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Cover crop effects on soil water relationships

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Interpretive summary

Cover crops help control erosion, fix nitrogen, reduce nutrient leaching, improve soil conditions, and protect seedlings, but they also use soil water. Such use may not cause a water shortage for the next crop where precipitation is adequate, as in humid regions, but may reduce yields where precipitation is low, as in semiarid regions. Therefore, cover crops are better suited to humid and subhumid regions than to semiarid regions. Most benefits lost where cover crops are not used can be recovered by using conservation tillage, which retains crop residues on the soil surface.

Key words: conservation tillage, cover crops, green manure crops, residue management, soil water content, soil water storage, water conservation.

ABSTRACT: Cover crops help control erosion, prevent nutrient leaching, fix nitrogen, improve soil conditions, and protect seedlings, but also use water, thus affecting soil water relationships for the next crop. Effects are positive when cover crops are managed to improve infiltration and decrease evaporation, or to remove water from a wet soil to allow timely establishment of the next crop. Effects are negative when they limit water for the next crop or aggravate a wet soil condition. Cover crops are better suited to humid and subhumid regions where precipitation is more reliable than to semiarid regions where precipitation is limited. Where cover crops are not used, use of conservation tillage that involves crop residue retention on the soil surface helps conserve soil water and provides many of the benefits of cover crops, except for nitrogen fixation, soil nutrient (especially nitrate) uptake to prevent leaching, excess water removal, and additional organic matter inputs.

Cover crops are grown, for the following reasons (among others):

- to provide soil cover and erosion control during otherwise non-cropped periods;
- to immobilize soluble nutrients (nitrates) to prevent their loss by leaching;
- to convert atmospheric nitrogen (by legumes) to biomass nitrogen that can mineralize in soil and become available for use by the next grain crop;
- to add organic matter to soils and improve soil aggregation; and
- to provide cover and protection to seedlings of perennial crops during establishment (Power 1996).

Specific reasons for growing cover crops vary among sites and regions, but a consequence in all cases is that they use soil water, which can positively, neutrally, or negatively affect the soil water supply for the next crop. In this report, we discuss conditions under which different effects generally prevail and management options that can be used to enhance positive effects and reduce or circumvent negative effects.

Winter cover crops may affect soil water relationships for summer crops by 1) decreasing evaporation due to the mulch formed, 2) increasing infiltration of rainfall, 3) using stored soil water by transpiration, and 4) changing the soil water use pattern by the summer crop (Smith et al. 1987). Maintaining cover crop residues on the soil surface through use of conservation tillage probably is the most effective way to increase plant-available soil water under field conditions (Frye et al. 1988). Such management improves soil water conditions by 1) decreasing runoff, 2) increasing soil organic matter and improving soil structure, and 3) decreasing soil water evaporation.

Cover crop effects on soil water relationships are positive or neutral where infiltration of precipitation is adequate and timely to replenish the soil water supply so the next crop does not become stressed for water, and on well-drained soils so that plants are not adversely affected by too much water. The soil water replenishment can occur before or after terminating growth of the cover crop. The time of termination becomes more critical as the probability of expected precipitation decreases. Where irrigation is possible, the required water can be applied as needed, regardless of when cover crop growth is terminated.

The net effect of a cover crop on soil water conditions for the next crop depends on precipitation timing and amount, water infiltration and evaporation, and transpiration by the cover crop (Frye et al. 1988). The growing season of cover crops and the time and method of their termination relative to planting time for the next crop also affect the soil water conditions. Precipitation and infiltration in humid and subhumid regions generally are adequate to replenish the soil water used by cover crops. When adequate storage occurs, the next crop is not stressed for water as a result of the cover crop having been grown. Soil water storage may even be improved due to less runoff, greater infiltration, and less evaporation when cover crop residues are retained on the soil surface. Timing of cover crop termination can have a major positive effect on soils in humid regions for which the water content must be reduced for achieving improved conditions for performing cultural operations and establishing the crop. When allowed to grow as long as possible, transpiration by the actively growing cover crop can help dry the soil so the operations can be performed in a more timely manner (Wagger and Mengel 1988).

