Conservation Tillage in Temperate Agroecosystems

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CHAPTER 14

Conservation Tillage in the Southern United States Great Plains

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4.1. INTRODUCTION

The southern Great Plains (SGP) is the southern portion of the Great Plains of the United States, a vast midcontinent region that early explorers called the "Great American Desert"[1] because precipitation was limited, there were few springs or streams, and the landscape was relatively flat and treeless. The explorers considered the region undesirable and wholly uninhabitable for people from the humid and forested eastern regions of the United States. This view of the "Great American Desert" remained in the public mind until after the end of the Civil War in 1865.

Early human inhabitants of the Great Plains were the Plains Indians, who were nomadic and nonagricultural. They were hunters, mainly of the bison (*Bison* spp.) that roamed freely on the wide, grassy expanses of the Plains. The grasses were mainly short types on the arid to semiarid western part and tall types on the subhumid eastern part of the region. Settlers from the eastern United States and Europe, both ranchers and farmers, inhabited the region during the latter decades of the 1800s. The farmers brought with them the implements and methods of farming that they had used in their region of origin. The grasses were turned under and the land was used mainly for growing grain crops. The methods of farming involved clean tillage (total incorporation of crop residues), and crop production generally was satisfactory in years of above-average precipitation. Overall, however, both the implements and methods of farming brought by the settlers were unsuitable for the harsh environment of the Great Plains that is characterized by low precipitation and generally high winds. The methods of farming were especially unsuitable when precipitation was below normal for several succeeding years. The major drought of the 1930s,[2] coupled with intense wind storms, clearly demonstrated the urgent need for developing farming practices adaptable to the Great Plains' environment. An outcome of the severe devastation of the land that occurred during the 1930s was the development of the stubble mulch tillage system, presently known as a type of conservation tillage. A widely accepted definition of

Table 14.1. MLRAs of the SGP

MLRA	Name	Total Area (km²)	Area in Cropland (%)	Elevation (m)	Precipitation (mm)
70	Pecos-Canadian Plains and Valleys	84,830	3	1200–2100	300–400
77	Southern High Plains	126,780	60	800–2000	375–550
78	Central Rolling Red Plains	130,370	35	500–900	500–750
80A	Central Rolling Red Prairies	52,700	40	300–500	625–900
80B	Texas North-Central Prairies	25,500	15	200–700	550–750

Source: Agriculture Handbook 296.[4]

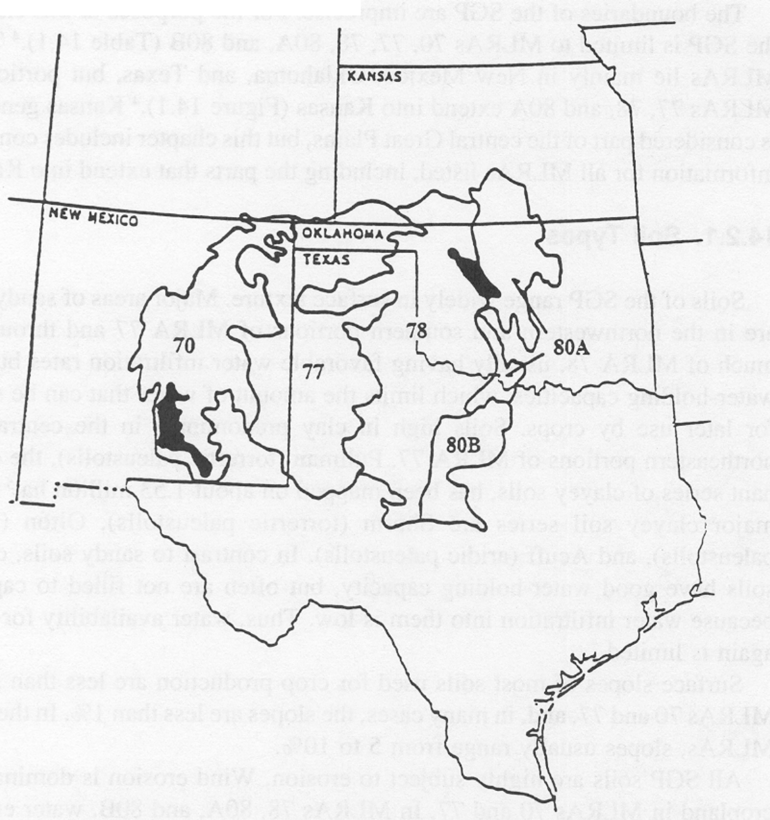

Figure 14.1. MLRAs of the SGP of the United States.

conservation tillage is any tillage or planting system that maintains at least 30% of the soil surface covered by residues after crop planting to reduce soil erosion by water. Where wind erosion is the primary concern, residues or plants of other crops equivalent to at least 1.1 Mg/ha of flat, small grain residue must be maintained on the surface during the critical erosion period.[3]

Presently, large portions of the region are extensively farmed, with cropland comprising up to twothirds of the land in some major land resource areas (MLRAs) (Table 14.1, Figure 14.1).[4] The remaining land is used mainly for livestock production; large ranches are common in some MLRAs. Relatively small areas are used for cities, roads, parks, etc. With current practices, the SGP as well as the entire Great Plains is a major crop-producing region, especially of grain crops.

14.2. FEATURES OF THE AGROECOSYSTEM

The boundaries of the SGP are imprecise. For the purposes of this chapter, the SGP is limited to MLRAs 70, 77, 78, 80A, and 80B (Table 14.1).[4] These MLRAs lie mainly in New Mexico, Oklahoma, and Texas, but portions of MLRAs 77, 78, and 80A extend into Kansas (Figure 14.1).[4] Kansas generally is considered part of the central Great Plains, but this chapter includes complete information for all MLRAs listed, including the parts that extend into Kansas.

14.2.1. Soil Types

Soils of the SGP range widely in surface texture. Major areas of sandy soils are in the northwestern and southern portions of MLRA 77 and throughout much of MLRA 78, usually having favorable water infiltration rates but low water-holding capacities, which limits the amount of water that can be stored for later use by crops. Soils high in clay predominate in the central and northeastern portions of MLRA 77. Pullman (torrertic paleustolls), the dominant series of clayey soils, has been mapped on about 1.53 million ha.[5] Other major clayey soil series are Sherm (torrertic paleustolls), Olton (aridic paleustolls), and Acuff (aridic paleustolls). In contrast to sandy soils, clayey soils have good water-holding capacity, but often are not filled to capacity because water infiltration into them is low. Thus, water availability for crops again is limited.

Surface slopes of most soils used for crop production are less than 5% in MLRAs 70 and 77, and, in many cases, the slopes are less than 1%. In the other MLRAs, slopes usually range from 5 to 10%.

