Northern Mexico and the U.S. southern Great Plains contain extensive dryland production regions. The northern boundary of the southern Great Plains is often drawn along the Kansas–Nebraska border (approximately 40° N lat). This arbitrary boundary divides the Great Plains into regions where, in the north, steppe prairies drained by the Missouri river watershed (except northern Kansas) merge into the central short grass prairies (Ostlie et al., 1997) that are drained by the Arkansas, Red, and other rivers to the south. The western boundary of the southern Great Plains is formed by the front ranges of the Rocky Mountains (Thelin and Pike, 1991) that extend from Colorado south through New Mexico (approximately 104° W long) and into Mexico along the East aspect of the Sierra Madre Oriental. The eastern boundary of the southern Great Plains occurs where semiarid dryland production merges into rainfed farming along the lower Plains of central Kansas, Oklahoma, and Texas (approximately 97° W long). Commercial dryland production of the southern Great Plains extends southward into northern Mexico and continues to the Tamaulipas, Nuevo León, and Coahuila border with San Luis Potosí and Zacatecas (approximately 23° N lat). Dryland agricultural production in Tamaulipas begins inland from the gulf coast, but transforms into tropical rainfed conditions to the south. The Sierra Madre Oriental, mean elevation 2200 m, disrupts the western flow of moisture from the Gulf of Mexico and reduces precipitation in the arid Mexican altiplano, which is an extension of the high deserts of the U.S. Great Basin (Merill and Miró, 1996). Except for subsistence farming, crop production without irrigation in Mexico is rarely attempted west of the Sierra Madre Oriental.

Dryland crop production area in the southern Great Plains accounted for more than 70% of the cropland planted in 2000 and varies from 55% in New Mexico to more than 90% to the east in Oklahoma (Table 10–1). In northern Mexico, the dryland area of 1 557 985 ha is about six times as large as the 255 390
Table 10–1. The cultivated area of principle crops under irrigated and dryland conditions for the Year 2000, by state (NASS, 2000; SIAP, 2000).

<table>
<thead>
<tr>
<th>State/Country</th>
<th>Irrigated (ha)</th>
<th>Dryland (ha)</th>
<th>Dryland portion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado</td>
<td>467,000</td>
<td>1,245,000</td>
<td>73</td>
</tr>
<tr>
<td>Kansas</td>
<td>1,091,000</td>
<td>5,134,000</td>
<td>83</td>
</tr>
<tr>
<td>New Mexico</td>
<td>139,000</td>
<td>171,000</td>
<td>55</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>202,200</td>
<td>2,557,000</td>
<td>93</td>
</tr>
<tr>
<td>Texas</td>
<td>1,857,000</td>
<td>4,862,000</td>
<td>72</td>
</tr>
<tr>
<td>Coahuila, Mexico†</td>
<td>85,584</td>
<td>66,285</td>
<td>44</td>
</tr>
<tr>
<td>Nuevo León, Mexico‡</td>
<td>49,278</td>
<td>160,647</td>
<td>77</td>
</tr>
<tr>
<td>Tamaulipas, Mexico§</td>
<td>120,528</td>
<td>1,331,053</td>
<td>92</td>
</tr>
</tbody>
</table>

† Since 1990, restricted availability of water for irrigation in Lazaro Cardenas dams, have shifted 50% of the irrigated lands in district No. 17 (80,000 ha) to dryland production.
‡ Since 2000, availability of water for irrigation in Venustiano Carranza dams, have shifted irrigation in district No. 04 (60,000 ha) to dryland production.
§ Since 2000, restricted availability of water for irrigation in Amistad and Falcon dams, have shifted irrigation in district No. 25 (210,000 ha) to dryland production.

ha of irrigated land. The overall portion of agricultural land cropped under dryland conditions in the southern Great Plains and northern Mexico depends on precipitation and cost and availability of irrigation. For example, about 50% of all cultivated farmland in the Texas High Plains region is under dryland production; however, declining water tables (Nativ and Smith, 1987) and volatile fuel costs will likely cause some irrigated land to return to dryland production (Musick et al., 1990). Competition between states for water resources is a contentious issue throughout the southern Great Plains and northern Mexico. Political solutions govern water availability and, frequently, shift crop production toward dryland practices. For example, the rights to runoff from watersheds supplying reservoir

Table 10–2. Cultivated area of selected dryland crops and corresponding irrigated area in the principal dryland farming regions of northern Mexico (SIAP, 2000).

<table>
<thead>
<tr>
<th>Region</th>
<th>Cultivated dryland area (ha)</th>
<th>Irrigated (ha)</th>
<th>Combined (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamaulipas</td>
<td>1,099,949</td>
<td>37,513</td>
<td>1,153,468</td>
</tr>
<tr>
<td>Nuevo León</td>
<td>170,290</td>
<td>89,463</td>
<td>302,878</td>
</tr>
<tr>
<td>Coahuila</td>
<td>17,794</td>
<td>4,823</td>
<td>22,617</td>
</tr>
<tr>
<td>Total dryland</td>
<td>1,331,053</td>
<td>160,647</td>
<td>1,557,985</td>
</tr>
<tr>
<td>Total irrigated</td>
<td>1,205,280</td>
<td>49,278</td>
<td>1,555,985</td>
</tr>
<tr>
<td>Total cultivated</td>
<td>1,451,581</td>
<td>209,925</td>
<td>1,813,375</td>
</tr>
</tbody>
</table>
Impoundments along the Rio Grande have forced a return to dryland production in much of northern Mexico and southwest Texas. The duration of restricted agricultural water use will be governed by climatic conditions required to concentrate sufficient precipitation to refill the nearly depleted reservoirs. However, the portion of farmland managed under dryland crop production in northern Mexico varies from as much as 92% in Tamaulipas to about 44% in Coahuila (Table 10-2).