In general, cover crops deplete soil water supplies while they are growing and conserve water when they are killed, if the residues are retained on the surface. The effect of soil water depletion in humid and subhumid regions generally is not critical on soils characterized by moderate to high water-holding capacities, but may be highly detrimental on soils with low water-holding capacity or a root-restricting layer at a shallow depth (Wagger and Mengel 1988). Water depletion by cover crops generally is detrimental in regions such as the semiarid Great Plains where precipitation is limited and the next crop is grown without irrigation. The following are some examples for different climatic regions.

Humid to subhumid regions

Although precipitation amount and distribution may vary greatly among locations and years, the average annual precipitation (P) to potential evaporation (E_p) ratio is greater than 50% ($P/E_p > 0.50$) in subhumid to humid regions (Hatfield 1990). In the United States and Canada, this generally corresponds to the region where annual precipitation is greater than about 750 mm (about 30 in). The western boundary of this region is not precise, but generally is considered to lie between 75 and 80 degrees west longitude where it

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Table 1. Soil water content at time of planting corn in 1985 and 1986 as affected by cover type and management (adapted from Ewing et al. 1991)

	1985		1986
Treatments	0-15 cm	15-30 cm	0-15 cm
		m^3/m^3	
Fallow	0.157	0.187	0.180
Top growth until planting*	0.113	0.162	0.082
Top growth removed†	0.141	0.173	0.126

* Top growth killed with herbicides time of planting corn

† Top growth cut at 5-cm height with rotary lawn mower and removed by hand raking one week before planting corn

Table 2. Rye cover crop (CC) tillage system effects on soil water content and corn grain yield (adapted from Campbell et al. 1984a)

	Soil water content by depth (cm)				
CC management	0-15	15-30	30-45	45-60	Yield
		% by weight			kg/ha
Disked (no CC)	8.9	9.9	19.4	21.4	6160a*
CC disked (1 d before planting)	5.7	6.6	15.7	19.5	5490ab
CC (herbicide after planting)	5.4	5.6	13.7	18.5	4930b
CC strip (herbicide, 50% cover)	4.6	4.6	14.2	18.9	5040b
CC strip (mechanical, 50% cover	2.4	3.9	14.2	18.2	3920c

* Means followed be the same letter are not significantly different at $P \leq 0.05$

grades into the Great Plains of the United States and the Prairie Provinces of Canada. In general, no traditionally wet or dry seasons occur during the year in the subhumid to humid regions on the North American continent.

Moschler et al. (1967) evaluated effects of different winter cover crops on soil water contents and corn (*Zea mays* L.) production on several soils in Virginia. Overall, a rye (*Secale cereale* L.) cover crop was best because of superior winter hardiness, susceptibility to killing with herbicides, and production of a relatively large amount of persistent residues. Water contents at the 0 to 15-cm (0-6 in) depth of a silt loam at Blacksburg were greater during most of the growing season for corn with a killed rye cover crop than where a cover crop was not used. Similar trends in soil water contents for the treatments occurred at other depths (to 60 cm; to 24 in). Maintaining the maximum amount of rye cover on the surface resulted in corn yields similar to those where the rye was plowed under before planting the corn at Blacksburg. For all comparisons of the study, corn planted in rye sod yielded 44% more than corn with conventional tillage in 4 of 13 cases and yields were similar in the other cases. Soil water contents were greater for sod-planted than for conventional-tillage corn, especially in the first half of the growing season.

On a sandy loam in the Southern Piedmont, corn planted into tall fescue sod and irrigated with different amounts of water yielded from 7760 to 8670 kg/ha (6930-7440 lb/a) when the sod was 20% strip killed and 8300 to 10200 kg/ha (7410-9110 lb/a) when 100% killed. Without irrigation, respective yields were 5450 and 8430 kg/ha (4870 and 7530 lb/a) (Box et al. 1976), which indicated soil water storage from precipitation was generally adequate for corn production with killed sod, but not when the cover crop competed with the corn for soil water.

Ewing et al. (1991) evaluated cover crop and subsoiling effects on soil water availability and corn yields on the Coastal Plain region of North Carolina. The soils were a loamy sand in 1985 and a sand in 1986, both known to respond to in-row subsoiling. The crimson clover (*Trifolium incarnatum* L.) cover crop was either removed one week before planting corn or sprayed with herbicides at planting with the residues maintained in place. Results were compared with those for a fallow (no cover crop) treatment. Precipitation was below the long-term average during both years, which resulted in low soil water contents, especially where the clover grew until corn planting (Table 1). As compared with the fallow treatment, the cover crop reduced corn yields 500 kg/ha (450 lb/a) in 1985 and 900 kg/ha (800 lb/a) in 1986. In 1985, subsoiling overcame the corn yield reduction, with the better yields attributed to greater subsoil water use by the corn. Results of the study suggested that cover crops should be desiccated 7 to 10 days before planting corn in the region to minimize soil water depletion under dry, early-spring conditions. The authors also recommended in-row subsoiling for Coastal Plain soils that respond to it.

