



# Then and Now: 125 Years of Dryland Wheat Farming in the Inland Pacific Northwest

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## ABSTRACT

This article is a history of dryland wheat (*Triticum aestivum* L.) farming in the low-precipitation (<300 mm annual) region on the Columbia Plateau of the Inland Pacific Northwest (PNW) of the United States. Numerous technological advances, environmental problems, and sociological factors influenced wheat farming since its inception in 1880. The wheat-based economy traces back to the pioneers who faced many challenges that included scarcity of water and wood, unprecedented wind erosion, drought, and minimal equipment. Throughout the years, major technological breakthroughs include: (i) horse (*Equus caballus*) farming to crude crawler tractors to the 350+ horse power tractors of today, (ii) transition from sacked grain to bulk grain handling, (iii) nitrogen fertilizer and herbicides, (iv) the rotary rodweeder, and (v) the deep furrow split-packer drill to allow early planting of winter wheat into stored soil water. Cultural practices have evolved from repeated passes with high-soil-disturbance tillage implements to today's conservation tillage management. The 2-yr winter wheat–summer fallow rotation continues as the dominant cropping system as it is less risky and more profitable than alternative systems tested so far. Improved wheat cultivars for deep furrow planting continue to be developed with good emergence, disease resistance, winter hardiness, grain quality, and other values. In the past 125 yr, average farm size has grown from 65 to 1400 ha and wheat grain yield increased from <1.0 to 3.4 Mg ha<sup>-1</sup>. Since the 1930s, government farm programs have provided unwavering support that, in the last several decades, accounts for about 40% of gross farm income.

The Columbia Plateau comprises 62,000 km<sup>2</sup> with about 60% in dryland crop production. Due to a wide range of precipitation, the Columbia Plateau is commonly divided into three distinct annual precipitation zones: (i) low, <300-mm; (ii) intermediate, 300 to 450 mm; and (iii) high, 450 to 600 mm. An overview of present-day cropping systems, cultural practices, soil fertility, weeds, diseases, economic considerations, farming advances, and research needs for rainfed farming in the PNW and other regions of the western United States is found in Schillinger et al. (2006).

Our focus here is the low-precipitation zone that encompasses 1.56 million cropland hectares in Washington and Oregon that is, by far, the largest contiguous crop production region in the PNW and indeed in the western United States (Fig. 1). We spotlight dryland wheat farming in Adams County, Washington, and Sherman County, Oregon. Agricultural research stations have been in operation at Lind and Moro in each of these counties, respectively, since the early 1900s and much of the research for the low-precipitation zone is still conducted at these sites. There have been many advances in farming

that led to an average increase in dryland wheat grain yield of 28 kg ha<sup>-1</sup> yr<sup>-1</sup> from the late 1920s to today (Fig. 2).

The pioneer wheat farmers who first arrived in the low-precipitation region in 1878 beheld unbroken expanses of bunch grass, mostly bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Love ssp. *spicata*] intermixed with big sagebrush (*Artemisia tridentata* Nutt.). Settlers arrived mostly from the U.S. Great Plains, first in covered wagons along the Oregon Trail and later by train, lured west by the promise made to citizens in the Homestead Act of 1862 of free and clear title to 65 ha (160 acres) of land to every head of family or single person 21 yr or older.

## CLIMATE IN RELATION TO AGRICULTURE

The semiarid Mediterranean-like climate is dominated by prevailing westerly winds and weather fronts from the Pacific Ocean. Winters are cool to cold and moist and summers are warm and dry. Average annual precipitation ranges from 150 mm in the drier south-central parts to 300 mm in the eastern fringes that border the intermediate and high precipitation Palouse region. About two-thirds of the precipitation occurs during October–March with about one-third as snow. One fourth of the annual precipitation occurs during April–June with July through September the driest months (Fig. 3). Rainfall intensities and volumes are low, usually not exceeding 2 to 3 mm h<sup>-1</sup> and 10 to 20 mm per event. Between 60 and 75%

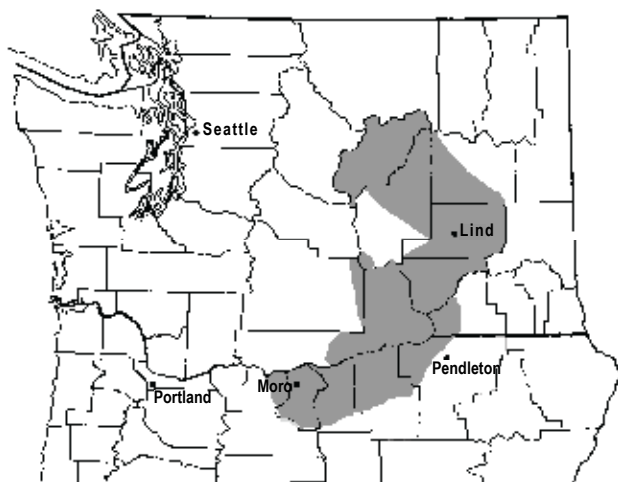
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**Abbreviations:** ARS, Agricultural Research Service; CRP, Conservation Reserve Program; CSP, Conservation Security Program; EQIP, Environmental Quality Incentives Program; HRW, hard red winter wheat; NASS, National Agricultural Statistics Service; OSU, Oregon State University; PNW, Pacific Northwest; SW, spring wheat; SOM, soil organic matter; SWW, soft white winter wheat; USDA, United States Department of Agriculture; WSU, Washington State University; WW-SF, winter wheat–summer fallow.



**Fig. 1.** The low (150- to 300-mm annual) precipitation zone of east-central Washington and north-central Oregon covers 1.56 million cropland hectares and is, by far, the largest contiguous cropping zone in the western United States. The Inland Pacific Northwest intermediate (300- to 450-mm) and high (450- to 600-mm) precipitation cropping zones are mostly to the east of the low-precipitation zone.

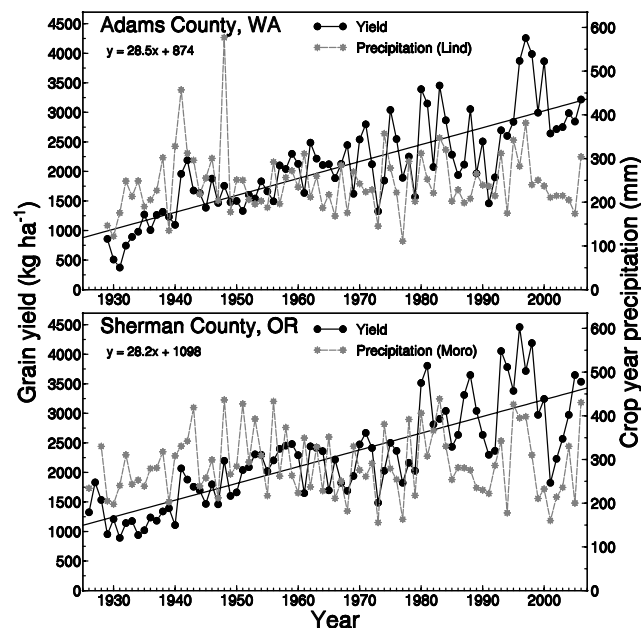
of overwinter precipitation is stored in the soil after crop harvest. These high precipitation storage efficiencies enhance the success of the alternate winter wheat–summer fallow (WW-SF) system that is not duplicated in summer rainfall environments with similar annual precipitation.

