 0.05$	%	$P < 0.05$
s-S†‡	1	Sorghum	10,244.00	ab	5.84	be	1,009.00	a	0.42	bf
t/S-s-o (no-tillage)	2	Sorghum	8,665.00	bc	4.61	dh	886.90	ab	0.60	ad
t/s-S-o (no-tillage)	2	Sorghum	9,125.00	bc	4.66	dg	894.60	ab	0.38	cg
t/S-s-o (min-tillage)	3	Sorghum	9,910.00	ac	6.29	bd	876.80	ac	0.91	a
t/s-S-o (min-tillage)	3	Sorghum	10,380.00	ab	7.08	ab	876.20	ac	0.55	be
t/S-s-s-o (no-tillage)	4	Sorghum	8,988.00	bc	5.27	bf	929.90	ab	0.72	ab
t/s-S-s-o (no-tillage)	4	Sorghum	11,216.00	a	6.53	ac	1,004.70	a	0.48	bf
t/s-s-S-o (no-tillage)	4	Sorghum	9,976.00	ac	5.79	be	908.70	ab	0.45	bf
t/S-s-s-o (min-tillage)	5	Sorghum	8,091.00	c	5.21	cf	767.50	ae	0.70	ac
t/s-S-s-o (min-tillage)	5	Sorghum	11,229.00	a	8.22	a	866.40	ac	0.66	ad
t/s-s-S-o (min-tillage)	5	Sorghum	9,300.00	ac	6.19	be	821.10	ad	0.48	bf
t-S-o	6	Sorghum	9,105.00	bc	6.26	bd	780.90	ae	0.23	eh
T/s-s-o (no-tillage)	2	Triticale	2,870.00	e	2.28	j	584.40	de	-0.02	i
T/s-s-o (min-tillage)	3	Triticale	4,072.00	de	4.37	ei	605.30	ce	0.00	hi
T/s-s-s-o (no-tillage)	4	Triticale	2,738.00	e	2.76	hj	516.50	e	-0.20	i
T/s-s-s-o (min-tillage)	5	Triticale	3,356.00	de	3.35	gj	564.40	de	-0.05	hi
T-s-o	6	Triticale	4,008.00	de	3.09	gj	734.40	ae	-0.20	i
t/s-s-O (no-tillage)	2	Oat	5,072.00	d	2.22	j	939.00	ab	0.23	eh
t/s-s-O (min-tillage)	3	Oat	4,380.00	de	2.67	ij	785.80	ae	0.09	gi
t/s-s-s-O (no-tillage)	4	Oat	5,174.00	d	2.49	j	942.00	ab	0.21	fh
t/s-s-s-O (min-tillage)	5	Oat	4,418.00	de	3.54	fj	666.90	be	0.36	dg
t-s-O	6	Oat	5,291.00	d	3.05	gj	825.50	ad	0.20	fh
$LSD_{0.05}$§			2,050.30		1.85		281.50		0.33	

continued

Table 2. Forage dry matter yield, plant available water at planting, water use efficiency (WUE), and precipitation storage efficiency (PSE) for all crop rotations and phases between 2013 and 2017 at the Southwest Research-Experiment Station near Garden City, KS

