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Cover Crop Effect on Subsequent Wheat Yield in the Central Great Plains

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David C. Nielsen,* Drew J. Lyon, Robert K. Higgins, Gary W. Hergert, Johnathon D. Holman, and Merle F. Vigil

ABSTRACT

Crop production systems in the water-limited environment of the semiarid central Great Plains may not have potential to profitably use cover crops because of lowered subsequent wheat (*Triticum asestivum* L.) yields following the cover crop. Mixtures have reportedly shown less yield-reducing effects on subsequent crops than single-species plantings. This study was conducted to determine winter wheat yields following both mixtures and single-species plantings of spring-planted cover crops. The study was conducted at Akron, CO, and Sidney, NE, during the 2012–2013 and 2013–2014 wheat growing seasons under both rainfed and irrigated conditions. Precipitation storage efficiency before wheat planting, wheat water use, biomass, and yield were measured and water use efficiency and harvest index were calculated for wheat following four single-species cover crops (flax [*Linum usitatissimum* L.], oat [*Avena sativa* L.], pea [*Pisum sativum* ssp. *arvense* L. Poir], rapeseed [*Brassica napus* L.]), a 10-species mixture, and a fallow treatment with proso millet (*Panicum miliaceum* L.) residue. There was an average 10% reduction in wheat yield following a cover crop compared with following fallow, regardless of whether the cover crop was grown in a mixture or in a single-species planting. Yield reductions were greater under drier conditions. The slope of the wheat water use–yield relationship was not significantly different for wheat following the mixture (11.80 kg ha^{-1} mm^{-1}) than for wheat following single-species plantings (12.32–13.57 kg ha^{-1} mm^{-1}). The greater expense associated with a cover crop mixture compared with a single species is not justified.

In recent years the USDA-Natural Resources Conservation Service has widely promoted the use of cover crops in cropping systems to improve soil health throughout the United States (USDA-NRCS, 2015; SARE, 2015). There are indisputable reasons for implementing cover crops such as providing protection from wind and water erosion and building soil organic matter levels (Bilbro, 1991; Langdale et al., 1991; Unger and Vigil, 1998; Blanco-Canqui et al., 2013). But in semiarid regions (250–500 mm annual precipitation) which are chronically short of water for stable dryland crop production, there may be significant costs associated with cover crop water use and reductions in subsequent cash crop yields that will make successful implementation of cover crops difficult to achieve.

Unger and Vigil (1998) presented a literature review of studies documenting the effects of cover crops on subsequent crop yields, primarily focused on soil water relationships. More recent studies have been done to characterize and quantify the effect of cover crops on subsequent crop yields. Some studies have shown positive effects on yield and some have shown negative effects. In Table 1 we present only a small fraction of these additional reports on cover crop effects on subsequent crop yields. In the studies that have been done in the semiarid environments of the central and southern Great Plains (Colorado, Kansas, Oklahoma, Texas) most studies have shown that growing cover crops reduced subsequent crop yields. Unger et al. (2006) cautioned that cover crop use in semiarid dryland regions could be detrimental to yields of subsequent crops because of the water that the cover crop used that was not

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Table 1. Previous research on cover crop/previous crop effects on yield of subsequent crops.

Study location	Annual precipitation	Years of study	Cover crop/Previous crop	Subsequent crop	Yield after fallow	Yield after cover crop	Source
	mm				kg ha $^{-1}$		
Khamishly, Syria	243–719	10	Medic and vetch	Wheat	2,570	1,900–2,010	Christiansen et al. (2015)
Central Kansas	na†	1	Oat	Soybean	2,843	2,194	Palen et al. (2015)
		1	Oat	Wheat	4,052	3,904	
		1	Oat	Soybean	866	517	
		1	10-species mixture	Soybean	866	349	
		1	Rye	Soybean	2,809	2,305	
Five Points, CA	Irrigated	10	Triticale/rye/vetch mixture	Tomato	111,400	105,300	Mitchell et al. (2015)
				Cotton	129,400	124,400	
Andover, SD	428‡	1	Radish, winter canola	Corn	13,390	13,020	Reese et al. (2014)
Andover, SD	307‡	1	Radish, winter canola, turnip	Corn	11,830	10,070	
Trail City, SD	247‡	1	Radish, turnip, lentil, pea, millet	Corn	6,900	7,660	
Boone, IA	na	2	Winter rye	Soybean	3,140	2,000	Singer and Kohler (2005)
			Winter rye (volunteer)	Corn	11,290	10,400	
Andover, SD	257–460§	2	3-species mixture, interseeded	Corn	10,660	10,570	Bich et al. (2014)
Trail City, SD	439§	1	3-species mixture, interseeded	Corn	6,900	7,310	
Aurora, SD	386–493§	2	3-species mixture, interseeded	Corn	9,600	9,190	
Boone, IA	na	4	Winter wheat (volunteer)	Corn	9,750	8,440	McDonald et al. (2008)
			Winter rye (volunteer)	Corn	9,750	9,100	
			Winter triticale (volunteer)	Corn	9,750	8,660	
Loomis, NE	na	1	6-species mixture	Wheat	4,370	3,230	Thompson et al. (2014)
Wilcox, NE	na	1	5-species mixture	Corn	9,910	9,280	
Glenvil, NE	na	1	7-species mixture	Corn	11,160	10,850	
Beaver Crossing, NE	Irrigated	1	Rye	Corn	15,550	15,490	
Ithaca, NE	Irrigated	1	5-species mixture	Soybean	4,300	4,300	
Denton, MT	262–364	2	Pea	Wheat	1,740	1,730	Miller et al. (2006)
Havre, MT			Pea	Wheat	2,630	1,480	
Amsterdam, MT			Pea	Wheat	2,480	2,610	
Culberson, MT	248–374¶	12	Lentil	Wheat	2,475	2,110	Allen et al. (2011)
Havre, MT	77–246§	4	Lentil	Spring Wheat	1,000	580	Lenssen et al. (2007)
			Mustard	Spring Wheat	1,000	530	
			Chickpea	Spring Wheat	1,000	700	
			Pea	Spring Wheat	1,000	630	
Culberson, MT	248–374¶	4	Lentil	Wheat	2,820	2,040	Pikul et al. (1997)
Culberson, MT	321–423§	4	Barley	Durum	3,211	2,490	Lenssen et al. (2010)
			Barley, pea	Durum	3,211	2,510	
			Foxtail millet	Durum	3,211	2,460	
Bozeman, MT	310–340	3	Pea	Wheat	3,230	3,160	Burgess et al. (2014)
			Lentil		3,230	3,230	
Moccasin, MT	275–441	3	Pea	Wheat	2,140	2,190	Chen et al. (2012)
Akron, CO	165–496	6	Pea, T1#	Wheat	3,920	3,020	Nielsen and Vigil (2005)
			Pea, T2		3,920	2,270	

(continued next page)

Table 1 (continued).