Soils freeze to depths of 40 cm or more during prolonged cold weather in the absence of snow cover. However, mild Chinook winds during the winter result in complete thaws several times per season. Average annual precipitation at Lind, WA, is 242 mm and at Moro, OR (300 km southwest of Lind), it is 288 mm (Fig. 3). The frost-free season ranges from 130 to 180 d.

Late-summer or early-fall planted wheat establishes before winter but most growth occurs in March through June. Because of dryness, most vegetation, excluding a few native plants, matures before or is dormant during the summer. Without irrigation, summer is unfit for growing any known commodity crop but is ideal for maturation and grain harvest of cool-season cereals.

Average wind speeds are low throughout the year. However, high winds lasting 24 to 36 h occasionally occur with frontal systems from the west and southwest. These are most common with the change of seasons in the fall and spring, and in the winter. Sustained wind speeds in these systems can approach  $70 \text{ km h}^{-1}$  with gusts up to  $125 \text{ km h}^{-1}$  or higher. These events are the main cause of soil erosion.

Weather records attest to annual and cyclic variations in total precipitation (Fig. 2) but otherwise no clear long-term trends or predictable patterns in the drylands are noted. Notwithstanding variations in total annual precipitation, early researchers and farmers noted that these were less important to wheat yields than effects caused by fluctuations in rainfall from April through June (Sievers and Holtz, 1922). Other workers concurred that high yields of wheat were most often

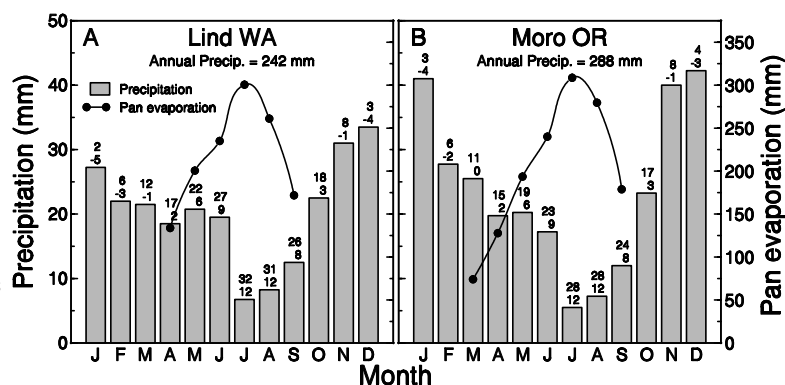


**Fig. 2.** Long-term average county-wide dryland wheat grain yields for Adams County, Washington, and Sherman County, Oregon, superimposed with crop-year precipitation from Lind, WA, and Moro, OR. Data show that grain yield in both counties has increased by an average of  $28 \text{ kg ha}^{-1} \text{ yr}^{-1}$  since reliable county-wide grain yield data became available in the late 1920s. Long-term average precipitation is 242 mm at Lind and 288 at Moro. The average value of wheat produced in the dryland region in Fig. 1 exceeds \$300 million annually. Yield data are from USDA-NASS (2007) and Oregon State University (Sandy Macnab, personal communication, 2006). Precipitation data are from the WSU Dryland Research Station at Lind and the OSU Sherman Station at Moro.

associated with high rainfall during these months (Stephens et al., 1932).

## TOPOGRAPHY AND SOILS

The topography is gently rolling over the entire low-precipitation region that is essentially a plateau of basalt dissected by canyons and coulees carved by a series of cataclysmic glacial outburst floods about 15,000 yr ago. The soils are derived from windblown sediments called *loess* that was deposited during the floods (Busacca, 1991). Elevation is 490 and 550 m above sea level at Lind and Moro, respectively, with some cropland



**Fig. 3.** Mean monthly precipitation (80 yr) and pan evaporation (75 yr) at Lind, WA, and Moro, OR. Numbers above individual bars are mean monthly maximum and minimum air temperature ( $^{\circ}\text{C}$ ).

in Douglas County, Washington, above 850 m. Where average annual precipitation exceeds 230 mm, soils are classified as Mollisols that originally (i.e., before farming) contained 1.5 to 2% soil organic matter (SOM) (Boling et al., 1998). In the drier parts, soils are mostly Aridisols and some Entisols with native SOM  $\leq 1\%$ . Soils are permeable, well drained, and in most areas deep enough to store winter precipitation. Cropland soils range from <1 to >7 m in depth. The productivity of shallow soils is often limited because of low over-winter water storage capacity. Soil textures are uniform to the underlying basalt bedrock and typically are fine sandy loams to silt loams that are highly erodible when exposed to wind. In Oregon, the predominant texture is silt loam but with less sand than in Washington and thus less susceptible to wind erosion.

Limited data from Oregon locations show that soils lost about 25% of their native SOM within the first 30 yr after the onset of farming, both in the surface and subsoil at sites in Umatilla and Morrow counties (Bradley, 1910). The SOM content in the virgin surface was approximately 2.5% and in the subsoil 1.7% at a depth of 45 cm. At Pendleton, with an average annual precipitation of 432 mm, the decline in SOM was 30% in 50 yr and 50% in 114 yr (Rasmussen et al., 1989; Albrecht et al., 2003). Soil organic matter decreased 7.2% from an initial content of 1.7% in the upper 30 cm of soil over 10 yr (1932–1942) in a WW-SF experiment at Moro, OR, with all residue plowed under (Horner et al., 1960). Similarly at Lind, WA, SOM decreased 8.2% in the tillage layer of a WW-SF rotation during 18 yr from 1922 to 1940, whereas SOM increased 4 to 13% with 0.9 to 3.6 Mg ha<sup>-1</sup> of supplemental straw added each crop year (Smith, 1941).

A long-term no-till continuous annual cropping experiment near Ritzville, WA (300 mm average annual precipitation), showed that SOM increased in the 0- to 5-cm depth after 8 yr to approach that in native soil for the area (Schillinger et al., 2007). Crop rotations, whether they were entirely annual wheat or contained spring barley (*Hordeum vulgare* L.) or oil-seed combinations were equally effective in increasing SOM in all no-till rotations over time. Soil organic matter content at the 5- to 10-cm depth changed little during the experiment and remained near the native levels. The native SOM content was established from soil in nearby cemeteries that were never farmed. The relatively rapid response of the surface soil in accumulating SOM with no-till is noteworthy and not in line with most thinking that soil quality parameters are slow to respond to management changes in very dry climates. There is also somewhat of a parallel of these results with the study at Lind, WA, by Smith (1941), showing that relatively small quantities of supplemental straw (in addition to that produced by the wheat crop) applied to a low SOM (1%) soil in a WW-SF rotation increased its SOM content in a few years.

