WATER CONSERVATION UNDER REDUCED TILLAGE SYSTEMS

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Key Words. Water, conservation, tillage, conservation tillage, no-till, mulch-till, reduced-till, slot mulch, residue management, fallow

INTRODUCTION

Water is important for dryland crop production. Seldom is rainfall sufficient or adequately distributed during a growing season so that dryland crops can produce to their fullest potential. It is necessary to have stored water available in the soil to supplement inadequate growing season rainfall for economical crop production. Stored water is especially important in the Inland Pacific Northwest of northcentral Oregon, southeastern Washington, and northern Idaho, where 65% of annual precipitation occurs during the six-month (Sept. 1 to Feb. 28) winter period and 30% during the four-month (March 1 to June 30) growing season. Stored water is also important in the Eastern Idaho Plateau where the low annual precipitation is nearly evenly distributed over the months of the year.

The water balance equation tells us that change in water content in the soil = precipitation + inflow - runoff + upward flow - drainage - evapotranspiration (ET). Any cultural practice that decreases runoff or ET can result in increased water in the soil. To store adequate quantities of water, deep soils (> 60 inches) with good infiltration and water holding capacity are required. Summer fallow has long been the traditional practice for storing water in soils for later use by crops. Fallow periods vary from 14 to 15 months where winter small grains are seeded to 21 months where spring small grains are seeded. Water storage efficiency for fallow is low, ranging from 10 to 35% in the Great Plains and the Southwest; to 30-37% in eastern Idaho and northern Utah; to 40-45% of precipitation in the Inland Pacific Northwest (Evans and Lemon, 1957). Good water conservation yields increased crop production, stability of production, and increased water use efficiency. Soil tillage and residue management play significant roles in collection and storage of precipitation in the soil.

Our objectives are to discuss insights in water conservation gained under the STEEP (Solutions to Economic and Environmental Problems) program (Oldenstadt et al., 1982) during these last ten years and problems that remain. New research information will be discussed under topics of crop residues, conservation tillage systems, fallow and models.

DISCUSSION

Crop Residues impact snow trapping, soil freezing, and water evaporation. We often do not recognize the importance of standing residues in catching and maintaining uniform snow cover. The effects are several. First, precipitation is more uniformly maintained over fields, by reducing snow drift and providing increased uniformity of stored water for plant use. Second, soil freezing is reduced significantly beneath a few inches of snow. Freezing frequently reduces water infiltration and causes runoff, flooding, and crop water loss. Third, recent evidence shows that freezing breaks wheat (*Triticum aestivum* L.) roots reducing root vigor and enhancing susceptibility to disease entry.

Standing stubble also can help prevent freezing of the soil surface during late winter diurnal freezing and thawing cycles after snow cover has melted. Pikul and Allmaras (1985), at Pendleton, Oregon, found that frost penetrated a bare soil surface 0.6 inch but did not form at the soil surface in standing stubble. Upward water migration to this frost zone increased water content in the bare soil surface where it was susceptible to loss by evaporation during and after thawing. During one 24-hour period, water loss from the top 4.3 inches of bare and stubble-covered soil was 0.09 and 0.01 inch respectively. Conservation tillage systems that leave standing stubble which traps snow alter the plant microenvironment sufficiently that winter wheat now is being grown successfully where only lower yielding spring wheat has been traditionally grown in the Northern Plains. This change from spring to fall planting along with increased soil moisture has increased average yields significantly and even allowed annual cropping in some instances where fallow is common practice. Residues also virtually eliminated wind erosion (Hayes, 1985). Similar benefits can be expected in the Pacific Northwest.

Residues alter the soil microenvironment throughout the year. They reduce radiation and wind velocity at the soil surface. Less heat, therefore, enters the soil and less water evaporates from cool, wind-protected soils. The cool soils delay plant growth, but the additional stored water increase crop productivity.

Untilled soils tend to reconsolidate and crust from precipitation and traffic. Crusted, wet, or frozen soil surfaces often restrict infiltration. Thus, no-till methods frequently have more runoff than conservation tillage methods that have at least light surface tillage (Johnson et al., 1984). Crusting problems tend to decrease after several years of conservation tillage because surface organic matter and biological activity increases and tilth improves.