Study location	Annual precipitation	Years of study	Cover crop/Previous crop	Subsequent crop	Yield after fallow	Yield after cover crop	Source
	mm				kg ha $^{-1}$		
El Reno, OK	365–478††	3	Soybean	Wheat	3,615	3,090	Northup and Rao (2015)
			Lablab	Wheat	3,615	3,500	
Vernon, TX	na, dryland	1	Crimson clover	Cotton, lint	470	580	DeLaune (2014)
			Pea		470	380	
	irrigated		6-species mixture	Cotton, lint	1,270	1,130	
Vernon, TX	na, dryland	3	Winter rye	Cotton, lint	290	256	Sij et al. (2004)
Vernon, TX	na, dryland	1	7-species mixture	Wheat	150	30	Mubvumba and DeLaune (2014)
Electra, TX	na, dryland	1	Not specified	Cotton	570	260	Baughman et al. (2007)
Garden City, KS	308–551	4	Pea	Wheat	3,760	3,360	Holman et al. (2014)
	439	1	6-species mixture	Wheat	940	200	
Tribune, KS	na	3	Hairy vetch, T1‡‡	Wheat	2,687	1,927	Schlegel and Havlin (1997)
			Hairy vetch, T2	Wheat	2,687	1,477	
	na	2	Hairy vetch, T1§§	Sorghum	2,640	2,010	
			Hairy vetch, T2	Sorghum	2,640	1,420	
Sidney, NE	347–548	3	Oat/pea mixture	Wheat	2,010	1,560	Lyon et al. (2004)
Colby, KS	220–466	6	Spring canola	Wheat	2,840	1,170	Aiken et al. (2013)
Big Sandy, MT	330–345	2	Spring pea	Wheat	2,300	1,940	Miller et al. (2011)
			Winter pea	Wheat	2,300	2,420	
Morris, MN	272–410§	2	Winter rye (terminated 3.5 wk before corn planting)	Corn silage	20,200	19,600	Krueger et al. (2011)
			Winter rye (harvested 2 d before corn planting)	Corn silage	20,200	15,700	

† na, not available.

‡ May through September.

§ April through September.

¶ April through October.

T1 is legume termination date approximately 100 d before wheat planting; T2 is legume termination date approximately 70 d before wheat planting.

†† September through April.

‡‡ T1 is hairy vetch termination date approximately 93 d before wheat planting; T2 is hairy vetch termination date approximately 50 d before wheat planting.

§§ T1 is hairy vetch termination date approximately 56 d before sorghum planting; T2 is hairy vetch termination date approximately 26 d before sorghum planting.

replenished by precipitation between the time of cover crop termination and planting the next crop. But even in some studies conducted in more humid conditions, negative effects on yield have been reported, although the yield reduction was attributed to effects other than cover crop water use (though soil water was not always measured). In those cases yield depressions were sometimes associated with emergence and stand establishment problems or N unavailability. In the results from the U.S northern Great Plains states and Canadian Prairie provinces, yields were not as frequently reduced by a prior cover crop and this is likely a result of the lower demand for water seen at those locations (Robinson and Nielsen, 2015)

Recent statements have been made which suggest that the results of these studies given in Table 1 (and others) that document the yield-reducing effects of cover crops on subsequent crop yield in semiarid environments do not apply to situations in which cover crops are grown in mixtures compared with single-species plantings. The reason given for disregarding the results of these previous studies was because cover crop mixtures use far less water than single-species plantings (R. Archuleta, NRCS, Greensboro, NC, personal communication, 2013; K. Buttle, NRCS, Scottsbluff, NE, personal communication, 2010; Berns and Berns, 2009) due to enhanced microbiological activity (soil fungal and bacterial associations) that improve drought tolerance through access to greater soil volume (East, 2013) (Dr. K. Nichols, formerly USDA-ARS, Mandan, ND, now Rodale Institute, Kurtztown, PA, personal communication, 2012). However, Nielsen et al. (2015a) reported that cover crop mixtures do not use less water than single-species plantings of cover crops, and Calderón et al. (2015) reported no differences in microbiological populations for cover crop mixtures compared with single-species plantings.

Several researchers have noted the importance of timely termination of cover crops to limit water use such that detrimental impacts on yields of subsequent crops can be minimized. Unger and Vigil (1998) noted that in semiarid regions, where the primary purpose of cover crops was soil surface protection from erosion, the recommendation was to allow the cover crop to grow until it provided sufficient ground cover, but to terminate it as early as possible to allow sufficient time for soil water storage before planting the next crop. Nielsen and Vigil (2005) observed that 6-yr average dryland winter wheat yields in northeastern Colorado were reduced by a prior spring-planted legume cover crop by 58, 59, 75, and 77% with termination 100, 90 79, and 69 d, respectively, before wheat planting (compared with summer fallow ahead of wheat). In contrast to these observations are the much lower yield reductions reported by Poore (2013) from a computer simulation study (50 yr) using the uncalibrated WEPS model (Wagner, 1996) in which a spring-planted pea cover crop was simulated to grow on silt loam soils in western Nebraska and southwestern Kansas. The simulated results showed no wheat yield reductions when the cover crop was terminated 90 d before wheat planting (compared with wheat after summer fallow), and 6 to 7%, 15 to 16%, and 18 to 20% yield reductions with termination 60, 30, and 15 d before wheat planting, respectively.

The objectives of this experiment were to determine water use, grain yield, and water use efficiency of wheat following cover crops compared with following fallow, and to determine if the water use, grain yield, and water use efficiency of wheat following a 10-species cover crop mixture was different from that of wheat following single-species cover crop plantings.

MATERIALS AND METHODS

The study was conducted during the 2012–2013 and 2013–2014 wheat growing seasons at the USDA-ARS Central Great Plains Research Station, 6.4 km east of Akron, CO, (40°09′ N, 103°09′ W, 1384 m elevation above sea level) and at the University of Nebraska High Plains Ag Lab, 9.7 km northwest of Sidney, NE (41°12′ N, 103°0′ W, 1315 m elevation above sea level). The soil type at both locations was silt loam (Akron: Weld silt loam [fine, smectitic, mesic Aridic Argiustoll]; Sidney: Keith silt loam [fine-silty, mixed, superactive, mesic Aridic Argiustoll]).