## WIND EROSION

Wind erosion and blowing dust are major environmental and

resource concerns that affected much of the low precipitation zone since farming began. Consequences are loss of topsoil and government regulation of PM<sub>10</sub> or less size<sup>1</sup> particulates as airborne pollutants and a human health hazard. Dry topsoils with their balance of silt, fine sand, and PM<sub>10</sub> contents are highly susceptible to drifting if loosened and exposed to high winds, and fine particulates can be carried hundreds of kilometers by suspension. The cost of dust storms that may occur several times a year in parts of the region is incalculable but translates to loss of farm productivity, impaired human health, vehicle accidents, closed roads and highways, damage to equipment, and cleanup expenses. Absence of surface scouring and minimal soil deposition in road ditches or other obstacles strongly indicates that suspension (not saltation and creep) is the dominant wind erosion mechanism for many soils on the Columbia Plateau (Kjelgaard et al., 2004; Sharratt et al., 2007). In a practical sense, this means that farmers are not “trading soil” with their neighbors, but rather suspended soil particulates are transported long distances with the wind—an irreplaceable loss. Wind events with speeds above the threshold value<sup>2</sup> for wind erosion are highest in the spring followed by winter and fall and lowest in the summer (Papendick, 1998). Wind erosion hazard is low during winter because surface soils are usually wet. Erosion is most severe in the late spring and late summer during tillage and planting when soils are dry and have limited cover.

Anecdotal accounts by early travelers passing through the sage and short grass areas in the dry season of pre-farming times tell of encountering “dustiness, suffocating dryness, and thirst” conditions (Meinig, 1968). However, the few instances mentioned do not seem to indicate a likeness to major dust storms that are often referred to after farming began. It is likely that the native cover, though scant, was adequate to protect the soil from severe blowing as recorded in later times. There are replete accounts in local newspapers and elsewhere of massive dust storms such as: “in 1906 a dust storm blew for 3 days with 15 cm of soil lost”; “in 1913 land began to blow from drought and many people left Cunningham (Washington, southeast of Lind)”; in 1903 “dust storms were frequent from horses pulverizing the land”; and “during dust storms it would get dark in the daytime, chickens would go to roost” (quotes from *History of Adams County Washington*, Adams County Historical Society, 1986a).

A lake core study conducted by Washington State University (WSU) scientists provides evidence that fallow–grain agriculture on the Columbia Plateau increased the aerial flux of sediments by at least fourfold beginning with farming in the 1880s (Busacca et al., 1998). Moreover, the study indicated that the atmospheric concentrations of PM<sub>10</sub> were considerably higher in agricultural times than before.

Wind erosion continues to be a menace in the low precipitation zone; however, soil loss rates are not well documented. The authors in recent years have observed fallow fields that lost 4 cm of loose topsoil in 1-d storms and up to 10 cm in a single season. The junior author recalls a farmer in south-central Washington having to replant his winter wheat three times after repeated blowouts. These observations are well within the realm of those for major storms in earlier times.

We estimate that, using a conservative bulk density value 0.5 Mg m<sup>-3</sup> for the surface layer of tilled summer fallow, the loss

<sup>1</sup> PM<sub>10</sub> refers to particles that are 10 microns in diameter (about one-seventh the diameter of a human hair) but the designation includes all particles this size and smaller.

<sup>2</sup> A wind event is defined as any period when the hourly wind speed at a height of 10 m exceeds 29 km h<sup>-1</sup> for 3 h or more where a 1-h period below threshold is allowed followed by at least 2 h above threshold.

of 4 cm of soil equates to 180 Mg ha<sup>-1</sup> of soil lost in these individual 1-d wind storms. Although conclusive data are lacking, we suspect that recurrent loss of suspended soil during wind storms, along with well-documented biological oxidation with intensive tillage (Rasmussen et al., 1989; Albrecht et al., 2003), is the major reason why SOM has declined so dramatically in the region since the onset of farming 125 yr ago.

The erosion/air quality problem is now receiving considerable research attention. In 1992 the USDA's Agricultural Research Service (ARS) and WSU initiated the Northwest Columbia Plateau PM<sub>10</sub> Project to research the mechanics of wind erosion and PM<sub>10</sub> emissions, and develop control measures adaptable for the plateau's farmlands and cropping systems (Papendick, 1998, 2004). Prediction methods are being developed to quantify topsoil loss and effects on downwind air quality in relation to causative factors such as wind and water characteristics, soil type, and land management. This research is in hand with the design of control measures to stabilize the soil surface and maximize cover for resisting soil erosion and particulate emissions.

## A WHEAT-BASED ECONOMY

Early on, wheat became established as the pioneer crop throughout the nonirrigated Inland PNW when it became evident that it could be grown profitably over a range of climatic and soil conditions. The first market for farmers and stockmen in the 1860s and early 1870s was meeting the food and feed needs of a sizable population of miners and military personnel in the area. Wheat, barley, oat (*Avena sativa* L.), and hay helped to meet these basic necessities. With the slowdown of mining in the mid 1870s, new opportunities for the expansion of the wheat industry were sought and began to emerge in the form of an unlimited downriver (Columbia River) export market (Meinig, 1968). After major problems of grain handling infrastructure and costs of shipment to Portland ports were solved, a new wheat-based economy began to solidify and the farming boom of the 1880s gained momentum. Another factor that spurred the PNW wheat export economy was its isolation from the Midwest wheat markets where competition would have been overwhelming. By the late 1890s, the Inland PNW had replaced California as the most important wheat-producing area of the far west (McGregor, 1982). The crop was valued because it was widely adapted and readily marketable and transportable, its worth was high in relation to its bulk and its price was subject to less fluctuation than other cereals (Stephens et al., 1932). The wheat-based agriculture has been profitable and persisted for 125 yr and today represents more than a \$300 million annual wheat export industry in the region.

## THE EARLIEST YEARS

### Settling the Low Precipitation Areas

Some of the first farmers came to the Inland PNW in the late 1860s and early 1870s by wagon on the Oregon Trail to Walla Walla, WA, first converting grasslands to crops in the intermediate and high precipitation areas with proximity to forests and perennial waterways. These lay mostly in the Palouse region located in southeast Washington, northern Idaho, and some in northeast Oregon (Meinig, 1968). By the late 1870s, most of the best land had been claimed and the farming frontier was

pushed into the drier untested areas. The pace of settlement into the interior was slowed because of doubts and uncertainties about survival under semiarid conditions along with the scarcity of water, and wood for shelters, fencing, and fuel. There were no trees in this dry country except sometimes along creek beds. In 1878, a small group of immigrants were induced by Philip Ritz, a nurseryman, to settle near Ritzville, WA (300 mm average annual precipitation). After losing their first wheat planting to ground squirrels (genus *Spermophilus*), a second crop in 1880 yielded well (Meinig, 1968). This and other positive experiences helped convince land seekers that the presence of short bunch wheatgrass native to the driest areas indicated land fit for wheat production and helped to stimulate rapid expansion of grain farming in the low precipitation region previously considered as nonarable (McGregor, 1982). Settlers initially lived in their covered wagons and tents and then in dugouts in the side of hills boxed out with rough lumber. Barns were usually the first permanent shelters built because taking care of horses was a top priority.