**CLIMATE**

The climate of the southern Great Plains and northern Mexico is a product of complex weather systems that integrate the effects of cold polar air masses interacting with moist air streams flowing from the Gulf of Mexico or the Pacific Ocean (Nativ and Riggio, 1989). Three principle climate factors govern dryland crop production in the southern Great Plains and northern Mexico, including: precipitation amount, evaporation demand, and growing season length. These factors often interact directly, for example, the evaporative demand usually declines with increasing precipitation amount.

**Precipitation Distribution**

Spatial distribution of precipitation commonly governs overall cropping intensity worldwide; however, temporal variation in precipitation resulting in prolonged droughts periodically governs agricultural production and growth in the southern Great Plains and northern Mexico. Johnson and Davis (1972) illustrated a 35-yr periodic precipitation pattern of excesses and deficits that were unknown to Euro-American settlers first entering the Great Plains around the turn of the 20th century. It was during a subsequent period with below average precipitation "drought" that the soil management practices in use failed to sustain row-crop agriculture and led to the Great Plains "Dust Bowl" of the 1930s. More recently, the centuries old Spanish mission of Guerrero Viejo, Mexico (built in 1751) first submerged by the Falcon dam in 1954, has emerged as a monument to an ongoing drought that reduced watershed runoff into the Rio Grande river beginning in 1993 (Sanchez, 1994). Improved dryland management can offset the effects of periodic drought conditions; however, an infrequent sustained drought can have a catastrophic impact on dryland production.

Superimposed over the long-term periodic climatic cycles common to this entire region are the familiar seasonal and short-term weather features. While precipitation frequency and amount on the southern Great Plains is erratic (Jones et al., 1985), precipitation is seasonally distributed with most accumulating as rain during the summer growing season (Berry, 1974; Curry, 1974; Houghton, 1974; Orton, 1974; Robb, 1974). When mean monthly precipitation at various Great Plains locations with similar total annual precipitation are compared, a pronounced summer rain season is observed for much of the southern Great Plains from Kansas to the Texas Panhandle (Fig. 10-1). Although precipitation is often
Fig. 10–1. Precipitation in the southern Great Plains primarily occurs during the summer growing season with peak monthly accumulation in June or July. However, temporal rain distribution transitions into a longer and bimodal rain pattern where the Great Plains grades into the Texas Plateau regions south into Mexico along the east facing aspect of the Sierra Oriental. Peak rain accumulations are distributed around May and September.

Marginal for crop production, the favorable monthly rain distribution, or timing, coincides with the demands of a growing crop.

Where the Great Plains merge with the plateau and coastal areas of Texas and Tamaulipas, a second rain season occurs during September and October and results in a bi-modal or spring and fall precipitation pattern (Fig. 10–1). This fall rain season is associated, generally, with warm and stationary fronts and with easterly waves or tropical lows that favor the formation of hurricanes (warmer sea-surface temperatures) and increase delivery of moist air inland from the Gulf.
of Mexico. The fall precipitation permits the establishment of annual winter cereal crops and legumes as residue-producing green fallow crops (Baumhardt and Lascano, 1999; Schlegel and Havlin, 1997).

**Amount**

Annual precipitation varies little spatially from north to south throughout much of the southern Great Plains region (Fig. 10–2) and often results in similar cropping practices. Precipitation maximums approaching 1000 mm occur along the eastern boundaries of this region and decrease markedly along an east to west transect. The semiarid, 500 to 600 mm annual precipitation, southern Great Plains area begins in the western half of Kansas, Oklahoma, Texas, and northern Mexico where dryland production systems rely on soil water stored during fallow periods.

Fig. 10–2. Mean annual precipitation and pan evaporation plotted as isohyetal rain contours for the southern Great Plains and Mexico. Precipitation increases from west to east, but does not vary from north to south. Evaporation follows a similar, but reversed, pattern.
Along the western Great Plains boundary, precipitation generally declines to the south beginning in eastern Colorado and extending into Coahuila, Mexico. Annual precipitation is reduced in this western Texas and northern Mexico region because it lies west of the primary rain-producing moist air streams that flow inland from the Gulf of Mexico.

Precipitation is the most important climate factor governing dryland crop production in northern Mexico. Precipitation generally declines when proceeding west from along the Gulf of Mexico in Tamaulipas and continuing through Nuevo León and Coahuila. Precipitation maximums approaching 1100 mm occur along the eastern boundaries of this region, but the arid and semiarid 300 to 500 mm precipitation area appears along the western boundaries of Nuevo León and Coahuila. Along the Gulf of Mexico, in Tamaulipas, precipitation increases from north to south and results in, correspondingly, more intense cropping practices. Precipitation is greatest over much of the region during the summer months of May through October (60% of annual precipitation), while the period from November through March could be termed the dry season with November and March usually being the driest months. Precipitation amounts along the Mexico—U.S. border in Nuevo León and Coahuila are, generally, similar from north to south; therefore, similar cropping practices are frequently employed in both regions.

**Evaporation—Temperature Distribution**

Evaporation is a process that integrates the effects of solar irradiance, temperature, and wind to transport water vapor from the soil, which, like precipitation, varies primarily along an east to west transect (Fig. 10–2). Unlike precipitation, however, pan evaporation increases from >1600 mm in the east to maximums >2400 mm along the western boundary of the Great Plains (Farnsworth et al., 1982). Peak evaporation occurs near southeast New Mexico, west Texas, and Coahuila, Mexico. For most of the southern Great Plains and northern Mexico region, evaporation along the Rocky Mountain foothills gradually increases to the south from 1600 mm in Colorado to approximately 2600 mm in Coahuila, Mexico. As shown in Fig. 10–2, evaporation, pan, exceeds precipitation by 200% in the eastern one-third of the southern Great Plains (central Kansas, Oklahoma, and Texas) and increases to more than 600% of precipitation in southwest Texas and northern Mexico.

