

# 11

## Dryland Cropping in the Western United States

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The major regions for dryland cropping in the western USA are in the inland Pacific Northwest (PNW) situated contiguously in eastern and central Washington, the Idaho panhandle, and in eastern and north-central Oregon, and the intermountain region of southeastern Idaho, northern Utah, and western Montana (Fig. 11–1). Elsewhere, limited dryland crop production is found in the foothills along the Central Valley in California, and except for small scattered areas is almost nil in Nevada and Arizona.

We define dryland cropping as that practiced where average annual precipitation is 600 mm or less and no irrigation is used. Approximate land area devoted to dryland cropping in the western USA is 4 380 000 ha (Table 11–1). Of this, 3 350 000 ha are in the PNW, 860 000 ha in the intermountain region and 170 000 ha in California. This chapter is focused on these dryland cropping regions (Fig. 11–1, Table 11–1). Because of climatic variability the PNW is subdivided into three average annual precipitation zones: (i) low, <300 mm of precipitation, (ii) intermediate, 300 to 450 mm of precipitation, and (iii) high, 450 to 600 mm of precipitation.

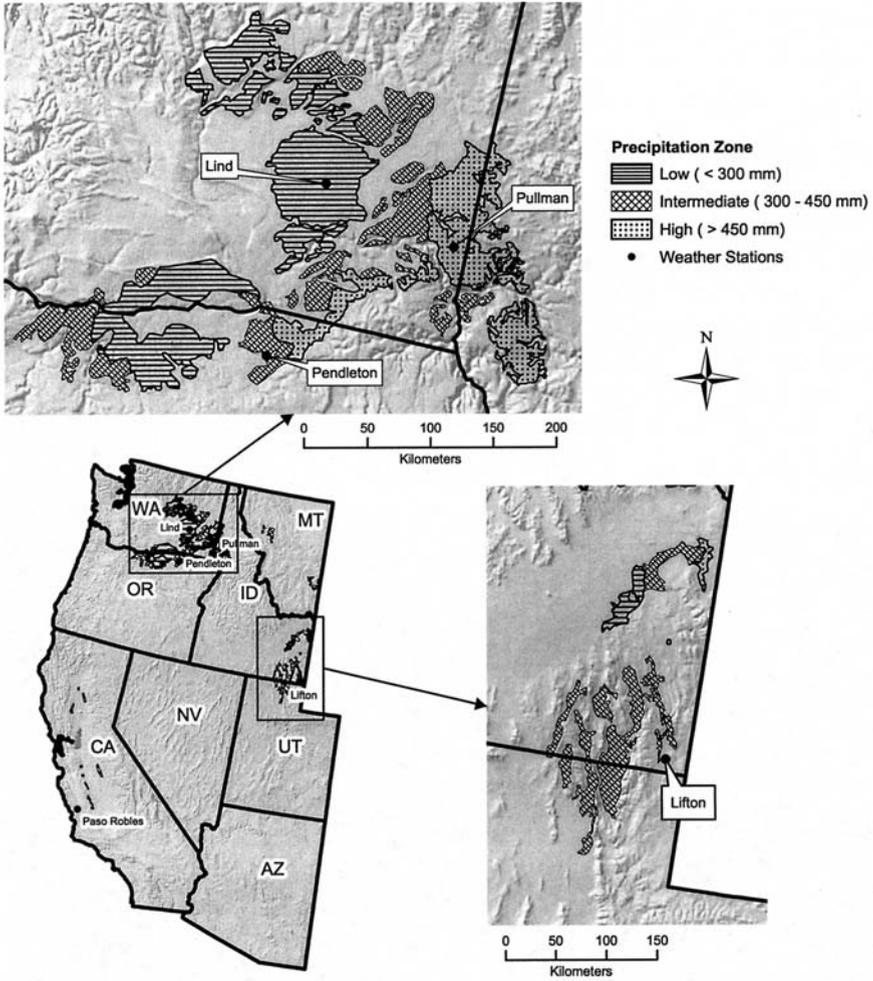


Fig. 11-1. Dryland cropping regions in the western USA.

### CLIMATE

#### Inland Pacific Northwest

The Mediterranean climate of the inland PNW is influenced by frontal weather systems carried on prevailing westerly winds off the Pacific ocean. The Cascade Mountains to the west impose a rain shadow effect. The Rocky Mountains to the east provide some protection from the coldest arctic air masses moving down from the north. Elevation ranges from 300 to 1400 m above sea level. The driest part of the cropping region is in south-central Washington that receives as little as 150 mm average annual precipitation, this being among the lowest for

Table 11-1. Land area devoted to dryland cropping in three regions of western USA.

Region	State†	Hectares	
1. Inland Pacific Northwest	Low (< 300 mm)‡	Washington	1 223 000
		Oregon	334 000
	Intermediate (300–450 mm)	Washington	621 000
		Oregon	323 000
		Idaho	25 000
	High (450–600 mm)	Washington	382 000
		Idaho	374 000
		Oregon	66 000
	2. Intermountain	Idaho	630 000
Utah		141 000	
Montana		89 000	
3. California	California	171 000	

† Total dryland crop hectares by state: Washington, 2 226 000; Idaho, 1 029 000; Oregon, 723 000; California, 171 000; Utah, 141 000; western Montana, 89 000.

‡ Numbers in parenthesis are average annual precipitation.

dryland wheat (*Triticum aestivum* L.) production in the world. Precipitation gradually increases from west to east (Fig. 11-2a, 11-2b, 11-2c). The eastern part of the area receives a maximum of 600 mm annually. Between 60 and 70% of annual precipitation occurs from November through April and about 20% of the total occurs as snow at higher elevations and latitudes (Papendick et al., 1995). Further details on climate and topographical influences can be found in Horner et al. (1944) and Naffziger and Horner (1958).

Crop production is heavily dependent on stored winter precipitation as indicated by significant correlation coefficient of 0.77 between grain yield of adequately fertilized wheat and soil water stored at the end of the wet season (1 April) (Leggett, 1959). Winter weather is cool to cold with mean daily temperature in December and January of 0°C but occasionally dipping to -10°C or lower. During extreme cold periods, soil that is not covered with snow may freeze to depths of 40 cm which can lead to heavy water runoff and soil erosion when ensuing weather changes to rain or causes snow to melt (Ramig et al., 1983). During summer, high pressure systems dominate the weather leading to warm, dry conditions and low relative humidity. Average afternoon temperatures in summer range between 20 and 35°C.

### Intermountain

The climate is transitional between the maritime climate of the Pacific coast and continental climate of the Great Plains, depending on the prevailing winds and temperatures. Average annual precipitation ranges between 275 and 500 mm and is nearly uniformly distributed throughout the year (Fig. 11-2d), showing a small peak in May and June caused by increased thunderstorm activity. Winter precipitation is mostly snow and soil is snow-covered for most of the winter. Temperature extremes are common during winter. Summers are moderately warm to hot but periodic rain showers help to elevate relative humidity.

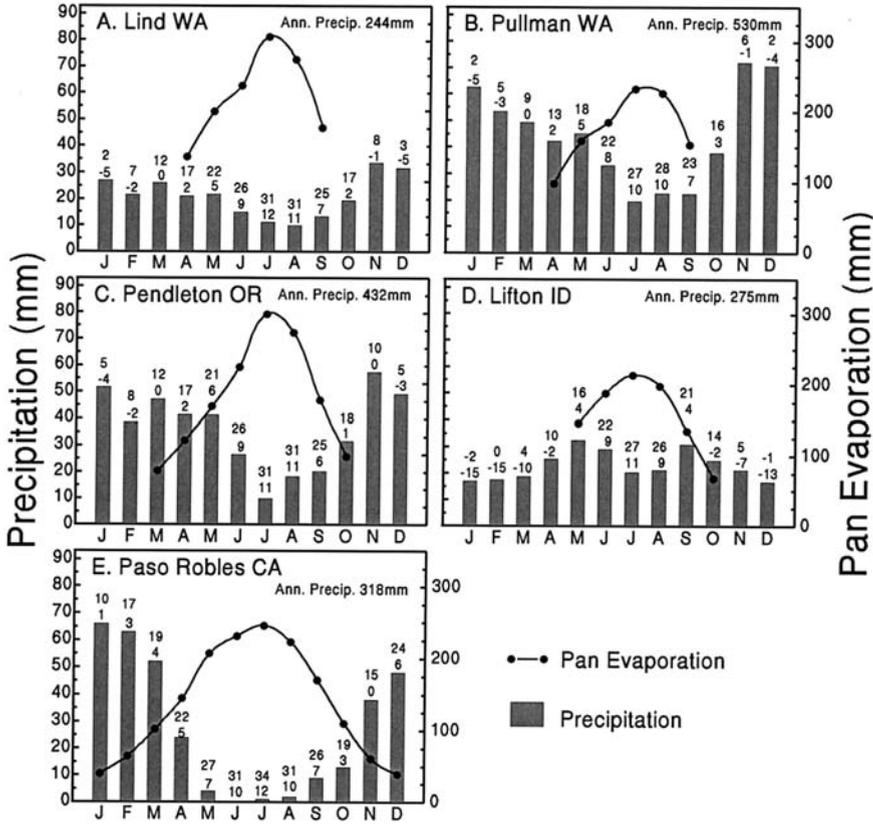


Fig. 11-2. Mean monthly precipitation (30 yr) and pan evaporation (15 yr) from five dryland cropping areas in the western USA. Numbers above individual bars are mean monthly maximum and minimum air temperature.