All SGP soils are highly subject to erosion. Wind erosion is dominant on cropland in MLRAs 70 and 77. In MLRAs 78, 80A, and 80B, water erosion dominates, but wind erosion is a major problem in localized areas. The potential for wind erosion is especially great on sandy soils throughout the SGP.

The clayey soils of MLRAs 70 and 77 usually have adequate fertility so that a response to fertilizer is not obtained under dryland conditions.[6] With irrigation, crops respond to nitrogen and, in some areas, to phosphorus applications. The sandy soils in MLRAs 70 and 77 and most soils in MLRAs 78, 80A, and 80B are less fertile, and crops usually respond to fertilization.

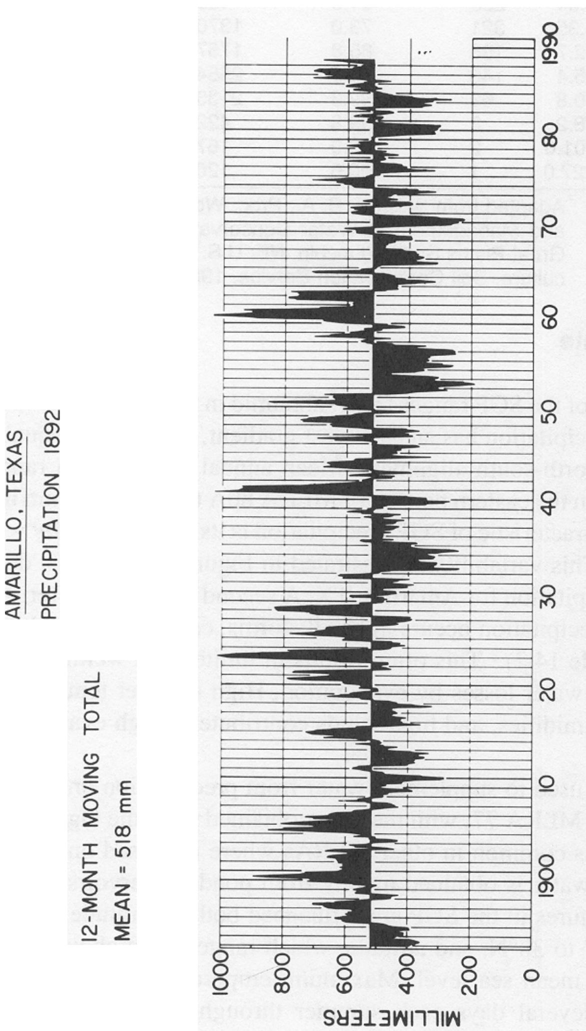

Figure 14.2. Long-term precipitation at Amarillo, TX, plotted as a 12-month moving total to show above- and below-average periods. Long-term average is 518 mm. Points on the curve represent deviation from the average for the past 12 months.

Table 14.2. Analysis of Precipitation by Storm Size, Bushland, TX, 1960–1979

Storm Size (mm)	Storms (no.)	Cumulative Storms (%)	Total Precipitation (mm)	Cumulative Precipitation (%)
0.00–1.27	561	36.8	226	2.4
1.28–2.54	229	51.9	459	7.4
2.55–6.35	321	73.0	1370	22.2
6.36–12.7	195	85.8	1757	41.2
12.8–25.4	143	95.2	2554	68.8
25.5–50.8	62	99.3	2133	91.8
50.9–76.2	8	99.8	422	96.9
76.3–101.6	2	99.9	167	98.9
101.7–127.0	1	100.0	120	100.0

Source: Adapted from Stewart, B. A., Proc. Workshop on Planning and Management of Water Conservation Systems in the Great Plains States (Lincoln, NE: U.S. Department of Agriculture, Soil Conservation Service, 1985).

14.2.2. Climate

The climate of the SGP ranges from subhumid in the eastern part to semiarid in the west. Precipitation has an east-west gradient, and lines of equal precipitation have a north-south alignment. Mean annual precipitation ranges from about 900 mm in the eastern portion of MLRA 80A to about 300 mm in MLRA 70. A major characteristic of SGP precipitation is its high variability within and among years. This variability is illustrated in Figure 14.2,[7] which depicts the long-term precipitation for Amarillo, TX. A second major characteristic is that much of the precipitation occurs in small storms, commonly less than 25 mm per storm (Table 14.2).[8] This often results in limited soil wetting and, consequently, major water losses by evaporation. High summer temperatures, low atmospheric humidities, and high winds contribute to high evaporative water losses.

Irrigation is used to supplement water from precipitation on about 45% of the cropland in MLRA 77, with the water obtained from the Ogallala Aquifer. Irrigation is less common in other MLRAs where it is used only in localized areas, and the water is obtained mainly from ponds, reservoirs, or streams.

Air temperatures in the SGP are influenced both by latitude, which ranges from about 32° to 38°N, and altitude, which ranges from about 300 to about 1370 m above mean sea level. Maximum temperatures usually approach or exceed 38°C several days each summer throughout the region. Minimum temperatures of –15 to –20°C occur during most winters in MLRAs 70 and 77, where altitudes are greatest. Temperatures limit the frost-free growing season to 180 to 190 days at the higher altitudes and from 210 to 220 days at the lower altitudes.[5] Winter wheat (*Triticum aestivum* L.), a cold-tolerant crop, is widely grown throughout the region, but is damaged by cold temperatures under some conditions, mainly when extremely cold temperatures follow periods of relatively mild temperatures.

14.2.3. Crops and Cropping Systems

The major crop in all MLRAs of the SGP, except MLRA 70, is winter wheat, which is grown for grain and for grazing by cattle. Under fully irrigated conditions (mainly in MLRA 77), grain yields of around 6.0 Mg/ha are achieved. Grain yields on dryland are highly variable and range from about 1.0 Mg/ha at the drier western locations to about 2.5 Mg/ha at the more humid eastern locations.

Grain sorghum (*Sorghum bicolor* (L.) Moench) is widely grown in MLRAs 77, 78, 80A, and 80B. With full irrigation (mainly in MLRA 77), grain yields often exceed 8.0 Mg/ha. Dryland sorghum grain yields are highly variable and usually average less than 3.0 Mg/ha.

Important crops in MLRA 70, where only about 3% of the land area is farmed, are forages and feed grains (various species). A major crop in the southern half of MLRA 77 is cotton (*Gossypium hirsutum* L.), where some is irrigated if groundwater is available. Other important crops in portions of MLRA 77 are corn (*Zea mays* L.), sugar beets (*Beta vulgaris* L.), and various vegetables. Cotton also is important in MLRAs 78, 80A, and 80B, and usually is not irrigated. Other important crops are alfalfa (*Medicago sativa* L.) and peanut (*Arachis* spp.) in MLRA 78; alfalfa, peanut, and soybean (*Glycine max* L.) in MLRA 80A; and oat (*Avena sativa* L.) in MLRA 80B.

