CONSERVATION TILLAGE FOR IMPROVING DRYLAND CROP YIELDS

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Water conservation is essential for successful dryland crop production in semiarid regions. Improved water (also soil) conservation has been achieved in many cases by using conservation tillage, including no-tillage, which is the ultimate type of conservation tillage. The purpose of this article is to review and discuss the principles and practices of conservation tillage and the results of some studies relative to their effect on conserving water for improving crop yields in dryland regions such as those in southern South America. Water and soil conservation is possible by using tillage methods that reduce the amount and/or rate of runoff and improve water infiltration in soil. This is possible even when crop residues are not retained on the soil surface, which is covered by the broad definition of conservation tillage. Improved water and soil conservation, however, usually occurs when crop residues are retained on the soil surface, as covered by the operational definition of conservation tillage. Water and soil conservation usually improves with increasing amounts of residues retained, and results of numerous studies involving conservation tillage, including no-tillage, show that increased water conservation increases the yield of dryland crops. Improved soil conservation resulting from use of conservation tillage helps protect soils for sustained crop productivity.

Key words: conservation tillage, dryland regions, soil water.

INTRODUCTION

The purpose of this article is to illustrate the benefits of using conservation tillage methods for improving dryland crop yields. Although the emphasis is on dryland crops, the principles involved, in most cases, also are applicable to irrigated crops. However, when water is available for irrigation, the need for using conservation tillage to conserve water often is greatly reduced and ignored.

Conservation tillage and *dryland*, two terms used in the title, also are used extensively throughout this article. Therefore, it is appropriate to define and briefly discuss these terms. *Conservation tillage* is "any tillage sequence, the object of which is to minimize or reduce loss of soil and water; operationally, a tillage or tillage and planting combination which leaves a 30% or greater cover of crop residues on the surface" (SSSA 1997, p. 111). Based on the first part of this definition, conservation tillage includes those methods that result in soil and water conservation, even if no crop residues are retained on the surface. Some of those will be mentioned, but the emphasis will be on tillage methods covered by the 'operational' portion of the definition, including *no-tillage*, which is the ultimate type of conservation tillage.

Dryland farming is "crop production without irrigation (rainfed agriculture)" (SSSA 1997, p. 30). This definition would include crop production in humid regions where water conservation generally receives little attention and removal of excess water may be required. In contrast, *dryland agriculture* is defined as "husbandry under conditions of moderate to severe water stress during a substantial portion of the year, which require special cultural techniques and adapted crops and systems for successful and stable agricultural production" (Oram 1980; cited by Stewart 1988). In North America, this definition of *dryland* is appropriate for the Great Plains and Pacific Northwest regions of the USA and the Prairie Provinces of Canada. It is appropriate also for the semiarid portions of Argentina, the Bolivian high plains, and the Paraguayan Chaco in South

America (Buschiazzo 200?) as well as on other continents, except Antarctica. This definition of dryland emphasizes the importance of water conservation for successful crop production, which will be stressed in this article for improving crop yields.

The *no-tillage (zero tillage) system* is "a procedure whereby a crop is planted directly into the soil with no primary or secondary tillage since harvest of the previous crop; usually a special planter is necessary to prepare a narrow, shallow seedbed immediately surrounding the seed being planted. No-till is sometimes practiced in combination with subsoiling to facilitate seeding and early root growth, whereby the surface residue is left virtually undisturbed except for a small slot in the path of the subsoil shank" (SSSA 1997, p. 114). No-tillage was used in some studies mentioned in this article.

SOIL CONSERVATION

Soil conservation may not have an immediate effect on crop yields, depending largely on soil losses resulting from ongoing erosion. For long-term soil productivity, however, erosion control is essential. As mentioned in the definition, use of conservation tillage is one means of minimizing or reducing soil losses.

Conservation tillage without surface residues

Without surface residues, soil erosion by water can be reduced by tillage that reduces the amount and/or rate of runoff or by increasing water infiltration into the soil. Some methods that provide for water erosion control in this manner include: a) contour tillage that prevents runoff, except when major storms occur; b) graded-furrow tillage that allows runoff at reduced flow rates; c) deep tillage that disrupts soil layers that impede water infiltration; and d) any tillage method that provides for temporary water storage on the surface, thereby providing more time for infiltration (Unger 1996).