**California**

Dryland cropping areas of California experience a typical Mediterranean climate with wet and cool winters and dry and hot summers (Fig. 11-2e). Frosts occur but soils commonly do not freeze. Like in the PNW, crop production is highly dependent on soil water stored during winter. Nonetheless, large water deficits exist during summer months when solar irradiance is high and precipitation is rare and amounts insignificant. Average annual precipitation in the region varies from 300 to 500 mm.

**SOILS**

**Inland Pacific Northwest**

Most soils in the dryland cropping areas are formed from a thick deposit of windblown silt, called ‘loess’, that in some locations is 75-m deep overlying

basalt rock (Busacca, 1989). Deposits along with natural soil erosion from wind and water have formed a unique topography that is steeply sloping with dune-like hills in the high precipitation zone. Farming is performed on 8 to 30% slopes with some slopes as steep as 45%. Such steep slopes often present a severe water erosion hazard during the wet winter season. In lower precipitation areas, topography is more gently rolling and wind erosion is a greater threat than water erosion. Loess and related sand dunes originated from wind reworking sediments deposited by cataclysmic glacial outburst floods that occurred about 15 000 yr ago (Busacca, 1991).

Pre-agricultural vegetation ranged from sagebrush-steppe in the driest areas to meadow steppe in areas of intermediate precipitation and to coniferous forest with increasing precipitation (Daubenmire, 1970). Soils under dryland crop production have developed mainly in post-glacial loess under perennial bunchgrass vegetation. These are dark, organic matter-rich prairie soils, that is, Mollisols in the U.S. classification system (Soil Survey Staff, 1999). In areas receiving <230 mm annual precipitation, soils are low organic matter desert soils or Aridisols, with Entisols on active and recently stabilized dunes (Boling et al., 1998). In northern, eastern, and southeastern areas, soils formed in loess under conifers are Alfisols. Some forest soils have quantities of volcanic tephra from eruptions of volcanoes in the Cascade range and are classified as Andisols. The pH of topsoil ranges from <6 to 6.5 in the high precipitation zone and becomes neutral to alkaline in lower precipitation zones where soils are more calcareous.

Soil texture is predominantly silt loam but with higher sand content in the lower precipitation zones. With intensive cultivation grain farming for more than 100 yr, many soils have lost 40 to 50% of their original content of organic matter from topsoil erosion and oxidation. Presently, organic matter content in the surface 10 cm of cultivated dryland soils ranges from more than 3% in the high precipitation zone to <1% in the low precipitation zone. Soils are generally permeable and in most areas deep enough to adequately store winter precipitation and retain between 23 and 29 cm of plant available water (Papendick, 1996). Some soils in north-central Oregon and central Washington are shallow and have considerably less water storage capacity, but still are sufficient for profitable crop production.

### **Intermountain**

Mollisol soils predominate in the diverse intermountain crop production area (NRCS, 2000). There are also minor areas of Inceptisols and Alfisols. Most of the Mollisols fit into the Xerolls sub-order, but in colder areas Cryolls are common. Soils are mostly derived from Quaternary parent material of various origins, although older parent material formations are widely found. Soil texture ranges from silt loam to loam with organic matter content between 1 and 2%. Native vegetation on the dryland cropped area is grassland, mixed grassland-shrub, and some coniferous forest.

### **California**

Soils in the undulating foothills along the Central Valley are medium to shallow in depth (<90 cm) and often stony. The majority of soils are Alfisols,

the remaining are Mollisols or Entisols. Native vegetation is mainly grassland-oak. The pH is neutral to slightly alkaline. Soil organic matter (SOM) content can be low following prolonged cultivation. Approximately 50% of California dryland soils have a moderately fine texture, 25% medium to moderately coarse and 25% moderately coarse. About 75% of the dryland crop production is on slopes >5% (Luebs, 1983).

## CROPPING SYSTEMS

### Inland Pacific Northwest-Low Precipitation

The low-precipitation (<300 mm average annual) dryland cropping region in east-central Washington and north-central Oregon covers 1 557 000 ha (Fig. 11-1, Table 11-1), and is by far the largest cropping zone in the western USA. About 410 000 ha is currently enrolled in the Conservation Reserve Program (USDA-FSA, 2000) where land is removed from crop production and growers are paid an average of U.S. \$125 ha<sup>-1</sup> yr<sup>-1</sup> to grow perennial grasses and shrubs for environmental and soil conserving benefits. This land is under contract for 10 yr during which tillage or harvest are not allowed.

A single family operates most farms and average farm size is 1200 ha. Family farms of 2500 ha or larger are common, especially in areas that receive <250 mm annual precipitation, where grain yield and profit per hectare are relatively low compared to higher precipitation areas. Since land was broken out of native grassland and sage in the 1880s, farming has been almost exclusively a tillage-based wheat-fallow system, where only one crop is grown every 2 yr. Today, winter wheat-summer fallow is practiced on 90% of cropland. Average long-term winter wheat grain yield after summer fallow ranges from 1.2 to 3.5 Mg ha<sup>-1</sup>.

The main purpose of summer fallow is to store a portion of overwinter precipitation to enable successful establishment of winter wheat planted into moist soil in late summer or early fall. Fallow also helps to ensure economic crop yields and reduces risk of crop failure from drought. Between 60 and 75% of precipitation received during winter months after wheat harvest is stored in the soil up to April. However, precipitation that occurs after April, as well as a considerable quantity of water stored in the soil, is lost during late spring and summer (Leggett et al., 1974). By the end of the fallow cycle, an average of only 30% of precipitation received during the 13-mo period is stored in the soil. The processes of water loss and seed zone water retention from summer fallow under PNW conditions have been described by Papendick et al. (1973) and Hammel et al. (1981).

A 3-yr winter wheat-spring cereal-fallow rotation is practiced on about 10% of the cropland. In general, growers will consider planting a spring cereal, primarily wheat or barley (*Hordeum vulgare* L.), if overwinter water recharge occurs to a soil depth of 1 m and at least 13 cm of plant available water is stored in the soil. Continuous annual cropping is practiced on <1% of land. Average grain yield of spring wheat and spring barley after winter wheat range from 0.7 to 2.5 Mg ha<sup>-1</sup>. Winter wheat after summer fallow is the dominant rotation as it

provides relatively stable grain yields and is less risky compared with spring wheat or barley. However, growers are increasingly interested in spring wheat due to recent release of high yielding cultivars. Many growers also want to increase intensity of cropping (i.e., decrease frequency of fallow) and reduce or eliminate tillage. Both practices help to control wind and water erosion and, in the long term, improve quality of dryland soils (Kennedy, 1998). Reduction in price of some nonselective herbicides and recently introduced no-till drills that fertilize and plant in one pass through the field leaving ample residue cover (Fig. 11-3), has sparked interest in more intensive cropping systems. Experience of researchers and growers with a wide array of alternative crops such as pea (*Pisum sativum* L.), canola (*Brassica napus* L. and *B. campestris* L.), condiment mustard (*Brassica* spp.), safflower (*Carthamus tinctorius* L.), sunflower (*Helianthus annuus* L.), and flax (*Linum usitatissimum* L.) has not yet revealed a crop that can compete agronomically or economically with cool-season cereals. Nonetheless there is strong interest and support for research on new crops and for more diverse rotations in the low precipitation environment.