The cropping system being investigated was a no-till proso millet–spring cover crop–winter wheat rotation. In this system, proso millet was harvested in mid-September and a cover crop was planted in early April. The cover crop was terminated in mid-June and winter wheat was planted in late September. The experiment was laid out as a split plot design with four replications at both locations. The main plot factor was irrigation treatment (rainfed or irrigated) and the split plot factor (six treatments) was prior cover crop species (four single-species cover crop plantings [flax, oat, pea, rapeseed], one 10-species cover crop mixture, and a no-till fallow treatment with proso millet residue). The species in the mixture were rapeseed, flax, oat, pea, lentil (*Lens culinaris* L.), common vetch (*Vicia sativa* L.), berseem clover (*Trifolium alexandrinum* L.), barley (*Hordeum vulgare* L.), phacelia (*Phacelia tenacetifolia* L.), and safflower (*Carthamus tinctorius* L.). The make-up of this mixture was recommended by Green Cover Seed, Bladen, NE (Keith Berns, personal communication, 2011) so as to provide the best chance of replicating the results reported by Berns and Berns (2009) in which cover crops grown in mixtures did not use soil water to produce biomass. Main plots (irrigation treatment) were 6.1 by 54.6 m (2013) and 12.2 by 36.6 m (2014) at Akron and 4.6 by 54.6 m (both years) at Sidney. A 4.6 m alley separated main plots to minimize border effects. Individual split plot dimensions were 6.1 by 9.1 m (2013) and 6.1 by 12.2 m (2014) at Akron, and 4.6 by 9.1 m (both years) at Sidney. Cover crop planting and termination dates, seeding rates, mixture composition and other cultural details are given in Nielsen et al. (2015a). Wheat was planted approximately 100 d following the herbicide application that terminated cover crop growth (planting dates and other cultural practices given in Table 2), except at Sidney in 2014 where planting occurred 65 d after cover crop termination due to late planting of the cover crop (cool wet conditions) and late termination (Nielsen et al., 2015a). Two herbicide applications were necessary at Akron in 2012 as the first application was ineffective at completely stopping cover crop growth and water use, especially that of rapeseed.

At Akron the irrigated plots were watered bi-weekly to simulate average precipitation at Blue Hill, NE [south-central Nebraska, near the site of the study by Berns and Berns (2009)] to determine if wheat water use efficiency was similar in a higher rainfall regime but with similar evaporative demand as at Akron (April through October pan evaporation of about 1830 mm per year; Kohler et al., 1959). The irrigated plots at Sidney were watered bi-weekly to simulate the 30-yr average precipitation at Sidney. Observed and average monthly precipitation and irrigation amounts are shown in Table 3. Irrigations at both locations were applied through linear move irrigation systems, and 13 to 19 mm of water was applied with each irrigation. Thus a wide range of water availability conditions were created over which to evaluate the water use/yield production function and water use efficiency for winter wheat following cover crops.

Soil water was measured at the center of each plot at 0.3-m intervals using a neutron probe (Model 503 Hydroprobe, CPN International, Martinez, CA) at both locations. At Akron the depth intervals were 0.3 to 0.6 m, 0.6 to 0.9 m, 0.9 to 1.2 m, 1.2 to 1.5 m, and 1.5 to 1.8 m. Soil water in the 0.0 to 0.3 m surface layer was determined using time-domain reflectometry (Trase System I, Soil Moisture Equipment Corp., Santa Barbara, CA) with 0.3-m waveguides installed vertically to average the water content over the entire layer. At Sidney all soil water measurements were made with only the neutron probe and the lowest layer measured at Sidney in both years was 0.9 to 1.2 m due to the presence of a restricting calcium carbonate layer that limited access tube insertion depth. The neutron probe was calibrated against gravimetric soil water samples taken in the plot area. Gravimetric soil water was converted to volumetric water by multiplying by the soil bulk density for each depth. Bulk density was determined from the dry weight of the soil cores (38 mm diam. by 300 mm length) taken from each depth at the time of neutron probe access tube installation.

Full season water use was calculated from the water balance as the difference between soil water readings at wheat planting and physiological maturity plus growing season precipitation. Precipitation was manually measured daily at both locations at weather observing sites approximately 300 m from the experimental areas. Runoff and deep percolation were assumed to be negligible. This was considered a reasonable assumption as the slopes in the plot areas were <1% and visual observations in the plot areas following heavy rains did not show evidence of runoff. Analysis of the soil water changes over time at the three lowest measurement layers did not show any evidence

Table 2. Cultural practices associated with cover crop termination and subsequent winter wheat planting and harvest at Akron, CO, and Sidney, NE.

Location	Year	Cover crop termination	Winter wheat planting date	Seeding rate	Variety	Row spacing	Fertilizer at planting	Harvest date	Harvest area
				kg ha^{-1}		cm	kg N ha^{-1}		m^{2}
Akron	2013	16 June 2012	19 Sept. 2012	67	Settler CL	19.1	67	8, 9 July 2013	11.0
	2014	27 June 2013	4 Oct. 2013	67	Brawl CL	19.1	67	21 July 2014	17.2
Sidney	2013	15 June 2012	20 Sept. 2012	62	Pronghorn	25.4	45	13 July 2013	18.1
	2014	18 July 2013	21 Sept. 2013	62	Settler CL	25.4	56	22 July 2014	18.1

Herbicides used to terminate cover crop growth

Location	Date	Herbicide	Herbicide company	Active ingredient	Application rate
					L ha^{-1}
Akron	16 June 2012	Gramoxone	Syngenta, Wilmington, DE	N,N'-dimethyl-4,4'-bipyridinium dichloride	3.51
	12 July 2012	Roundup	Monsanto, St. Louis, MO	N-(phosphonomethyl)glycine	2.34
		Brash	Agrillance, St. Paul, MN	2,4-dichlorophenoxyacetic acid and 3,6-dichloro-o-anisic acid	1.53
Akron	27 June 2013	Roundup	Monsanto, St. Louis, MO	N-(phosphonomethyl)glycine	2.34
		Brash	Agrilliance, St. Paul, MN	2,4-dichlorophenoxyacetic acid and 3,6-dichloro-o-anisic acid	1.17
Sidney	16 June 2012	Roundup	Monsanto, St. Louis, MO	N-(phosphonomethyl)glycine	2.34
Sidney	18 July 2013	Roundup	Monsanto, St. Louis, MO	N-(phosphonomethyl)glycine	2.34
		Banvel	BASF, Florham Park, NJ	3,6-dichloro-o-anisic acid	0.58

Table 3. Monthly precipitation (P) at Akron CO, and Sidney NE, during the wheat growing season (emergence to physiological maturity) and long-term averages (Pavg). Also shown are irrigation amounts applied to the irrigated treatments at each site (half the plots, with the other half receiving no irrigation).