Evaporation is spatially correlated with air temperature; therefore, those regions with the greatest evaporation correspond to areas with the higher mean maximum July temperature (approximately 38°C). Generally, air temperatures fluctuate proportionally with the interception of solar irradiance at the soil surface, that is, air temperatures (and growing season length) will increase when traveling along a north to south transect. The Gulf of Mexico, however, regulates the daily fluctuations and seasonal extremes in temperature depending on proximity. For example, Fig. 10–3 shows that mean maximum July temperatures increase as the inland distance increases from south to north toward west Texas and Chihuahua. The temperature regulating effect of the Gulf also limits the mean maximum air temperatures to 32°C along the coastal bend of Texas and Tamaulipas, Mexico; thus, regulating evaporation.
Fig. 10-3. Mean maximum air temperature for July and the number of frost-free growing season days plotted as isohyetal contours for the southern Great Plains and Mexico. Maximum air temperature means approaching 38°C appear in the southwest beyond the temperature regulating affect of the Gulf of Mexico. Frost-free days increase from a minimum of about 160 d in the north to >300 d in the south. Some of south Texas and practically all of Mexico experience no freeze events and therefore employ year-round cropping systems.

Annual growing season length or number of frost-free days (between the last spring frost and the first frost in the fall) of the southern Great Plains and northern Mexico regions are, as a first approximation, correlated to higher mean summer temperatures. Growing season lengths, expectedly, increase from a minimum of about 160 d near 40° N to >300 d south of 28° N (Fig. 10-3). Areas having approximately the same growing season duration, as indicated by contours, extend not strictly along an east to west transect, but, rather, from the southwest to the northeast. This pattern reflects some temperature regulation effects of the moist air flowing inland from the Gulf of Mexico, and the effects of increasing elevation to the north and west. Temperature regulation by the Gulf of Mexico prevents frost along the coast of northern Mexico inland to the Sierra...
Water deficits are the difference between evaporation demand and precipitation received. Seasonal and annual water deficits govern both the successful crop rotation practices applied in a region and its relative cropping intensity. Generally, dryland production is possible in much of the southern Great Plains and northern Mexico where the temporal distribution in water deficit does
not occur during the growing season, that is, growing season precipitation is sufficient to supply most of the crop water needs. Spatially, the mean annual water deficit increases from about 750 mm in the eastern part of the southern Great Plains and eastern Mexico (mouth of Rio Grande River) where the Gulf effects are greatest to more than 2000 mm along the El Paso-cd. Juárez border where the Gulf effects are attenuated (Fig. 10–4). As with precipitation, water deficits do not vary significantly from north to south; therefore, cropping systems can be similar along a north to south transect if growing season duration does not affect crop selection. Water deficit does become more severe, however, from north to south through the western half of the Great Plains and into Coahuila, Mexico. This transect corresponds to the areas with high evaporation and low precipitation.

**CROPPING PRACTICES**

Dryland cropping practices used throughout the southern Great Plains and northern Mexico share the common goal of conserving precipitation as soil water for subsequent crop use, but these practices are often necessarily unique in adaptation to site-specific crop, climate, and soil properties. Wheat (*Triticum aestivum* L.) is one crop that is universally grown throughout this region. Overall, wheat is well adapted for annual or biennial (intervening fallow) monoculture and often included in rotation sequences with summer crops and fallow periods to increase soil water storage. For example, wheat is grown in a grain sorghum (*Sorghum bicolor* (L.) Moench) fallow (W-S-F) rotation that produces two crops over a 3-yr period (Fig. 10–5) throughout the southern Great Plains (Norwood et al., 1990; Jones and Popham, 1997). In both Kansas and Texas, the annualized

**WHEAT-SORGHUM-FALLOW**

![Diagram of wheat-sorghum-fallow (W-S-F) rotation](image)

*Fig. 10–5. The wheat-sorghum-fallow (W-S-F) rotation diagramed as a 3-yr cycle beginning with wheat establishment in October (top). Wheat is harvested 10-mo later in July and the soil is fallowed until June of the second year (11 mo) when grain sorghum is grown using soil water stored during fallow to augment summer rainfall. After sorghum harvest in November of the third year the soil is again fallowed for 10-mo when wheat is planted and the cycle repeated.*
grain yield of wheat grown every year or with an intervening fallow, alternate years, was less than that achieved by the W-S-F rotation (Table 10–3). Depending on location, alternative summer crops may be substituted for grain sorghum in this cropping sequence, including corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), and sunflower (*Helianthus annuus* L.), but insect hazards and inconsistent yield performance impede wide adoption (Unger, 1984; 2001).

Corn is grown throughout the southern Great Plains where irrigation is available, but is not well adapted for dryland water stress conditions. Nevertheless, dryland corn production appears in southern Texas, northern Mexico (Smart and Bradford, 1999), and Kansas where no-till residue management increases storage of fallow precipitation as soil water that sustains corn growth and yield during dry years (Norwood and Currie, 1996). Using selected planting dates and populations, Norwood and Currie (1997) compared summer crop yields of the W-S-F rotation with a wheat-corn-fallow (W-C-F) cropping sequence. Under stubblemulch tillage, mean dryland corn yields were 5.02 Mg ha$^{-1}$ compared with 4.52 Mg ha$^{-1}$ yields for grain sorghum; however, no-tillage residue management increased corn and sorghum yields in southwestern Kansas to 6.29 Mg ha$^{-1}$ and 5.02 Mg ha$^{-1}$, respectively. Similarly, success with dryland corn production in southern Texas depended on soil water storage provided by no-tillage residue management (Smart and Bradford, 1999).