Both soft white and hard red winter and spring wheat cultivars are grown. In general, available cultivars have excellent yield potential, disease resistance, winter hardiness, and end-use quality. However, growers in the low-precipitation zone have not been able to take full advantage of the extensive progress in soft white winter wheat development because all cultivars, except one, released in the past 35 yr are semidwarfs that carry dwarfing genes (Allan, 1980). Semidwarfs have short coleoptiles and length of coleoptile is correlated with ability of winter wheat to emerge from the soil when planted deep to moisture. Stand establishment of winter wheat on summer fallow is a crucial factor affecting grain yield (Bolton, 1983). Growers in this zone need cultivars that emerge rapidly (7–10 d) with limited moisture and up to 15 cm of dry soil covering the seed (Schillinger et al., 1998). In response to the expressed needs of growers, breeding of standard height



Fig. 11-3. No-till cropping preserves surface residue for erosion control and other environmental benefits and holds good economic potential for the future.

and tall soft white winter wheat lines with good emergence potential has recently been included in breeding objectives for low-precipitation areas.

### **Inland Pacific Northwest-Intermediate Precipitation**

The PNW intermediate (300- to 450-mm average annual) precipitation zone comprises about 970 000 ha in dryland crop production (Table 11-1, Fig. 11-1). Much of the intermediate zone is traditionally farmed in a winter wheat–summer fallow rotation, changing to a more crop intensive 3-yr rotation of winter wheat–spring barley–fallow as precipitation increases. Historic reasons for winter wheat–fallow are more stable crop yields, improved weed control, and restrictive requirements of past federal farm programs on cereal grain allotments. Since the elimination of farm program provisions in 1995, fallow hectareage has been reduced because of more intensive cropping systems such as winter wheat–spring cereal–fallow rotation or annual cropping. An important benefit of rotation and more intensive cropping is reduction of soil erosion.

The 2-yr winter wheat–fallow rotation has a greater risk of diseases and winter annual grass weed infestation compared to a 3-yr rotation because of its higher frequency of winter wheat. Spring barley provides somewhat better root disease control for winter wheat compared with spring wheat in a 3-yr rotation. Researchers and growers have tested the agronomic and economic feasibility of alternative crops with drought tolerance such as narrow-leaf lupine (*Lupinus angustifolius* L.), canola, and mustard for inclusion in cereal-based systems. For example, spring canola or condiment mustard are adapted and can substitute for a spring cereal.

The more intensive winter wheat–spring broadleaf and winter wheat–spring cereal rotations are practiced in areas with higher and more dependable precipitation. There is some successive cropping of spring cereals, either barley or wheat in areas with shallow soils (<1-m deep) where the soil profile is filled to capacity with water during winter, or where there is high potential for erosion.

Soft white winter wheat is the highest yielding crop in all rotations and, historically, provides the best economic return. Average grain yields range from 3 to 6 Mg ha<sup>-1</sup> with a straw yield of 4 to 8 Mg ha<sup>-1</sup> (Papendick, 1996). Both soft white or hard red spring wheat are grown. Spring barley yields following winter wheat range from 2 to 4 Mg ha<sup>-1</sup> in more productive areas and produce half the residue compared to winter wheat. Spring legumes include dry pea, processing pea, lentil (*Lens culinaris* Medik.), and chickpea (*Cicer arietinum* L.). Some growers have experimented with warm-season crops like corn (*Zea mays* L.), safflower, sunflower, and proso millet (*Panicum miliaceum* L.), but these crops are not popular because of high soil water use, frequent lack of adequate summer heat units, variable grain yield, and lack of accessible markets.

### **Inland Pacific Northwest—High Precipitation**

This zone receives more than 450 mm annual precipitation and comprises 822 000 ha of dry-farmed cropland. The territory includes the steeply sloping Palouse area of eastern Washington and northern Idaho, recognized for world

record grain yields of dryland winter wheat that average 6.5 to 7 Mg ha<sup>-1</sup> and can exceed 9 Mg ha<sup>-1</sup>. At these production levels straw yields range from 8 to 11 Mg ha<sup>-1</sup>. Precipitation is adequate for annual cropping. In most years, available soil water content to a soil depth of 1.8 m is maximum in early spring and is efficiently extracted by healthy winter wheat by harvest. Because of its consistent high yields, winter wheat is the major profit-making crop, and is grown in rotation with spring crops of barley, wheat, pea, lentil, chickpea, canola, and condiment mustard. Fall-planted barley and canola are occasional replacements for winter wheat. Of spring crops in rotation with winter wheat, typically 40% is barley or wheat, 40% pea or lentil, and 20% other crops, including grass seed or fallow (Papendick, 1996). Grain and residue yields from spring cereals are 50 to 70% of those for winter wheat. Lentil and dry pea grain yields average 1.5 to 2 Mg ha<sup>-1</sup> and produce an equal quantity of residue. A serious shortcoming of grain legumes is the low crop residue produced to carry into the following winter wheat crop.

A common 2-yr rotation is winter wheat-pea or lentil, used because the legume crop improves yield of the succeeding wheat crop 10 to 20% compared to yield following a spring cereal (Guy and Gareau, 1998). Some continuous cropping of winter wheat has been practiced because the market for wheat was favorable, and in some cases to maintain a high allotment for wheat hectareage established for the USDA Farm Program. But yields of continuous winter wheat are 30 to 50% less than grown in rotation with spring crops because of heavier weed infestations, increased diseases, as well as poorly understood soil and unweathered residue inhibitory factors (Wuest et al., 2000).

With elimination of cropland base in the USDA Farm Program, and an increased emphasis on resource conservation and environmental protection, 3-yr rotations of winter wheat-spring barley or spring wheat-grain legume, or a cereal-only rotation of winter wheat-spring barley-spring wheat are commonly practiced. Alternatively, spring crops are canola or mustard that are adapted and yield well. Longer rotations and higher crop diversity improve pest control by breaking up weed, insect, and disease cycles and facilitates use of reduced- and no-till practices. The 3-yr rotation has been enhanced by advancements in spring wheat breeding, with new cultivars producing grain yields of 4 to 5 Mg ha<sup>-1</sup>.

In past years, enrollment of cropland in Conservation Reserve Program (CRP) was limited for economic reasons, that is, the maximum payment was sufficiently less than profit from producing a crop. However, with recent sign-ups, payments to growers have been as high as U.S. \$225 ha<sup>-1</sup> yr<sup>-1</sup> and enrollments are increasing, being boosted by low wheat prices, uncertainty about government subsidy support, and soaring fertilizer, fuel, machinery, and other operational costs. Still, only 75 000 ha or <10% of cropped area is currently enrolled.

### **Idaho-Utah-Montana Intermountain Area**

The dryland intermountain cropping area covers 860 000 ha (Fig. 11-1, Table 11-1). Dry cropland is often interspersed with irrigated areas. Cropland is 600 to 2000 m elevation above sea level and usually surrounded by mountains.

A cool climate (Fig. 11–2d) and short growing season dictates production of mostly cool- season crops. Winter and spring wheat, spring barley, and hay are major crops (Idaho Agricultural Statistics Service, 2000; Montana Agricultural Statistics Service, 2000; Utah Agricultural Statistics Service, 2000). Cool-season grain legumes and *Brassica* oilseeds are minor crops sometimes grown in rotation with small grains. Alfalfa (*Medicago sativa* L.) and grass hay is often grown in rotation with small grains, but also cropped in monoculture.

Variability in elevation, temperature, precipitation, and soils dictate different cropping systems throughout in the region. Nearly 38% of dry cropland, or 325 000 ha, is currently enrolled in CRP. Where annual precipitation is below 350 mm, winter wheat-summer fallow is the dominant cropping system. Winter wheat grain yields after fallow range from 1.5 to 3.5 Mg ha<sup>-1</sup>, depending on water availability. Winter wheat is planted in September or early October and harvest starts in August, but can extend into September. Due to cool temperatures, precipitation storage efficiency during fallow may be somewhat higher compared to the inland PNW. Similar to the PNW, soil water content in the fall is not appreciably affected by summer rainfall (Massee and Siddoway, 1970). Massee and McKay (1979) showed that standing stubble increased soil water storage by trapping snow and that wheat yield increased by 0.34 Mg ha<sup>-1</sup> for each 30 cm of snow trapped.