		Akron			Sidney		
Year	Month	P	Pavg†	Irrigation	P	Pavg‡	Irrigation
		mm					
2012–2013	Oct.	15	23	0	26	23	13
	Nov.	4	14	0	3	12	0
	Dec.	10	11	0	6	8	0
	Jan.	3	8	0	4	7	0
	Feb.	10	9	0	16	9	0
	Mar.	49	21	0	8	23	0
	Apr.	37	42	25	58	41	13
	May	40	73	143	81	73	25
	June	50	62	71	74	80	20
	July	–§	–	–	30	63	0
	Growing season	269	263	239	306	276	71
2013–2014	Oct.	27	23	0	35	23	0
	Nov.	8	14	0	14	12	0
	Dec.	3	11	0	1	8	0
	Jan.	25	8	0	8	7	0
	Feb.	10	9	0	27	9	0
	Mar.	21	21	0	12	23	0
	Apr.	38	42	0	13	41	0
	May	97	73	22	97	73	36
	June	83	62	112	81	80	14
	July	58	67	0	19	66	0
	Growing season	387	330	134	301	342	50

† 1908–2013.

‡ 1946–2013.

§ No Akron values given for July in 2013 because crop reached physiological maturity in June.

of increasing soil water content that would indicate deep percolation.

Water use efficiency was calculated as grain yield (kg ha^{-1}) divided by full season water use (mm). Plant biomass samples were collected at harvest from one sample site near the center of each plot. Sample size areas were 0.19 m^2 (2013) and 0.38 m^2 (2014) at Akron and 0.25 m^2 at Sidney. Samples were oven-dried at 60°C to 0 g kg^{-1} moisture content. Harvest index was calculated as seed weight divided by total aboveground biomass weight.

Residue cover and precipitation storage efficiency between cover crop termination and wheat planting were evaluated at Akron in both years. Residue cover was evaluated at Akron by the method described by Nielsen et al. (2012) in which four photographs in each plot were taken with a digital camera held level with the horizon and at arm's length to the south of the photographer at midday to minimize shadows. Each digital image was subsequently analyzed using SamplePoint Measurement Software v. 1.53 (Booth et al., 2006; USDA-ARS, 2012). The SamplePoint software was set to select 64 randomly located points in each image. The software operator classified each of the 64 points as either crop residue or soil. The residue cover percentage was calculated as the fraction of 64 sample points that overlaid crop residue. The results from the four areas photographed in each plot were averaged to give a single value of residue cover for each plot at each sampling time. Residue cover was evaluated following cover crop planting (only millet residue was present at this time), following cover crop termination, and immediately following wheat planting in 2012 and 2013. An additional measurement of residue cover was made in 2012 just before wheat planting. No residue cover measurements were made at Sidney.

Precipitation storage efficiency before wheat planting was calculated as the difference between soil water content at cover crop termination and at wheat planting divided by precipitation over that interval. Available soil water at wheat planting was calculated for each 30-cm soil layer as

$$(\text{Volumetric water} - \text{lower limit}) \times \text{layer thickness}$$

where the lower limit of water availability was determined previously from the lowest volumetric water observed under winter wheat for this soil type (Ritchie, 1981; Ratliff et al., 1983). Lower limit values used were given in Nielsen et al. (2011).

Analysis of variance for residue cover following cover crop termination and following wheat planting, precipitation storage efficiency, available soil water at wheat planting, cover crop water use, grain yield, water use efficiency, wheat biomass and harvest index was performed with Statistix 10 software (Analytical Software, Tallahassee, FL). Treatment effects were considered significant when the probability of achieving a greater value of F in the analysis of variance was equal to or less than 0.05.

Because of the widely differing water availability conditions from precipitation and irrigation between years and locations, we chose to analyze each of the location–year–irrigation treatment data sets as separate analyses. Considering each of the location–year–irrigation treatment combinations as a separate water availability environment and assuming environment as a random effect and crop as a fixed effect, the analysis of variance showed significant environment and crop treatment differences for precipitation storage efficiency, available soil water at wheat planting, wheat water use, yield, water use efficiency, biomass, and harvest index (Table 4). There were also significant environment by crop interactions for precipitation storage efficiency, wheat water use, yield, water use efficiency, and biomass, but not for available soil water at planting and harvest index. Therefore, the data were analyzed as eight individual randomized complete block analyses by location and year and water treatment.

We previously reported that there were no consistent significant differences in soil water contents or growing season crop water use among the different cover crop species (Nielsen et al., 2015a). In the current analysis we found that six of eight data sets showed no significant cover crop species effects on available soil water at wheat planting, and seven of eight data sets showed no significant cover crop species effects on wheat water use, yield, and water use efficiency (data not shown). Therefore, orthogonal contrasts were computed to compare the effects of fallow vs. cover crop ahead of wheat and to compare the effects of a cover crop mixture vs. single-species cover crops ahead of wheat.

In addition to the randomized complete block analysis of previous cover crop effects on water use efficiency computed as yield divided by water use, differences in water use efficiency due to previous cover crop were also assessed by computing linear regressions of wheat yield vs. water use (production functions). Regression slopes and intercepts were compared for significant differences using Statistix 10 software.

Table 4. Probability that the null hypothesis of no treatment differences due to location-year-irrigation treatment environment or previous cover crop treatment or the interaction of environment and cover crop is true. Environment was considered as a random effect and crop as a fixed effect in the analysis of variance.

Parameter	Environment	Crop	Environment × Crop
Precipitation storage efficiency†	<0.01	<0.01	<0.01
Available soil water at wheat planting	<0.01	<0.01	0.07
Wheat water use	<0.01	<0.01	0.02
Wheat yield	<0.01	<0.01	0.02
Wheat water use efficiency	<0.01	<0.01	0.01
Wheat biomass at harvest	<0.01	<0.01	0.02
Harvest index	<0.01	<0.01	0.15

† Precipitation storage efficiency between cover crop termination and wheat planting.

RESULTS

Precipitation

The precipitation received during the winter wheat growing seasons at the various locations during the 2 yr of the study ranged from 269 mm (Akron 2012–2013) to 387 mm (Akron 2013–2014) (Table 3). The sum of growing season precipitation plus irrigation ranged from 351 mm (Sidney 2013–2014) to 521 mm (Akron 2013–2014). As stated earlier, the much greater irrigation amounts applied at Akron compared with Sidney are the result of attempting to simulate the greater average growing season precipitation experienced in south-central Nebraska. These conditions provided a broad range of water availability for quantifying cover crop effects on subsequent wheat water use, yield, and water use efficiency.