As railroads were completed in the early 1880s, regular travel service was offered by the Northern Pacific railroad from Portland, OR, to the east with tracks branching from the main lines passing through sections of the low precipitation areas. The influx of settlers into the low precipitation areas accelerated in 1884 when the service was supplemented by daily "immigrant" trains that replaced wagon trains by transporting not only the pioneers but also their household goods, farm machinery, and livestock at low fare (Meinig, 1968). Accounts during settlement tell of pioneers arriving from the east by train with one or two horses or oxen, a walking plow, harrow, rake, and so forth along with household essentials. Others with little or no capital worked full or part-time for settled homesteaders on threshing crews, clearing land of sagebrush, and doing other manual labor to acquire essentials to begin farming on their own.

The public domain in Oregon also remained largely free range in the 1870s dominated by stockmen who raised large herds of cattle (*Bos taurus*) for sale to the region's mining industry. In the early 1880s experimentation with wheat in a number of localities indicated good success and a rapid land takeover by farmers began that enveloped much of the arable lands in a few years. The Homestead Act favored wheat farming because allocations of public land in the low precipitation areas were too small for profitable cattle operations but not for grain production. Wheat farming also brought barbed wire fences that were a major obstruction to cattle spreads and movement of herds to sales destinations. By 1890, the open-range cattle era was virtually extinct (Meinig, 1968). The sheep industry survived and coexisted in proximity with grain agriculture because animals could graze and be wintered in pockets of marginal lands (e.g., scablands, dissected areas, and foothills) where wheat farming or cattle ranching was impossible or unprofitable (Meinig, 1968).

### Settler Ancestry

Most of the first pioneers in the drylands were from the midwestern states and only a relatively small number were foreign born. Of these, most had first settled in the Midwest and came to the PNW as individuals or families but not as groups (Meinig, 1968). This contrasts with the settlers in the frontiers



**Fig. 4.** An early stationary grain thresher powered by 12 horses. Note the conveyor system at the back of the thresher for elevating straw to the top of the pile. Steam engines had almost completely replaced horses to power threshing machines by the turn of the century. Photo from Brumfield (1968).

of the Central and Northern Plains of the United States, where 40 to 50% were foreign born and often formed ethnic groups in localized areas.

One exception to the majority of settlers in the Inland PNW were Volga Germans, often referred to as German Russians, whose first group of more than 100 people in 32 wagons came west from Nebraska and settled near Ritzville in Adams County, Washington, in 1883 (Koch, 1977). They, and several subsequent groups, were descendants of Germans who accepted inducements in the 1760s from the Russian government to settle on undeveloped land along the lower Volga River and north shore of the Black Sea in Russia. When these promises and privileges were rescinded 100 yr later, many left to avoid losing their German traditions and escape mandatory Russian military service. They were a hardy group of people with strong wheat production backgrounds who quickly developed roots in the PNW.

### Land Acquisition

Land in the public domain could be acquired by homesteads, preemptions, or timber cultures (McGregor, 1982). Homesteads were limited to 65 ha per adult. Achieving ownership consisted of filing a claim, and “proving up the land” for a minimum of 5 yr (3 yr for Civil War veterans), and payment of a \$15 filing fee. “Proving up” required building a minimum shelter, living on the property for a specified period, and cultivating and raising crops on at least a part of the land each year. An alternative under the preemption law was to reside 6 mo, make certain improvements, and pay \$3.09 ha<sup>-1</sup> for the land. An additional 65 ha could be acquired under the Timber Culture Act by planting and maintaining 4 ha of trees on the claim for 10 yr. Land could also be purchased from sections granted to the Northern Pacific Railroad for \$6 to \$15 ha<sup>-1</sup> with liberal credit terms (McGregor, 1982).

### Getting Started

Native vegetation was a mix of sagebrush and short bunch wheatgrass. In some ways the “short” was a misnomer because of early settler accounts stating that bunch grass stood as high as a horse’s belly. Sagebrush was as tall as a man on horseback on some of the deepest soils, that is, soils most ideal for wheat farming. It often took settlers several years to prepare the entire homestead for cultivation. In some areas, exposed rocks had to be removed. Clearing was a slow, laborious process and was done piecemeal in the winter after the farming was completed.

Sagebrush was removed by dragging large railroad timbers or rails with horses to uproot the woody plants, or by grubbing with an axe or hoe. Large sagebrush was cut for fuel, something that was in short supply in the early years. Smaller pieces along with other materials were piled and burned. Pioneers noted the delectable flavor acquired by using sage wood to smoke pork as part of the meat curing and preservation process.

Supplying water for domestic use was a monumental task for most homesteaders. Water had to be hauled in barrels by wagon from springs or hand-dug wells often 10 to 20 km from the home site. Water was beyond reach of hand-dug wells and not accessible on the farm site until power drills became available that could penetrate 40 to 100 m through the underlying basalt rock. Another laborious and time-consuming task was fencing the homestead to confine the farmer’s livestock and maintain field boundaries. Barbed wire, invented in 1874, was a major advancement in this regard and though it was expensive, it was much more effective for containing livestock than the smooth wire it replaced.

After the land was cleared of sagebrush it was plowed (much of it for the first time with a one-bottom walking plow), hand seeded, and then raked or harrowed to cover the grain. Many farmers did not yet have access to equipment and tools available in the Midwest. The walking plow was eventually replaced by moldboard plows with multiple gangs pulled by 8 or 12 horses. During the 1880s, farmers planted wheat in the spring on an annual basis. Not until about 1890 did farmers have access to true winter wheat cultivars that could be planted in the fall and survive through winter (see wheat cultivar development section). The first crops were often damaged or destroyed by rodents until controls, natural or man-made, evolved. Pioneer accounts tell of cradle scything or mowing and gathering the first crops into stacks for threshing with a hired machine powered by horses (Fig. 4). In one early account, the first wheat crop was harvested by pulling up the stalks and stored in a shed until winter when the grain was rubbed out of the straw by hand for the next year’s seed (Adams County Historical Society, 1986a). However, throughout most of the 1880s and onward, farmers harvested wheat with a header pushed by horses that unloaded unthreshed grain into a header wagon (Fig. 5a) that was then transported to a stationary thresher powered by a steam engine (Fig. 5b).