January and February average minimum air temperature of -15°C (Fig. 11–2d) demonstrates the critical need for insulating snow cover for winter wheat survival. But prolonged snow cover increases snow mold of winter wheat (see disease section), a common problem of the region. Small seedlings are affected less by snow mold than larger wheat plants (Massee and McKay, 1979). The recommended September planting date for winter wheat is a compromise between large seedling size from early planting for best yield potential and later planting and smaller seedlings for reduced snow mold.

Some flexible cropping is practiced in areas that receive 350 to 400 mm annual precipitation, but most growers still practice winter wheat-summer fallow. The most common flexible cropping system is a 3-yr winter wheat–spring cereal–fallow rotation. Annual cropping of continuous cereals, hay, or its combination is practiced in some areas where annual precipitation exceeds 400 mm. Continuous annual cereal cropping consists of winter wheat in rotation with spring barley or spring wheat.

Spring crops are planted as early as possible and harvested in August or September. Winter wheat grain yield in the annual crop areas ranges from 3 to 6 Mg ha<sup>-1</sup>, and spring wheat and barley grain yields 2 to 4 Mg ha<sup>-1</sup>. Grass hay produces a single cutting in early summer. Alfalfa is grown in monoculture or mixed with grass and usually produces two to three cuttings per season, with the first cutting in May in warmer areas and the final cutting in September. Hay dry matter yields range from 4 to 8 Mg ha<sup>-1</sup> per growing season.

## California

California leads the USA in number of crops grown and in overall crop production, but dryland cropping is a minor component of the state total. Wheat

and barley are produced on a continuous annual basis on about 80 000 ha with grain yield ranging from 1.7 to 3.9 Mg ha<sup>-1</sup>. Cereal crops are planted in late fall and harvested in May or June. Grass, alfalfa, or cereals produced for hay are grown on another 90 000 ha (Table 11-1).

Summer fallow is practiced only when fall precipitation is below average and there is high risk and lower grain yield potential for annual-cropped cereals. When growers choose summer fallow, cattle typically graze on stubble until February, then the soil is disked and harrowed. A combination of cultivation and herbicides is generally used to control weeds.

Dryland crop production is scattered along the western (coastal mountains) or eastern (Sierra Nevada) foot hills of the Central Valley (Fig. 11-1). In the late 1970s it was estimated that 800 000 ha was under dryland production (Hatfield, 1983; Luebs, 1983). Area has rapidly declined (USDA, 1999) due to leveling land to make irrigation possible, construction of buildings, government incentives for taking land out of production, and conversion of land into vineyards. Generally, land that remains in dryland production is not suitable for irrigation because of undulating or hummocky topography.

## CULTURAL PRACTICES

### Tillage and Planting

#### The Winter Wheat-Summer Fallow Rotation

Growers in the winter wheat-summer fallow production areas typically conduct eight or more tillage operations during fallow. Timing and extent of tillage varies depending on quantity of surface residue, weed infestations, soil type, potential for water runoff on frozen soils, and individual preference.

A typical sequence of conventional tillage practices during fallow is outlined in Table 11-2. Beginning just after wheat harvest, a V-shaped sweep implement is used to kill weeds such as Russian thistle (*Salsola iberica* Sennen and Pau), if present, by severing the tap root. After surface soil has been moistened by fall rain, fields at higher elevations and latitudes are generally chiseled in November to a depth of 25 cm or more to create channels open to the subsoil to aid infiltration of runoff when soils are frozen (Pikul et al., 1992). In late winter a nonselective herbicide may or may not be used to control winter grass weeds. Initial spring tillage is conducted from mid-March through April and commonly consists of one or two operations with a duck-foot cultivator plus attached harrow or a single operation with a tandem disk. Spring tillage disrupts soil capillary continuity to create a dry surface tillage mulch that retards evaporation of stored water during dry summer months (McCall, 1925). Aqua or anhydrous ammonia (NH<sub>3</sub>-N) is injected into soil with shanks in April or May. To control Russian thistle and other weeds, and to set the seed zone moisture line (break between disturbed soil on top and nontilled soil below), three to five secondary tillage operations with rodweeders [a 2-cm square rotating rod operated up to 10 cm below the soil surface (see Fig. 11-4)] are performed in spring and summer.

Table 11-2. Field operations for three fallow tillage management methods in a winter wheat-summer fallow cropping system. Long-term research at Lind, WA, showed that with judicious use of herbicides, tillage operations can effectively be reduced from eight or more (conventional tillage) to as few as three (delayed minimum tillage), resulting in significant erosion control benefits and with no adverse agronomic effects (modified from Schillinger, 2001).

Date	Conventional tillage	Minimum tillage	Delayed minimum tillage
Aug.†	V-shape sweep; 30-cm shank spacing, 36-cm-wide sweep to kill Russian thistle after wheat harvest	Nonselective herbicide for post-harvest control of Russian thistle.	Nonselective herbicide for post-harvest control of Russian thistle.
Nov.	Chisel; 30-cm shank spacing, straight point, 25-cm depth.	Chisel; 120-cm shank spacing, straight point, 40-cm depth.	
Feb.	Nonselective herbicide to control winter grass weeds.	Nonselective herbicide to control winter grass weeds.	Nonselective herbicide to control winter grass weeds.
Mar.‡	Primary tillage- cultivator, overlapping 18-cm-wide sweeps, 13-cm depth + 5-bar spring-tooth harrow (two passes). Or, tandem disk, 13-cm depth (one pass).	Primary tillage and application of aqua NH <sub>3</sub> with undercutter implement with overlapping 80-cm-wide V-blades, 13-cm depth + rolling harrow.	
Apr.	Aqua NH <sub>3</sub> -N injection at 20-cm depth with shanks spaced 30-cm apart.		
May	First rodweeding, 10-cm depth	First rodweeding, 10-cm depth	Primary tillage and application of aqua NH <sub>3</sub> with undercutter implement with overlapping 80-cm-wide V-blades, 13-cm depth + rolling harrow.
June	Second rodweeding, 10-cm depth	Second rodweeding, 10-cm depth	First rodweeding, 10-cm depth
July	Third rodweeding, 10-cm depth	Third rodweeding, 10-cm depth	Second rodweeding, 10-cm depth
Sept.§	Sow winter wheat with deep furrow drill, 40-cm row spacing	Sow winter wheat with deep furrow drill, 40-cm row spacing	Sow winter wheat with deep furrow drill, 40-cm row spacing

† Post-harvest control of Russian thistle is generally not necessary when good stands of winter wheat are achieved.

‡ Attached rolling harrow is to break up large clods and fill air voids. Should not be used on soils lacking in clod structure.

§ Surface residue may exceed 2250 kg ha<sup>-1</sup> at the end of fallow when minimum tillage or delayed minimum tillage practices are used. If so, tillage to cut, align, or otherwise bury straw may be needed to allow effective grain drill operation.



Fig. 11–4. Rodweeders are commonly used to control weeds during the spring and summer of the fallow cycle. Growers can easily cover 130 ha or more per day with a 20-m-wide rodweeder implement.

Intensive tillage operations during fallow often bury surface crop residue, pulverize soil clods, and reduce surface roughness (Schillinger and Papendick, 1997). Blowing dust from excessively tilled fields leads to major soil losses and reduces air quality. Therefore, many growers are converting to minimum and delayed conservation tillage methods; using herbicides instead of tillage whenever feasible to reduce tillage to as few as three operations during fallow (Table 11–2). Long-term research at Lind, WA, showed that minimum and delayed conservation tillage significantly increased surface residue and clod retention for controlling erosion with no adverse agronomic (Schillinger, 2001) or economic (Janosky et al., 2002) effects compared to conventional tillage. Water content in the seed zone at the end of fallow was not affected by tillage treatment, suggesting that finely divided soil particles in tillage mulch may not be as important for retarding evaporative water loss during the summer as previously thought. Rather, creating an abrupt break between the tilled and nontilled layer with initial spring tillage, which severs capillary channels from the subsoil to the surface, appears to be the dominant factor regulating over-summer evaporative water loss. In addition, initial spring tillage could be delayed until mid-May because late winter application of a nonselective herbicide provided excellent weed control for several months.