Tillage methods that provide control of soil erosion by wind include those that: a) form ridges and furrows (for example, listing (SSSA 1997, p. 113)), b) roughen or form clods on the soil surface (for example, chiseling), and c) bring clod-forming materials to the surface from deep in the profile of sandy soils (deep plowing) (Dollar 1988). Under emergency conditions, that is, when erosion by wind is occurring, a "sand fighter" or rotary hoe (implements that break the surface-soil crust to form clods) can be used to rapidly roughen a rain-smoothed soil surface (Woodruff *et al*. 1972). Unfortunately, the roughness usually disappears during the next rain. Chiseling or listing at wider-than-normal spacings can also help control wind erosion under emergency conditions (Soil Conservation Service 1955).

Conservation tillage with surface residues

Although soil erosion by wind and water can be reduced by some tillage methods when surface residues are not present, greatly improved erosion control occurs when adequate amounts of crop residues are retained on the soil surface. The level of control achieved is strongly influenced by the percent of the surface covered by residues (Figure 1). Clearly, when adequate residues are present, erosion by water and wind is greatly reduced or eliminated. Such erosion control is covered by the operational part of the conservation tillage definition.

WATER CONSERVATION AND CROP YIELDS

Precipitation is limited and generally erratic in semiarid regions. As a result, dryland crops usually become water-stressed

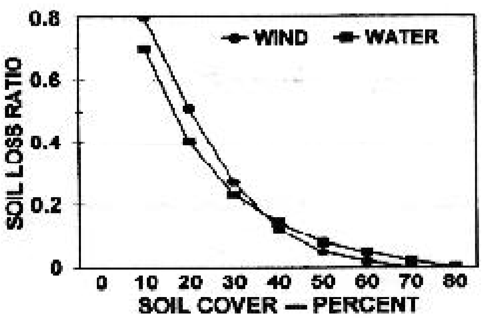

Figure 1. Relationship between soil loss ratio (soil loss with cover divided by soil loss from bare soil) and percentage surface cover (adapted from Papendick *et al.* 1990).

Figura 1. Relación entre el radio de pérdida de suelo (pérdida de suelo dividido la pérdida de suelo de un suelo desnudo) y porcentaje de cobertura (adaptado de Papendick *et al.* 1990).

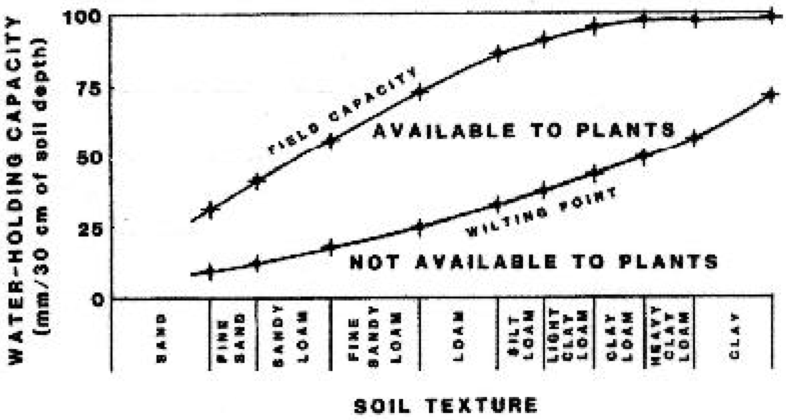

Figure 2. Typical water-holding characteristics of different-textured soils (adapted from Anonymous 1955).
Figura 2. Capacidades de retención de aguas típicas de suelos con diferentes texturas (adaptado de Anónimo 1955).

at some time during the growing season, which causes a crop yield decrease or even a failure following severe stress. The yield reduction depends on the severity and timing of the stress. Because precipitation may not occur at the most opportune time, storage in soil of sufficient water from precipitation is highly important for minimizing the adverse effects of water stress during a crop's growing season. The storage may occur during the interval between crops or during the growing season. The amount of water that can be stored depends on soil texture (sand, silt, and clay content) (Figure 2) and depth (effective crop rooting depth). In Figure 2, effects of texture on the amount of water that different soils can retain for plant use (difference between wilting point and field capacity) are illustrated.

Conservation tillage methods without surface residues that influence control of erosion by water have a similar effect on soil water conservation. That is, if runoff is prevented or reduced and water infiltration is increased, the potential for storing that water in soil for subsequent use by a crop is increased, provided the soil has adequate storage capacity to retain that water. Tillage methods for controlling erosion by wind when residues are not present may or may not increase soil water storage. Tillage resulting in ridges and furrows or surface depressions may increase water storage. In contrast, tillage that only roughens or forms clods on the surface may have little or no effect on water storage. Likewise, emergency tillage with a "sand fighter" or rotary hoe that roughens the surface after a rain may have little or no effect on soil water storage because the roughness usually disappears during the next rain.