In some areas of Oregon and Washington, land was claimed for homesteading in a matter of several years. In other areas, especially in the 1890s and later, because of isolation and quality, acquisition was patchy and more gradual. By 1908 homesteading was over and land could be obtained only by purchase, lease, or inheritance. The reality of farm economics by then made clear that most operations could not survive on the original 65-ha homestead at production levels of the low precipitation zone. Other hazards such as extreme cold, severe winds, dust storms, hail, and late frost added to the instability of farming. Many farms with financial resources and sound management grew in size as owners acquired land from others who quit farming during down turns in the economy or for personal reasons. By 1910, the average farm size in the drier areas was about 260 ha (Meinig, 1968). Most farmers today in the drylands are descendants of the original settlers.

## WHEAT FARMING IN THE EARLY 1900s

To ensure progress and stability, the first settlers had much to learn about farming in the semiarid PNW where the climate was considerably different than anywhere else in the United States and most places in the world. For some, it was regarded as a mix between the dry season of California and the cold winters of the Midwest. Farmers with Midwest background found it most difficult to adjust to the long summer dry season. There was a minimal knowledge base of information, and thus they had to innovate on their own and rely on trial and error and experimentation to adapt practices imported from other areas to the soils and climatic conditions of the new lands. Considerable machinery technology was available in the United States at the time of first settlements in the 1880s that could be adapted to wheat farming but most manufacturing was in the east and capital was not readily available to import equipment on a large scale to the PNW. However, improved economic conditions at the turn of the century accelerated wheat farming and by the early 1900s railroads were bringing in an array of the latest farm equipment including gang plows (Fig. 6), four-horse spike-tooth harrows (Fig. 7), stationary threshers, steam engines, rodweeder (stationary bar type, Fig. 8), drills (Fig. 9), wagons, and combines (Fig. 12a).

Advocacy by leading dryland farmers and opinion leaders fostered public support for establishing three experiment stations prominent in conducting some of the first and subsequent agricultural research in the dryland areas. The Sherman County Branch Experiment Station at Moro, OR, was established in 1910 under the administration of Oregon Agricultural College to conduct research on crop improvement, crop rotations, cultivar development, and tillage for the WW-SF system. Similarly, the Adams County Branch Experiment Station near Lind, WA, was established in 1915 under the administration of State College of Washington to conduct research on summer fallow agriculture. The Pendleton Field Experiment Station near Pendleton, OR, was established in 1928 under Oregon Agricultural College to develop farming systems east of the Cascade Mountains that would sustain soil fertility, reduce soil erosion, and increase farm profit. All three continue to operate today conducting research on dryland agriculture in their respective geographic areas.

## CULTURAL PRACTICES

### Primary Fallow Tillage

Summer fallow was recommended in the late 1880s to improve and stabilize wheat yields, and by the early 1890s it was widely adopted by farmers in the low precipitation areas to reduce crop loss from drought (Meinig, 1968). Tillage research for winter wheat production in the Great Basin at Nephi, UT, initiated in 1904 was fallow-based with indirect reference that it was the “ordinary practice” (Farrell, 1910; Cardon, 1915). Similarly, the first published tillage research on wheat production in Oregon (1913) and Washington (1916) is based on alternate years of crop and clean fallow, mentioned as a “practice of necessity” (Stephens et al., 1932). No doubt the idea followed from the Great Plains where the practice was standard in low precipitation areas. In time it was known to offset yield decline after a few years of farming by accelerating the release of

N from SOM. However, in the development of fallow culture in the Inland PNW, many variations of tillage and stubble management were advocated and practiced by farmers because of differences with conditions in the Great Plains.

For the first several decades, most fallow tillage was moldboard plow-based (Fig. 6). A quote from Stephens et al. (1923) with reference to fallow tillage states, “Of all tillage operations plowing is considered the most important and necessary. Very little experimental work has been done in attempting to find out whether any other cultural operation, such as disking, will take the place of plowing. For very light soils, a disking sufficiently thorough to keep the ground free from weeds occasionally may take the place of plowing, but no implement yet invented is as valuable as the plow for killing weeds and preparing an ideal seed bed.”

Nine years later the same authors summarized options used by farmers to include: “(i) disk the stubble in the fall, (ii) burn the stubble in the fall or spring, (iii) plow the land in the fall, (iv) leave the stubble standing in the winter and disk the land in the spring, and (v) leave the land uncultivated until it is plowed in the spring” (Stephens et al., 1932). All of these practices were used by farmers in some form, but most left stubble standing over winter and plowed their fallow in the spring.

Research in Oregon and Washington showed fall tillage was detrimental to overwinter water storage because it limited water penetration during the period of maximum precipitation (McCall and Wanser, 1924; Stephens et al., 1932). Yields of winter wheat were consistently highest with early spring plowing. The explanation was that early tillage slowed water loss from evaporation and transpiration by weeds and volunteer growth (Stephens and Hill, 1917). It was also claimed the tillage mulch benefited water retention during the summer by slowing evaporation through the dry, loose surface soil from the deeper layers (McCall and Wanser, 1924; McCall, 1925). The slowness with which animal-powered farming operations were conducted meant that much of the land had a heavy growth of volunteer wheat and weeds before they could be plowed under. Thus, as later research would show, the effects of timing of spring primary tillage on soil water retention was directly related to weed control rather than other factors.

Downy brome (*Bromus tectorum* L.), a winter annual whose growth habit mimics that of winter wheat, is the most problematic grass weed for WW-SF farming due to high frequency of winter wheat. The first report of downy brome (brought in by the railroad) appeared in 1908 in Adams County, Washington, although this weed is not mentioned in the early research publications. Deep burial of seed and young plants with moldboard plowing in the spring likely kept downy brome under control before the advent of conservation tillage practices in later years.

To reduce wind erosion from susceptible soils, the tandem disk, harrow, and sweep cultivator were considered as alternatives to plowing under extreme dryland conditions. An economical advantage of these substitutes was a lower energy requirement, but that was offset by the requirement for additional weeding because weed seeds are not buried deep as with moldboard plowing.

Tillage affected levels of  $\text{NO}_3\text{-N}$  in the soil. Accumulation was greatest with early spring plowing when water contents were highest after winter, and 10 to 15% less with intermediate dates

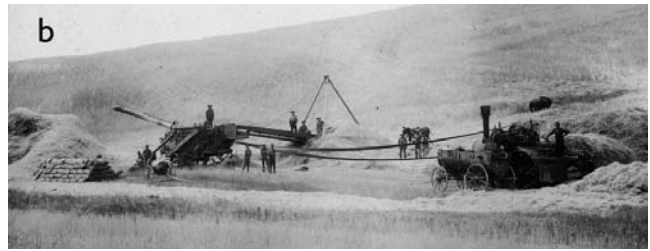


Fig. 5. (a) Cutting and loading wheat in the field with a header into a header wagon for transport to a threshing site. The header is equipped with a reel that lays the wheat stalks across a reciprocating sickle bar for cutting standing grain and onto a canvas platform for elevating into the wagon. It is ground driven, cuts a swath 3.5 to 6 m wide, and is pushed from the rear by six horses. Photo courtesy Terry Olson family, Ritzville, WA. (b) Stationary threshing. The wheat spikes and straw on the header wagon lay on a rope netting that holds the load together as it is lifted off by the derrick with a rope and pulley and dropped beside the thresher. From there it is hand pitched into the thresher that separates the grain from straw with grain fed into sacks and the straw blown into a pile. The thresher is belt powered by a steam engine that burns wheat straw. This mode of harvesting required up to 30 men to operate and was common during the last decades of the 1800s and was replaced by the combine in the early 1900s. Photo from Northwest Museum of Arts and Culture, Spokane, WA, L83-113.48.