Data presented in Table 1 from research near Albion, Idaho, in the Eastern Idaho Plateau reveal the effect of antecedent water on overwinter runoff and soil water storage (Massee, unpublished data). The silt loam soils in this area have little structure, are low in organic matter, and usually freeze every winter. Precipitation during the winter of 1984-85 was 13.4 inches; 150% of the longtime average. Much of the precipitation occurred as snow that insulated the soil from freezing. Antecedent water in the chiseled and irrigated (3.5 inches) treatment increased runoff and reduced water storage

Table 1. Fall chiseling and antecedent water effects on overwinter runoff and water storage at Albion, Idaho, during the winter of 1984-85; a winter of above average precipitation, mostly as snow, and non-frozen soils.

Fall stubble treatment	Winter precipitation, inches	Runoff, inches	Storage, inches	Storage efficiency, %
Stand	13.4	1.3	10.3	77
Chisel	13.4	1.7	8.5	63
Chisel plus irrigation (3.5 inches)	13.4	4.6	3.1	23

in the soil profile compared to the chiseled only treatment. The increase in runoff (2.9 inches) was almost equivalent to the fall irrigation. Absence of frozen soil beneath the snow cover resulted in similar runoff and water storage when comparing the standing stubble and chiseled stubble treatments. In most years the soil freezes and fall chiseling wheat stubble increases soil water storage during the winter significantly. In this year all three treatments had stored about equal quantities of water in the 8-foot-soil profile by spring.

A similar antecedent water condition sometimes occurs where erosion has depleted soil fertility so that associated reduction in crop growth fails to deplete water stored in the soil profile (Massee and Waggoner, 1985). Where six inches of topsoil was mechanically removed to simulate erosion, 1.2 inches less stored water was removed by the crop than on adjacent normal soil. During the subsequent winter an identical 1.2 inches less water was stored by the eroded soil so both soils finished the storage period with equal amounts of stored water.

At Pendleton, Oregon, soil under standing wheat stubble stored 87% of overwinter precipitation. Only 64% of precipitation was stored in soil where stubble had been fall plowed (Ramig and Ekin, 1978). This amounted to an additional 2.6 inches of water which increased green pea (Pisum sativum L.) production 25% or 600 lbs/acre. The value of stubble on storage of precipitation the first winter after harvest for fallow in three precipitation zones in northcentral Oregon is presented in Table 2 (Ramig and Ekin, 1984). Average weights of residue at the Ione, Moro, and Pendleton locations were estimated at 4000, 6000, and 9000 lbs/acre, respectively. Stubble increased soil water storage efficiency significantly compared to burned stubble, but differences between flailed and standing stubble were less than seven percent and insignificant.

Table 2. Influence of stubble management on water storage efficiency in northcentral Oregon the first winter[v] after winter wheat harvest (Ramig and Ekin, 1984).

Location	Mean[*] annual precipitation, inches	Elevation above sea level, feet	Fall stubble management	Water storage efficiency[§], %
Ione	9.75	1401	burn	--
			flail	63
			stand	56
Moro	11.51	2002	burn	66
			flail	78
			stand	78
Pendleton	16.63	1592	burn	57
			flail	67
			stand	70

[v] August 1 through February 28.
[*] 28-year (1956-1983).
[§] Data are the average of 4 years.

At Tetonia, Idaho, in the Eastern Idaho Plateau, Massee and McKay (1979), reported that soil under standing stubble stored 4.6 inches more water than where stubble had been burned in the fall. Tetonia is at an elevation of 6200 feet and much of the precipitation occurs as drifting snow. Winter wheat yields were increased 5 bushels per acre for each foot of trapped snow.

Conservation Tillage Systems uniquely affect the soil and residues. Tillage implements that bury a minimum of residue and preferably leave the residue standing to trap snow are recommended where residue-borne crop diseases are not a problem. Residues on the soil surface are generally beneficial. Table 3 shows example measurements of residues remaining following one pass with specific tillage implements. The chisel plow, light field cultivator, and paraplow leave the most residue on the surface.

Water conservation with selected tillage and residue management systems is presented in Tables 4 and 5. The combined effects of snow trapping, improved infiltration, and evaporation control are evident. The data in Table 4 are from cropland in eastern Nebraska where the Great Plains type annual precipitation averaged 27.6 inches and the 7 month winter precipitation was 9.1 inches. Data in Table 5 are for two tillages and three residue treatments in eastern Washington (Saxton, unpublished data). These data show that for the two years reported, winter water storage increased where tillage (paraplow) improved infiltration and where residue was left standing to trap snow and reduce evaporation. The paraplow loosens consolidated soil surface layers yet leaves virtually all residues upright on the surface. The soil surface is only slightly roughened and can readily be direct seeded without intervening tillage. Flailed residues formed a mat on the soil surface but were not erect to trap blowing snow. For comparison, plots denuded of surface residues by burning stored the least water. Burning is shown to be a poor practice for water conservation and in addition causes a loss of organic matter and nutrients.