Where adequate water is available, either from precipitation in the more humid eastern portion of the region or from irrigation, crops usually are grown annually (one crop per year). Often, crops such as wheat, sorghum, cotton, and peanut are grown continually (the same crop in the same field each year), unless weeds or other pests (insects or diseases) warrant crop rotations. Where such problems occur, another adaptable crop may be grown or a crop rotation may be implemented. Crop rotations involving a winter and a summer crop, for example, winter wheat and grain sorghum, are highly effective for controlling problem weeds. Such rotation is especially appropriate where water for irrigation is limited because fallow periods between crops provide time for additional water storage in soil for use by the next crop.[9,10] Sugar beet usually is rotated with other crops, mainly to help control sugar beet diseases.

On dryland, especially on the drier portions of the region, crops may be grown annually, but crop-fallow systems are more common. The main systems involving fallow on dryland are wheat-fallow (one crop in 2 years) and wheat-sorghum-fallow (two crops in 3 years). In some cases, grain sorghum and cotton are grown in rotation.[11]

Cotton often is grown continuously, both with irrigation and on dryland. On dryland, skip-row planting patterns often are used. Typical patterns are two rows planted and one row skipped, two rows planted and two rows skipped, and four rows planted and two rows skipped. In such cases, plant roots extend into and extract water from the nonplanted rows, thus resulting in yields not greatly different from those in which all rows are planted. Advantages of skip-row planting include lower production costs because less seed is planted and the harvested area is smaller; easier weed control; wheel traffic can be confined to the skipped rows, thus minimizing soil compaction near the planted row; and high-residue crops can be planted in skipped rows to provide vegetative barriers for wind erosion control.[11]

14.3. ADOPTION OF CONSERVATION TILLAGE

14.3.1. Conventional Tillage Systems

As in other regions, tillage that is considered or termed "conventional" changes with advances in technology. This was illustrated by Greb et al.[12] for winter wheat production on dryland in Colorado in the central Great Plains (CGP). During the early years, bare fallow achieved by plowing and harrowing was common. Later, SM tillage became the "conventional" system. Presently, a limited tillage system involving a combination of tillage and herbicides for weed control and land preparation for the next crop is being widely used in the CGP and could appropriately be called the conventional system for that region.

Early tillage systems in the SGP closely paralleled those in other Great Plains regions for crops such as winter wheat. Clean tillage for which all crop residues were plowed under was the primary method used by early settlers in the SGP. Such tillage continued to be used during the early decades of the 1900s, and was a major factor leading to the devastating dust storms that plagued the SGP during the drought of the 1930s.[2] During that drought, crop growth was extremely limited. Not enough plant material from either growing plants or crop residues was available to help control erosion. The irrigation methods that could have increased crop yields and stabilized the soil had not been developed in the SGP by the 1930s.

The SM tillage system was initially developed at Lincoln, NE in the late 1930s. Within a few years, research and development work on SM tillage was done throughout the Great Plains, including Bushland, TX.[13] With this system, large sweeps or blades undercut the surface at a depth of about 5 to 10 cm while retaining most residues on the surface. SM tillage is effective for controlling erosion, especially that caused by wind, provided adequate residues are available. It is generally considered to be *the* conventional tillage system, especially for dryland wheat and grain sorghum production in MLRA 77.[11] If the requirement of 30% surface cover or of 1.1 Mg/ha of small-grain-equivalent amount of residues on the surface after crop planting is satisfied, SM tillage can appropriately be called conservation tillage. Chisel plows are also widely used for dryland wheat production, but tillage systems involving the chisel plow seldom retain enough residues on the surface in parts of the region for the system to be classified as conservation tillage. For irrigated wheat, mainly in MLRA 77, the land usually is disced, chiseled, disced again, and furrowed to control irrigation water flow. Moldboard plowing is used by some producers, but its use has declined sharply in the last 10 to 20 years.

At more humid locations in the SGP where wheat grain yields are greater, surface residue amounts may exceed 3.0 Mg/ha and cause difficulties in seeding the next crop. Under such conditions, the first postharvest tillage may be offset discing. Subsequent tillage may employ a SM implement. In cases in which cheatgrass (*Bromus secalinus* L.) is a serious problem, moldboard plowing at approximately 4-year intervals is one effective control measure.[11]

Tillage practices for grain sorghum are similar to those for wheat, except that lister plowing (ridge tillage) is used for sorghum where a major potential for wind erosion exists. Ridge tillage helps control wind erosion by providing surface roughness in the direction perpendicular to prevailing winds.

Much of the SGP cotton is grown on soils having relatively high sand contents. Because cotton residues have a low value in controlling erosion, practices other than surface residue management must be relied upon for doing so. Terracing and ridge tillage on the contour are effective for controlling water erosion. To help control wind erosion, the land is moldboard plowed, listed, or chiseled to reduce compaction and to bring erosion-resistant clods to the surface.[11,14] Other practices for controlling wind erosion include mulching with cotton gin trash or stover of other crops — for example, pearl millet (*Pennisetum americanum* (L.) K. Schum);[15] growing high-residue-producing crops that serve as a wind barrier on the skipped rows in which cotton is planted in a skip-row pattern;[16,17] or planting a small grain cover crop between cotton rows before the cotton is harvested. In most cases water storage was greater with a mulch than with bare soil.[15,18]

Dryland cotton is planted in lister furrows or on ridges formed by lister plowing. In either case, the ridges help control wind erosion.[11] Cotton to be irrigated commonly is planted on previously formed ridges.

14.3.2. Development of Conservation Tillage Systems

Russel[19] showed the tremendous value of surface residues for reducing stormwater runoff and for increasing soil water storage (SWS), thus providing additional water for use by subsequent crops. Both also have a major impact on soil erosion. Reducing runoff minimizes water flow across the surface, thus also minimizing soil transport across the surface. Increased water storage increases the potential for improved plant growth, thus providing more vegetative matter by either growing plants or residues postharvest for greater protection of the surface against erosion by wind or water. Water conservation and erosion control are prime requisites for successful crop production in the SGP.

The early research by Russel[19] and others, which led to the development of SM tillage, also showed that runoff and evaporation decreased and SWS increased with increasing amounts of surface residues (Table 14.3).[19] Although the potential for increased water conservation with no-tillage was illustrated by this early research, no-tillage systems of crop production were not practical at that time because of weed control and equipment limitations.