Fig. 6. Thirty horses pull a 9-bottom moldboard plow near Lone, OR, in March 1924. This team was able to plow about  $10 \text{ ha d}^{-1}$ . Note the lack of crop residue even before the soil is plowed. Photo from Brumfield (1968).



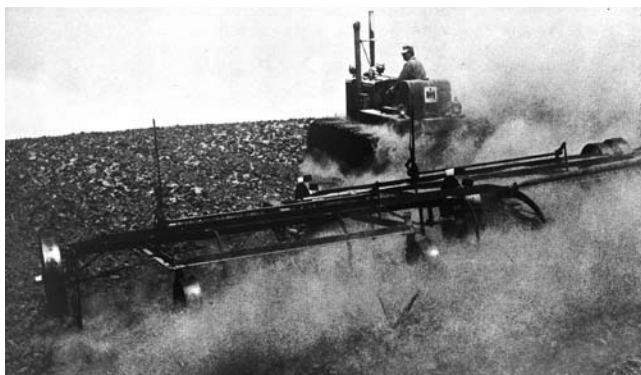
Fig. 8. A stationary (i.e., nonrotating) rodweeder that had two rods spaced 1 m apart. By walking forward on the plank, the driver tilted the front rod down underneath the soil as seen here. When the front rod became plugged with weeds or residue, the driver stepped to the end of the plank to bury the second rod and raise and clear the first rod. The driver needed to tilt the rodweeder back and forth several hundred times during the day. Plugging during rodweeding was eliminated with the introduction of the rotating rodweeder in 1907 (see Fig. 10). Photo from Brumfield (1968).



Fig. 7. The spike-tooth harrow was commonly used to control weeds in summer fallow before the advent of the rotating rodweeder (see Fig. 10). Most early farmers thought it was necessary to pulverize the surface soil to maintain soil water during summer fallow. Those who pulverized the surface soil were considered good farmers. The combination of primary spring tillage with a moldboard plow followed by repeated harrowing operations to create a soil surface devoid of residue, clods, and roughness led to massive and recurrent wind erosion. Photo from Adams County Historical Society (1986b).



Fig. 9. An early model hoe grain drill with rows spaced 20 cm apart. Seed was dropped through rotating flutes in the seed box down tubes behind the openers to the soil surface. Chains were attached behind each tube to lightly cover the seed with soil. Photo from Brumfield (1968).



**Fig. 10.** The rotary rodweeder is an essential implement used to control Russian thistle and other weeds in summer fallow. Typically, two or three rodweeding operations are required from May through August. The rodweeder is ground-powered and has a 2-cm square rod that rotates opposite the direction of travel at a depth of 7 to 10 cm with little disturbance to surface residue. A 30-horsepower International TD 9 crawler tractor pulls 10 m of rodweeder in this 1965 photo. Photo from Washington Association of Wheat Growers, Ritzville, WA.

and with fall instead of spring plowing (McCall and Wanser, 1924). Disking was less efficient than plowing in promoting nitrification. These researchers showed there was a strong correlation between soil water and accumulated  $\text{NO}_3\text{-N}$  with the yield of straw and grain but that soil water was the dominant factor. A combination of high  $\text{NO}_3\text{-N}$  levels and low soil water could reduce grain yields. Thus, if water content was low at the beginning of fallow, farmers were advised to delay the time of spring plowing for a month or so to reduce  $\text{NO}_3\text{-N}$  accumulation.

### Secondary Tillage

The main purpose of secondary tillage during fallow was to control spring and summer weeds; however, the retentive effects of the tillage mulch in saving water were recognized (McCall and Holtz, 1921). Since its introduction to the area in the early 1900s, Russian thistle (*Salsola iberica*) has been the most troublesome broadleaf weed in the low-precipitation region. Russian thistle seed germinates and emerges during the spring and summer in repeated flushes after rainfall events of 10 mm or more and quickly sends a taproot deep into the soil profile (Pan et al., 2001). Repeated harrowing (Fig. 7) (and in later years rodweeding) operations were required to control Russian thistle in summer fallow. Hand weeding with a hoe was also common. Many farmers harrowed fields immediately after early plowing in the spring to smooth and firm the soil and create a dust mulch. However, not all farmers in the driest areas followed this practice for different reasons, but mostly because it increased wind erosion (McCall and Holtz, 1921). The experiment stations recommended limiting cultivation to that essential for weed control because each pass further pulverized the soil and increased the hazard of wind erosion.

Russian thistle produces seed soon after wheat harvest, but farmers were inclined to not disk or plow stubble for weed control in the fall because fall tillage was shown to inhibit absorption of winter precipitation and be of less benefit than spring plowing to the yield of the next crop. Mature Russian thistle plants break loose at the soil surface and travel several kilome-

ters with the wind, scattering seed as they tumble through fields. A comprehensive review of weeds in dryland wheat farming in the PNW is provided by Appleby and Morrow (1990).

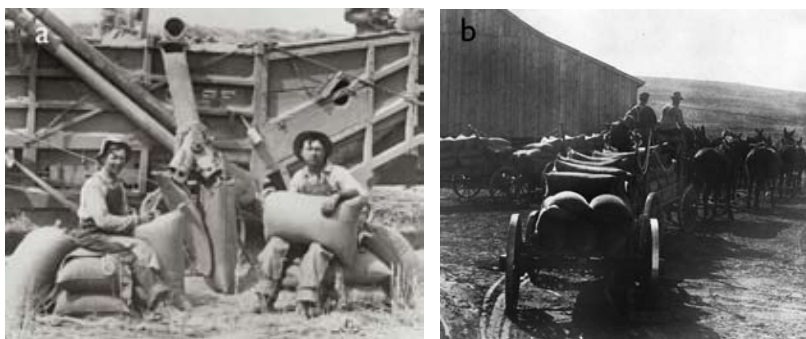
The rotary rodweeder (Fig. 10), invented in 1907 at Cheney, WA, became a popular and essential implement for controlling weeds in summer fallow and was much more effective than the spike-tooth harrow (Fig. 7) or the nonrotating rodweeder (Fig. 8). The implement is equipped with a horizontal square steel rod that rotates opposite to the direction of the travel as it undercuts the soil at an adjusted depth to uproot plants. The rotary rodweeder eliminated a plugging problem associated with an older version that used a stationary rod. It is used extensively on every WW-SF farm in the Inland PNW today and has been exported to other dryland areas in the western United States and the world.