Table 3. Amounts of residue remaining on the surface after one pass with specific tillage implements.

Implement	Percent surface residue remaining after tillage
(Hayes and Young, 1982):	
Moldboard plow (7 inches deep)	0-5
Chisel plow (chisels 2 inches wide)	75
Heavy tandem disk	60
Offset disk	50
Field cultivator (12 to 16-inch sweeps)	80
(Anonymous, 1985):	
Brillion soil builder	56
Glencoe soil saver	36
John Deere mulch tiller	48
Noble chop-n-chisel	48
Howard paraplow	92

Table 4. Water conserved from precipitation[v] over the winter by some tillage systems for corn at Lincoln, Nebraska (Yasar and Wittmus, 1976).

Tillage system	Water saved	
	Inches	% of precipitation
Plow	4.2	46
Chisel plow	6.3	69
Sweep plow	5.2	57
Chisel disk	6.4	71
Chisel coulter	6.7	74
Till-plant	7.0	77
No-till	5.3	58

[v] Winter period precipitation was 9.1 inches.

Table 5. Effect of wheat stubble management and tillage on inches of water stored overwinter[v] in 1984 and 1985 at Winona, WA. Data are the average of two years.

Stubble treatment	Post harvest tillage		Stubble treatment average
	None	Paraplow	
None	4.6	7.1	5.9
Flailed	4.9	5.8	5.4
Burned	1.4	3.8	2.6
Tillage average	3.6	5.6	

[v] Precipitation at La Crosse, WA, 10 miles south of Winona was:
Nov. 23, 1983 to April 4, 1984 - 7.6 inches
Oct. 2, 1984 to April 2, 1985 - 9.2 inches

Fall chiseling is practiced in areas where soil freezing is common or weed growth occurs after wheat harvest (Papendick and Miller, 1977). Chiseling is usually to a depth of 8 to 12 inches with narrow, pointed chisels spaced 12 to 24 inches apart. Chiseling improves water infiltration in soils having a compacted layer (Allmaras et al., 1977; Allmaras et al., 1982) and unfrozen chisel grooves when the soil surface is frozen. In southeastern Idaho, post-harvest chiseling increased overwinter water storage in 6 out of 10 years by 1.5 to 2.5 inches over no fall tillage (Massee and Siddoway, 1969; Massee and Siddoway, 1970). In eastern Washington, fall chiseling to a depth of 9.8 inches increased overwinter water storage 3.4 inches compared with no-tillage in a winter with frequent soil freezing (Lindstrom et al., 1974). Water storage efficiency was 87% with chiseling and 50% with no-tillage. In a mild winter with little soil freezing there was no difference in water storage between the treatments. In north central Oregon, post-harvest chiseling to a depth of 14 inches with narrow chisels spaced two feet apart increased overwinter water storage 1.5 inches compared with no-tillage only once in ten years (Ramig, unpublished data). Chiseling has increasingly replaced moldboard plowing as the initial tillage in zones of high precipitation or high frequency of frozen soil because of enhanced water storage. Where annual precipitation is 12 inches or less and little or no frozen soil occurs, fall chiseling has decreased storage when compared with no-tillage.

Slot mulching is a new conservation tillage practice that gives evidence of increased water confinement and infiltration. Slot-mulching involves compacting part of the crop residues into a narrow continuous slot 2 to 4 inches wide by 8 to 10 inches deep. Ideally, the slots should be on the contour and spaced 12 to 24 feet. Surface runoff is readily intercepted and infiltrated by these open mulched slots. The remaining standing residues pose little problem to subsequent tillage and provide good snow trapping and evaporation reduction. During a snowmelt period in 1979, slot-mulched treatments had 90% less runoff and 98% less soil erosion than no-tilled plots or conventionally-tilled plots (Saxton et al., 1981). Detailed measurements and calculations have confirmed a high infiltration potential for mulched slots (Redinger et al., 1984).