Also in the Coastal Plain region (Campbell et al. 1984a), soil water contents at 0 to 60 cm 15 days after planting corn were lower where a rye cover crop was killed with herbicides or by discing than where conventional tillage without a cover crop was used. Corn early growth and yields paralleled the water contents (Table 2). In a study involving soybean (Campbell et al. 1984b), a rye cover crop extracted 25 mm (1.0 in) water from the 0- to 37-cm (14.5 in) depth of soil during the 25 days after the land was disked (conventional tillage treatment) and when the rye desiccated. The lower water content delayed soybean germination and early-season growth, but yields were greater with the cover crop system because of greater water conservation during a late-season drought.

For a silt loam in Missouri, Zhu et al. (1991) compared effects of cover crop [Canada bluegrass (*Poa compressa* L.), chickweed (*Stellaria media* L.), and downy brome (*Bromus tectorum* L.)] and no cover crop (check) treatments on soil water contents and no-tillage soybean (*Glycine max* L.) production. The cover crops were allowed to grow until they reseeded themselves. Because chickweed reached maturity earlier than bluegrass or brome, water content and soybean yield reductions were less with chickweed. Water contents in late April for the chickweed, bluegrass, and brome treatments were 8, 23, and 31% less than for the check treatment. The brome and bluegrass treatments delayed soybean growth 7 to 14 days, decreased soybean yields 41 to 73%, and used water 36 to 75% less efficiently compared with the control treatment. In contrast, these differences for chickweed as compared with the check treatment were slight. Soybean yields for 3 years averaged 2460, 2010, 1460, and 680 kg/ha (2200, 1790, 1300, and 610 lb/a) with the control, chickweed, brome, and bluegrass treatments, respectively. Results of the study suggested chickweed has potential as a winter cover crop for soybeans in the Midwest region. An added attraction for chickweed was that it reseeded itself, which eliminated the cost for cover crop establishment and control.

Although drastic yield reductions occurred in some years, mean cotton (*Gossypium hirsutum* L.) yields for a study in Arkansas were greater with than without a cover crop. The yield response was highly dependent on conditions during the growing season, and cover crops used also had an effect (Keisling et al. 1994). Cotton yields in cover crop plots generally were lower in years with a dry spring and early summer whereas higher yields were obtained in years with a normal spring through June 1 and good rainfall in July and August. Other than for the check [no cover crop, 2260 kg/ha (2020 lb/a)], mean yields (1979-1988) were highest [2510 kg/ha (2240 lb/a)] with rye + hairy vetch (*Vicia villosa* Roth) and lowest [2350 kg/ha (2100 lb/a)] with vetch. The yield increases were attributed, in part, to greater soil porosity, hydraulic conductivity, and water retention with cover crops. Improved soil nitrogen fertility may have been involved also, but the greater response to rye + vetch than to vetch alone indicates nitrogen alone did not cause the response.

In Ontario, Canada, late killing resulted in more surface plant material than early killing of a rye cover crop. Late killing decreased soil water content early in the soybean growing season in one year, but increased it in another year. Reduced soybean growth early in one year vanished as the season progressed and yields were not affected by the time of killing the rye (Wagner-Riddle et al. 1994).

Reducing runoff and increasing infiltration are important ways by which cover crop residues retained on the soil surface increase soil water storage. When the residue cover slows runoff, more time is available for water infiltration. The residue cover also protects the surface from raindrop impact, thus reducing aggregate breakdown and the potential development of a surface seal or crust, which could reduce infiltration. Numerous studies have shown runoff is less and infiltration is greater where crop residues are maintained on the soil surface than where the residues are removed or plowed under (e.g. Andraski et al. 1985; Griffith et al. 1977; Harrold and Edwards 1972; Laflen et al. 1978; Mutchler and McDowell 1990; Onstad 1972; Rockwood and Lal 1974). Retaining cover crop residues on the soil surface should produce similar results.