### Planting

Winter wheat was planted into dry soil or after the first substantial fall rain that generally occurred after mid-October. Germination always resulted from autumn precipitation, not from residual water stored in the soil. Farmers generally planted winter wheat 4 to 8 cm deep. Shallow depths gave the best stands if planting was late in the season when soils were cold (Stephens et al., 1923). Yields were markedly decreased from planting after mid-November because low temperatures extended the emergence time to a month or more and sometimes until early spring. However, there was no advantage and some risk with planting too early unless enough rain occurred to ensure rapid germination and sustain growth after sprouting until the next event. The average and most profitable planting rate was between 65 and 85  $\text{kg ha}^{-1}$ . Farmers favored thick stands of wheat for suppressing weed growth and planting rates were sometimes increased for that purpose. Planting rate studies at the experiment stations showed slight increases in yields of winter wheat planted in rows spaced 18 cm apart compared with rows spaced 36 cm or more apart. Mention was made that wheat planted more densely in the row emerged more quickly and grew more rapidly than when thinly planted in wider rows (Stephens et al., 1923). The authors also state that maximum yields could not be produced by spacing rows as widely as 36 cm apart.

Yields from spring wheat were highest from the earliest dates at which planting could be done, this usually being late February through March (Stephens et al., 1932). Seeding rates averaging 50 to 85  $\text{kg ha}^{-1}$  gave the best yields and there was little or no benefit from higher rates (Stephens et al., 1932). The planting rate appeared to be less of a factor in determining yields as long as stands were heavy enough to compete with weeds.

Furrow drills (Fig. 9) were recommended for planting wheat in the Great Plains in the 1920s or earlier with advantages claimed for fast emergence and protection from winter kill. Experiments at Moro, OR, in the late 1920s showed that yields of winter wheat planted with a double disk drill at 15-cm row spacing were equal to those planted with a furrow drill at 30-cm spacing.



**Fig. 11. (a)** Sacking wheat off the stationary thresh-er in 1909. Each sack was sewn by hand, which required skill and effort to keep pace with thresh-ing. A sack of wheat averaged 55 kg and each had to be stacked, loaded, unloaded, and stacked again manually during transport to the warehouse for export. Sacking was standard until the 1930s when it shifted to bulk handling. Photo from North-west Museum of Arts and Culture, Spokane, WA, L86-48.62. **(b)** Beginning the haul of sacked wheat from the farmstead to the railhead with two wag-ons in tandem drawn by eight mules. Wagon beds were 5 m long and could carry up to 60 sacks, but 40 sack loads were more common. Hauling wheat was a major chore after harvest and for some it took several months or until Christmas. For many farmers the distance to the warehouse required several days for a round trip. Photo from Sherman County Historical Society, Moro, OR.

## Harvesting

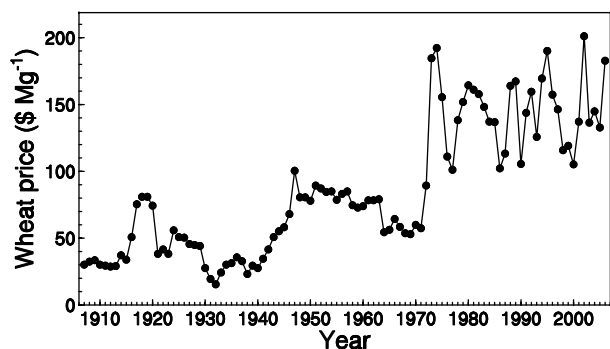
Wheat harvest at the turn of the century was labor intensive and expensive, requiring a crew upward of 30 men at a harvest site. A first step was gathering the wheat stalks with a “header,” a machine equipped with reels and a reciprocating sickle that clipped and placed the stalks onto a moving canvas platform and elevator for loading into a header wagon (Fig. 5a). The machine was ground-driven, some 3 or 4 m wide, and pushed by a team of six to eight horses. From there the wagons transported the material to a central site where it was stacked in a pile for threshing by a stationary machine powered by a steam engine that burned wheat straw (Fig. 5b). The threshed grain was fed into sacks that were sewn shut by hand and stacked on the ground (Fig. 11a). Most commonly, each sack held 55 kg of grain. Two men could sew and stack 800 sacks in a long day (French, 1958). The straw was blown or elevated into a pile by the threshing machine. The threshing operation was custom hired because individual farmers could not afford their own threshing machine and steam engine. High numbers of trans-ient labor were needed for harvest.

Farmers hauled the sacked grain for sale in flat bottom wag-ons on dirt roads to railheads (Fig. 11b). This was often a 2-mo chore with horses and sometimes took from the end of harvest until Christmas. Distance for some farmers was 50 km, requir-ing a round trip on dusty roads of several days or more. The introduction of the gasoline-powered truck in the early 1920s was a great improvement over animal power for transporting wheat. For example, in one account it required a 1-d round trip to transport 70 sacks to Lind, WA, with two wagons in tandem drawn by eight mules. In the same time period, a Ford Model T truck made six trips each carrying 25 sacks for a total of 150 sacks.

Horse-pulled and ground-driven combines first appeared in 1898 (Fig. 12a) and began replacing stationary threshers in earnest about 1910. These machines were drawn by 27 to 34 horses and cut a swath of 3.5 m or more. The harvest crew was reduced to seven or less men with three or four to operate the combine and two or three to manage the horses. Harvest with the com-bine usually lasted 4 to 6 wk but sometimes it was not com-pleted before snowfall after which fields were often abandoned.



**Fig. 12. (a)** The ground-driven, horse-drawn combine replaced the station-ary thresher (see Fig. 5b) in earnest about 1910. The larger machines with 6-m headers required a four- to six-man crew and 27 to 34 horses or mules. Straw was spread on the ground and grain was sacked and piled into small stacks of four or five sacks in the field before hauling to ware-houses. Photo from Brumfield (1968). **(b)** Gasoline engines began to replace the ground-drive combine in the late teens that reduced manpower re-quirements and horses by about one-third. Photo from Northwest Museum of Arts and Culture, Spokane, WA, L93-62.10.



**Fig. 13.** Average October price for soft white common wheat in Portland, OR, from 1907 to 2006. The cost of shipping wheat to Portland is deducted from the price farmers received for their wheat. In 2007, farmers paid \$13.60 and \$9.37  $\text{Mg}^{-1}$  in Adams County, Washington, and Sherman County, Oregon, respectively, to transport their wheat to Portland (multiply by 0.027 to get the cost per bushel of wheat). Data are from USDA-NASS (2007), compiled by Sandy Macnab, Oregon State University Extension, Moro, OR.