If conservation tillage practices, as outlined in Table 11–2, were widely practiced in winter wheat–summer fallow production zones, a sharp reduction in wind erosion and suspended dust emissions could be expected, leading to improved air quality with no hardship to the livelihood of growers. It must be emphasized, however, that no-till summer fallow (chemical fallow) shows limited potential in low precipitation areas because of increased evaporative loss of seed-zone soil water during dry summer months compared with tillage (Lindstrom et al., 1974; Schillinger and Bolton, 1993).

Winter wheat is planted starting in late August in 35- to 45-cm wide rows with deep furrow split-packer drills. These drills are specifically designed to place seed as deep as 20 cm below the preplanting soil surface into moist soil (Fig. 11–5). Highest winter wheat grain yields are generally achieved with early planting (Donaldson, 1996; Donaldson et al., 2001) despite certain fungal diseases associated with this practice (see disease section). In dry years when seed zone water is inadequate for seed germination and emergence, growers will either plant shallow (2–3-cm deep) into dry soil using either hoe or disk type drills with 15- to 30-cm row spacing, delay planting until the arrival of fall rains, or postpone planting until spring.

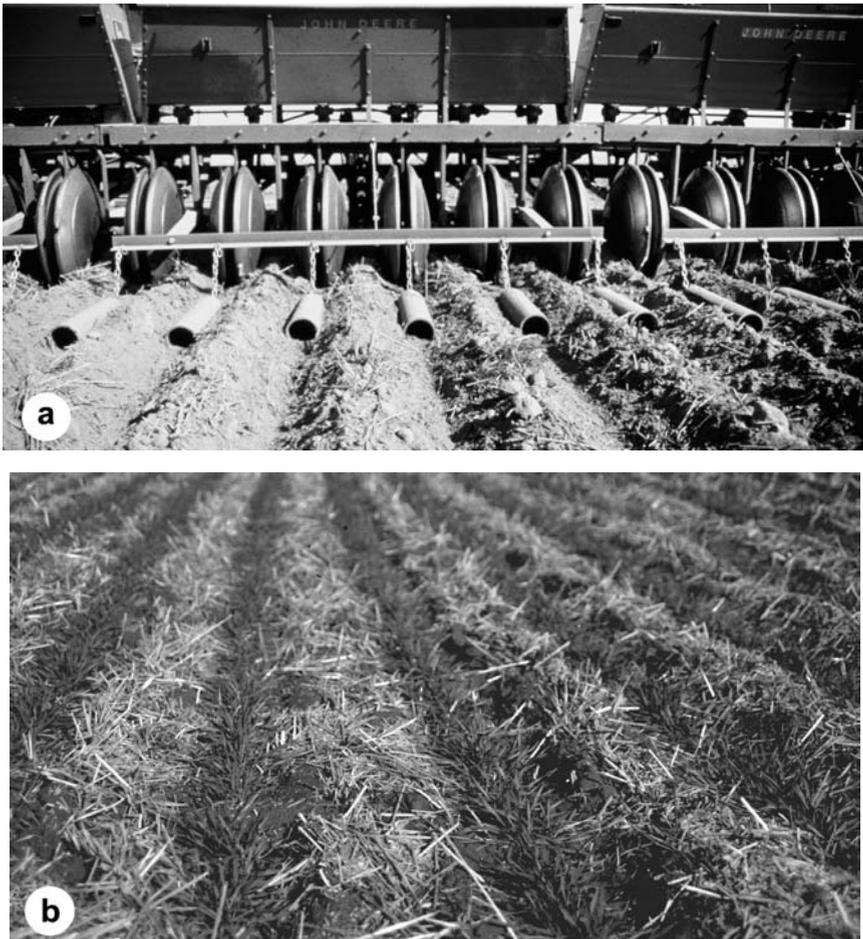


Fig. 11–5. (a). In low-precipitation regions, winter wheat is planted deep into carryover soil moisture in summer fallow with deep-furrow split-packer drills. This drill has 40-cm row spacing and is equipped with drags behind each opener to reduce thickness of soil covering seed for fast emergence. (b) Uniform stand establishment for high grain yield potential combined with ample surface residue for erosion control.

### Intermediate and High Precipitation Zones

Tillage practices vary widely in intermediate and high precipitation areas where water erosion, rather than wind erosion, is the major soil conservation problem. Implements found on most farms include a moldboard or chisel plow, tandem disk, field cultivator, harrow or rotary hoe, rodweeder or culti-weeder, and either hoe or double-disk drills. Conventional tillage and planting operations and soil conservation practices in these regions have been described in detail by Papendick et al. (1983), Papendick et al. (1995), and Ramig et al. (1983).

Tillage and planting practices in the intermediate precipitation zone have similarities with those employed in both low and high precipitation zones. There is considerable use of summer fallow in the intermediate precipitation zone, but potential for wind erosion is less because of finer-textured and better aggregated soils. The chisel plow or tandem disk are common primary tillage implements, whereas the moldboard plow is rarely used or only in certain regions. With the 3-yr winter wheat–spring barley–fallow rotation, secondary tillage before planting spring barley may consist of two or three cultivator and harrow operations followed by shank fertilizer application. Most drills used for spring-planted crops have rows spaced 15- to 30-cm apart and are equipped to deliver starter fertilizer with or near the seed (Wilkins, 1996). Fallow operations preceding the winter wheat crop mimic those used in the low precipitation zone (Table 11–2). Similar to the low precipitation zone, deep fall chiseling of stubble is often employed to reduce runoff from rain or snowmelt on frozen soils.

In high-precipitation annual crop areas, excessive residue from high yielding winter wheat, if left on the surface, commonly interferes with cultural operations. The moldboard plow has historically been used to completely invert the top 15 to 25 cm of soil to bury winter wheat stubble in the fall and prepare a seedbed for the subsequent spring crop. Widespread use of the moldboard plow continues to contribute to severe water erosion on steep slopes in the Palouse region. Water erosion is generally not severe during the first winter after moldboard plowing, especially if the moldboard plow furrow is turned uphill. Major water erosion can occur in a 2-yr rotation after the subsequent pea or lentil crop that produce little residue. In the more common 3-yr winter wheat–spring cereal–grain legume rotation, spring cereal residue is usually chiseled rather than moldboard plowed. Cereal residue is long lived in this climate and if retained on the surface, enough will persist through the season of a legume crop and provide ground cover during establishment of the following winter wheat crop (Guy and Cox, 2002). Water erosion is less in 3-yr compared to 2-yr rotations, but still not at acceptable levels.

Some growers dispose of wheat straw by burning fields either in the fall or spring and follow with reduced- or no-till planting of the next crop. Even without surface cover, soil erosion under burned reduced- and no-till plantings is considerably less than on moldboard plowed fields. But field burning is being increasingly criticized due to negative impact of smoke on air quality. To conserve surface residue for erosion control and water conservation many growers use chisel plows to create channels for water infiltration or use tandem disks that when properly adjusted chop crop residue to leave 60% or more of the cereal

stubble on the soil surface. Reducing straw length and amount on the soil surface facilitates fertilizing and planting operations. Spring cereals produce considerably less residue than winter wheat and these are more manageable in tillage and planting operations. Factors related to crop residue retention, burial, and decomposition as affected by tillage and cropping system have been described by Douglas et al. (1999) and Elliott et al. (1999).

Interest continues to increase in all precipitation zones in development and implementation of no-till technology for dryland cropping systems. No-till is defined as planting directly into residue of the previous crop without tillage that mixes or stirs soil before planting. No-till opens the door in all production zones for energy savings, excellent control of wind and water erosion, and improved soil quality. Current estimates indicate that 5% of dry cropland in the western USA is planted using no-till (CTIC, 2001). Adoption is slow for reasons of transition costs, lack of experience and expert knowledge with no-till, grower resistance to change, and uncertainties with crop yields and risks of crop loss from unpredictable agronomic factors. However, potential long-term economic, resource conservation, and environmental benefits are all favored by no-till and provide incentives for a gradual continuing shift to this technology currently viewed as the farming practice of the future.