Table 14.3. Water Storage, Runoff, and Evaporation from Field Plots at Lincoln, NB, 10 April to 27 September 1939

Treatment	Storage	Runoff (mm)	Evaporation	Loss (%)[a]
Straw, 2.2 Mg/ha, normal subtillage	30	26	265	83
Straw, 4.5 Mg/ha, normal subtillage	29	10	282	88
Straw, 4.5 Mg/ha, extra loose subtillage	54	5	262	82
Straw, 9.0 Mg/ha, normal subtillage	87	Trace	234	73
Straw, 17.9 Mg/ha, no-tillage	139	0	182	57
Straw, 4.5 Mg/ha, disced	27	28	266	83
No straw, disced	7	60	254	79
Contour basin listing	34	0	287	89

Source: Adapted from Russel, J. C., *Soil Sci. Soc. Am. Proc.*, 4, 65, 1939.

[a] Based on total precipitation, which was 321 mm for the period

Herbicides for weed control in field crops became available in the early 1950s. Soon thereafter, no-tillage research was initiated for both dryland winter wheat and grain sorghum in the SGP at Bushland, TX.[20-22] Major limitations to no-tillage in the early studies were limited effectiveness of herbicides for controlling weeds and low residue production by dryland crops. The amounts of residue produced were not adequate to appreciably enhance water infiltration or suppress soil water evaporation.

Major improvements in herbicides were made during the late 1950s and in the 1960s, which led to widespread interest in developing no-tillage cropping systems. These studies showed that the no-tillage system of crop production was highly effective for controlling soil erosion, both wind and water, and for improving water conservation. The need for improved soil and water conservation in the SGP led to further conservation tillage (including no-tillage) research at several SGP locations in the 1960s.

14.3.2.1. Southern High Plains

In 1968, Unger et al.[23] applied atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine]* at 3.4 kg of active ingredient per hectare (a.i./ha) and 2,4-D [2,4-dichlorophenoxy)acetic acid] at 1.1 kg a.i./ha to some plots at Bushland, TX (MLRA 77) soon after harvest of irrigated winter wheat. The herbicides were used to control weeds and volunteer wheat during the ensuing fallow period (about 11 months later) before planting grain sorghum. On other plots, weeds were controlled by disc or sweep tillage as needed, or by a combination of one sweep tillage operation and herbicides as indicated above. The irrigated wheat produced about 11 Mg/ha of residues. Soil water contents

* Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that also may be suitable.

Table 14.4. Effect of Tillage during Fallow after Winter Wheat Harvest in 1968 on Soil Water Content at Sorghum Planting in 1969, Bushland, TX

Treatment	Soil Water Content (mm)
Tandem disc tillage	145 c[a]
Tandem disc plus sweep tillage	135 c
Sweep tillage	163 b
Sweep tillage plus herbicides	196 a
Herbicides only (no-tillage)	203 a

Source: Adapted from Unger P. W. et al, *J. Soil Water Conserv.*, 26, 147, 1971.

[a] Values followed by the same letter are not significantly different at the 5% level (Duncan multiple range test).

at sorghum planting in May 1969 (Table 14.4)[23] were similarly high for the herbicides-only and the sweep tillage-herbicides combination treatments and similarly low with disc tillage only and disc plus sweep tillage treatments. At sorghum planting, about 4.6 Mg/ha of residues remained on the surface of herbicide-treated plots, but <0.2 Mg/ha on disc tillage plots.

In the foregoing study,[23] sorghum yields were not obtained, but in subsequent residue management studies after irrigated winter wheat from 1974 to 1981, plant-available soil water contents at sorghum planting averaged 213, 174, and 155 mm, and dryland sorghum grain yields averaged 3.23, 2.62, and 2.12 Mg/ha with no-, sweep, and disc tillage treatments, respectively.[9,10] Yield responses were not as great when irrigated wheat was followed by dryland sunflower (*Helianthus annuus* L.) [24] or irrigated corn.[25] However, Musick et al.[26] obtained major water storage and sorghum yield increases with no-tillage as compared to clean (disc) tillage when both the wheat and grain sorghum were irrigated.

Baumhardt et al.[27] evaluated the effects of disc and no-tillage management of wheat residues on SWS and on dryland and irrigated grain sorghum yields on Pullman soils at Bushland and Lubbock, TX. SWS was greater with no-tillage than with discing at Bushland where wheat produced 11 Mg/ha of residues. At Lubbock, where the residue amount was only 2 Mg/ha, water storage differences were slight. Average sorghum grain yields on dryland for 2 years were greater (1.19 Mg/ha increase) with no-tillage than with disc tillage at Bushland, but only in 1 of 2 years at Lubbock (0.96 Mg/ha increase). With irrigation, grain yields were not affected by tillage treatments at Bushland, but were 1.11 Mg/ha greater with no-tillage than with disc tillage at Lubbock.

Water storage and sorghum yields increased with increases in amounts of wheat residues placed on the soil surface at Bushland (Table 14.5).[28] This study clearly illustrated the value of surface residues for enhancing SWS, which is of major importance in stabilizing crop yields in the semiarid portions of the SGP.

Table 14.5. Straw Mulch Effects on Soil Water Storage during Fallow,[a] Water Storage Efficiency, and Grain Sorghum Yield at Bushland, TX, 1973–1976

Mulch Rate (Mg/ha)	Water Storage[b] (mm)	Water Storage Efficiency[b] (%)	Grain Yield (Mg/ha)
0	72 c[c]	22.6 c[c]	1.78 c[c]
1	99 b	31.1 b	2.41 b
2	100 b	31.4 b	2.60 b
4	116 b	36.5 b	2.98 b
8	139 a	43.7 a	3.68 a
12	147 a	46.2 a	3.99 a

Source: Adapted from Unger, P. W., *Soil Sci. Soc. Am. J.*, 42, 486, 1978.

[a] Fallow duration of 10 to 11 months.
[b] Water storage determined to 1.8 m depth. Precipitation averaged 318 mm.
[c] Column values followed by the same letter are not significantly different at the 5% level (Duncan multiple range test).

Annual cropping of dryland winter wheat using conservation tillage practices can usually be achieved without difficulty. SM or chisel tillage is used most often. The major limitation is the amount of residue available. Often, 30% of the surface is not covered with residues at planting for the practice to qualify as conservation tillage. Use of no-tillage for continuous wheat on dryland has shown promise.[29]

For annually cropped irrigated winter wheat, usually large amounts of residue are produced. Even if the land is disced one or two times between crops, which is a common practice, adequate residues can be retained on the surface to qualify as conservation tillage. Most attempts to grow irrigated wheat annually using a no-tillage system were not successful because of a surface residue buildup that caused planting, seedling vigor, and weed control problems.[30,31] For annual wheat, alternating between no-tillage and limited tillage was satisfactory.

Cotton residues (stalks) have little value for controlling erosion and they are shredded before the land is plowed in preparation for the next crop, usually cotton. Moldboard plowing, listing, or chiseling produces a rough, cloddy surface that helps control wind erosion.[11,14] However, the sandy soils on which much of the cotton is grown in the SGP are highly erosive and severe erosion frequently occurs.