Cotton (*Gossypium hirsutum* L.) is a drought tolerant summer crop planted where the growing season typically exceeds 200 d. It is often grown as an annual monoculture because of its potential profitability; however, the crop produces very little residue to protect the soil from wind erosion. A Texas South Plains wind erosion control practice of planting wheat after cotton harvest and chemically terminating it in the spring before replanting an irrigated cotton summer crop was evaluated under dryland conditions using conservation tillage by Keeling et al. (1989). In that study, both growing season precipitation and, consequently, yields of lint and protective residues were above average for dryland production. Without irrigation, the terminated wheat annual cotton cropping (TW-C) sequence relies on adequate fall and spring rain to establish and grow both the green fallow residue and cotton crops. During years with below average precipitation, Baumhardt and Lascano (1999) reported inconsistent production of either wheat residue or cotton lint with TW-C because of poor crop establishment and

<table>
<thead>
<tr>
<th>Crop sequence</th>
<th>Sorghum (Mg ha$^{-1}$)</th>
<th>Wheat (Mg ha$^{-1}$)</th>
<th>Combined rotation</th>
<th>Annualized yield (Mg ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tribune, KS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous wheat (1 yr)</td>
<td>–</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>Wheat-fallow (2 yr)</td>
<td>–</td>
<td>2.38</td>
<td>2.38</td>
<td>1.19</td>
</tr>
<tr>
<td>Wheat-sorghum-fallow (3 yr)</td>
<td>2.41</td>
<td>2.28</td>
<td>4.69</td>
<td>1.56</td>
</tr>
<tr>
<td>Bushland, TX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous wheat (1 yr)</td>
<td>–</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Wheat-fallow (2 yr)</td>
<td>–</td>
<td>1.53</td>
<td>1.53</td>
<td>0.76</td>
</tr>
<tr>
<td>Wheat-sorghum-fallow (3 yr)</td>
<td>3.40</td>
<td>1.55</td>
<td>4.95</td>
<td>1.65</td>
</tr>
</tbody>
</table>
limited soil water to augment summer rain. An alternative cropping sequence that produces erosion-controlling residue and provides an opportunity to replenish the soil water between summer crops is an alternate year cotton and sorghum rotation (Baumhardt et al., 1993b).

Throughout the southern Great Plains and northern Mexico, farmers use rotation sequences that rely on fallow periods that allow storage of precipitation as soil water to improve crop establishment and grain production reliability at the expense of reduced cropping intensity. In south Texas and northern Mexico, the common practices of immediately planting a second crop or promoting regrowth of the current crop for a second harvest (ratooning) are being adapted to include a fallow period to increase storage of precipitation as soil water regardless of tillage (Table 10–4) while producing an annual crop. Efforts to intensify dryland crop production have included the introduction of short-season opportunity crops grown within fallow periods that otherwise prevent annual cropping. For example, the W-C-F cropping sequence was intensified to produce three crops in 3 yr by including millet (Fig. 10–6) within a winter wheat-corn-fallow-millet sequence (Peterson et al., 1993) or sunflower within a winter wheat-corn-fallow-sunflower rotation (Anderson et al., 1999). Livestock are often integrated into the W-S-F production systems by using vegetative wheat and the adjoining sorghum residue as forage for grazing (Shroyer et al., 1993; Redmon et al., 1995). These management practices and cropping sequences have the potential for increasing dryland production intensity; however, crop residue resources must be protected to conserve soil water.

### Tillage

Tillage practices are commonly used throughout the region to optimize soil water storage during fallow periods for subsequent crop production by reducing water losses to weeds, evaporation, or runoff. The initial use of inversion tillage implements to control weeds during fallow was replaced by sweep or stubblemulch tillage (Unger and Baumhardt, 2001), which was developed to reduce soil erosion by wind (Allen and Fenster, 1986). Stubblemulch tillage undercut crop residues, killed weeds, and retained evaporation suppressing residues at the soil surface resulting in greater water storage and crop yields (Unger, 1978, 1984; Unger and Baumhardt, 1999). Although stubblemulch tillage is widely adopted

### Table 10-4. Tillage effects on precipitation storage as soil water, and dryland sorghum grain yields in a continuous sorghum-fallow cropping system, Rio Bravo, Tamaulipas, 1984 to 1985 (Salinas-Garcia, 1985). August to February fallow precipitation averaged 308 mm.

<table>
<thead>
<tr>
<th>Tillage systems</th>
<th>Water at sorghum planting</th>
<th>Water storage efficiency</th>
<th>Grain sorghum yield†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>%</td>
<td>Mg ha⁻¹</td>
</tr>
<tr>
<td>No-tillage</td>
<td>125</td>
<td>41</td>
<td>3646 a</td>
</tr>
<tr>
<td>Offset disk-tillage</td>
<td>118</td>
<td>38</td>
<td>2838 b</td>
</tr>
<tr>
<td>Moldboard-tillage</td>
<td>123</td>
<td>40</td>
<td>3863 a</td>
</tr>
</tbody>
</table>

† Values followed by the same letters are not significantly different at the 5% level (Duncan's multiple range test).
The wheat-corn-millet (W-C-M) rotation diagramed as a 3-yr cycle beginning with wheat establishment in October (top). After wheat is harvested, (10-mo later) the soil is fallowed (11 mo) until corn is grown, Year 2, using stored soil water to augment summer rainfall. In Year 3, a second, shorter 8-mo fallow after corn is followed by planting millet, which is harvested in mid-September when the sequence is repeated.

For dryland production on the southern Great Plains, no-tillage is still a superior method for conserving precipitation because of more complete residue cover (Steiner, 1994). Alternatively, similarities in conservation of precipitation as soil water and the subsequent crop yield differences between conventional and no-tillage systems, generally, have been slight because of limited dryland crop residue production (Salinas-García, 1981).