After water has infiltrated a soil, controlling evaporation is important for retaining that water for later use by plants. Retaining crop residues on the soil surface reduces evaporation (e.g. Bond and Willis 1969; Frye et al. 1988; Hanks and Woodruff 1958; Jacks et al. 1955; Smika 1976; Unger 1976; Unger and Parker 1976), and results should be similar when cover crop residues are retained on the surface. A surface residue mulch reduces the evaporation rate, but does not decrease the amount of water that ultimately can be lost from a soil. Therefore, the mulch is most effective during short-term droughts (7 to 14 days, according to Bond and Willis 1969) and may have limited effect when the drought persists for a long time.

Summary for subhumid and humid regions. It is obvious precipitation amount and distribution relative to termination of a cover crop affect the soil water content at planting, and subsequent crop growth and yield; soil type and depth also are contributing factors. For maximum protection of the land, a cover crop should be allowed to grow until it provides sufficient ground cover. However, it should be terminated as early as possible to allow sufficient time for soil water storage before planting the next crop. Soil water use by cover crops also can be reduced by grazing or otherwise removing the plants. However, retaining cover crop residues as a surface mulch reduces runoff and increases infiltration, which enhance soil water storage. This effect would be reduced if the cover crop plants were grazed or removed. When cover crop residues are persistent and remain on the surface after killing them, they can provide water conservation benefits well into the growing season of the next crop.

Semiarid regions

Precipitation in semiarid regions ranges from 0.20 to 0.50 of the potential evaporation (P/E_p of 0.20 to 0.50; Hatfield 1990). Because of the limited precipitation, soil water conservation is highly important for successful dryland (rainfed) crop production in semiarid regions. The U. S. Great Plains and adjacent Canadian Prairies are the dominant semiarid regions in North America. In these regions, precipitation ranges from about 300 mm (about 12 in) adjacent to the Rocky Mountains to about 750 mm (about 30 in) at the eastern edge where it grades into the subhumid region. Most precipitation occurs in the late spring and summer months, but considerable snow occurs in some years, especially in the northern parts of the region. Another semiarid region is in California, Oregon, and Washington, which receive mostly winter precipitation.

Predominantly summer precipitation regions. Research conducted at various locations in the Great Plains before about 1960 showed that green manure crops often reduced yields of subsequent crops due to competition for water (Power 1990). [Note: Although green manure crops and cover crops are defined differently (Soil Conservation Society of America 1976), some of their functions are similar, and they are used interchangeably in this report.] Army and Hide (1959), for example, showed effects of green manure crops on wheat yields at two locations in Montana (Table 3). Because of lower yields in many cases, green manure and cover crops generally were not grown because they used water that subsequently was not available for the next crop. In recent years, however, new research on green manure and cover crops has been initiated because of improvements in germplasm, tillage and seeding methods, equipment, and crop production systems, along with concerns regarding fossil fuel shortages, mainly for nitrogen fertilizer production (Power 1990). Most of this research has been conducted in the northern Great Plains and in Canada where a spring wheat-fallow system that involved 3 months of wheat growing followed by 21 months of fallow was used for many years (Power 1990). Erosion, mainly by wind, often was serious during the long fallow unless the soil surface was protected by residues, and saline seeps developed under some conditions. To minimize these problems, more intensive or alternative cropping systems have been or are being introduced (B.J. Wienhold, Mandan, ND, personal communication, 1997). Included are spring wheat/winter wheat/sunflower (*Helianthus annuus* L.); spring wheat/corn/peas (*Pisum* spp.); and spring wheat in rotation with soybean, peas, safflower (*Carthamus tinctorius* L.), sunflower, buckwheat (*Fagopyrum esculentum* Moench), or canola (*Brassica* spp.). The fallow period is shorter for a winter wheat-fallow system (14 to 17 months), which is more commonly used in the central Great Plains, but erosion still can be severe during fallow. Hence, improved erosion control is another reason for evaluating cover crops in the Great Plains.