Residue Cover, Precipitation Storage Efficiency between Cover Crop Termination and Wheat Planting, Available Soil Water at Wheat Planting, and Wheat Water Use

Fallow Treatment vs. Cover Crop

Residue cover values following cover crop termination and residue dry-down (Table 5) and following wheat planting were only measured at Akron. Under the dryland (rainfed) condition, the residue cover following cover crop termination was not significantly greater for the cover crop treatments than for the proso millet fallow treatment, averaging 68.4% for the fallow treatment and 73.0% for the cover crop treatments. However, for the irrigated treatments, where the additional available water increased cover crop biomass production (Nielsen et al., 2015b) and increased decomposition of the proso millet residue, the cover crop residue cover (average 81.9%) was greater than the proso millet residue cover in the fallow treatment (average 60.7%). Residue cover following wheat planting was greater in all four data sets where cover crops had been grown (average 44.9%) compared with the fallow treatment (average 24.1%) which showed a large loss of residue cover due to residue decomposition and destruction by the grain drill during planting. These differences in residue cover led to consistently greater precipitation storage efficiency where the cover crops were present (average 20.1% at Akron, 39.6% at Sidney) compared with the fallow treatment (average 1.4% at Akron, 19.3% at Sidney). Averaged over both sites, both years, and both water availability conditions, precipitation storage efficiency between cover crop termination and wheat planting averaged 29.8% for the five cover crop treatments compared with 10.4% for the proso millet residue fallow treatment. The available water at wheat planting was always numerically greater for the fallow treatment compared with the cover crop treatment, but only significantly so for five of the eight data sets. This was due to a longer fallow period in the fallow treatment and the cover crops using moisture (Nielsen et al., 2015a). Averaged over all eight data sets the available water at wheat planting was 16% greater for the fallow treatment (263 mm) than for the average cover crop treatment (226 mm). Likewise, wheat water use was always numerically greater for the fallow treatment than for the cover crop treatment, but only significantly so for six of the eight data sets. Averaged over all eight data sets the wheat water use was 8% greater for the fallow treatment (511 mm) than for the average cover crop treatment (471 mm).

Ten-Species Mixture vs. Single-Species Plantings of Cover Crops

Residue cover values at cover crop termination were not significantly different for the 10-species cover crop mixture compared with the average of the single-species plantings (Table 6) except for the Akron-Irrigated data set collected in 2012 at cover crop termination. Following wheat planting, residue cover was not different for the mixture compared with the single-species plantings in any of the four data sets. There were, however, significant differences in precipitation storage efficiency between cover crop termination and wheat planting for three of the eight data sets, with precipitation storage efficiency being greater for the mixture treatment in two of those data sets and lower for the mixture in one data set. Averaged over all eight data sets, precipitation storage efficiency was not different for the mixture (30.4%) compared with the single-species plantings (29.7%). Available water at wheat planting was significantly greater for the mixture compared with the single-species plantings only for the Akron-Irrigated data set in 2013–2014. Averaged over all eight data sets the available water at wheat planting was not significantly different for the cover crop mixture treatment (233 mm) compared with the average of the single-species cover crop treatments (225 mm). Water use was not significantly different for wheat following the 10-species mixture compared with wheat following the single-species cover crops in any of the eight data sets or averaged over all eight data sets.

Wheat Grain Yield, Water Use Efficiency, Biomass Dry Weight, and Harvest Index

Fallow Treatment vs. Cover Crop

Grain yield was significantly greater for the fallow treatment compared with the average cover crop treatment at both Akron and Sidney (under both water treatments) for the 2012–2013 crop (Table 5). The percent increase in yield was greatest (66%) for the dryland treatment at Akron and least for the irrigated treatment at Akron (10%). At Sidney wheat yield was 22% greater for the fallow treatment than for the cover crop treatment in the dryland situation and 20% greater for the irrigated situation. The much lower wheat yields at Akron for the 2012–2013 crop compared with the 2012–2013 crop at Sidney are a result of the lower water use (lower available water at planting and lower growing season precipitation) and a hail storm a week before physiological maturity resulting in some yield loss due to shattering. Under the generally wetter conditions encountered during the 2013–2014 growing season, there were no significant differences in wheat yield between the fallow treatment and the average cover crop treatment.

Wheat water use efficiency ranged from 3.70 kg ha^{-1} mm^{-1} for the average cover crop treatment under the driest condition (Akron-Dryland in 2012–2013) to 9.83 kg ha^{-1} mm^{-1} for the wettest condition (Akron-Irrigated in 2012–2013) when the average wheat water use was 643 mm, averaged across all six previous crop treatments (one fallow treatment and five cover crop treatments). Generally, water use efficiency was not different between the fallow treatment and the average cover crop treatment except for dryland treatments during the 2012–2013 growing season at both Akron and Sidney when water use efficiency was greater for the wheat grown on fallow. These two data sets had the lowest yields.

Table 5. Percent residue cover at cover crop termination and at winter wheat planting, precipitation storage efficiency (PSE) between cover crop termination and wheat planting, available soil water at wheat planting, wheat water use, grain yield, water use efficiency, biomass dry weight at harvest, and harvest index at Akron, CO, and Sidney, NE. Table shows the orthogonal contrast of the values from the fallow treatment with proso millet residue compared with the average value for all of the five cover crop treatments (flax, oat, pea, rapeseed, and 10-species mixture).

Location	Year	Water treatment	Previous crop	Residue cover following cover crop termination	Residue cover following wheat planting	PSE	Available water at planting†	Water use	Grain yield‡	Water use efficiency	Biomass dry weight	Harvest index
				————	%	————	mm		kg ha^{-1}	kg ha^{-1} mm^{-1}	kg ha^{-1}	
Akron	2012–2013	Dryland	Fallow	73.3	27.3	2.9	168	324	1845	5.62	7,870	0.26
			Cover Crop	74.7	49.7	20.0	151	293	1110	3.70	5,625	0.23
			P	0.67	<0.01	<0.01	0.40	0.10	0.01	0.01	0.06	0.62
		Irrigated	Fallow	67.8	28.5	7.9	272	699	6855	9.81	16,800	0.45
			Cover Crop	83.0	54.4	28.6	202	632	6210	9.83	14,600	0.47
			P	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.96	0.09	0.60
Akron	2013–2014	Dryland	Fallow	63.5	23.3	3.2	329	536	4460	8.32	9,920	0.49
			Cover Crop	71.3	37.8	17.1	292	500	4240	8.47	8,775	0.52
			P	0.15	<0.01	<0.01	0.16	0.14	0.47	0.79	0.10	0.39
		Irrigated	Fallow	53.6	17.4	−8.3	336	617	5625	9.13	12,065	0.50
			Cover Crop	80.7	37.7	14.7	318	585	5435	9.30	11,455	0.51
			P	<0.01	<0.01	<0.01	0.07	0.04	0.43	0.73	0.40	0.65
Sidney	2012–2013	Dryland	Fallow			39.5	208	440	3310	7.57	8,930	0.43
			Cover Crop			49.0	158	396	2710	6.82	7,800	0.43
			P			0.11	<0.01	<0.01	<0.01	0.08	0.18	0.99
		Irrigated	Fallow			28.4	263	584	4180	7.21	10,170	0.43
			Cover Crop			42.3	217	532	3490	6.53	10,445	0.41
			P			<0.01	<0.01	<0.01	0.01	0.08	0.78	0.33
Sidney	2013–2014	Dryland	Fallow			3.9	256	426	3895	9.15	13,240	0.31
			Cover Crop			36.9	238	401	3730	9.30	12,910	0.30
			P			<0.01	0.01	0.05	0.26	0.73	0.73	0.66
		Irrigated	Fallow			5.4	268	461	4335	9.50	13,485	0.31
			Cover Crop			30.1	235	424	4105	9.68	13,855	0.32
			P			<0.01	0.02	0.01	0.22	0.74	0.69	0.84
Average			Fallow	64.5	24.1	10.4	263	511	4315	8.29	11,560	0.40
			Cover Crop	77.4	44.9	29.8	226	471	3880	7.96	10,685	0.40
			P	<0.01	<0.01	<0.01	<0.01	0.07	0.16	0.44	0.21	0.92

