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THE EFFECT OF COVER CROPS ON THE WATER BUDGET IN DEFICIT IRRIGATION ROTATIONS

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ABSTRACT

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 rain-fed 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 also 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.

MATERIAL AND METHODS

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 so that long-term treatment impacts could be determined. Fallow replacement crops (cover crop, annual forage, or short-season grain crop) were either grown as standing cover, harvested for forage (annual forage crop), or harvested for grain.

In experiment 1 (2007-2012) both winter and spring crop species were evaluated. Winter species included yellow sweet clover (*Melilotus officinalis* (L.) Lam.) hairy vetch (*Vicia villosa* Roth ssp.), lentil (*Lens culinaris* Medik.), Austrian winter forage pea (*Pisum sativum* L. ssp.), Austrian winter grain pea (*Pisum sativum* L. ssp.), and triticale (×*Triticosecale* Wittm.). Spring species included lentil (*Lens culinaris* Medik.), forage pea (*Pisum sativum* L. ssp.), grain pea (*Pisum sativum* L. ssp.), and triticale (×*Triticosecale* Wittm.). Crops were grown in monoculture and in two-species mixtures of each legume plus triticale. Crops grown for grain were grown in monoculture only. Winter lentil was grown in place of yellow sweet clover beginning in 2008. Crops grown in place of fallow were compared with a wheat-fallow and continuous wheat rotation for a total of 16 treatments (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 only grown in 2012, and that treatment was replaced with spring oat grown for grain beginning in 2013. Additional treatments initiated in 2013 were yellow 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 1ft (2013 only) and 1.5ft (2014-subsequent years) of 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 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.

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-foot 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.

Table 1. Fallow treatments 2007-2011.

Season	Crop	Year produced				
		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†	x	x		x	x	x
""	Fallow				x	x	x
""	Flex-Fallow/Spring oat (1.5' PAW 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

† oat, triticale, pea, buckwheat, forage brassica and forage radish

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 3). 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 hay treatments (0.06 in.) (Table 4). 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 5). 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 amount of 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 semiarid climates. Fallow had the greatest amount of soil moisture, and all other treatments had less (Table 6). 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, which was due to 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.

Precipitation storage efficiency (PSE) =

$$\frac{\text{Soil water content at wheat planting - Soil water content at fallow crop termination}}{\text{Precipitation between fallow crop termination and wheat planting}}$$

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 7). 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 similar PSE to grain pea, winter triticale, and winter lentil/winter triticale (Table 7). 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 only grown in 2012, and beginning in 2013 spring oats was 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 8). 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 similar plant-available soil water as 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 9). 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 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.

Table 3. 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.)			mm (in.)			mm (in.)		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 4. 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.)			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 5. 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 6. 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.)			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 sea/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 7. 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†
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	

†Letters within a column represent differences at LSD 0.05

Table 8. 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.)			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	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			

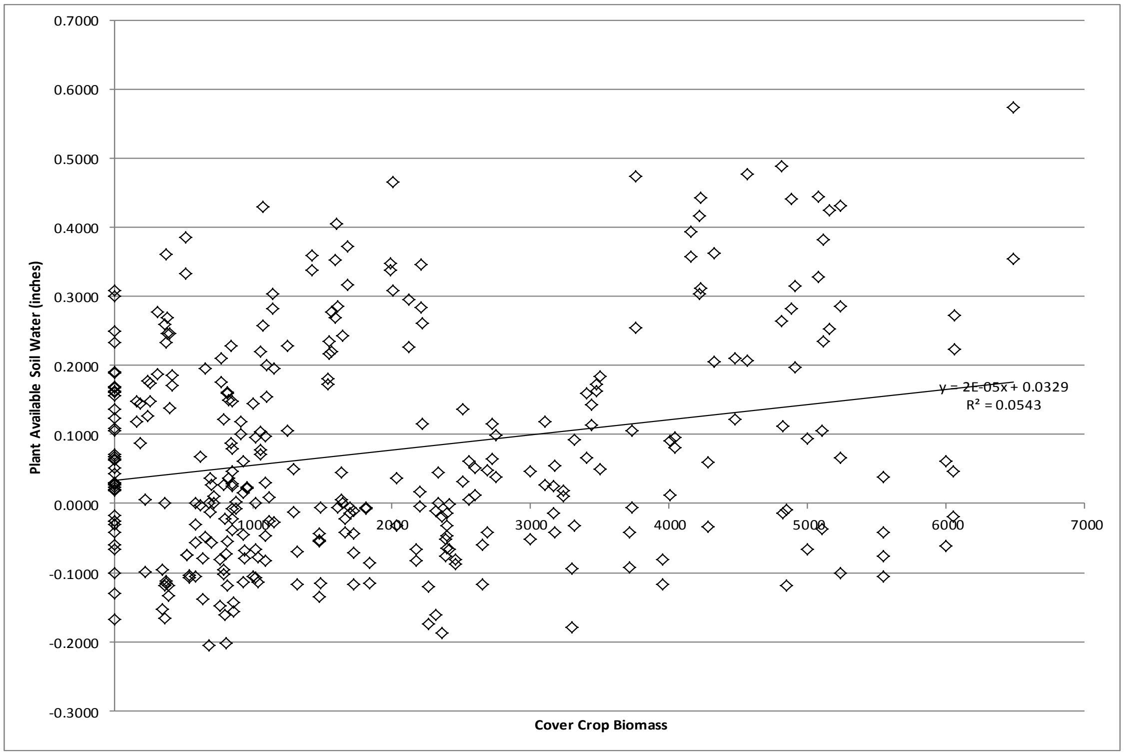
[1]Different letters within a column represent differences at LSD 0.05

Table 9. 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.)		(in.)
Cocktail*	4.31	A	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		

*Cocktail (oat, triticale, pea, buckwheat, forage brassica, & forage radish)

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



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 less than cover or hay crops, and this difference resulted in reduced wheat yields. Increasing surface residue tended to increase the amount of soil moisture in soil surface (0–3 in.), which could help improve stand establishment in dry years. However, there was a large amount of variability in soil moisture stored at this depth, 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.

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