Results with green manure crops in Canada and the northern Great Plains have been variable with respect to yields of the next crop. At Swift Current, Sask., Biederbeck (1988) grew four annual legumes [black lentil (*Lens culinaris*), fieldpea (*Pisum sativum*), Tangier flatpea (*Lathyrus tingitanus*), and chickling vetch

Table 3. Average (37 year) wheat grain yields following green manure crops and fallow at two Montana locations (adapted from Army and Hide 1959)

Previous crop/condition	Moccasin, MT	Huntley, MT
	kg/ha	
Fallow	1100	1570
Fieldpea	1140	1080
Sweetclover	1050	790
Rye	1140	1070
Ave. annual precipitation (mm)	323	272

Table 4. Grain yield of spring wheat grown after fallow, wheat, and several annual legumes at Swift Current, Saskatchewan, Can., 1985-1989 (adapted from Biederbeck 1988 and Power 1990)

Treatment	1985	1986	1987	1988	1989	Avg.
			kg/ha			
Summer fallow	1260	3060	2180	1080	2450	1960*
Continuous wheat	830	2630	1150	330	1690	1330
Annual legumes†						
Incorporated	1230	3780	1660	540	2510	1950*
Desiccated	--	2950	2120	440	1950	--
Matured	890	1870	1200	110	1640	1140*

* Indicated yields must be divided by two because the systems result in one crop in 2 years.
† Average of four species, incorporated or desiccated with herbicide at bloom stage or allowed to mature.

Table 5. Soil water contents to 1.2-m depth at seeding and spring wheat yields following fallow and several medic cultivars in Montana (adapted from Sims 1989a)

1980 land use	Water, 1981	Yield, 1981	Yield, 1983
	mm	kg/ha	
Fallow	223	1950	2630
Barrel medic (Ghor)	216	2560	2210
Barrel medic (Jemalong)	216	2540	2240
Barrel medic (Cyprus)	206	2450	2250
Strand medic (Harbinger)	211	2760	2390
Snail medic (Robinson)	208	2270	2340
Black medic (George)	211	3750	2900

Table 6. Soil water contents at and after various methods of terminating sweetclover growth at Carrington, ND, in 1991 (adapted from Gardner 1992)*

Date and treatments	1.2-m depth	1.8-m depth
June 10	mm	
Sweet clover fallow	206	330
Black fallow	290	427
October 9		
Sweet clover-not terminated	157	254
Sweet clover-sprayed with herbicide	218	345
Sweet clover-plow	246	373
Sweet clover-sweep	251	404
Sweet clover-rotary mower	259	394
Sweet clover-disk	269	404
Sweet clover-hay	284	419
Black fallow	284	434
LSD	53	53

* Treatments imposed June 10. Rainfall was 312 mm between June 10 and October 9

(*Lathyrus sativus*)] as green manure crops and followed them with spring wheat. The green manure crops were seeded as early as possible and either disked or killed with herbicides at the full-bloom stage (6 to 7 weeks after planting). Plants on a part of each plot were not treated and allowed to mature. All residues were incorporated the next spring. Water use was confined mainly to the upper 60 cm (24 in), which was much shallower than for continuous spring wheat. At freeze-up time, soil water contents in green manure plots usually were 65 to 75% of those in fallow plots. When incorporated into the soil at the bloom stage, 5-year average wheat yields were similar in green manure and fallowed plots, with differences slight among the green manure crops. Allowing green manure crops to mature substantially reduced wheat yields whereas desiccating them resulted in intermediate yields (Table 4).

Whereas winter wheat would winterkill where residues are incorporated, growing winter wheat is possible where green manure crops are desiccated with their residues retained on the surface to provide cover and trap snow to control winter kill (Power 1990). This approach provides an opportunity to grow either type of wheat if soil water conditions become favorable.

For another study at Swift Current (Zentner et al. 1996), wheat grain yields after a green manure crop (black lentil) generally were lower than after fallow, primarily because of lower soil water contents after the green manure crop. The lentil was plowed under at the full-bloom stage, usually 8 to 10 weeks after planting. Wheat yields were lower, even though growing season precipitation was above average in 5 of the 6 years of the study. The authors concluded that for an annual green manure crop to be used successfully on the soil studied (brown soil), the green manure crop should be planted as early as possible (late April to early May) and terminated early in July, even if nitrogen fixation is reduced.

Results of the above studies show that green manure crops can replace fallow in some cases in Canada, which, besides maintaining yields of the next crop, can improve erosion control and may improve soil conditions. The feasibility of growing green manure crops will depend on economics, government policies, and other factors.