† Available soil water at wheat planting in the 0- to 180-cm soil profile at Akron and in the 0- to 120-cm soil profile at Sidney.

‡ Grain yield reported at 125 g kg^{-1} moisture content.

Table 6. Percent residue cover at cover crop termination and at winter wheat planting, precipitation storage efficiency (PSE) between cover crop termination and wheat planting, available soil water at wheat planting, wheat water use, grain yield, water use efficiency, biomass dry weight at harvest, and harvest index at Akron, CO, and Sidney, NE. Table shows the orthogonal contrast of the values from the 10-species cover crop mixture treatment compared with the average value for all four single-species cover crop treatments (flax, oat, pea, rapeseed).

Location	Year	Water treatment	Previous crop	Residue cover following cover crop termination	Residue cover following wheat planting	PSE	Available water at planting†	Water use	Grain yield‡	Water use efficiency	Biomass dry weight	Harvest index
				——————% ——————			mm		kg ha^{-1}	kg ha^{-1} mm^{-1}	kg ha^{-1}	
Akron	2012–2013	Dryland	Mixture	78.3	54.3	21.6	152	304	1315	4.21	5,325	0.27
			Single Species	73.8	48.5	19.5	150	291	1060	3.58	5,700	0.22
			P	0.25	0.21	0.68	0.95	0.43	0.30	0.35	0.76	0.48
		Irrigated	Mixture	87.2	56.9	35.9	224	645	6130	9.47	16,680	0.39
			Single Species	82.0	53.8	26.7	197	628	6225	9.92	14,080	0.49
			P	0.03	0.38	<0.01	0.19	0.23	0.78	0.38	0.03	0.05
Akron	2013–2014	Dryland	Mixture	69.3	30.9	11.3	300	515	4510	8.75	7,925	0.61
			Single Species	71.9	39.5	18.5	290	496	4170	8.40	8,990	0.50
			P	0.46	0.06	0.07	0.73	0.49	0.33	0.58	0.12	0.02
		Irrigated	Mixture	76.9	33.6	3.1	334	607	5545	9.13	11,205	0.53
			Single Species	81.7	38.8	17.6	314	580	5410	9.34	11,520	0.51
			P	0.07	0.37	0.02	0.05	0.13	0.52	0.65	0.69	0.64
Sidney	2012–2013	Dryland	Mixture			53.3	167	400	2845	7.07	9,630	0.42
			Single Species			48.0	156	395	2680	6.76	7,345	0.44
			P			0.36	0.34	0.65	0.36	0.50	0.02	0.27
		Irrigated	Mixture			49.2	220	534	3545	6.65	10,275	0.43
			Single Species			40.6	217	532	3480	6.50	10,485	0.41
			P			0.04	0.72	0.78	0.78	0.70	0.78	0.26
Sidney	2013–2014	Dryland	Mixture			38.6	239	403	3660	9.09	12,510	0.25
			Single Species			36.4	237	401	3750	9.35	13,010	0.31
			P			0.49	0.73	0.85	0.50	0.49	0.51	0.11
		Irrigated	Mixture			30.6	228	411	4030	9.84	12,335	0.31
			Single Species			30.0	236	427	4125	9.64	14,235	0.32
			P			0.86	0.40	0.14	0.54	0.59	0.04	0.93
Average												
			Mixture	77.9	43.9	30.4	233	477	3950	8.03	10,735	0.40
			Single Species	77.3	45.2	29.7	225	469	3860	7.94	10,670	0.40
			P	0.84	0.72	0.80	0.53	0.70	0.79	0.85	0.93	0.91

† Available soil water at wheat planting in the 0- to 180-cm soil profile at Akron and in the 0- to 120-cm soil profile at Sidney.

‡ Grain yield reported at 125 g kg^{-1} moisture content.

Neither wheat biomass dry weight nor harvest index were significantly affected by the previous crop treatment (fallow vs. cover crop). Six of the eight data sets showed numerically greater biomass for the wheat following fallow compared with the wheat following cover crop.

Ten-Species Mixture vs. Single-Species Plantings of Cover Crops

For all eight data sets shown in Table 6 there were no significant differences in wheat grain yield and water use efficiency when comparing the 10-species mixture with the single-species plantings. For five of the eight data sets there were no significant differences in biomass dry weight between wheat grown following a cover crop mixture and wheat grown following a single-species cover crop. Significantly greater wheat biomass was observed for the wheat grown after the mixture compared with the single-species planting for the Akron-Irrigated treatment and the Sidney-Dryland treatment during 2012–2013. For the Sidney-Irrigated treatment during 2013–2014, the greater wheat biomass was produced following the single-species cover crop plantings than following the cover crop mixture. There was a significant effect of the mixture on harvest index in two of the eight data sets but the effect was not consistent. The cover crop mixture reduced harvest index compared with the single-species cover crops for the Akron-Irrigated data set in 2012–2013, but increased harvest index compared with the single species cover crops for the Akron-Dryland data set in 2013–2014. Averaged over all eight data sets, the cover crop mixture did not significantly affect wheat grain yield, water use efficiency, biomass dry weight, or harvest index differently than the single-species cover crops.