Fallow. The water conservation period in a fallow-wheat rotation was divided into three segments in a study in northcentral Oregon (Ramig and Ekin, 1984). The fallow-winter segment was from August 1 after wheat harvest through February 28 when water conservation ceased until the next winter after seeding. When stubble was flailed or left standing after harvest, over 70% of the fallow-winter precipitation was stored in the soil profile at two locations in northcentral Oregon (Table 6). Only 60% was stored where the stubble was burned.

Table 6. Effect of post harvest wheat stubble management in a wheat-fallow rotation on water storage efficiency for three segments of the fallow period in northcentral Oregon. Data are averaged for two locations and four years.

	Water storage efficiency (%)* for:			
Fall stubble management[v]	Fallow winter Aug 1-Feb 28	Fallow summer Mar 1-Oct 31	Crop winter Nov 1-Feb 28	Total storage period 19 months
Burn	61	-112	53	38
Flail	72	-125	56	40
Stand	74	-124	56	42

[v] All sprayed with 0.5 lb. (a.i.) per acre of isopropylamine salt of N-(phosphonomethyl) glycine in 25 gallons solution in early March. Chisel-rodded in late April.

* Percent of rainfall for each period.

The fallow-summer segment was the eight months from March 1 through October 31. All treatments were sprayed to control weeds in early March, tilled with sweeps, and rodweeded as needed to control weeds during this period. No additional water was stored during this period because of long, hot, dry summers and stirring of soil by cultivation. An equivalent of all or 100% of the summer rainfall, which project from 2 to 9 inches, was lost by evaporation plus some water from the surface 8 inches of the tilled fallow. Soil profiles that had the greatest amounts of stored water in the spring lost the greatest amount during the summer. Lindstrom et al. (1974) have reported similar over-summer losses of precipitation and water from fallow in Washington. Wheat normally was seeded in late September or early October.

After seeding, about 55% of the precipitation that occurred during the November 1 through February 28 crop-winter segment was stored. Storage efficiency was lower during the crop-winter segment than during the fallow-winter segment because infiltration was reduced by the antecedent water in the soil profile and destruction of favorable surface soil structure by fallow cultivation and seeding. The flailed and standing stubble treatments with some residual residue on the surface stored slightly more water during the crop-winter than the bare burned treatment. The inefficiency of water storage during the hot, dry fallow-summer and the crop-winter segments is apparent. Storage efficiency for the total 19-month fallow period ranged from 38 to 42%.

Time of tillage is important for water conservation. Tilling too early when soils are wet, destroys soil structure and causes soil compaction. Delayed tillage permits water loss by evaporation and transpiration by weeds. Massee and McKay (1979) report that in southeastern Idaho, where summer and fall rainfall is limited, seedbed moisture at fall planting time in fallow closely parallels the amount present when initial spring tillage is done. They recommend shallow tillage to a depth of 3 to 3.5 inches when water content in the 3 to 6-inch depth is 15 to 18% (w/w). Delayed tillage lost water by evaporation and transpiration with resultant dry seedbeds in the fall.

In a tillage by herbicide experiment conducted during three separate wheat-fallow seasons (1980 through 1984) in northern Idaho, seed zone moisture was not affected by tillage time (Lish and Thill, 1984; Lish et al., 1983). Seed zone (0 to 6 inches) and soil profile (0 to 6 feet) water concentration at the end of fallow (September) usually were equal regardless of initial tillage time (March through June or no-tillage) and number of tillage operations (0 through 5). July and August precipitation ranged from 0.9 inch in 1981 to 2.2 inches in 1982, which probably compensated for earlier differences in seed zone moisture concentration among tillage treatments. Time of herbicide application (fall or early spring) and herbicide treatment, likewise, did not affect seed zone or soil profile water concentration during fallow. In the Eastern Idaho Plateau, Massee (unpublished data), found that no-till (chemical) fallow stored 12.1 inches water and conventional tilled fallow stored 11.8 inches water in the 8 foot soil profile during fallow. Seed zone moisture in the nine-inch seed zone was 8.9% for the no-till fallow and 9.6% for the conventional tilled fallow.