Water conservation benefits of conservation tillage involving residues result from several factors, with the benefits generally improving with increasing amounts of surface residues. The benefits result from: a) protecting the surface against raindrop impact, thus reducing soil aggregate dispersion and surface sealing, which decrease water infiltration (Loch 1989); b) retarding the rate of water flow across the surface, thus providing more time for infiltration; and c) reducing soil water evaporation by shading and cooling the soil and by reducing wind speed at the soil surface.

The value of surface residues resulting from using conservation tillage to conserve water and increase crop yields has been shown in numerous studies, but space will permit giving only a few examples. In Ohio (USA), although not in a semiarid region, runoff and soil sediment losses during a rainstorm were much lower from watersheds planted to corn (*Zea mays* L.) where clean tillage with contour row and no-tillage with contour row than where clean tillage with sloping row treatments were used (Table 1) (Harrold, Edwards 1972). Although the slope was much greater, soil loss was negligible from the no-tillage watershed. Runoff also was low,

Table 1. Runoff and sediment yield from maize watersheds at Coshocton, Ohio (USA), during a severe rainstorm (adapted from Harrold, Edwards 1972).

Tabla 1. Escurrimiento y pérdida de sedimento en un cultivo de maíz en Coshocton, Ohio (EE.UU) durante una tormenta severa (adaptado de Harrold, Edwards 1972).

Tillage	Slope (%)	Rainfall (mm)	Runoff (mm)	Sediment yield (Mg ha^{-1})
Plowed, clean tillage, sloping rows	6.6	140	112	50.7
Plowed, clean tillage, contour rows	5.8	140	58	7.2
No-tillage, contour rows	20.7	129	64	0.07

which provided an opportunity to store more water, but soil water information was not reported.

In Australia, July and August 1992 rains totaling 346 mm on an Alfisol resulted in average runoff of 136 mm from no-, shallow-, and deep-tillage treatment plots that were bare. In contrast, only 4 mm of runoff occurred with those treatments from plots covered with straw (Cogle *et al.* 1998), thus resulting in much greater water storage than in the bare soil.

Water conservation and crop yield increases occurred in India when soils were mulched with plant residues (Friesen, Korwar 1987, Mahto, Sinha 1980), with mulch application soon after plant emergence being the most effective treatment (Mahto, Sinha 1980). Using no-tillage should give similar results, provided surface residue amounts are adequate and weeds are effectively controlled. Weed control with no-tillage in some studies in India, however, was not as good as with plowing (Agarwal, De 1977) or hand weeding (Mane, Shingte 1982), which resulted in lower crop yields with no-tillage. Effective weed control is a prerequisite for successful crop production with no-tillage under all conditions.

A winter wheat (*Triticum aestivum* L.) – fallow – grain sorghum [*Sorghum bicolor* L. (Moench)] – fallow cropping system (designated WSF) is used extensively in the USA southern and central Great Plains. This system results in two crops during the 3-year cycle with 10 to 11 months of fallow between successive crops. After harvesting irrigated winter wheat, Unger (1984) used different tillage treatments (Table 2) to manage the residues during the fallow period until

Table 2. Tillage treatment effect on soil water storage during fallow after irrigated winter wheat, dryland grain sorghum yield, total water use by sorghum, and water use efficiency (WUE) for sorghum grain production at Bushland, Texas (USA), 1978-1983 (adapted from Unger 1984).

Tabla 2. Efecto del tratamiento de labranza en la retención de agua durante el barbecho luego de trigo de invierno irrigado, rendimiento de grano de sorgo en secano, agua total usada por el sorgo y eficiencia del uso del agua (WUE) para la producción de grano de sorgo en Bushland, Texas (EE.UU), 1978-1983 (adaptado de Unger 1984).