### Fertility

Value of fertilizer and organic residues for crop production on semiarid soils in dryland regions was recognized many years ago (Smith et al., 1946). Nitrogen is by far the nutrient most often deficient to ensure optimum yield of all nonlegume crops. Nitrogen application almost universally increases cereal yield in all precipitation zones on soils with low available soil N. Magnitude of nutrient response usually correlates with degree of deficiency, in the general order of N, S or P, and K, followed by micronutrients. Nutrient interactions can change this pattern, but only the interaction between N and S is routinely encountered in dryland cereal production. Nitrogen fertilizer application can intensify S deficiency and decrease yield under severe S deficiency (Rasmussen and Douglas, 1992).

Nitrogen response by cereal crops is influenced by amount of precipitation, soil depth, previous crop, and level of residual N in soil (Miller et al., 1988; Payne et al., 2000). The N rate for optimum grain yield of dryland wheat varies widely from year-to-year, mostly related to available soil water. Nitrogen fertilization stimulates straw yield more than grain yield because vegetative growth is produced before onset of drought stress; increased straw production may lead to high water use by the crop with less water remaining for grain production. Amount of precipitation during April, May, and June has a pronounced effect on grain yield, especially for spring-planted cereals.

Nitrogen-use efficiency ranges from 23 kg grain kg<sup>-1</sup> N in wet years to 4 kg grain kg<sup>-1</sup> N in less favorable years. Soil testing for water and available N in the spring of the crop year provides a reasonable estimate of potential yield and N requirement (Leggett, 1959; Fiez et al., 1994). Synchronizing N supply with crop demand for N often increases N-use efficiency, but fertilizer often needs to

be applied before growing-season precipitation is known. Thus, growers rely on weather trends and past experience to apply an 'average' amount of fertilizer. The crop previously grown also has a pronounced effect on yield of the subsequent wheat crop, mainly due to its effect on soil water in drier areas (Rasmussen et al., 1989). Grain legume crops can provide N to soil which adds to their value as a rotation crop. A year of summer fallow mineralizes about  $0.12 \text{ kg N ha}^{-1}$  per mm of average annual precipitation. Applied N for cereals ranges from 0 to  $135 \text{ kg ha}^{-1}$ . Soft white wheat (no protein requirement), hard red winter wheat (12% protein), and hard red spring wheat (14% protein) generally require 32, 41, and 48 kg of available N, respectively, for each expected megagram of grain yield (Halvorson et al., 1986; Mahler and Guy, 1998).

Most fertilizer N is applied as anhydrous or aqua  $\text{NH}_3$  because it costs less than other sources. Nitrogen is shanked 10- to 15-cm deep with 30- to 40-cm shank spacing. In general, highest N-use efficiency occurs when N is applied at planting. In a winter wheat–summer fallow system, N can be applied in mid-fallow (April–June) without loss through leaching or denitrification when annual precipitation is  $<350 \text{ mm}$ . When annual precipitation is between 350 and 450 mm, N application just before planting is recommended. Above 450 mm precipitation, improved N-use efficiency for winter wheat is achieved by split application, applying N at planting followed by a second application in the spring. Spring application can be limited in the high precipitation region due to wet soils, and aerial application of N in the spring is common. Spring-planted cereals benefit from placement of some fertilizer near the seed to enhance early growth (Klepper et al., 1983; Koehler et al., 1987). Most newer no-till drills can apply fertilizer with or near the seed during planting.

Sulfur is the second most deficient nutrient for crop growth. Sulfur deficiency occurs primarily in the intermediate and high precipitation zone of Oregon and Washington and on some soils in California. Cereals generally do not respond to S application when grown on soils with a calcareous horizon within 75 cm of the soil surface, since this layer contains significant available S (Rasmussen and Allmaras, 1986). Cereals occasionally exhibit S-deficiency symptoms during early stages of plant growth, but these will disappear after roots extend into the calcareous layer. Cereal crops require about 1 kg of S for every 16 kg of N and application of 12 to  $20 \text{ kg S ha}^{-1}$  is common. *Brassica* crops require 3 to 10 times as much S as do cereals at equal yield. Sulfur is applied most commonly as ammonium thiosulfate or ammonium polysulfide combined with N application.

Phosphorus (P) is the third most limiting nutrient. Application of P can increase retention of tillers and hasten maturity. Phosphorus deficiency in cereals is affected little by tillage and frequency of cropping, but becomes more prevalent with higher crop yield potential. Phosphorus deficiency occurs more often on upper slope positions where much of the topsoil has been lost through erosion (Pan and Hopkins, 1991). Band placement of P fertilizer is more efficient than broadcasting P. Band placement of P plus N fertilizer with or near the seed in cool-wet environments often enhances plant development. Deficiencies of potassium (K), zinc (Zn), manganese (Mn), and boron (B) occur only rarely in dryland cropping, especially in low-precipitation zones.

Fertilizer applications that increase crop residue production generally enhance SOM levels over unfertilized conditions (Smith and Elliott, 1990). Nitrogen has the greatest impact, primarily because it has the greatest effect on dry matter production. Stubble mulching and other forms of conservation tillage conserve more SOM than does incorporating residue. Higher SOM increases microbial biomass, which in turn improves aggregate stability, aeration, water infiltration, and water movement through soil. Long-term N fertilization that has increased SOM also increases mineralizable N in soil (Rasmussen et al., 1998). Increased SOM content raises the amount of N that soil can supply and alters fertilizer N need.

Nitrogen fertilizer is decreasing soil pH because most fertilizer-N used in the western USA is ammonium ( $\text{NH}_4^+$ )-based and acid-forming (anhydrous and aqua  $\text{NH}_3$ , urea,  $\text{NH}_4^+$ -nitrate [ $\text{NO}_3^-$ ],  $\text{NH}_4^+$  sulfate [ $\text{SO}_4$ ], etc.). Increasing acidity in soil reduces biological activity, increases fungal populations, reduces availability of many important nutrients, and slows rate of N cycling in soil. Yield of most crops tend to decrease when pH goes below 5.3, although yield of lentil, pea, and alfalfa are reduced at pH 5.6 or less (Mahler and McDole, 1987). Soil acidity does not pose a problem where annual precipitation is <400 mm because soils have high pH and contain free lime below the 30- to 45-cm depth. Soil acidity can limit crop yields in regions with annual precipitation above 400 mm. Periodic liming may eventually be required to sustain crop yield.

### Weeds

The most troublesome annual grass weeds for dryland cereal-based farming in the western USA are downy brome (*Bromus tectorum* L.), wild oat (*Avena fatua* L.), and jointed goatgrass (*Aegilops cylindrica* Host.). Russian thistle is a difficult annual broadleaf weed in low-precipitation areas. Annual broadleaf weeds in cereals generally are less problematic than grass weeds because they can be selectively controlled with herbicides. Most legume and oilseed crops grown in rotation with cereals have good herbicide options for grass weed control. Effective weed management systems integrate cultural, mechanical, and chemical control strategies as appropriate.

Downy brome, also called cheatgrass (Ogg, 1993), and jointed goatgrass (Donald and Ogg, 1991) are winter annuals with growth cycles similar to winter wheat. Although these weeds are problematic in all precipitation zones, the 2-yr winter wheat–summer fallow rotation has the greatest risk for infestations because of high frequency of winter wheat. Early-planted winter wheat on summer fallow can be competitive against downy brome and jointed goatgrass, particularly if precipitation for germination of weed seeds does not occur for several weeks after planting. In higher precipitation zones, where winter wheat is generally grown only once in a 3-yr rotation, the additional year out of winter wheat helps control these weeds. Some new herbicides offer effective in-crop control of downy brome, but herbicide resistance is expected to develop within a few years unless stringent herbicide-resistance management strategies are followed. Successive spring cropping is an effective control strategy for downy brome and jointed goatgrass by reducing weed seed survival in soil.

Wild oat is a major problem in all crops. There is a great diversity within the wild oat species. Prolific seed production, seed longevity, and wide adaptation, make this weed difficult to control. Herbicide resistance in wild oat is an increasingly important issue.

Russian thistle (Holm et al., 1997) presents a formidable obstacle to successful spring cereal production in low-precipitation areas. Spring cereals have less early growth and slower canopy closure compared with winter wheat. Russian thistle seeds germinate in repeated flushes during the spring after rainfall events of 3 mm or more. Heavy infestations may reduce grain yield of spring cereals by 50% (Young, 1988). Post-harvest control of Russian thistle, either with a V-shaped sweep tillage implement or with herbicides, is an important management practice to prevent seed production and halt its soil water use.