At Bozeman, Montana, several medic (*Medicago* spp.) cultivars increased soil nitrates, but had little effect on soil water contents at spring wheat seeding time. As a result, wheat after the medics yielded more than in fallow plots in 1981. In 1983, wheat yielded somewhat less after the medics, except after black medic (*M. lupulina*), which resulted in greater yields than fallow in both years (Table 5; Sims 1989a).

Soil water contents due to methods of terminating sweet clover growth at Carrington, North Dakota, are shown in Table 6 (Gardner 1992). Whereas the water content in fallow plots did not change between June 10 (termination date) and October 9, water contents increased substantially with some termination treatments, causing water contents with some treatments to be only slightly less than with the fallow treatment. Clearly, green manure crop management and termination date influence soil water contents and, therefore, yield potential of the next crop.

Sims (1989b) in Montana showed soil water use by green manure crops can be controlled by using evapotranspiration models or soil sampling as a guide to determine when green manure crops should be terminated. The results of Sims (1989b) and Gardner (1992) clearly suggest careful green manure crop management can minimize potential adverse effects on subsequent crops by avoiding excessive depletion of soil water.

Whereas use of green manure crops had mixed effects (positive to negative) on yields of subsequent crops (mainly spring wheat) in Canada and the northern U.S. Great Plains, generally negative effects on winter wheat yields occurred in the central and southern Great Plains. At Akron, Colorado, Vigil and Nielsen (1996) determined the effect of growing legumes (Austrian winter peas, spring field peas, and Indianhead lentils) during fallow on subsequent winter wheat yields, economics of the system, and termination dates for the legume. Austrian winter peas produced the most above-ground dry matter and nitrogen in the dry matter [130 kg/ha (116 lb/a)], but also reduced wheat yield by 400 kg/ha (360 lb/a) for the earliest termination date (late May) and at least 1050 kg/ha (940 lb/a) for the latest termination date (July to early August). Based on data for 2 years, water use by the legume the previous year accounted for 88% of the wheat grain yield variability. Using a N cost of \$0.42/kg (\$0.19/pound) and N production of 130 kg/ha (116 lb/a), the legume produced about \$55.00 worth of N/ha (\$22/a). However, the wheat yield reduction was valued at about \$150/ha (\$61/a). If the legume forage were harvested for hay, its value could be \$130/ha (\$53/a), which is still less than the grain yield reduction. Nitrogen fixed in soil would be of some value, but still much less than the grain yield reduction. Obviously, growing a legume during fallow is not a viable option economically under the conditions of this study at Akron, Colorado.

For a wheat-corn-fallow rotation at Stratton, Colorado, Poss (D. J. Poss, Ft. Collins, CO, personal communication, 1997) planted Austrian winter peas immediately after corn harvest (October or November) and Trapper spring peas in March, and harvested the peas in late June. Winter peas yielded 1520 kg/ha (1360 lb/a) and spring peas yielded 2080 kg/ha (1860 lb/a). Soil water contents were lower with both types of peas than with fallow (without peas) at wheat plant-

Table 7. Mean soil water contents at time of pea harvest and wheat seeding and wheat grain yields at Stratton, Colorado (adapted from D. J. Poss, Ft. Collins, CO, personal communication, 1997)

	Available soil water to 1.8-m depth at		
Treatment	Pea harvest, 1995	Wheat seeding, 1995	Yield, 1995
	mm		kg/ha
Austrian winter peas	152	121	1520
Trapper spring peas	195	168	2080
Control (no peas)	227	176	2130

Table 8. Straw mulch effects on soil water storage efficiency during fallow at Sidney, Montana; Akron, Colorado; and North Platte, Nebraska, 1962-1965 (adapted from Greb et al. 1967)

Mulch rate	Fallow period precipitation	Water storage efficiency
(kg/ha)	mm	%
0	355	16
1700	355-549	19-26
3400	355-648	22-30
6700	355-648	28-33
10100	648	34

Table 9. Straw mulch effects on soil water storage during fallow after wheat, sorghum grain yield, and water use efficiency (WUE), 1973-1976, Bushland, Texas (adapted from Unger 1978)

	Water storage			
Mulch rate	Amount	Efficiency	Yield	WUE
kg/ha	mm	%	kg/ha	(kg/m³)
0	72c*	22.6c	1780c	0.56
1000	99b	31.1b	2410b	0.73
2000	100b	31.4b	2600b	0.74
4000	116b	36.5b	2980b	0.84
8000	139a	43.7a	3680a	1.01
12000	147a	46.2a	3990a	1.15