DISCUSSION

Of the eight separate data sets considered in the previous Results section, the cover crop treatment significantly reduced wheat water use in six of those sets compared with the wheat water use following fallow, but only reduced wheat grain yield in four sets, and water use efficiency in one set. Two of those four sets when wheat yield was affected occurred during 2012–2013 at Akron when rapeseed was not adequately terminated with the first herbicide application and continued to use water until the second herbicide application. This observation reinforces the conclusion presented by Unger and Vigil (1998) that timely termination of cover crops is essential in semiarid environments (discussed further below). The other two data sets in which wheat yields were significantly affected by previous cover crop treatment were in 2012–2013 at Sidney. In the dryland set only the flax and oat cover crops significantly reduced wheat yield compared with the wheat on fallow, and in the irrigated set only the oat cover crop significantly reduced wheat yield compared with the wheat on fallow (data not shown). In none of the data sets did the presence of the cover crop mixture grown ahead of wheat significantly reduce wheat yield compared with the wheat on fallow. This is in contrast to the results of previous studies (Table 1) conducted in Akron, Sidney, Garden City, and Tribune, KS, which have shown significant yield reductions in wheat yields following the growth of another crop (Nielsen and Vigil, 2005; Lyon et al., 2004; Holman et al., 2014; Schlegel and Havlin, 1997). Lyon et al. (2007), Nielsen et al. (1999), and Nielsen et al. (2002) likewise showed that previous crop water use depleted soil water availability to the subsequent wheat crop and significantly reduced wheat yield.

The yield data collected in the present study at Akron and Sidney in 2013–2014 likely showed no significant effect of cover crop treatment on wheat yield because of the greater starting soil water contents and precipitation in that year. Additionally, precipitation storage efficiencies during the period between cover crop termination and wheat planting were generally very low (Table 5) for the proso millet fallow treatment compared with the cover crop treatments. This was due to the poor condition of the millet residue at this time (about 9 mo after millet harvest) compared with the new cover crop residue. In these other studies mentioned in the previous paragraph, the prior wheat residue was in much better condition (much still standing) than the proso millet residue in the current study (very degraded and flat) and consequently precipitation storage efficiencies for the fallow treatments in these previous studies were likely not as different from those in the cover crop/previous crop residue. In other words, a likely reason that consistent significant reductions in wheat yield were not observed in the present study due to cover crop growth and water use compared with wheat on fallow was because of the poor condition of the millet residue that led to very low storage of precipitation, and relatively much greater cover crop residues that led to greater storage of precipitation. These data demonstrate that under some conditions (greater water availability and poor condition of existing residue) cover crops may be grown without causing significant yield reductions to the next wheat crop. However, even though in some years there may be no (or only minor) wheat yield depressions following cover crops, in those years there will be lowered economic returns due to the costs associated with cover crop seed and planting and termination operations that a farmer must consider and account for. These may be offset if the cover crop can provide some economic benefit through forage harvest or grazing, as seems to fit the current definition of cover cropping (Franzluebbers and Stuedemann, 2008). Lyon et al. (2004) reported that an oat/pea forage mixture reduced the following winter wheat yield, but was economically similar to a winter wheat–fallow system. Nielsen et al. (2015b) concluded that the biomass production of both single-species plantings and mixtures at Akron and Sidney was likely sufficient to allow for some removal for livestock feed. However, in some years with low precipitation or limited stand establishment, removal of any amount of biomass would have to be considered carefully in light of the potential for increased soil loss by wind erosion.

Even though only four of the eight data sets in the present study showed significant wheat yield reductions due to the preceding cover crop growth and water use, in all eight data sets the yield following cover crop was numerically lower than the yield following fallow. The average yield following a cover crop was about 10% lower than the yield following fallow, regardless of whether the cover crop was grown as a mixture or as a single species, but ranged from 3 to 40%.

Figure 1 shows the relationship between wheat water use and grain yield from all of the data collected in the current study. The water use/yield production function (from linear regression analysis) is nearly identical to a previously published water production function for wheat generated from data collected at Akron (Nielsen et al., 2011). Clearly wheat yield is highly correlated with water use (Table 7, top). Although a statistically significant wheat yield depression from prior cover crop growth and water use was not consistently seen in the data sets analyzed in this study, all eight of the data sets had numerically higher wheat yields from the fallow treatment compared with the average cover crop treatment (Table 5). Farmers need to be aware that water use by the cover crop that is not replenished by precipitation or irrigation during the period between cover crop termination and wheat planting will reduce available soil water and wheat water use, and consequently reduce wheat yield at the rate of about 12.39 kg ha^{-1} for every millimeter that water use is reduced (Table 7, top).

Linear regressions performed on each of the six separate data sets defined by previous cover crop treatment (Fig. 1, separate colors for each cover crop treatment; Table 7, top) showed the regression slopes ranging from 11.33 kg ha^{-1} mm^{-1} (wheat on fallow) to 13.57 kg ha^{-1} mm^{-1} (wheat following rapeseed), but neither the slopes nor the intercepts of these regressions were different from one another (Table 7, bottom), with the slope of the wheat following the cover crop mixture being 11.80 kg ha^{-1} mm^{-1}. Additionally, the analysis presented in Table 6 did not indicate any difference in wheat water use efficiency for wheat following the cover crop mixture compared with wheat following the single-species cover crops. Therefore, we conclude that growing a cover crop mixture did not improve the water use efficiency of subsequent wheat production.

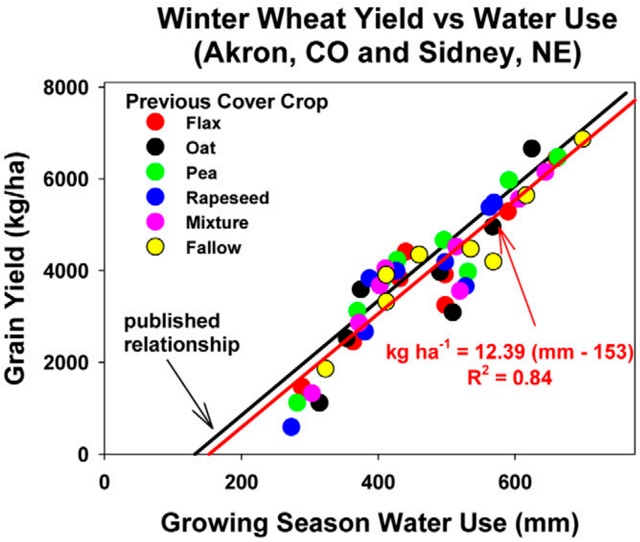

Fig. 1. Winter wheat water use and yield following fallow, flax, oat, pea, rapeseed, and a 10-species mixture of cover crops grown at Akron, CO, and Sidney, NE, in 2013 and 2014. The published relationship is from Nielsen et al. (2011).

Table 7 (top). Regression slopes and intercepts of linear regression lines fit to mean wheat water use and yield data following five cover crop treatments or no-till fallow at Akron, CO, and Sidney, NE, in 2012 and 2013 (for regression with form Yield = a × [water use – b]), and matrices of regression slope and intercept comparison statistics.

Previous crop	Slope (a)	x-axis offset (b)	R^2
	kg ha^{-1} mm^{-1}	mm	
Flax	12.32	158	0.88
Oat	13.12	173	0.76
Pea	12.67	144	0.89
Rapeseed	13.57	181	0.82
Mixture	11.80	138	0.86
Fallow	11.33	123	0.89
All	12.39	153	0.84
Previously published†	12.49	132	

† Nielsen et al. (2011).