	Water storage[a]		Grain yield	Total water use	WUE[b]
Tillage treatment	(mm)	(%)	(Mg ha^{-1})	(mm)	(kg m^{-1})
Moldboard	89 b[c]	29 b	2.56 bc	360 bc	0.71
Disk	109 b	34 ab	2.37 cd	363 bc	0.65
Rotary	85 b	27 b	2.19 d	357 c	0.61
Sweep	114 ab	36 ab	2.77 b	386 ab	0.72
No-tillage	141 a	45 a	3.34 a	401 a	0.83

[a] Based on average fallow period precipitation (316 mm) stored as soil water. Growing season precipitation averaged 301 mm.
[b] Water use efficiency based on grain yield, growing season precipitation, and soil water content changes.
[c] Column values followed by the same letter or letters are not significantly different at the 5% level based on Duncan's multiple range test.

planting dryland grain sorghum at Bushland, Texas (USA). The greater soil water contents and sorghum yields with conservation tillage (sweep and especially no-tillage) resulted from more residues retained on the surface than with other treatments. Because more water was stored and, hence, available with the no-tillage treatment, total water use by sorghum also was greater with no-tillage. Despite the greater water use, the no-tillage treatment still resulted in the greatest water use efficiency because of the greater grain yield. In a similar study at Bushland, water storage was 217, 170, and 152 mm and sorghum grain yields were 3.14, 2.50, and 1.93 Mg ha^{-1} with no-, sweep-, and disk-tillage treatments, respectively (Unger, Wiese 1979).

In the above studies at Bushland, irrigated wheat produced more residues than the amount normally produced by dryland (non-irrigated) wheat in the region. Hence, because water conservation increases with increasing amounts of residues retained on the soil surface, soil water storage and subsequent grain sorghum yields were greater than would be expected under strictly dryland conditions where less residues usually are available. That, indeed, was the case where both crops in the WSF system were grown under dryland conditions in some studies at Bushland where effects of using no-tillage and *stubble mulch tillage* were compared. Stubble mulch tillage involves tilling the soil with blade or sweep implements that undercut the surface to loosen the soil and control weeds, but retain most crop residues on the soil surface. Provided adequate residues are available to provide for a 30% cover of the surface, stubble mulch tillage is a type of conservation tillage. In studies at Bushland, soil water storage contents and grain yields of dryland wheat and grain sorghum were similar with no-tillage and stubble mulch tillage treatments (Jones, Popham 1997, Unger 1994) because surface residue amounts also were similar with both treatments.

In the studies by Unger (1984) and Unger and Wiese (1979), increased water storage with conservation tillage (sweep and especially no-tillage) resulted from the greater surface residue amounts, which, in turn, resulted in greater infiltration or lower evaporation. Effect of the different processes, however, could not be determined in those studies. For a field study at Akron, Colorado (USA), however, soil water evaporation was clearly reduced where residues were retained on the soil surface by using conservation tillage (minimum- and no-tillage) (Smika 1976). One day after 13.5-mm rain, soil water contents to the 15-cm depth were similar where conventional-, minimum-, and no-tillage treatments were imposed after harvesting winter wheat. Surface residue amounts were 1.2, 2.2, and 2.7 Mg ha^{-1} with the respective treatments. After 34 days without rain, the soil water content was <0.1 $m^3 m^{-3}$ to 12-, 9-, and 5-cm depths, respectively, showing a clear evaporation reduction advantage for the no-tillage treatment.

The benefits of surface residues for reducing soil water evaporation were also shown by Steiner (1989), who analyzed data from several studies for crop growth modeling purposes. When expressed on a weight basis, wheat straw was about twice as effective as sorghum stubble, which was about twice as effective as cotton (*Gossypium hirsutum* L.) stalks for reducing evaporation. These differences resulted from the different densities of the residues. When expressed on a residue-layer thickness basis, all types of residue resulted in similar reductions in evaporation. In both cases, evaporation decreased with increasing amounts of surface residues.

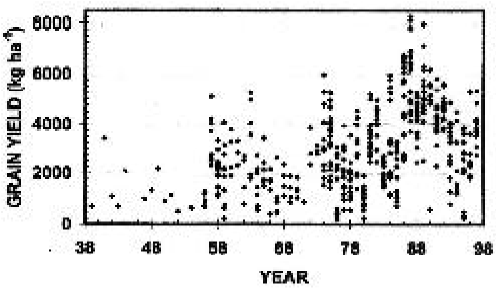

Figure 3. Grain yields for dryland grain sorghum in studies conducted at the USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas 1939-1997 (from Unger, Baumhardt 1999).

Figura 3. Producción de sorgo en condiciones de secano en estudios realizados por el USDA-ARS de Bushland, Texas entre 1939 y 1997 (Unger, Baumhardt 1999).