In contrast to stubblemulch tillage, subsoil paratill or chisel tillage is not used for weed control, but to fracture dense soil layers that impeded rooting and infiltration. Water conservation and dryland yields have been increased in some Great Plains locations due to increased rain infiltration and available soil water (Pikul and Aase, 1999). Subsoiling was recommended by Gerard (1987) as an annual treatment to offset normal soil consolidation on the southern Great Plains. However, rapid soil consolidation negated benefits of subsoiling to increase infiltration of furrow irrigation when averaged during the entire growing season (Allen and Musick, 2001). Compared to subsoiling, stubblemulch and no-tillage are superior water conservation practices because residue retained at the soil surface intercepts raindrop impact and reduces the formation of crusts that govern rain infiltration; thus, overriding the effects of profile-modifying tillage such as chiseling (Baumhardt et al., 1993a) or paratillage (Baumhardt and Jones, 2002).

Specialized Tillage

Basin tillage, tied ridging, or furrow diking is a tillage practice of periodically forming small earthen dams between the ridges of a ridge-furrow tillage system (Plate 10-1). Furrow diking is used to detain runoff on the soil surface and increase the opportunity time for water to infiltrate (Jones and Stewart, 1990).
This practice was pioneered on the southern Great Plains in 1931 by a Colorado wheat farmer and was practiced extensively in the central Great Plains within the decade (Jones and Clark, 1987). In Texas, furrow diking decreased storm runoff and increased mean dryland yields of sorghum by 760 kg ha\(^{-1}\) and cotton lint by 32% or 116 kg ha\(^{-1}\) (Gerard et al., 1984). Adoption of this practice is growing, but as Baumhardt et al. (1993b) noted, when rain is not timely for crop use or is insufficient to produce runoff, the benefits of diking are diminished unlike the more consistent water conservation benefits of residue management.

Specialized tillage practices vary throughout the southern Great Plains and northern Mexico depending on locally unique management concerns. For example, cotton is a tropical tree grown as an annual crop that often resumes perennial growth habits in northern Mexico and south Texas; therefore, a fall plow-down is required to terminate its growth and eliminate host-plant food resources for boll weevils (*Coleoptera: Curculionidae*). Relying on conventional moldboard plowing to terminate cotton regrowth and bury the stalks also loosens the soil and increases evaporation. A reduced tillage solution that conserves soil water for dryland production prevents cotton regrowth with a “stalk-puller” implement to uproot cotton from the soil (Plate 10-2) in an operation that is both less expensive and much faster (Smart and Bradford, 1997).

**Planting**

Planting practices governing seed placement and population vary with crop requirements, for example, more adaptable cereal crops like wheat are planted using less precise seed drill equipment with row spacing of 0.2 to 0.3 m compared with summer row crops like corn, cotton, and sorghum that benefit from precise unit planter seed placement. Row widths of drill planted cereals vary little except when grown as an interim residue cover. Lascano et al. (1994) describe a TW-C system that uses unplanted drill rows to provide strips corresponding to the subsequent cotton row location. The cereal crop and residues between strips provide a protective cover that protects the growing cotton crop from blowing sand and intercepts raindrop impact to increase rain infiltration (Baumhardt and Lascano, 1996).

Strip-cropping practices first employed strips of residue to control wind erosion in row crops, but were subsequently replaced by bare-fallow strips to increase the soil water reservoir available for dryland crops (Burnett, 1968). As a dryland management practice, various skip-row planting geometries were developed, for example, row widths (0.76–1.0 m) and planting patterns such as one skipped row for every two planted rows. Although these studies showed that the crop yields per row length increased with blank strips compared with solid planted row geometries, those increased yields did not offset the corresponding reduction distributed over the entire planted area (Newman, 1967). Alternatively, narrow-row planting geometries (Plate 10–3) that attempt to distribute the crop evenly within the field optimize light interception by the crop and the amount of total evapotranspiration partitioned for crop use (Steiner, 1986). Typical row crop spacing varies from 1.0 to 0.76 m in much of the southern Great Plains, but reducing row widths from 1.0 to 0.76 m increases potential crop yields by about 25%.
Continued research with dryland cotton suggest that narrow, 0.38 m, row widths may further increase yields (Gerik et al., 1998); however, yield can be limited by high plant populations and lost to lodging in narrow rows of sorghum (Jones and Johnson, 1991). Because of great differences in soils and climate throughout the southern Great Plains and northern Mexico, suitable planting populations and row widths for dryland production systems vary regionally.

**Fertility**

Efficient water use is crucial to successful dryland crop production; however, as concluded by Viets (1962), poor soil fertility can limit crop root development, growth, and yield regardless of water use. The soil fertility management practices developed during the intervening 40 yr on the southern Great Plains and northern Mexico continue to vary with the dryland cropping system employed and are often unique to the site and soil; therefore, few soil fertility management generalizations can be made. An exception is that the mixed or montmorillonitic clay mineralogy in much of the Great Plains soils (Johnson et al., 1983) and northern Mexico (PIFSV, 1985) provides sufficient potassium (K) to meet crop needs and, consequently, masks any crop response to fertilizer K. Also, many soils in the more arid southern Great Plains and northern Mexico are calcareous and react with phosphorous (P) fertilizer, which fixes P in fine-textured soils and limits P fertilizer benefits. For example, Eck (1988) reported no significant wheat grain or straw yield increase in response to 20 to 40 kg ha\(^{-1}\) of P fertilization on a clay loam soil. Coarse-textured soils fix less P so that crops grown under favorable water conditions often respond to supplemental P fertilization, especially, when applied as bands near the seed zone (Bronson et al., 2002). Because of inconsistent dryland crop response to P fertilization in the southern Great Plains and northern Mexico, much greater attention is focused on meeting crop nitrogen (N) requirements.