14.3.2.2. Central Rolling Red Plains

Most crops in the central rolling red plains (MLRA 78) are not irrigated. Groundwater in most of the MLRA is scarce, and water for irrigation is derived from ponds or reservoirs that have limited storage capacity. While irrigation is limited in MLRA 78, some research involving conservation tillage for irrigated crops has been conducted in the region. At Munday, TX, irrigated winter wheat grain yields averaged 4.13 Mg/ha with clean and 3.48 Mg/ha with reduced tillage during a 5-year study. For one crop, yields were significantly lower with reduced tillage (4.46 vs 5.86 Mg/ha). Gerard and Bordovsky[32] attributed the lower yields to fewer heads associated with a lower plant population because of planting problems, in which large amounts of residues were present, and possibly because of reduced tillering. For this and the following studies, reduced tillage involved weed control with herbicides between crops and cultivation during the growing season.

For annually cropped, irrigated grain sorghum at Munday, differences in grain yield, water use, and water-use efficiency due to reduced and clean tillage treatments were not significant. For clean tillage, plots were disced twice, bedded (ridge-tilled), and cultivated before and after planting. Use of herbicides provided additional growing season weed control.[33] Clark[34] evaluated the effects of conventional and reduced tillage systems and furrow diking treatments on dryland cotton production on Abilene clay loam (fine, mixed, thermic pachic argiustoll) at Chillicothe, TX. Treatments involved diking all, alternate, or no furrows. Cotton lint yields were not affected by tillage system, but furrow diking significantly increased yields. Average yield increases over the undiked treatment were 16 and 36% with alternate and every furrow diking, respectively. This study showed that in the absence of surface residues, furrow diking can be an effective water conservation practice, at least on some soils. On the Pullman soil at Bushland, furrow diking in conjunction with no-tillage wheat residue management (dikes installed before planting wheat) did not increase SWS or sorghum yields over those obtained with no-tillage alone.[35] Surface residue amounts and soil slopes undoubtedly contributed to the different responses. Residue amounts were greater and slopes were less at Bushland than at Chillicothe.

In another study at Chillicothe, Clark et al.[36] determined the production potential and practicality of reduced, conventional, and narrow row tillage systems for dryland cotton production. Furrow diking was a key operation for each system. The reduced tillage system significantly reduced runoff and increased water storage, lint yield, water use efficiency, and profitability as compared to the conventional and narrow row systems. Net return to land, management, and risk was $244/ha with reduced tillage, which was 50 and 114% greater than with the conventional and narrow row systems, respectively.

For dryland grain sorghum production at Munday, conventional tillage involved discing twice, bedding, and cultivating before and after planting. Reduced tillage involved using glyphosate (*N*-(phosphonomethyl) glycine) to control weeds between harvest and planting, and cultivation to control weeds during the growing season. The treatments did not significantly affect grain yields, water use, or water use efficiency.[33]

Much of the wheat in Oklahoma in MLRA 78 is annually cropped. SM tillage was used there in the 1960s. Although generally successful, common problems involved weed control and poor plant populations that resulted from planting in stubble with less than adequate drills.[37]

Scientific and technological advances since the 1960s have made reduced or no-tillage systems feasible for wheat production in western Oklahoma where the systems are known as "Lo-Till." Lo-Till is any of several systems that rely on herbicides alone or in combination with tillage to provide adequate weed control during the noncrop period and to provide a favorable seedbed for the next crop. With the large amounts of residues usually produced by wheat in the region, maintaining adequate residues on the surface is not a major problem. The systems still qualify as conservation tillage, even when some tillage is performed. Use of conservation tillage increased SWS in some cases.[38] Use of a no-tillage system often resulted in the greatest soil water content.[39]

In comparisons involving Lo-Till and cooperators' practices, early results indicated a 0.66 Mg/ha average grain yield increase with Lo-Till (3.76 vs 3.11 Mg/ha). Use of Lo-Till systems provided better soil water conditions that allowed earlier and/or more timely planting than was possible with conventional tillage. Earlier planting provided more forage for grazing by cattle, thus offsetting the greater cost of herbicides used with the Lo-Till system.[37] Although early results were favorable, growing wheat annually without tillage resulted in major weed (mainly cheatgrass) problems and reduced plant vigor after 3 or 4 years at some locations. Major tillage at 3- or 4-year intervals helps overcome these problems.[40] At other locations, wheat has been grown successfully by using no-tillage continuously,[41] but delayed planting or use of a contact herbicide can also avoid the cheatgrass problem, thus avoiding the destruction of improvements in soil properties achieved through the use of no-tillage.[42]

Epplin et al.[43] compared conservation and mechanical tillage systems for weed control where winter wheat was grown annually in Oklahoma. The additional cost of herbicides, where they were relied upon for weed control, exceeded the value of fuel and labor saved by using mechanical weed control methods. However, because of less investment in equipment, some conservation tillage systems were competitive with mechanical systems on a total cost basis.

14.3.2.3. Other Land Areas

The MLRAs discussed in this section are small compared to MLRAs 77 and 78. Of the three, MLRA 70 is the largest (Table 14.1).[4] However, only about 3% of it is used for cropland. This MLRA is at a higher elevation and receives less precipitation than MLRA 77, which is east of MLRA 70. In general, tillage practices applicable to MLRA 77 are also applicable to MLRA 70. MLRAs 80A and 80B, which are east of MLRA 78, are located at a lower elevation and generally receive more precipitation than MLRA 78. Wheat, grain sorghum, and cotton are major crops in all three MLRAs, and tillage practices in MLRAs 80A and 80B generally are the same or similar to those used in MLRA 78. Other important crops adaptable to conservation tillage are peanut and soybean in MLRA 80A and oat in MLRA 80B. Research results involving these crops are not available from MLRAs 80A and 80B.

Soybean often is grown after wheat at various locations using conservation tillage practices, either double-cropped or in rotation. Similar conservation tillage practices should be suitable for soybean in MLRAs 80A and 80B. Peanut is highly susceptible to various diseases. At Yoakum, TX, in MLRA 87 (Texas Claypan area), moldboard plowing resulted in better disease control and greater yields than discing or no-tillage. Weed control was difficult with no-tillage, especially for grassy species.[44] At several locations in MLRA 78, weed control with herbicides was satisfactory and no increase in disease incidence occurred when peanut was strip-till planted into wheat residues, as compared to planting after moldboard plowing. Strip-till planting reduced soil erosion, but it reduced yields 10 to 15%.[45]

14.4. CRITICAL FACTORS RELATED TO ADOPTION OF CONSERVATION TILLAGE

Most soils of the SGP are suitable for crop production by conservation tillage methods and, unless high residue conditions prevail, do not have a cold temperature limitation (slow warming in the spring) due to surface residues.[46] However, lower soil temperatures with no-tillage were beneficial for wheat production where grazing by livestock was involved.[41]

The extensive area of sandy soils with low water-holding capacities may not benefit as much as finer-textured soils from conservation tillage with respect to water conservation efforts. Sandy soils also are subject to compaction by normal cultural operation and by animal trampling when crops are grazed by them.[47] However, provided adequate residues are available initially, these soils can be loosened if needed, for example, by chiseling, and still retain enough residues on the surface for the system to qualify as conservation tillage.