Lindstrom et al. (1974) have reported that May to September water loss from fallow was not influenced by type of spring tillage (sweep or disking) in eastern Washington. Tillage was performed in early April before appreciable weed growth. One week later large clods were broken, the tilled layer firmed, and a fine soil mulch produced by skew treading. Conventional rod weeding was done as necessary to control weeds and maintain a fine soil mulch. Summer evaporation loss is small (0.33 mm/day) during the summer after a 4 to 6 inch fine dust mulch develops. Seed zone water at the end of fallow was higher where spring tillage was used than where no-tillage chemical fallow was used. Stand establishment was 80% or greater in tilled fallow but only 50% on no-tilled chemical fallow. Wilkins et al. (1984) report standing residues may also reduce tillering of wheat plants and resultant production. Papendick et al. (1973) reported that in eastern Washington more favorable seed zone moisture was maintained in fallow with a deep soil mulch treatment produced by rodweeding at a depth of 4 to 6 inches than with a shallow soil mulch weeded at 2 to 3 inches. Wheat emergence 8 days after seeding was 57 and 18% for the deep and shallow soil mulch treatments. Seed zone moisture is very important for timely seeding and emergence which fosters crop establishment, soil erosion control, and high yields.

Models to predict heat and water fluxes for the critical points in the two-year wheat-fallow sequence are beginning to be developed. A model to predict winter wheat emergence was proposed by Lindstrom et al. (1976). This model used soil temperature, water potential in the seed zone, and planting depth. Wheat emergence predictions were reasonably good but differences in varietal response to water potential were noted. Later, a numerical model was developed to investigate the dynamic aspects of heat and water flow in the upper soil layers with emphasis on the effects of conventional and no-till fallow on these processes and ultimately on seed zone water content (Hammel et al., 1981). This model should be further developed for the many soil-climatic areas in the Inland Pacific Northwest because adequate seed zone moisture in fallow is essential for good stand establishment, erosion control, and profitable wheat production. Evaporative water loss for chemical no-till fallow over a 90-day simulation period using measured meteorological inputs was 70% greater than for conventional tilled fallow. Resultant water content in the seed zone was too low for successful stand establishment in the chemical fallow. Thus, for southeastern Washington, some tillage appears necessary for retention of adequate seed zone water for successful early winter wheat establishment.

A simulation model suitable for describing the dynamic aspects of water and energy transfer in a surface residue-soil system was developed and used to determine soil heat and water budgets and their effect on the decomposition rates of surface and incorporated residues (Bristow, 1983). The residue loading rate was 2700 pounds per acre which formed a layer 0.4 inch thick and yielded an area index (projected area of residue per unit soil area) of 1. For Pullman, Washington conditions, surface residues decreased evaporation roughly 30% when compared to bare soil. Monthly trends, however, indicated that surface residues could enhance water loss during long periods without rain. This is an agreement with Pikul et al. (1985) who reported September and October evaporation rates of 0.006 inch per day for northcentral Oregon when there were no late season rains to consolidate the 2 inch thick residue-soil layer consisting of a dry mixture of straw soil aggregates, and primary soil particles. Evaporation rates during a dry year were generally one-third of the evaporation measured during a wet year. Rains that consolidated this residue soil layer caused the water conservation benefits of soil mulch to disappear. Soil water evaporation rates did not decline as potential evaporation declined during August through November. Further detailed modeling of water exchanges as related to soil heat flux are needed before we can accurately predict seed zone water at seeding time. Improved grain drill openers could enhance use of marginal seed zone water by placing the seed in the optimum moisture zone for early germination, emergence and growth (Wilkins et al., 1983). Noori et al. (1985) report that injection of small quantities of water with the seed when seeding into seedbeds with marginal seedzone water increased plant emergence and final yield that gave significant economic returns.

SUMMARY

Efficient water conservation during the first winter after harvest is favored in the Pacific Northwest by dry soils and cool, wet winters. Additional research with slot mulching and fall paraplow tillage may develop water conservation systems that will replace fallow as a means for profitable agriculture in many areas. In low precipitation zones, where fallow is necessary, research is needed on systems that reduce summer evaporation losses so some water may be stored during the summer. This will be a difficult task in light of the physical laws controlling evaporation. However, even slight progress would enhance water storage efficiency. Probably the time for improved water conservation in wheat-fallow systems is the winter after the crop is seeded. No-till (chemical fallow) needs further research to determine whether good seed zone water can be maintained until planting time. Injection of small quantities of water into seedzones of marginal soil moisture content when seeding wheat has increased rate, final stands and yields and warrants further testing to determine feasibility on field scale. Standing residues could trap snow and reduce evaporation to store more water, but may reduce tillering and resultant production (Wilkins et al., 1984). If tillage is found necessary for adequate seed zone water to establish cereal crops, research into mechanically placed dams or dikes in deep furrow rows planted on the contour may well increase present 50% water storage efficiencies and reduce erosion.

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