Nitrogen fertilizer applications have the greatest potential to return dramatic crop responses through increased vegetative growth and grain yield. However, under dryland conditions, N fertilizer applications must strike a balance between expected crop requirements to achieve a desired yield and the production potential as limited by precipitation plus available soil water. One common production risk becomes growing a large vegetative plant during the early growing season that consumes stored soil water resources before producing grain (Jones et al., 1997). For this reason, dryland crops grown in the southern Great Plains and northern Mexico that visibly benefit from fertilization in terms of early vegetative growth often fail to achieve consistently greater grain yield, especially, in the southwest where the precipitation deficit is greater. Alternatively, the soil must be supplied with N to replace any removed in the crop product, thus avoiding soil nutrient mining beyond N mineralization that would reduce the soil organic carbon (C) content and depress overall soil productivity.

Annual N fertilizer requirements vary by crop, and desired productivity levels. For example, a simple recommended N fertilization rate is 20 kg Mg\(^{-1}\) for grain sorghum, 100 kg Mg\(^{-1}\) for cotton, and 25 kg Mg\(^{-1}\) for ungrazed wheat grown in south and southwest Texas assuming a constant yield response (Stichler
and McFarland, 1997). Similar recommendations can be found for other locations that reflect differences in the soil and climatic conditions. Nitrogen management, however, is complicated by variable crop response to N application rates, fertilizer placement, potential nutrient leaching, and N buffering in the soil (Westfall et al., 1996). Porter et al. (1996) concluded that 24 to 28% of the fertilizer N remained in the soil during a no-till W-S-F rotation and attributed the greater dryland biomass yields with 56 and 112 kg ha$^{-1}$ of fertilizer N to more available nitrate (NO$_3^-$) in the soil. At Bushland TX, cropping systems with intervening 10- to 11-mo fallow periods mineralize about 50 kg ha$^{-1}$ of N (Eck and Jones, 1992), which diminishes some expected yield benefits of supplemental N fertilization. Nitrogen fertilizer applications should be adjusted to augment the accumulated N mineralized in the soil during fallow (Halvorson and Reule, 1994). To implement better use of the buffered N that accumulates in the soil, producers throughout the southern Great Plains and northern Mexico determine the soil nutrient status with a timely test.

Weeds, Disease, and Insects

Weed, disease, and insect management issues are addressed elsewhere in this monograph; however, the temperate to subtropical climatic variability of the southern Great Plains and northern Mexico provides challenging conditions for protecting crops. Dryland crop production systems must prevent (i) competition for limited water and nutrient resources by weeds and (ii) the reallocation of plant photosynthate to offset the negative impact of disease and insect injury. Early southern Great Plains studies have shown that water consumption by weeds growing during fallow significantly reduces soil water storage regardless of tillage method (Wiese and Army, 1958). Weed competition for nutrient resources further emphasizes the importance of controlling weed growth during fallow and cropping seasons for successful dryland crop production regardless of location. Chemical weed control has reduced the use of secondary growing season cultivation and, to a lesser extent, primary tillage in much of the southern Great Plains, but the chemical costs often preclude their use on smaller farms in northern Mexico. Even so, reduced tillage (conservation tillage) is rapidly increasing as an alternative management system throughout the southern Great Plains and northern Mexico because of improved water conservation (Harris et al., 1987; Bradford and Smart, 1997).

Cropping sequences are commonly used throughout the Great Plains to minimize the development of significant weed-crop competition. Monoculturing any crop leads to unintended selection of weed species, which flourish under similar growing conditions and have similar physiological characteristics that complicate chemical control. For this reason, winter wheat is grown with an intervening fallow or in rotation with summer crops to eliminate the selection processes favoring annual weeds like jointed goatgrass (Aegilops cylindrica L.) and Downy brome (Bromus tectorum L.) or cheatgrass. Anderson (1994) noted crop rotations from winter cereals to summer grain crops reduced the quantity of soil-borne weed seed in as few as 1 to 2 yr. Summer crops benefit similarly from being grown in rotation with winter cereals; however, annual summer crops, for
example, grain sorghum and cotton, are frequently grown during alternate years as a means to shift herbicide control spectrum and seasonal chemical applications for control of troublesome weeds.

In the southern Great Plains and Mexico a number of efficient competitors for water and nutrient resources include: pigweed (mixture of *Amaranthus palmeri* S. Watts and *A. hybridus* L.), Russian thistle (*Salsola iberica* Sennen & Pau), kochia (*Kochia scoparia* (L.) Schrad.), Johnson grass (*Sorghum halepense* (L.) Pers.), tumblewindmillgrass (*Chloris verticillata* Nutt.), tumblegrass (*Schedonardus paniculatus* (Nutt.) Treb.), and witchgrass (*Panicum capillare* L.) to name a few (USDA-NRCS, 2002). However, plant tenacity, efficient seed production, and inadvertent vine redistribution by tillage implements amplifies the impact of field bindweed (*Convolvulus arvensis* L.) competition in the southern Great Plains and in Mexico (Labrada et al., 1996). In addition to competition for water and nutrients other management concerns vary with the integration of livestock into production systems. For example, Johnson grass may be harvested as forage except when grown under drought stress or exposed to frost conditions when the plant produces hydrocyanic acid and becomes toxic to grazing livestock (CNAP, 2000), that is, prussic acid poisoning. Some weed species also complicate disease control by providing alternative hosts to disease pathogens, notably: Johnson grass serves as an overwintering host for Maize Dwarf Mosaic virus and ergot caused by fungus *Claviceps africana* which infect grain sorghum (Velasquez-Valle et al., 1998).