The U.S. Department of Agriculture-Agricultural Research Service Laboratory at Bushland, Texas, was established in 1938. From 1939 to 1997, 37 studies involved dryland grain sorghum. A preliminary examination of data for those studies indicated sorghum grain yields more than tripled during the period from 1939 to 1997 (Unger, Baumhardt 1999). Based on regression analysis using average values for individual years for the data shown in Figure 3, the equation for the yield increase is $y = 50.34x - 1121.9$, where y is grain yield in kg ha^{-1} and x is year of record. This shows that the average yearly yield increase was about 50 kg ha^{-1}. For the results, $r^2 = 0.400$ and $P = 0.001$.

To determine which factors were primarily responsible for the yield increases, Unger and Baumhardt (1999) assembled 502 treatment years of data on grain yield, annual precipitation, growing-season rainfall, soil water content at planting, soil water use, and growing-season evapotranspiration for years of those studies. Based on correlation and regression analyses, annual precipitation, growing-season rainfall, soil water use, and growing-season evapotranspiration were weakly related to the yield increases with time. Therefore, soil water content at planting was the dominant factor contributing to the observed grain yield increases.

Certainly, changes in cultivars and hybrids used, weed and insect control practices, fertilizer applications (none needed in most cases), etc. contributed to the overall yield increases, but data for such changes were not available in most cases. However, for a uniformly managed study conducted from 1956 to 1997, yields increased 139%. Of that total, 46 percent of the increase resulted from using improved hybrids. The remaining 93 percent were attributable primarily to increasing soil water contents at planting with time during that period, especially for the period before 1970 as compared with the period after 1970 (Figure 4). This change corresponded with the time when major changes in tillage practices occurred at the Laboratory. Before 1970, the primary tillage methods were clean and stubble mulch tillage for weed control during the period between crops. These methods were still included in some studies after 1970, but use of no-tillage became common in the early 1970s. Use of no-tillage results in more crop residues on the surface, which reduces evaporation and potentially increases infiltration, as shown previously. The greater retention of surface residues, along with greater use of herbicides for weed control, contributed to the greater soil water contents at planting (Figure 4). This, in turn, contributed to the generally greater grain yields in the latter years of the period considered.

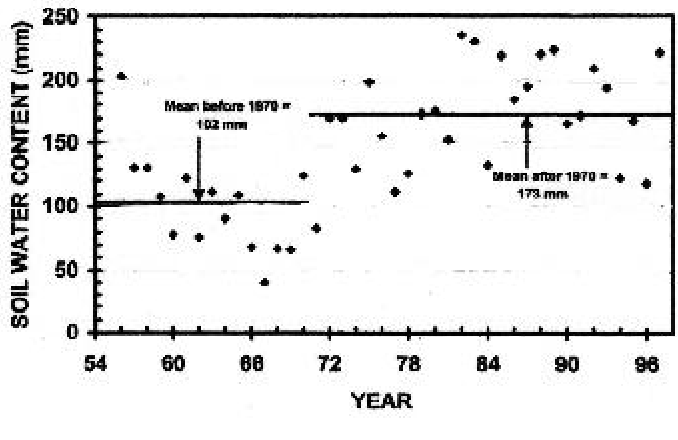

Figure 4. Average annual volumetric plant-available soil water content at planting time for dryland grain sorghum in studies conducted at the USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas, 1956-1997 (from Unger, Baumhardt 1999).

Figura 4. Contenido anual promedio de agua del suelo en el momento de la siembra de sorgo de secano en estudios realizados en el USDA-ARS de Bushland, Texas entre 1956 y 1997 (Unger, Baumhardt 1999).

CONCLUSIONS

1. Conservation tillage is an effective practice for conserving water and soil.

2. Water and soil conservation is possible by using any tillage method that reduces the amount and/or rate of runoff and increases water infiltration into soil, even when crop residues are not retained on the soil surface, which is covered by the broad definition of conservation tillage. Improved water and soil conservation usually occurs when crop residues are retained on the surface, as specified by the operational portion of the conservation tillage definition.

3. Improved water conservation through use of conservation tillage, including no-tillage, which is the ultimate type of conservation tillage, improves the potential for greater yields of dryland crops, which occurred in numerous studies in the semiarid portion of the USA Great Plains, and has potential for improving dryland crop yields under dryland conditions in other regions.

4. Improved soil conservation through use of conservation tillage helps maintain soil resources for sustained crop productivity, which is important under any crop production system.

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