			2016							
			Dry matter yield		Plant available water		WUE		PSE	
Rotation	Treatment	Crop	lb/a	$P < 0.05$	Inches in 6 ft depth	$P < 0.05$	lb/a inch^{-1}	$P < 0.05$	%	$P < 0.05$
s-S†‡	1	Sorghum	8,024.90	a	6.88	ad	568.40	bc	0.43	cf
t/S-s-o (no-tillage)	2	Sorghum	7,065.40	ab	3.27	fh	861.80	a	0.74	ab
t/s-S-o (no-tillage)	2	Sorghum	7,145.40	ab	6.58	ad	463.10	bf	0.48	be
t/S-s-o (min-tillage)	3	Sorghum	7,674.10	a	5.22	bf	613.70	b	0.87	a
t/s-S-o (min-tillage)	3	Sorghum	7,766.70	a	7.03	ac	497.50	be	0.48	be
t/S-s-s-o (no-tillage)	4	Sorghum	6,633.60	ab	3.87	eg	561.60	bc	0.60	ac
t/s-S-s-o (no-tillage)	4	Sorghum	7,678.70	a	6.28	ae	549.10	bc	0.36	cf
t/s-s-S-o (no-tillage)	4	Sorghum	7,644.80	a	7.56	ab	565.10	bc	0.47	be
t/S-s-s-o (min-tillage)	5	Sorghum	6,053.40	bc	4.71	cg	446.40	bf	0.51	bd
t/s-S-s-o (min-tillage)	5	Sorghum	7,701.30	a	7.20	ab	454.60	bf	0.50	bd
t/s-s-S-o (min-tillage)	5	Sorghum	7,599.70	a	8.55	a	518.00	bd	0.57	bc
t-S-o	6	Sorghum	7,695.90	a	6.47	ad	498.60	be	0.18	fg
T/s-s-o (no-tillage)	2	Triticale	3,301.50	gef	1.32	h	370.90	cg	-0.19	h
T/s-s-o (min-tillage)	3	Triticale	5,131.10	cd	4.03	eg	509.70	bd	0.19	eg
T/s-s-s-o (no-tillage)	4	Triticale	4,411.20	de	3.04	fh	456.60	bf	0.04	gh
T/s-s-s-o (min-tillage)	5	Triticale	5,043.80	cd	4.58	dg	515.90	bd	0.27	dg
T-s-o	6	Triticale	4,226.70	def	2.52	gh	457.60	bf	0.03	gh
t/s-s-O (no-tillage)	2	Oat	1,856.40	h	3.60	fh	199.00	g	0.75	ab
t/s-s-O (min-tillage)	3	Oat	2,963.50	fgh	4.00	eg	337.30	cg	0.59	ac
t/s-s-s-O (no-tillage)	4	Oat	2,061.00	gh	3.31	fh	247.00	fg	0.54	bd
t/s-s-s-O (min-tillage)	5	Oat	2,477.10	gh	3.76	fg	291.40	dg	0.64	ac
t-s-O	6	Oat	2,364.10	gh	3.53	fh	262.90	eg	0.72	a
$LSD_{0.05}$§			1,392.30		2.43		242.28		0.29	

continued

Table 2. Forage dry matter yield, plant available water at planting, water use efficiency (WUE), and precipitation storage efficiency (PSE) for all crop rotations and phases between 2013 and 2017 at the Southwest Research-Experiment Station near Garden City, KS