Overall, climatic conditions in the SGP permit the use of conservation tillage systems. In fact, climatic factors of limited and erratic precipitation, high potential evaporation, high summer temperatures, and high wind speeds are reasons why conservation tillage should be used in the SGP.

14.4.1. Crop Residue Level Effect

Although suitable systems are available for most SGP crops, problems remain that will delay the adoption of conservation tillage in some cases. These include inadequate residue production by dryland crops in drier portions of the region, high residue production at more humid locations, and low residue production by cotton and peanut. The potential for greater disease incidence in peanut also is of concern in conservation tillage. To make conservation tillage more widely adaptable, practices, equipment, or materials needed include those that (1) retard residue losses where residue production is limited, (2) hasten residue decay or provide for the removal of some residues where large amounts are produced, (3) provide for satisfactory crop establishment under high-residue conditions, and (4) allow low-residue-producing crops such as cotton and peanut to be grown economically in conjunction with crops that produce adequate residues for soil and water conservation purposes.

On dryland, residue production by crops may not be adequate to provide enough residue for management by conservation tillage methods. Residue production by cotton and peanut crops is especially limited. Even if tillage practices that retain all residues of these crops on the soil surface are used, sufficient amounts may not be available for the practices to qualify as conservation tillage. These crops, however, can be grown in rotation or in strip-cropping systems involving other crops that provide more residues, thus affording soil and water conservation benefits.

A major limitation to enhanced water conservation with no-tillage and conservation tillage in general in the SGP is low-residue production by dryland crops, especially in the drier western portion of the region. Because of limited residues, stormwater runoff is greater from no-tillage than from conventional (SM) tillage watersheds. Runoff is greatest during fallow after sorghum when surface cover by residues is least. However, although runoff is greater with no-tillage, soil water contents due to tillage methods at planting of either crop usually are similar, apparently because soil disturbance by tillage increases evaporative losses of soil water. This negates the advantage that SM tillage provides with respect to runoff. Because soil water contents at planting often were similar, differences in dryland winter wheat and grain sorghum yields due to tillage also were slight.[48]

Surface residues resulting from the use of conservation tillage led to increased water storage,[9,10,28] reduced evaporation,[49] moderation of summer maximum soil temperatures,[46] and reduced wind speeds at the soil surface.[50] Undoubtedly the greatest climatic limitation to the adoption of conservation tillage in most of the SGP is limited precipitation. Precipitation is often too low to provide enough water for good growth of dryland crops, thus not producing adequate residues to be managed for conservation purposes.

14.4.2. Crop Rotation Effect

Winter wheat and grain sorghum are two major crops of the SGP and can be successfully grown by conservation tillage methods when grown in rotation. Weed control with herbicides or a combination of herbicides and tillage often is satisfactory in this rotation. However, this rotation results in only two crops in 3 years, which may not be satisfactory for producers that require full utilization of land resources for their farming enterprise to be economical.

Growing either winter wheat or grain sorghum annually by conservation tillage is possible, but weed and volunteer crop plant control problems occur in some cases, especially when a no-tillage system is used. The problem generally is most severe when the crops are irrigated or grown in the more humid eastern portion of the SGP. Under such conditions, planting and seedling vigor problems may be encountered. Occasional clean tillage or use of reduced tillage systems minimizes these problems.[30,31,40,51,52] In other cases, annual wheat has been grown successfully by no-tillage methods under these conditions.[41]

In efforts to overcome the problem of severe wind erosion on sandy soils in which cotton is grown, Keeling et al.[53] and Lyle and Bordovsky[54] grew cotton in rotation with sorghum and wheat, which provided adequate cover to control erosion. Lint yields of irrigated cotton generally were not affected by tillage method (conventional, minimum, or no-tillage). However, dryland cotton usually yielded more with minimum and no-tillage than with conventional tillage when the cotton was rotated after sorghum or wheat and when planted after wheat used as a cover crop, then killed. Economic returns were greater with no-tillage, which should make the system acceptable to producers.[53-55]

Harman et al.[56] reported greater economic returns for no-tillage than for conventional tillage dryland cotton grown in rotation with irrigated barley (*Hordeum vulgare* L.). The soil was Sherm clay loam (fine, mixed, mesic torrertic paleustoll) at Etter, TX. Herbicide costs were $155/ha greater with no-tillage than with conventional tillage, but long-term annual profits were $82/ha greater with no-tillage because of an average lint yield increase of 110 kg/ha and lower machinery depreciation costs.

14.4.3. Economic Considerations

Most crop producers operate under some constraints with respect to capital, land, and equipment resources. For the production of crops, these resources are managed primarily to meet their immediate needs and, secondarily, to meet their perceived long-term needs. To achieve these ends, producers generally select crop production options that involve the least risk. Because conservation tillage is a relatively new practice, at least under many circumstances, producers may avoid using this practice and continue to use practices that have proven adequate through past experiences. Adoption of conservation tillage may also require the purchase of new or different equipment, an investment that producers may not care to make unless there is little or no risk involved with respect to meeting their needs.

A major consideration is the producer's managerial ability. Conservation tillage requires a relatively high level of management because it is a system that does not begin and end with a given crop. For satisfactory crop production by conservation tillage methods, practices applied to the current, or even the previous, crop may affect future crops, especially when weeds are controlled with herbicides. Also, producers must be capable of dealing with unexpected problems.

The use of economically feasible practices is essential for long-term economically sound crop production, regardless of the tillage system employed. Studies have shown that various conservation tillage systems adaptable to the SGP are economically feasible.[55-57] A major advantage often was shown for conservation tillage, especially when long-term equipment costs and depreciation were considered in the analyses. When only short-term costs and returns were considered, conservation tillage sometimes was less economical because herbicide costs are high for some production systems. High short-term costs could cause producers that have limited capital or credit available to them to opt for systems that involve lower short-term costs.

Commodity price support programs administered by governmental agencies usually are based on the production of certain crops grown on pre-established areas of land. Under such constraints, producers may lose flexibility of land use for other crops, which may also thwart implementation of conservation tillage systems. This is especially true if the conservation tillage system would involve two or more crops in a rotation.