Other weeds of secondary importance, or those that are becoming increasingly problematic, include: kochia [*Kochia scoparia* (L.) Schrad.], Italian ryegrass (*Lolium multiflorum* Lam.), prickly lettuce (*Lactuca serriola* L.), mayweed chamomile (*Anthemis cotula* L.), prostrate knotweed (*Polygonum aviculare* L.), quackgrass (*Elytrigia repens* L. Nevski), horseweed (*Conyza canadensis* L. Cronq.), common lambsquarter (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), Canada thistle (*Cirsium arvense* L. Scop.), and field bindweed (*Convolvulus arvensis* L.). See Appleby and Morrow (1990) and Ogg et al. (1999) for comprehensive overview of integrated weed control in Pacific Northwest dryland cropping systems.

### Diseases

Fungi that infect roots, crowns, and stems are the primary yield-limiting pathogens for dryland cereals in the western USA. Foliar diseases such as rust and smuts are not as damaging to cereals as in many other regions because of low humidity and winter-dominant precipitation combined with integrated genetic, chemical, and cultural management practices for their control (Smiley, 1996).

Fusarium foot rot, caused by *F. culmorum* and *F. graminearum*, and commonly called dryland foot rot, is prevalent in winter wheat in low-precipitation wheat–summer fallow areas. Fusarium can survive for many years in soil (Inglis and Cook, 1986) and can even persist in soil that is too dry for other fungi (Cook and Papendick, 1972). Wheat becomes susceptible to Fusarium when under water stress, which typically occurs between anthesis and maturity. Diseased internodes have a chocolate brown color and the damaged cells stop water flow in the xylem, which impedes kernel development and causes spikes to turn white. Fungicides and resistant cultivars to suppress Fusarium are not available, although varieties with ability to tolerate or avoid plant water stress tend to be less susceptible to this disease (Cook, 1980). Growers should avoid planting too early (i.e., not before 20 August) and limit N fertilizer to evade early water stress and disease expression.

Snow molds are important on winter wheat in the intermountain region and at higher elevations and northern latitudes in the PNW. This group of diseases is caused by at least three genera of fungi, but the most important are *Typhula*

species responsible for speckled snow molds. Snow molds are caused by both soil-borne and residue-borne pathogens that infect leaves under the snow and then grow into crowns. Wheat dies if covered with snow for more than 120 consecutive days. Some growers have blown on coal dust to hasten snow melt, but control of the disease is mostly accomplished by rotation to spring cereals which escape infection, or by growing the few cultivars of winter wheat that can survive snow mold even with 100% destruction of leaves.

Cephalosporium stripe, caused by *Cephalosporium gramineum*, and strawbreaker foot rot, caused by *Tapesia yallundae* and *T. aciformis*, are residue-borne pathogens of winter wheat. Cephalosporium stripe develops when the pathogen invades the xylem. Early stages of symptom development, that is, while plants are still in the tillering or stem extension stages, can be recognized as yellow stripes running the full length of leaves and down leaf sheaths. As the disease continues to develop, plants are typically stunted and die shortly after heading and before grain fill. The pathogen then grows into surrounding parenchyma tissue of dead culms where it can survive for 2 yr or more in buried straw (Bruehl, 1968). Root infection occurs from spores produced on undecomposed infested straw in soil, apparently through wounds produced on roots through soil heaving or other mechanical damage. Spores produced in infected roots are then carried upward in the transpiration stream, ultimately plugging the vascular system (Wiese, 1987). Plugging of the vascular system results in shriveled or no kernels, white spikes, and reduced grain yield. Harvest and tillage operations return host debris and inoculum to soil. Sources of genetic resistance exist and attempts are being made to incorporate Cephalosporium stripe resistance into winter wheat cultivars (Cai et al., 1998).

Strawbreaker foot rot (eyespot) develops as a consequence of infection at the base of tillers and the mainstem just above or at the soil surface (Bruehl et al., 1968). These infections develop as elliptically-shaped lesions, also known as eyespots, that progress through successive layers of leaf sheaths and finally into the culm. Severely-infected tillers and stems break over, hence the name 'strawbreaker'. The fungus responsible for strawbreaker foot rot overwinters on infected stubble and conidia are dispersed by raindrop-splash to young winter wheat plants when temperatures are cool (below 10°C). Resistant cultivars, crop rotations, and chemical control can limit yield losses due to disease.

Rhizoctonia root rot caused by *Rhizoctonia solani* (Kühn) AG8, is the most important disease of spring wheat and barley planted directly into cereal stubble (Weller et al., 1986). Rhizoctonia is a minor disease of wheat and barley grown with conventional tillage but can be devastating for these crops under no-till. Practices that limit severity of this disease in no-till cropping systems are: (i) elimination of volunteer and other grass weeds that serve as hosts for the pathogen during the "green bridge" period 2 to 3 wk and preferably 2 to 3 mo before planting barley or wheat (Smiley et al., 1992) and; (ii) soil disturbance in the seed row 5 to 6 cm below the seed at time of planting (Roget et al., 1996). There are presently no cereal cultivars resistant to Rhizoctonia. In addition, as most broad-leaf crops are susceptible to Rhizoctonia, crop rotation is of little or no benefit (Cook et al., 2002).

For broadleaf crops, fusarium wilt, caused by *Fusarium oxysporum* f. sp. *pisi*, and Aphanomyces root rot, caused by *Aphanomyces euteiches* f. sp. *pisi*, reduce yield of pea (Hagedorn, 1984). Both pathogens survive for long periods as resistant spores in soil. Fusarium wilt resistant cultivars are widely grown, but there are no pea cultivars resistant to Aphanomyces root rot. Residue-borne *Ascochyta* spp. can cause leaf blight of pea, lentil, and chickpea, but most devastating losses have been with chickpea. In the 1980s, Ascochyta blight destroyed chickpea production in northern Idaho and a moratorium was placed on production. In 1993 Ascochyta blight resistant cultivars of chickpea were released and production has returned.

## CONSERVATION CHALLENGES

### Wind Erosion

Wind erosion in many dryland farming regions is a major cause of soil loss and degrades off-site urban air quality by small particulate emissions. Soil particles  $<840\ \mu\text{m}$  (0.84 mm) in diameter are often described as the 'erodible fraction' (Chepil, 1941). Many soils in the western USA have significant quantities of these particle sizes because of their loessial and volcanic origin combined with low organic matter content after more than a century of farming.

Saxton et al. (2000) showed that several soil types in the Columbia Plateau of the inland PNW are dominated by particles  $<75\ \mu\text{m}$  diameter that are readily suspended and transported for long distances during dust storms (suspension erosion). At least 4 cm of loose topsoil in summer-fallowed fields has been lost in single 1-d wind storms in Washington (W.F. Schillinger, personal communication, 2003; R.I. Papendick, personal communication, 1977). There is little opportunity for erosion control once particles become airborne, thus control strategies focus on reducing wind velocity at the soil surface by crop and residue cover or aggregation if moisture and soil structure provide this capability. These soils also contain many small particulates  $<10\ \mu\text{m}$  in diameter (PM-10) that are considered a health concern when inhaled into lung tissue. Communities in California, Arizona, Washington, and elsewhere are developing control strategies for this environmental and health concern in cooperation with regional growers.

In addition to suspension erosion, larger soil particles and aggregates ( $>75\ \mu\text{m}$ ) are eroded by movement at the soil surface (creep) or short duration suspensions (saltation), thus plant material on the surface, soil clods, and rough soil surfaces provide protection as well as particle trapping (Fryrear, 1984; Horning et al., 1998). Best management practices for controlling wind erosion in dryland farming areas have been outlined by Papendick (2004).

### Water Erosion

Water erosion is most severe during winter when residue cover is lacking such as with newly-planted winter wheat after summer fallow or grain legumes. The heaviest erosion is typically on slopes when rapid snowmelt and/or rain occur on thawed soil overlying a subsurface frozen layer (McCool, 1990). In many

areas of the inland PNW and intermountain region soil freezing may occur to depths of 10 cm several times during winter with occasional freezing to 40 cm (Papendick and McCool, 1994). Partial or complete soil thawing frequently occurs between freezing events.