			Average							
			Dry matter yield		Plant available water		WUE		PSE	
Rotation	Treatment	Crop	lb/a	$P < 0.05$	Inches in 6 ft depth	$P < 0.05$	lb/a inch^{-1}	$P < 0.05$	%	$P < 0.05$
s-S[†‡]	1	Sorghum	7,489.23	ab	5.11	ae	712.05	a	0.33	cf
t/S-s-o (no-tillage)	2	Sorghum	5,614.20	d	2.81	ji	650.98	ab	0.43	bd
t/s-S-o (no-tillage)	2	Sorghum	6,378.03	bd	4.15	dh	578.68	ad	0.26	df
t/S-s-o (min-tillage)	3	Sorghum	6,393.03	cd	4.00	ei	586.48	ad	0.77	a
t/s-S-o (min-tillage)	3	Sorghum	7,399.90	ac	5.23	ad	672.93	ab	0.36	ce
t/S-s-s-o (no-tillage)	4	Sorghum	5,831.48	d	3.28	gj	597.28	ad	0.66	ab
t/s-S-s-o (no-tillage)	4	Sorghum	7,599.05	ab	4.64	be	702.55	a	0.27	df
t/s-s-S-o (no-tillage)	4	Sorghum	7,670.70	ac	5.08	ae	690.08	ab	0.36	ce
t/S-s-s-o (min-tillage)	5	Sorghum	6,056.93	d	3.74	fi	571.45	ad	0.40	be
t/s-S-s-o (min-tillage)	5	Sorghum	7,652.23	ac	5.75	ac	648.08	ac	0.37	ce
t/s-s-S-o (min-tillage)	5	Sorghum	6,695.80	bd	5.79	ab	561.03	ad	0.41	be
t-S-o	6	Sorghum	8,400.45	a	6.36	a	639.75	ac	0.70	ef
T/s-s-o (no-tillage)	2	Triticale	1,752.15	g	2.09	j	276.95	g	-0.05	g
T/s-s-o (min-tillage)	3	Triticale	3,510.38	ef	4.03	dh	441.33	df	0.20	ef
T/s-s-s-o (no-tillage)	4	Triticale	2,477.23	fg	3.12	gj	334.05	eg	0.08	fg
T/s-s-s-o (min-tillage)	5	Triticale	4,033.75	e	4.60	cg	491.90	ce	0.26	df
T-s-o	6	Triticale	3,200.00	e	2.80	ji	596.00	ad	-0.09	g
t/s-s-O (no-tillage)	2	Oat	1,896.35	g	2.86	ji	304.55	fg	0.36	ce
t/s-s-O (min-tillage)	3	Oat	2,057.63	g	3.40	gj	312.38	fg	0.30	cf
t/s-s-s-O (no-tillage)	4	Oat	2,004.75	g	3.09	hj	322.63	fg	0.45	be
t/s-s-s-O (min-tillage)	5	Oat	1,918.53	g	3.96	ei	262.38	g	0.55	ac
t-s-O	6	Oat	2,250.00	ef	3.29	gj	544.20	bd	0.46	be
LSD $_{0.05}$[§]			1,293.90		1.33		158.54		0.26	

† Crop within rotation is identified by capitalization.
‡ S is forage sorghum, T is triticale, and O is oat.
§ T-S-O treatment started in 2015.
¶ Means in columns followed by different letters are statistically different at $P \leq 0.05$.

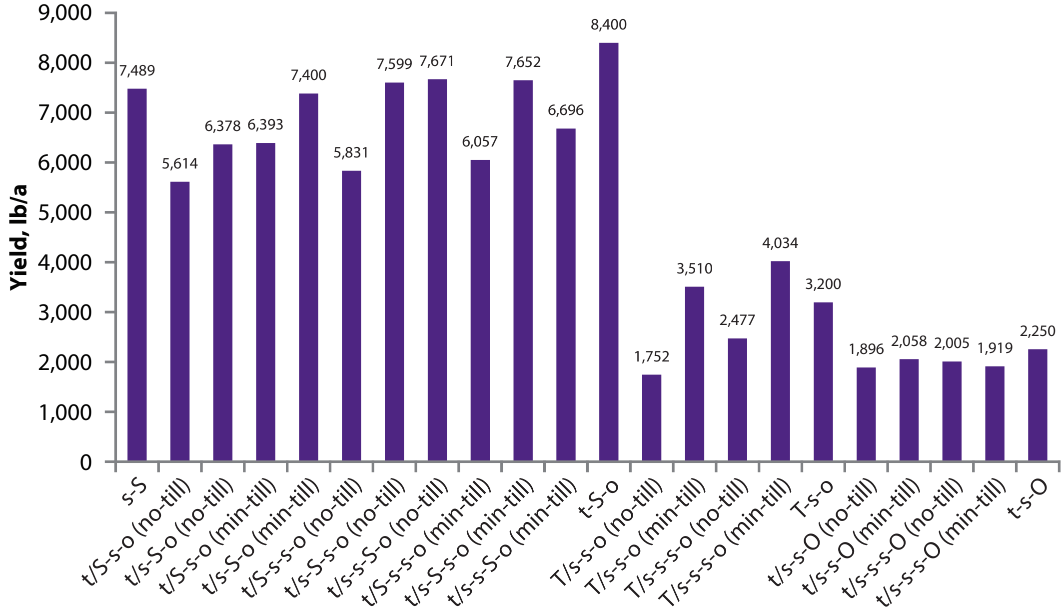

Figure 1. Forage dry-matter yield for all crop rotations and phases averaged across years from 2013 to 2016. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