Some crops are well-adapted to certain soils and climatic conditions, for example, cotton on portions of MLRA 77. Other crops are less economical when grown in place of cotton. Hence, cotton remains the choice of producers, even though severe wind erosion often occurs in the cotton-growing region. Unless suitable alternative crops become available or strict erosion control regulations are imposed, cotton will remain the producers' choice crop for the region.

Adoption of conservation tillage in the SGP has suffered in part from a lack of strong and effective leadership on the part of agency personnel responsible for implementing sound soil and water conservation practices. Conflicting reports concerning conservation tillage may also cause producers to doubt the effectiveness of these systems for their production situation. Unless producers are provided with sound information and strongly encouraged to use it, many producers may not adopt this soil and water conservation practice that is so needed in the SGP.

14.5. ACCEPTANCE OF CONSERVATION TILLAGE

Acceptance of conservation tillage by farmers varies with crops being grown and areas within the region. Some form of conservation tillage (usually SM tillage) often is used for winter wheat in the drier western areas, but it is much less common in the more humid eastern areas, especially where wheat is grown continually (annual cropping). Major reasons for low acceptance of conservation tillage in the more humid wheat-growing areas are the continuing problem with cheatgrass control, difficulty in crop establishment where large amounts of residue remain on the surface, poor vigor of plants growing in residues, and a general perception that it is not economical.

Similar problems are encountered for irrigated wheat in MLRA 77, except that cheatgrass problems are slight. Discing and chiseling of annually cropped, irrigated wheat, can result in retaining adequate residues for conservation purposes, provided that these implements are used wisely. Subsequent ridge-tillage for furrow-irrigated wheat may result in surfaces virtually devoid of residues.

Some producers view surface residues as a hindrance to successful and economical wheat production and thus burn the residues. Fortunately, residue burning does not necessarily increase the potential for erosion on the fine-textured soils irrigation is practiced because tillage can provide a rough surface on which to control wind erosion and water erosion is not a serious problem. In addition, irrigation can be used to assure crop establishment when timely precipitation does not occur. Unfortunately, residue burning increases the soil organic matter decline rate,[58] which may have long-term implications with respect to sustaining crop production in the region.

In a broad sense, acceptance of conservation tillage for sorghum production has followed patterns similar to those for wheat. SM tillage often is used for dryland sorghum in drier areas, especially when it is grown in rotation with wheat. In more humid areas, where it is grown annually, conservation tillage is rarely used. For irrigated sorghum, few residues remain at planting because of one or more discings, possibly a chiseling, and tillage that forms ridges on which the sorghum is planted and furrows for irrigation water flow. Some producers have accepted conservation tillage for irrigated sorghum, especially when it is grown in rotation with wheat.

Few producers practice conservation tillage for annually cropped cotton, mainly because cotton does not produce enough residue to qualify as conservation tillage, even if all residues were retained on the surface. In any case, to reduce problems with cultural operations for the next crop, cotton stalks are usually shredded, then incorporated by tillage that forms ridges to help control erosion and on which the cotton is planted. Some producers, however, use conservation tillage when cotton is grown in rotation with grain (wheat or sorghum) crops or when cotton follows a winter cover crop. In both cases, the goal is improved control of erosion, mainly that caused by wind.

For the SGP region as a whole, the Conservation Technology Information Center (CTIC) national survey[59] indicated that some form of conservation tillage was used on 30% of the cropland in 1985. Of the total area devoted to conservation tillage, no-, ridge, minimum, and reduced tillage were used on 4, 1, 55, and 40% of the area, respectively.[60] The 30% use value for conservation tillage, however, may be too high because major portions of Colorado and Kansas were included in the SGP for the CTIC survey. Areas of those states are not considered a part of the SGP for the purposes of this chapter. Wheat and sorghum are major crops in Colorado and Kansas, and some form of conservation tillage often is used for their production. In contrast, conservation tillage rarely is used for cotton, which is not grown in Colorado and Kansas. Hence, the adoption value undoubtedly is biased in favor of conservation tillage when those states are included in the SGP.

Much information regarding conservation tillage systems has become available in recent years, and satisfactory systems are now available for many crops in the SGP region. These systems, when properly implemented, have the potential to greatly reduce soil erosion and improve water conservation. This potential, along with the growing emphasis on protection of the environment, should lead to greater adoption of conservation tillage by producers in the region. Major recent advances in equipment suitable for crop production by conservation tillage methods will provide an impetus for adoption of this resource-conserving tillage method. In addition, strong education and/or demonstration programs should be implemented to apprise producers of conservation tillage practices and the value of those practices for conserving soil and water resources and for protecting the environment.

14.6. ENVIRONMENTAL ISSUES RELATED TO CONSERVATION TILLAGE

14.6.1. Use of Agrochemicals and Fertilizers

Adoption of conservation tillage systems, especially those involving no-tillage or herbicide-tillage combinations, usually requires applications of more herbicides than used with conventional tillage systems, mainly to control weeds before crops are planted. When applied according to manufacturers' directions, within safe limits (wind speeds, sprayer calibrations, etc.), and according to other acceptable practices, most herbicides commonly used in the SGP pose no serious threat to the environment. However, some herbicides degrade slowly and may be transported by water or by soil that erodes from the point of application. This could result in water contamination or adverse effects on nontarget plants under some conditions, especially where runoff and soil losses are large as they are in the more humid areas of the SGP.

In general, transport of herbicides is less under conservation than under conventional tillage conditions because water and soil movement across the land is less with conservation tillage. An exception would be where residues amounts are too low to adequately protect the surface, which can result in soil surface sealing and, consequently, greater runoff[48] and potentially greater herbicide losses. Preliminary results, however, indicate that less than 0.1% of applied atrazine is lost in runoff water from no-tillage watersheds and that losses of other herbicides are greater with conventional than with conservation (no-) tillage from a clay loam soil.[61] Deep percolation of water is negligible on fine-textured soils of the SGP.[62]

Chemical use for controlling insects usually is similar under conservation and conventional tillage conditions. In some cases, however, insect problems have been less severe with conservation than with conventional tillage. For example, greenbug (*Schizaphis graminum* Rondani) infestations and damage to grain sorghum[63] and wheat[64] were less under conservation than under conventional tillage conditions in the SGP. Lower infestations suggest that fewer chemicals would be required to control greenbugs in locations in which conservation tillage is practiced.

Fertilizer applications for crops under conservation and conventional tillage conditions usually are similar in the SGP. However, a response to additional fertilizer may be obtained where large amounts of residue are retained on the soil surface, as with no-tillage. For such conditions, an increase of 20 to 25% in applications of nitrogen fertilizer was recommended in some cases at more humid locations.[65] Responses to additional fertilizer, therefore, may occur in more humid areas of the SGP.