Few dryland crop regions in the western USA have erosion rates  $<4.5 \text{ Mg ha}^{-1}$  and most are  $>9 \text{ Mg ha}^{-1}$  (NRCS, 2000). Annual water erosion rates for conventional till winter wheat–spring barley–summer fallow rotation in the intermediate precipitation zone range from 18 to  $45 \text{ Mg ha}^{-1}$ . In the high-precipitation Palouse Basin in southeast Washington and northern Idaho, water erosion rates with conventional moldboard plow tillage used in past years averaged  $45 \text{ Mg ha}^{-1} \text{ yr}^{-1}$  in a single winter season, but rates above  $60 \text{ Mg ha}^{-1}$  were common and could reach  $450 \text{ Mg ha}^{-1}$  on some steep slopes (USDA, 1978). Presently, more than 40% of Palouse Basin cropland is under conservation tillage and water erosion rates have been reduced by  $7 \text{ Mg ha}^{-1} \text{ yr}^{-1}$  from previous (USDA, 1978) levels. Soil erosion from dry farmed cropland in all regions of the western USA still exceeds tolerable rates (NRCS, 2000). Further adoption of conservation tillage and a continued move toward no-till is needed to reduce soil erosion.

## ECONOMIC CONSIDERATIONS

During the last decade of the 20th century, three primary factors dominated economics of dryland crop production, and wheat in particular, in the western USA. These factors are: (i) robust technical progress, (ii) erratic world grain market prices, and (iii) unwavering income support to growers from the federal government. New technologies such as improved cultivars with greater disease resistance and higher yield potential, more effective and affordable herbicides, a wide range of fertilizers and delivery systems, and marked improvements in reduced- and no-till farming methods have increased grain yields and favored more intensive cropping.

The most obvious consequence of these technological improvements has been a reduction in summer fallow and commensurate increase in cropping intensity in the western states (Smith and Young, 2000). But winter wheat-summer fallow has remained more profitable than more intensive cropping systems in low-precipitation regions (Young et al., 2001). Furthermore, foreign producers have vigorously adopted new technologies and since 1998, with favorable weather, world wheat markets are often glutted. By 1998 to 2001, prices for soft white wheat slumped to historic lows in real terms of U.S.  $\$76 \text{ Mg}^{-1}$  (U.S.  $\$2.50 \text{ bushel}^{-1}$ ). The problem of excess supply was further exacerbated by recession in east Asia where most wheat produced in the western USA is sold.

Growers' loss of income in the market place has been cushioned by government subsidies. Before 1996, the U.S. government relied on crop hectareage restrictions to control production levels, and safety net programs to protect growers' incomes by increased payments to growers when prices were low. In 1996, the 'Freedom to Farm Act' eliminated crop hectareage restrictions and substituted a declining schedule of fixed payments that were to be phased out by 2003. With low prices starting in 1998, the U.S. Congress reversed the declining schedule of

payments by adding large annual supplemental payments. Total payments to wheat and other cereal grain growers reached record levels by 2001. For many growers these payments accounted for more income than grain sales.

In response to low market prices, the 2002 Farm Bill returned to subsidy payments that varied with production levels and were higher when grain prices declined. Over time, most analysts agree that subsidies for grains in the USA and Europe increase surpluses and perpetuate low prices. Farmland prices also increase in areas where subsidies are provided.

### ADVANCES IN DRYLAND FARMING

Potential for economic and environmental benefits is a major driving force in the ongoing gradual shift by dryland growers to adopt reduced- and no-till farming methods. Ironically, economics are probably the main factor limiting rapid adoption of conservation practices. Transition costs and uncertainty about crop yields are often cited as main obstacles to change along with lack of experience by individual growers, limited research for answers when problems occur, and general lack of technical know-how and experts in reduced- and no-till dryland agriculture. However, with the current increase in research, significant advancements in no-till farming technology and large-scale adoption by growers is anticipated in the coming decade. Specific advances for dryland crop production in the western USA since 1980 include:

- Understanding for timely and effective elimination of volunteer cereals and other grass weeds (*green bridge*) to control root disease.
- Continued development and release by university and USDA breeding programs of high-yielding winter and spring cereal cultivars with improved resistance to pests, and with high end-use quality.
- Availability of a wide array of affordable nonselective and in-crop herbicides. Weed control remains a pressing issue. The low profit margin of many crops grown under dryland conditions often does not allow for expensive chemical weed control programs.
- Placement of some of the fertilizer near the seed to improve early growth and grain yield in spring cereals.
- Rapid advances in no-till drill technology for precise placement of seed and fertilizer in one pass through standing residue.
- Finding that minimum tillage fallow can replace conventional intensive fallow to provide improved erosion protection with equal operating costs and without loss of wheat grain yield.
- Introduction of the wide V-blade adjustable-pitch sweep implement to effectively retain residue, clods, and surface roughness for wind erosion control and retain soil moisture during summer fallow.
- Adoption of alternatives to cereals such as canola, mustard, and chickpea to provide rotation and economic diversity in higher precipitation areas.
- Recognition of the need for uniform straw and chaff distribution by combines during cereal harvest to enhance drill performance, efficient growth, and optimum yield of the subsequent crop.

- Understanding that crop yield and fertilizer need vary widely depending on slope position and soil type. Combine yield monitors, GPS, and GIS systems allow the use of variable rate fertilizer application across the field.
- Finding that achievable amounts of crop residue cover (i.e., 25–50% compared with bare soils) on wind-erosion-prone summer fallow can reduce fine particulate (PM-10) concentrations to allowable levels during dust storms.

## NEEDS FOR RESEARCH

Research needs for dryland crop production regions of the western USA include the following:

### Stubble Management

- Develop management methods for handling large quantities of winter wheat stubble in intermediate and high precipitation areas without heavy tillage or burning. This includes low-impact tillage to facilitate planting as well as development of no-till drills that can pass through high residue loads on steep slopes and maintain accurate placement of seed and fertilizer.
- Determine why straw of various wheat cultivars decomposes at different rates, and ultimately breed cultivars with fast and slow decomposing straw for high and low precipitation areas, respectively.

### Cultivar Breeding

- Continue and expand breeding efforts to develop high-yielding crop cultivars that can resist or tolerate fungal diseases which occur across a multitude of dryland environments. This is especially important for winter and spring cereal crops which are dominant in all dryland production regions of the western USA. A rotation crop that could break the *Rhizoctonia* root rot disease cycle in low-disturbance no-till systems would be particularly valuable.
- Develop standard height and tall winter wheat cultivars with the ability to emerge from deep planting depths and low moisture conditions in summer-fallowed soils in low-precipitation areas. Successful early-fall establishment of winter wheat is critical for optimum grain yield and high straw production.
- Continued development of high-yielding spring wheat cultivars, including facultative spring wheat, that have vigorous early growth in cool soils to compete against broadleaf weeds.
- Develop perennial wheat cultivars that can provide an economically viable grain yield for four or more years before replanting is needed. Perennial wheat may be especially useful for shallow, rocky, or other soils of low inherent productivity or soils that are prone to erosion.

- Field testing of new crops for more intensive and diverse crop rotations. This is important in all regions, and especially critical in wheat–summer fallow areas where few suited noncereal crops have yet been identified.

### **Reduced- and No-Till Systems**

- In all cropping regions, develop economically-viable and environment-friendly cropping systems that are adaptable with reduced- and no-till technology.
- Refine low-impact tillage methods to reduce frozen soil water runoff and erosion from planted winter wheat fields.
- Characterize soil changes in quality and productivity associated with long-term no-till management.

### **Weed Control and Ecology**

- Develop herbicides with different modes of action to control annual grass weeds like downy brome, wild oat, and jointed goatgrass in cereal crops and to avoid the development of herbicide resistance in these persistent weed species.
- Conduct weed ecology studies for applying integrated pest management (IPM) concepts and principles for controlling weeds in reduced- and no-till systems.

### **Economics**

- Develop management strategies to minimize economic impacts during the “transition period” changing from conventional farming to no-till, including (i) change in soil and weed ecology, (ii) agronomic factors affecting crop yields, (iii) equipment costs, and (iv) extension of technical information on new farming techniques.
- Up-to-date economic analysis and farm enterprise budgets for new crops and cropping systems.

### **Precision Agriculture**

- Develop and refine precision agriculture technology for variable landscapes to allow for more effective and economical use of fertilizer, herbicide, seed, and other inputs.

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