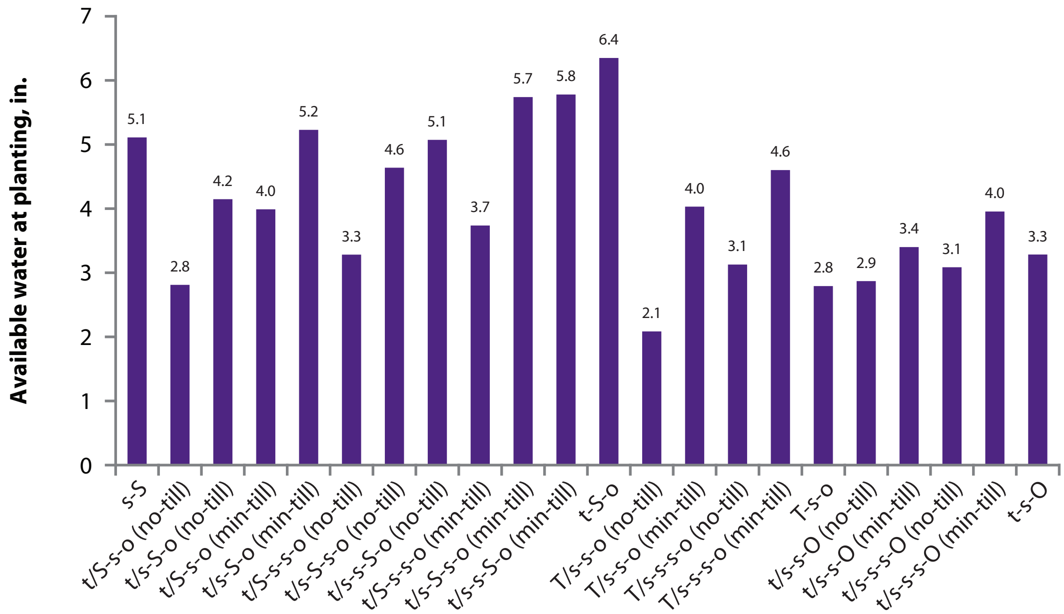

Figure 2. Plant available water in a six-foot soil profile at planting for all crop rotations and phases averaged across years from 2013 to 2016. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