As for pesticides, losses of nutrients could occur in runoff or with eroded soil, especially in the more humid areas. Soluble nutrients could also move to groundwater on highly permeable soils. On fine-textured soils of the SGP, nutrient losses in runoff have been slight[66,67] and deep movement is negligible because percolation of water is slight.[62]

14.6.2. Groundwater Quality

Deep percolation of water on the fine-textured soils of the SGP, mainly those of MLRA 77, is negligible.[62] The groundwater (specifically, the Ogallala Aquifer) that underlies most of MLRA 77 is at a depth of about 60 m below the surface. Because of these conditions, the potential for groundwater contamination by pesticides and nutrients is slight on fine-textured soils. On more permeable soils and where a water table occurs at shallower depths, percolating water containing nutrients or pesticides could potentially contaminate the groundwater. Nitrate-nitrogen levels ranged from 2.1 to 34.0 mg/L in the groundwater under a no-tillage watershed in MLRA 80A at El Reno, OK. The range was from 0.05 to 8.8 mg/L with conventional tillage and 0.02 to 2.5 mg/L under native grass. In MLRA 78 at Woodward, OK, the ranges were 0.2 to 12.2 and 1.4 to 9.5 mg/L under no-tillage and native grass watersheds, respectively.[67] Nitrate-nitrogen also increased in groundwater under minimum tillage watersheds, apparently due to increased nutrient transport to the groundwater because of reduced runoff (greater infiltration) with no-tillage.[68] Greater nitrogen mineralization with conservation tillage also may have been involved.[42] Improved practices such as precise timing and placement of nitrogen fertilizer with respect to crop needs should result in reduced nitrate-nitrogen levels in the groundwater.[69]

As for nutrients, soluble pesticides could be transported to the groundwater on permeable soils where the water table is at a shallow depth. However, tests have detected no pesticides in groundwater at several SGP locations.[69] Soil conditions undoubtedly play a major role in pesticide transport, but interception and retention by crop residues that reduce pesticide (herbicide) transport in runoff across the surface and to groundwater also are involved. In addition, microbially active soil beneath the residue mulch retains the herbicides and enhances their transformation rates.[70]

14.6.3. Soil Erosion

The potential for erosion and, hence, for environmental pollution exists on all soils of the SGP. In MLRA 77, where the surfaces are relatively flat, water erosion generally is slight. In addition, most runoff is into shallow, flat-bottomed lakes (playas) that dot the region. Runoff into these lakes does not enter major streams; therefore, sediments in the runoff have a limited effect on the environment.

In MLRAs 78, 80A, and 80B, runoff water from croplands flows into streams. Thus, if erosion occurs, sediments are carried into the streams, which would affect water quality. However, sediment losses in these MLRAs were less from no-tillage and reduced-tillage than from conventional tillage watersheds that were cropped to winter wheat and grain sorghum.[66,67] For example, annual sediment losses at El Reno, OK, were 6.4 and 0.4 Mg/ha with conventional and no-tillage treatments, respectively. At Woodward, OK, losses with the respective treatments were 15.9 and 0.9 Mg/ha annually.

Wind erosion affects the environment well beyond the site at which the erosion occurs. For example, dust carried aloft by storms in the Great Plains was found in the eastern United States during the 1930s,[2] and dust from storms in recent years often has darkened the sky many kilometers from where the dust originated. Wind erosion is possible on most SGP soils if wind speeds are adequate; surfaces are dry, smooth, and unprotected; and soil materials are finely divided or structureless and lack cohesion. On most fine-textured soils, emergency tillage that roughens the surface usually controls wind erosion.[71] However, on sandy soils that lack cohesion, wind erosion control is more difficult. Such soils are common at various locations in the SGP, and environmental concerns are causing an intensification of efforts to devise improved measures for controlling wind erosion.

14.6.4. Resilience of Tillage Systems Without Pesticide Inputs

Within the last few decades, crop production in the SGP has become highly dependent on pesticide use, not only with conservation tillage, but also with conventional tillage. Herbicides are the main pesticides, but insecticides are used frequently for some crops. Occasionally, chemicals are used to control plant diseases and other crop-damaging organisms. Except for herbicides, pesticide requirements are virtually identical for crop production under conventional and conservation tillage conditions. Hence, crop production in either case often would suffer if pesticide inputs were eliminated. Undoubtedly, pesticide use could be reduced by the adoption of integrated pest management strategies,[72] but such strategies are not available for all crops under all conditions in the SGP.

Herbicides often are used for crop production by conventional tillage methods, primarily for growing season weed control. Many weeds can be controlled by cultivation, but hand weeding may be required as well. In such cases, the cost of cultivation and hand weeding may exceed the cost of herbicides, which would reduce profits for producers. In addition, labor for timely hand weeding may not be available, which could result in lower yields and further reduce profits. Frequent cultivations may adversely affect soil conditions and increase the potential for erosion on some soils.

Use of some herbicides is relied upon for weed control for most conservation tillage systems. For the no-tillage system, all weed control is with herbicides. Use of herbicides could be reduced for all except the no-tillage system if more intensive tillage would still provide for retention of adequate residues on the surface for effective soil and water conservation. Another requirement would be that cultivation equipment be available for effective growing-season weed control. Cultivation is difficult when relatively large amounts of crop residues are present on the soil surface. No-tillage, which is the conservation tillage system that has shown the greatest promise for conserving soil and water resources when adequate residues are retained on the soil surface, would not be an option if the use of herbicides were eliminated.

14.7. GENERAL SUMMARY AND CONCLUSIONS

Contrary to the opinions of the early explorers, the SGP has become an important agricultural region of the United States. In general, low and erratic precipitation and soils that are subject to both wind and water erosion, ensure that improved soil and water conservation are major goals of conservation tillage in the SGP.

Most soils of the SGP are suitable for crop production by conservation tillage methods. However, precipitation in the SGP is highly variable within and among years. As a result, residue production by dryland crops often is low, which is a major limitation of conservation tillage in the drier western portion of the SGP, even for grain crops such as winter wheat and grain sorghum that produce more residues than cotton. Cropping systems involving fallow are sometimes used to increase SWS for subsequent crops at the drier locations. In the more humid eastern portion, high residue production by crops such as annually grown winter wheat may result in crop establishment and plant vigor problems. Under the higher precipitation conditions, weed control problems also may be more severe, and clean tillage may be used to minimize the weed control problems.

Conservation tillage systems are available for most crops of the SGP. One of these is SM tillage, which was developed to help control wind erosion and is now widely used in the SGP. However, adoption of herbicide-based conservation tillage in the SGP has been limited. In addition to those already mentioned, constraints to adoption of conservation tillage include producer needs, preferences, and managerial ability; economic considerations; lack of alternative crops; limitations imposed by governmental price support programs; and lack of strong and effective leadership on the part of agency personnel responsible for implementing sound soil and water conservation practices.

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