Plant diseases develop into recurrent problems when the risk of contact between virulent pathogens and suitable hosts is sustained in a favorable environment. Alternatively, control of plant disease relies on management practices that minimize risk factors. Practically all dryland production systems used on the southern Great Plains and northern Mexico employ fallow periods with multi-crop sequences that interrupt pathogen-host contact. Notable dryland exceptions, however, are annual wheat or cotton production that many farmers find sufficiently profitable to risk culturing various pathogens. With time, growing inoculum of *Rhizoctonia solani*, *Fusarium* sp., *Pythium* sp., and *Thielaviopsis basicola* pathogens will accumulate and be manifested as seedling diseases that reduce cotton stand establishment (Horn et al., 2002) or as common wheat root rot caused by *Cochliobolus sativus* (Conners and Atkinson 1989). Plant disease management alternatives for monocropped systems are confined to timely planting of pathogen-free fungicide-treated seed from disease tolerant or resistant varieties. This common solution in the southern Great Plains may not always be available on smaller farms of northern Mexico where tillage is used to bury pathogens along with infected crop residues.

In Mexico and the southern Great Plains, the effects of reduced tillage on the development and severity of crop diseases depends on the sensitivity of the pathogen to resulting environmental changes. Reduced tillage depresses soil temperatures, conserves soil moisture, and retains crop residue on the soil surface; however, these factors may promote potential pathogen development and severity of a disease. For example, in Kansas the winter wheat tan spot caused by *Pyrenophora tritici-repentis* was more severe where residues remained on the soil surface (Bockus and Classen, 1992). Similarly, Fernandez et al. (1993) noted
increased survival of *Fusarium graminearum*, *C. sativus*, and *Leptosphaeria nodorum* in infected wheat, corn, and soybean residues left on the soil surface during zero-tillage fallow. Disease injury to crops is most severe where continuous monoculture cropping is practiced (Holtzer et al., 1996) and monoculture crops such as continuous cotton are becoming more common. Knowledge of the important crop diseases in an area, the conditions that favor their development, and history of disease in each field are important for disease management practices such as selecting appropriate crop rotations.

Dryland cropping systems throughout the southern Great Plains and northern Mexico experience many of the same insect pressures as found in neighboring irrigated fields, but crops are often less able to recover from injury. The insect pressures increase along a north to south transect, becoming progressively worse in the warmer climate of subtropical northern Mexico that favors insect pests compared to the southern Great Plains with its killing frosts. Many insect problems occur sporadically, but dryland production systems that rely on reduced tillage systems to conserve water often sustain greater insect pressure, because of more favorable soil temperature and water content associated with higher surface residue amounts (Smart and Bradford, 1997). Dryland production systems that use tillage can vary depth, frequency, and degree of soil disturbance to influence surviving insect populations, that is, greater soil disturbance may reduce the likelihood that some overwintering insects will survive to cause damage the next season. Early-season weed growth in fallowed dryland, especially in northern Mexico, may attract egg-laying adults and serve as an alternative food source for young larvae that later move from wild plants to cultivated crops. For this reason, crop rotation may be an important tool to significantly impact insect pest populations.

CONSERVATION PROBLEMS AND PRACTICES

Water and wind driven soil erosion is a significant concern throughout the southern Great Plains and northern Mexico regions. Wind erosion, however, has probably had the greatest impact on the southern Great Plains including a well-known region of approximately 50 million hectares centered near southwestern Kansas called the 'Dust Bowl' (Hurt, 1981). Inversion tillage practices, in use on the southern Great Plains for decades before the 1930s, buried initial rangeland residues during land breakout and subsequent crop residues that were needed to protect the soil from scouring surface winds. Emergency tillage practices were developed to roughen the soil with clods that do not blow but rather deflect the wind (Soil Conservation Service, 1955). While both wind and water erosion are recognized as major problems in northern Mexico (Moreno and Oliva, 1990), much of the cropland subject to high potential soil loss achieves annual wind erosion of 18 Mg ha\(^{-1}\), especially in the soils with surface textures of loamy fine sand and fine sandy loam (INIFAP, 2000). Because of limited precipitation in northern Mexico, crop residues are, generally, insufficient to protect the soil from wind in the late winter and early spring. Some of the most effective wind erosion control tillage practices incorporate few residues, which protect the soil surface
(Woodruff et al., 1972); however, residue production under dryland conditions is limited on the southern Great Plains. Papendick et al. (1990) noted that wind and water erosion are controlled, similarly, with increasing crop residue cover.

Water erosion of soil on the southern Great Plains and northern Mexico decreases with declining precipitation along an east to west transect. Areas where water erosion poses a significant hazard are, generally, under rainfed crop production conditions in contrast to the dryland conditions found in the southwestern part of the Great Plains where precipitation produces limited runoff. For example, Jones et al. (1985) reported that <1% of rainstorms during a 20-yr period supplied about 10% of the total precipitation and produced 38% of the runoff from tilled watersheds. The measured mean annual soil erosion from watersheds after conventionally tilled wheat was 0.2 Mg ha\(^{-1}\) at Bushland, TX compared with 6.4 and 15.9 Mg ha\(^{-1}\) measured in central and western Oklahoma, respectively, (Smith et al., 1991). Although rains are more frequent during the spring, damaging fall rain events produced significant runoff and sediment losses because residue cover was insufficient to protect the soil from raindrop impact. Residue covering the soil surface intercepts raindrop impact, sediment entrainment by storm runoff is checked, and soil erosion reduced.

Conservation of water may be the most critical issue common to both the southern Great Plains and northern Mexico. Sufficient moisture is present most years for dryland crop production in northern Mexico, but periods of water stress during the growing season are common and expected (Aldana et al., 1988). Dryland crop production must include water-conserving management such as fallow, contour rows, terraces, furrow dikes, and conservation tillage practices to reduce water runoff and increase soil water storage. In the southern Great Plains, successful crop rotation sequences include residue-crop production and fallow periods as a means to increase the amount of precipitation stored as soil water.