* Column values followed by the same letter are not significantly different at $P \leq 0.05$

Table 10. Progress in fallow systems with respect to water storage and wheat yields, Akron, Colorado (adapted from Greb 1979)

		Water storage		
Years	Fallow tillage method	Amount	Efficiency	Yield
		mm	%	kg/ha
1916-30	Maximum; plow, harrow (dust mulch)	102	19	1070
1931-45	Conventional; shallow disk, rod weeder	118	24	1160
1946-60	Improved conventional; begin stubble mulch in 1957	137	27	1730
1961-75	Stubble mulch; begin minimum with herbicides in 1969	159	33	2160
1976-90	Estimated; minimum; begin no-tillage in 1983	183	40	2690

ing, which reduced subsequent wheat grain yields (Table 7). The general decrease in soil water from pea harvest to wheat planting was attributed to low precipitation and inadequate weed control. Although wheat yields are reduced, the cover crop provides protection against erosion and, if some of the crop is harvested as forage, most of the seed cost and income loss due to decreased wheat yields can be recovered.

The climate becomes increasingly harsh from north to south in the Great Plains with regard to dryland crop production. As a result, soil water storage during the noncrop period has been stressed for dryland crops in the central to southern Great Plains. Although some research with cover crops has been conducted in the central Great Plains (see studies above), only limited research on cover crops has been conducted in the southern Great Plains in recent years. Segarra et al. (1991) studied the effects of cover crops for cotton in Texas where precipitation is limited, the irrigation water supply is declining, and the potential for erosion, especially by wind, is great. For one treatment, wheat drilled after cotton harvest with stalks left standing was killed the following April with herbicides. Average cotton lint yields with the killed-wheat treatment were similar to those for a wheat (for grain)-cotton system with irrigation, but were lower after killed-wheat under dryland conditions because of below average rainfall. For both conditions, however, yields with the killed-wheat treatment were greater than with conventional tillage, indicating that soil water use by the wheat cover crop was not detrimental to cotton production. Soil water contents were not reported.

For the southern Great Plains, the closest to a cover crop during fallow for a winter wheat-fallow system was research at Bushland, Texas, on "delayed fallow" for which weed control after wheat harvest in summer was delayed until weed growth began the next spring. Water storage during fallow was 65 mm (2.6 in) with one-way disk tillage, 103 mm (4.1 in) with stubble mulch tillage, and 87 mm (3.4 in) with delayed stubble mulch tillage (Johnson and Davis 1972). Although delayed stubble mulch tillage helped control erosion and did not greatly decrease soil water storage or wheat yields as compared with stubble mulch tillage, it was not adopted because of increased weed problems and the generally low water storage efficiencies for the wheat-fallow system.

The wheat-fallow system has been largely replaced by a winter wheat-fallow-grain sorghum-fallow system (designated WSF) (two crops in 3 years) or continuous cropping (one crop each year) in the southern Great Plains. The WSF or similar systems are also used throughout the Great Plains. Improved water conservation due to improved crop residue management practices with conservation tillage, including stubble mulch and no-tillage, have led to the improved results for the WSF and continuous cropping systems.

Residue management research began with the introduction of stubble mulch tillage for wind erosion control in the late 1930s. Crop residues retained on the surface with stubble mulch tillage also provided for water erosion control and it was soon realized that they improved soil water conservation. A general boost in water conservation occurred when no-tillage and other conservation systems that retained more crop residues on the soil surface were introduced. Studies by Greb et al. (1967) and Unger (1978) in the Great Plains illustrated the value of increased amounts of surface residues for increasing soil water storage (Tables 8 and 9). Improved weed control, fertilizer practices, and varieties probably contributed to the major improvements in soil water storage and wheat yields reported by Greb (1979) (Table 10).

The above studies showed the potential for storing precipitation as soil water increased when increasing amounts of crop residues were retained on the soil surface. Numerous other residue management studies in the central and southern Great Plains have shown similar results. In general, soil water storage and dryland crop yields with no-tillage have equaled or exceeded those with stubble mulch tillage (Greb 1974, 1978; Jones et al. 1994; Jones and Popham 1997; Norwood 1992, 1994; Peterson et al. 1996; Smika and Wicks 1968; Unger 1984, 1994; Unger and Wiese 1979; Vigil et al. n.d.; Wicks and Smika 1973). Lower evaporation with no-tillage contributed to the greater water storage (Smika 1976) and may be the dominant factor where surface residues are limited (Jones and Popham 1997). In the latter study, runoff was greater with no-tillage than with stubble mulch tillage, but water storage during fallow still was greater with no-tillage. Stubble mulch tillage exposed moist soil to the atmosphere, resulting in evaporative losses of soil water greater than the amounts gained by the lower runoff.