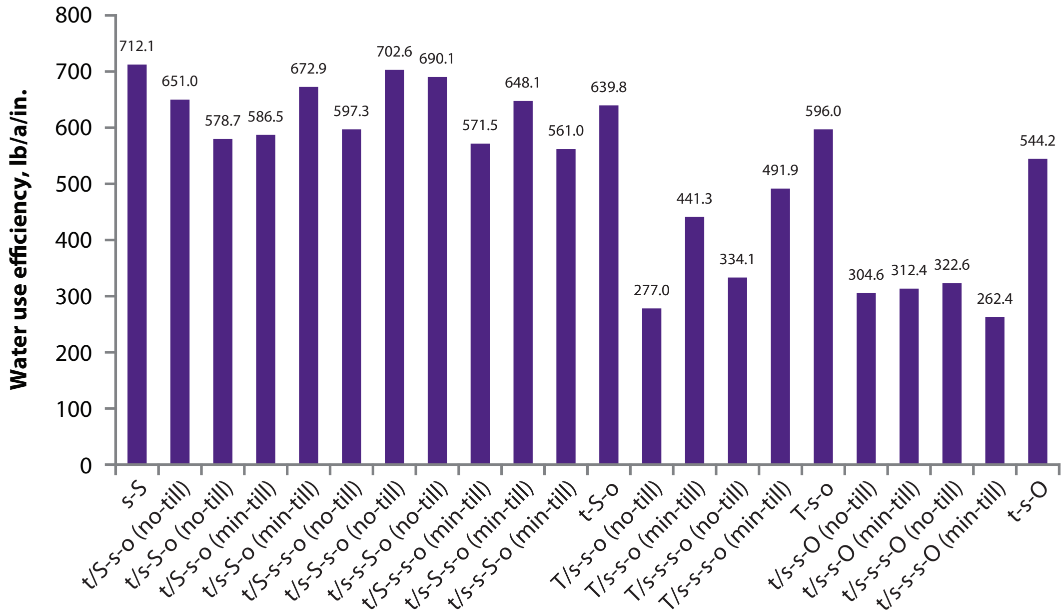

Figure 3. Water use efficiency (WUE) [forage dry matter yield/((ending-beginning soil water content) + growing season precipitation)] for all crop rotations and phases averaged across years from 2013 to 2016. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.

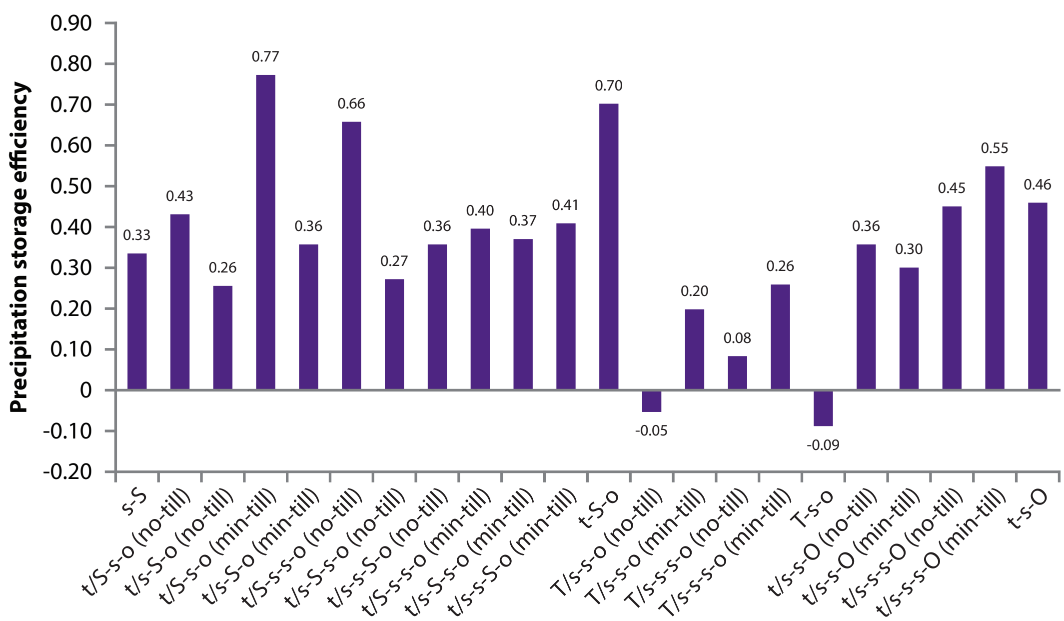

Figure 4. Precipitation storage efficiency (PSE) [precipitation/(ending-beginning soil water content)] for the fallow period preceding the crop for all crop rotations and phases averaged across years from 2013 to 2016. Triticale-forage sorghum-oat was implemented in 2015. Crop is identified by capitalization in X axis. S = Forage sorghum. S-S = Continuous forage sorghum. T/S = Winter triticale/double crop forage sorghum. O = Spring oat.