**ECONOMIC AND SOCIAL CONSIDERATIONS**

Agricultural sustainability in the southern Great Plains and Mexico varies by region, developing into a contentious point between productivity and resource conservation. On the Great Plains, farm production initially expanded in response to an unrealistic U.S. government homesteading policy that provided too little land and no technical support on semiarid farming practices (Cooke et al., 1936). Although governmental policy eventually provided both production guidance and increased land allowances, extensive damage to the soil resource had occurred throughout the southern Great Plains and contributed significantly to the 'Dust Bowl' soil erosion problems. The dryland farms of northern Mexico are clearly smaller than the dryland farms in the Great Plains and, as was observed for the Great Plains by Cooke et al. (1936), may not be sustainable if intensively farmed to meet family income needs. For example, a common reoccurring problem on dryland farms in northern Mexico has been the inadequacy of feed grain supplies to meet domestic demand, which results in either feed-grain purchases or livestock liquidation at low prices.
Wind erosion on the southern Great Plains during the “Dust Bowl” raised public awareness of the fragility of the soil resource. New U.S. government farm programs were developed to encourage farmers to use conservation practices such as contour plowing, listing, and strip cropping (USDA-AAA, 1937). Many subsequent farm programs have done little to promote conservation practices until the inclusion of compliance provisions enacted since 1985, which encourage less tillage (Dhuyvetter et al., 1996). Also, current governmental programs less rigidly control cropping strategies and have allowed freer introduction of alternative crops or more intensive crop rotations. The resulting dryland cropping systems are both innovative and, potentially, more adaptable for use throughout the southern Great Plains and Mexico.

Agricultural expansion in the southern Great Plains was greatest between 1910 and 1920 due, in part, to growing agricultural mechanization (Hurt, 1981) that also promoted tenant farming (Cooke et al., 1936). The southern Great Plains farm communities of the 1930s suffered depopulation as a consequence of expanding farm mechanization, but a new generation of farmers face depopulation as declining Great Plains irrigation expand drylands (Williams and Bloomquist, 1996). A concern is that depopulation of the southern Great Plains may lead to potential collapse of communities and destabilize agriculturally based economies. Popper and Popper, (1987) describe a scenario whereupon the U.S. government would then step in to buy abandoned Great Plains farmland and restore it to an undisturbed range condition, that is, the creation of a “Buffalo Commons.”

The economic conditions of farmers living on the northern Mexico dryland areas are much different than farmers of the Great Plains in that fewer government agricultural programs are directed toward dryland crops in contrast to rainfed crops such as sugarcane. As highlighted in Table 10—I, the current agricultural trends from irrigated to dryland production suggests that farmers of northern Mexico now face challenges to maintain their quality of life that are as important as those faced by Great Plains farmers during the “Dust Bowl” era. Dryland farmers of northern Mexico are adapting older equipment to apply developing technologies for use on smaller farms that generate less income. When possible, dryland farmers produce high value labor intensive crops or include livestock grazing. Advances in farm technology coupled with improved education programs to apply technology may advance both farm income and social conditions in northern Mexico.

RESEARCH NEEDS

Agronomic research on dryland production in the southern Great Plains and northern Mexico must continue to address the fundamental issues of water management and cropping sequence. Because of the extensive range in producer resources and experiences, the needed research must vary widely from practical field assessment of applied cropping practices to systematically developing detailed basic knowledge of biological and physical factors regulating dryland agriculture. Soil water evaporation and rain infiltration are the two basic processes that determine the water available to meet dryland crop requirements. Research
to improve residue management practices must promote increased precipitation storage as soil water by reducing evaporation and runoff during fallow periods. Concurrent evaluation of soil amendments or tillage and residue management practices that increase rain infiltration maybe integrated to optimize soil water conservation for dryland cropping systems. Cropping sequences with long intervening fallow periods often experience runoff once the soil profile is filled and have poor precipitation storage efficiency. Research is needed to develop cropping sequences that minimize or eliminate fallow periods once the soil water reservoir has been filled. Fortunately, most research results are not unique to a region and can usually be adapted for general application.

Dryland production would benefit from continued research to intensify the regional agriculture from Colorado to Tamaulipas through new cropping sequences or the selection of alternate or opportunity crops. For example, successful dryland corn cropping practices or integrating livestock production into already successful dryland cropping systems is needed to increase overall profitability. In northern Mexico, grain sorghum occupies approximately 47% of the total planted land area and is greater than corn, wheat, safflower (*Carthamus tinctorius* L.), cotton, and dry bean (*Phaseolus vulgaris* L.) crops ranked in order of economic importance. Overall agricultural production in northern Mexico and the Rio Grande Valley in Texas is shifting toward vegetable crops with the introduction of improved, drip, irrigation technology because of greater profitability. However, suitable cropping sequences must include dryland management to extend limited water supplies for vegetable irrigation. Research needs for the development of new technology include: improvement in water-use efficiency by tillage practices or by the adaptation of new varieties to dryland conditions. Production cost may be lowered using improved weed, insect, and disease control through new crop protection chemicals and applications for reduced and no tillage systems.

Knowledge from research to intensify dryland crop production will also provide avenues to reduced risk as crop production in virtually all parts of the southern Great Plains and northern Mexico shift from irrigated to dryland methods. Few agricultural producers are likely to convert from irrigated to dryland cropping practices without first transitioning through some type of deficit irrigation practice. Future agronomic research should address this water management transition, but most dryland cropping sequences currently being investigated throughout the southern Great Plains and northern Mexico lack any deficit irrigation component. The shift of land from irrigated to dryland production may cause a cascade return of marginal cropland areas to rangeland. The ecological and environmental impacts of such a transition to rangeland should be investigated and management practices to facilitate the transition developed.

Finally, as the array of biotechnology tools expands, researchers may offer many potential innovations to deal with problems of crop stress typically associated with dryland crop production. Dryland productivity can be increased through continued crop development for improved quality and yield of fiber, forage, grain, and residue using traditional and nontraditional plant breeding programs. These and other crop improvements, such as adapting common crops to new crop protection chemistries, will require further development of agricultural production methods to optimize benefits cropping systems for dryland conditions.
REFERENCES