Table 7 (bottom). Matrices of regression slope and intercept comparisons. Matrix values are the probability that the null hypothesis (slopes [or intercepts] of the water use-yield regression lines are equal) is true. Probability values were computed using the facility of Statistix 10 software to compare regression lines.

Regression slope comparison

Previous crop	Flax	Oat	Pea	Rapeseed	Mixture
Oat	0.82				
Pea	0.90	0.90			
Rapeseed	0.70	0.91	0.78		
Mixture	0.85	0.71	0.75	0.60	
Fallow	0.70	0.60	0.59	0.47	0.86

Regression intercept comparison

	Flax	Oat	Pea	Rapeseed	Mixture
Oat	0.90				
Pea	0.32	0.50			
Rapeseed	0.82	0.94	0.51		
Mixture	0.80	0.92	0.47	0.98	
Fallow	0.81	0.95	0.42	0.98	1.00

Additionally, in none of the data sets shown in Table 6 did wheat following the 10-species mixture use less water, have greater yield, or have greater water use efficiency compared with the single-species cover crop treatments. Apparently the presence of a greater diversity of prior crop species and root types, and presumably associated greater diversity of soil microorganisms, compared with single-species cover crops did not affect the efficiency with which water was used to produce grain by a subsequent wheat crop. We were not able to measure a greater diversity of soil microorganisms where a cover crop mixture was grown compared with single-species plantings (Calderón et al., 2015). The main factor determining yield development in this study appears to have been water availability either from available soil water at planting or from seasonal precipitation or irrigation.

The lowest water use efficiency values (Tables 5 and 6) were observed for the Akron 2012–2013 data set. There are two main reasons for these low values, and both can be seen in Fig. 1. In that figure the six data points with the lowest water use and yield are from the Akron 2012–2013 data set. The points are below the regression line because of a hail storm on 24 June 2013 (a week before physiological maturity) which resulted in seed loss due to shattering for the dryland plots but not for the irrigated plots. The second reason for the lower observed water use efficiency for this data set is computational. As we move from right to left along the water use axis in Fig. 1 and approach the *x* axis intercept (a quantification of the amount of evaporation), the fraction of total water use attributable to evaporation and not used for yield formation increases. Therefore, the computed water use efficiency decreases. Other factors will also influence water use efficiency, such as timing of growing season precipitation and fraction of total water use that comes from stored soil water as opposed to growing season precipitation. For example, a year with a full profile of soil water at planting will result in greater water use efficiency than a year in which a large fraction of water use comes from growing season precipitation. However, in this current study the primary reasons for lower water use efficiency for the Akron 2012–2013 dryland data set are, again, late season hail causing some shattering yield loss and greater fraction of growing season water use attributable to evaporation at low water use values.

While some of the previous studies shown in Table 1 did not deal with cover crops terminated at early developmental stages (e.g., Lenssen et al., 2007), they still demonstrate the significant yield-reducing effect of a preceding crop's water use on the subsequent crop yield. Clearly, late termination dates do not have little effect on subsequent crop yields in semiarid regions, which raises the question whether recommendations by USDA-Natural Resource Conservation Service are correct. The NRCS recommendation for cover crop termination at Havre, MT (the site of the Lenssen et al. (2007) study) is for termination 35 d before cover crop planting (http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=34072.wba). In contrast, the data from Lenssen et al. (2007) showed major yield reductions (about 40%) for spring wheat planted 240 to 280 d after previous crop harvest compared with wheat after fallow. Similarly, the data from Nielsen and Vigil (2005) at Akron showed that cover crops terminated 100 d before winter wheat planting reduced wheat yields by 900 kg ha^{-1} (6-yr average), which contrasts with the NRCS recommendation for Akron to terminate cover crops 35 d before planting to have little or no effect on wheat yield. The NRCS recommendations appear to be based on computer simulation results reported by Poore (2013). Clearly, the recommendation of Unger and Vigil (1998) that cover crops be terminated as early as possible after acquiring sufficient biomass and ground cover to provide erosion protection should be followed in semiarid production regions.

We did not investigate the use of fall-seeded cover crops, even though fall-seeded cover crops would likely produce biomass more quickly in the spring (if they did not winterkill) than spring-seeded crops and allow for earlier termination or greater residue cover at termination. Both of these results would likely be positive for soil water storage before fall wheat seeding. However, there are several potential problems with the use of fall-seeded cover crops in this environment. The first potential problem is successful establishment of a fall-seeded cover crop following a summer crop such as proso millet (as we used in this experiment) which is harvested in early to mid-September. Successful establishment of a fall-seeded cover crop is even more difficult following a longer-season summer crop such as sunflower (*Helianthus annuus* L.) or corn (*Zea mays* L.). Precipitation in the region declines rapidly in late summer and through the fall. Sufficient soil moisture to establish a fall crop decreases considerably if harvest of the summer crop does not occur until mid-September or later. A second potential problem is a consequence of the relatively short growing season in the semiarid portion of the central Great Plains. Even if a fall-seeded cover crop is successfully established following a summer crop, little biomass would accumulate before the end of the fall growing season. A third potential problem that must be considered is that valuable standing crop residues would be destroyed during the process of seeding the cover crop, and cover crop biomass would be insufficient by the end of the fall growing season to compensate for that loss. The loss of standing crop residue reduces soil protection against wind erosion (Bilbro and Fryrear, 1994; Nielsen and Aiken, 1998) and snow capture for soil water storage (Aase and Siddoway, 1980; Nielsen, 1998).

CONCLUSIONS

A large volume of previous work conducted in the semiarid Great Plains of the United States has shown that prior crop water use generally will reduce yields of the subsequent crop. While this study did not show consistent statistically significant wheat yield reductions due to cover crop growth ahead of wheat production, neither did it show yield increases due to cover crops grown ahead of the wheat. Additionally, cover crop mixtures did not use less water than cover crops grown as single species and wheat yields following the cover crop mixture were not different from wheat yields following the single-species plantings of cover crops. The water use efficiency of wheat production was not different for wheat following a cover crop mixture compared with wheat following single-species plantings of cover crops or wheat following a fallow period as determined by the slopes of the water use/yield relationships. Therefore, the large amount of previous research detailing the generally detrimental effects on yield due to previous crop water use in dryland semiarid environments should be used to guide decisions about cover crop use in the central Great Plains region. If cover crops are needed to augment existing crop residues to provide erosion protection or for supplemental livestock feed, the added expense generally seen for cover crop mixtures compared with single-species plantings (Nielsen et al., 2015a) is not likely to be justified.

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