Predominantly winter-precipitation regions. Winter cover crops in predominantly winter-precipitation semiarid regions, in general, have the same effect on soil water contents as cover crops in semiarid regions with predominantly summer rainfall. The cover crops help protect the soil surface from raindrop impact and thereby maintain greater infiltration rates (Folorunso et al. 1992), which could be a major advantage when subsequent crops are irrigated. Cover crops, however, require water for growth and soil water contents in cover crop plots at the time of crop incorporation generally are lower than in fallow plots with no cover crop. According to Stivers and Shennan (1991), water content to the 0.60-m (24 in) depth was reduced 20 mm (0.8 in) in oat (*Avena sativa* L.) plots, but only 10 mm (0.4 in) in vetch plots relative to that in fallow plots. In contrast, 3-year average water contents were 74 mm (2.9 in) less in barley (*Hordeum vulgare* L.), 79 mm (3.1 in) less in barley + vetch, and 66 mm (2.6 in) less in vetch cover crop plots than in fallow plots (J. P. Mitchell, Davis, CA, personal communication, 1997). Over-winter soil water content gain in fallow plots was 94 mm (3.7 in) in 2 years, but only 41 mm (1.6 in) in the third year when rainfall was lower. Clearly, rainfall amount has a major effect on soil water storage and implications are that timing of cover crop termination would also affect water storage.

Summary for semiarid regions. Water use by cover crops (including green manure crops) can greatly reduce yields of subsequent crops in semiarid regions. The impact of soil water use by the cover crops, in general, is greater in the central and southern U. S. Great Plains than in the northern Great Plains and the Canadian Prairie provinces. Some satisfactory results were obtained in the latter regions where systems involving cover crops were compared with a spring wheat-fallow system. Winter wheat rather than spring wheat is more common in the central and southern Great Plains. Also, crop rotations such as winter wheat-grain sorghum-fallow in the central and southern Great Plains and winter wheat-corn-fallow in the central Great Plains are widely used. These differences in cropping systems along with the generally harsher climatic conditions make the use of cover crops less desirable in the southern than in the northern regions. Where cover crops are grown, timely cover crop termination and effective weed control are essential for minimizing the potential adverse effects on subsequent crops. Because of the need to conserve water, use of conservation tillage systems for which crop residues are retained on the soil surface has received considerable attention in the semiarid portions of the Great Plains. Except for not fixing atmospheric nitrogen, not removing nutrients (nitrates) from soil to prevent their leaching, and not providing additional organic matter for improving soil conditions, benefits of surface residues in conservation tillage systems are essentially the same as those provided by cover crops.

Summary and conclusions

A consequence of growing cover crops (including green manure crops) is that they use soil water, which can have positive, neutral, or negative effects on the soil water supply for the next crop. The effect is positive when cover crops are managed to improve infiltration and decrease evaporation after they are terminated (residues retained on the soil surface) or to enhance soil water extraction from overly-wet soils (allowing them to grow as long as possible). The effect is negative when not enough time is available after cover crop termination to recharge the soil with water before the next crop is planted or when the greater infiltration and reduced evaporation aggravate an overly-wet soil condition. In general, cover crops are more suited for use in subhumid to humid regions because of greater and more reliable precipitation than in semiarid regions where precipitation generally is limited and highly erratic. Where precipitation is adequate and reliable, as in subhumid to humid regions, cover crops can be terminated or removed (by haying or grazing) to provide time to recharge the soil water supply for the next crop. Where precipitation is limited, as in semiarid regions, cover crops often reduce yields of subsequent crops because of reduced soil water supplies. Under such conditions, use of conservation tillage that involves crop residue maintenance on the soil surface has improved water conservation and crop yields, and has provided benefits similar to those obtained with cover crops, except for fixation of atmospheric nitrogen (with legumes), uptake of soil nutrients (nitrates) to prevent their leaching, and provision of additional organic matter to improve soil conditions.

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