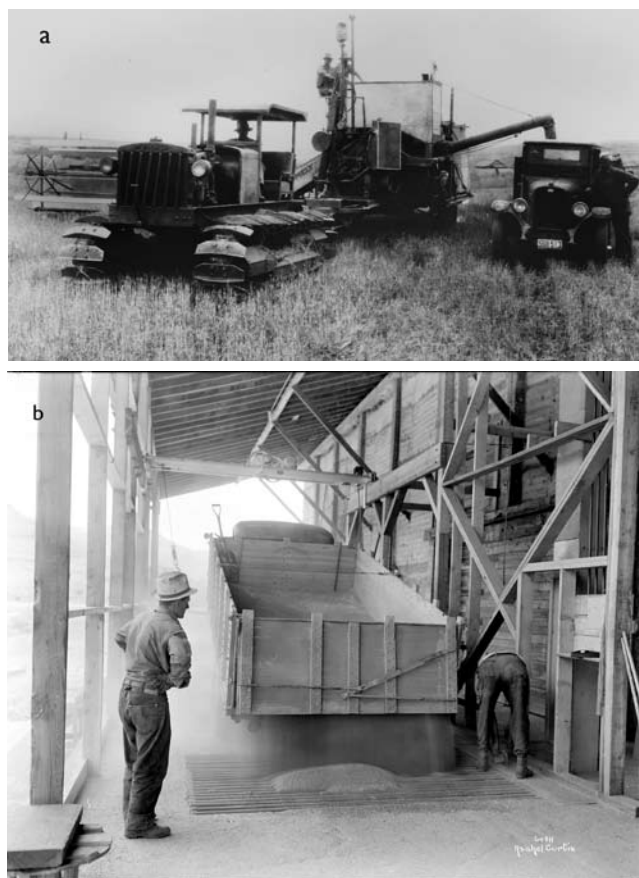
A small 2.4 m wide swath combine designed especially for use on steep slopes was manufactured from 1906–1918 by Idaho National Harvester Co. in Moscow, ID (Keith, 1976). The machine was pushed by eight horses and took only a driver and a sack sewer to operate. Several of these small combines were sold to farmers in the Palouse region and elsewhere, but there is no evidence that this machine was used in the dry WW-SF region.

A major advancement starting in the early teens with the advent of the automobile was the gasoline engine to power the combine except for pulling (Fig. 12b). This reduced the need for horses by about one-third. In a few years the horse-drawn, motorized-combine became the dominant method of harvest and by the early 1920s stationary harvesting was virtually obsolete.

## FARMING IN THE 1930s AND BEYOND: A TIME OF TRANSITION

### The 1930s and World War II Years

Like the rest of the United States, the depression years of the early 1930s wreaked havoc on production and farm economics. Crop yields (Fig. 2) and grain prices (Fig. 13) were low and there was much unemployment. Nevertheless, advances in wheat farming continued to occur with positive effects on production and quality of life in rural areas. Gasoline and diesel powered tractors replaced horses in earnest in the 1930s. Steel wheel tractors came first but heavier-duty crawler types by Caterpillar and International were not far behind (Fig. 14a). The first tractors ranged in size from 30 to 50 horsepower. Horses disappeared from the farm as tractors replaced them to pull tillage equipment, drills, and combines. At the same time barbed wire fences were removed from farm fields. By 1940 farming in the drylands was well mechanized. Sacked wheat was obsolete by the mid-1930s replaced by bulk handling (Fig. 14a), and grain was hauled to elevators by trucks (Fig. 14b). Harvesting grain on a farm was reduced to a three or four person operation. Planting was accomplished with a configuration of three or four drills each 3 m wide pulled by a crawler tractor.



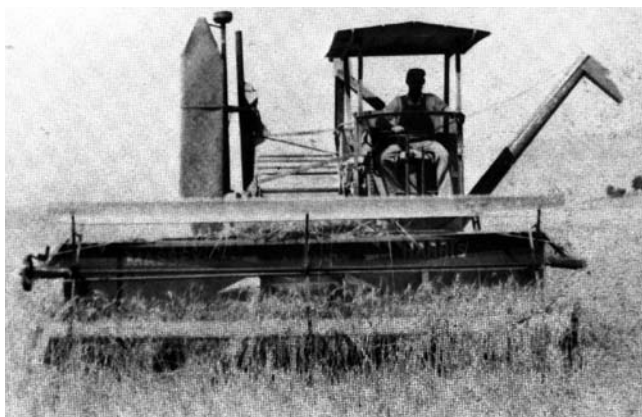
**Fig. 14.** (a) This farmer in 1930 was an early convert to bulk grain harvesting. Handling grain in bulk instead of sacks dramatically reduced manpower requirements and heavy labor. An early model 30-horsepower crawler pulls the gas-powered combine. Photo from Northwest Museum of Arts and Culture, Spokane, WA, L89-35. (b) Unloading bulk wheat at a grain elevator during the 1930s. The front of the truck was raised by a mechanical lift. Photo from Special Collections, Washington State Historical Society.

The war years placed increased demand on production with improved prices. Rural electricity was available soon after World War II that made life easier on the farm.

Anecdotal evidence indicates that wind erosion was less after tractors replaced horses. One reason given was that the trampling effect of horse traffic on the land, when it was dry, dislodged and loosened the soil making it susceptible to drifting. However, with the tractor and because of wind erosion, there was a shift to primary spring tillage that better conserved surface residues such as the sweep cultivator and disk plow. Stubble mulching was strongly advocated by the experiment stations as a system to control wind erosion as indicated by the invention of the skew treader in 1949 at Pendleton, OR, for managing long straw after harvest so that it interfered less with tillage and planting in fallow (Horning and Oveson, 1962).

### Progress in the 1950s and Later

Some of the most dramatic changes in wheat farming over 40 yr occurred in the early 1950s. These included: (i) the old standard Turkey Red winter wheat replaced by the new higher yielding club and soft white winter wheat cultivars, (ii) self propelled combines (Fig. 15) replaced the pull machines reducing harvest labor requirements to two or three persons, (iii) skew treaders,



**Fig. 15.** The first self-propelled combine available to wheat farmers was the Massey Harris Co. Model 21. Manufacture of this machine began in 1939. The combine had a 4 m wide header and could harvest about 12 ha d<sup>-1</sup>. Photo from Adams County Historical Society (1986a).

rotary hoe, sweep cultivators, and the chisel plow made stubble mulch farming feasible for reducing soil erosion, (iv) cheap N fertilizer became available to replenish depleted soils, and (v) chemical herbicides became available for in-crop broadleaf weed control. Items i, iv, and v directly enhanced crop yields in the short- and long-term.

The impacts of wheat cultivar improvements are discussed in another section. The availability of N fertilizer was an especially major advancement. After years of fallow, maintenance and/or gain in wheat yield was limited by N deficiency. Growing legumes in the rotation to supply N was impractical because in the dryland environment their depletion of soil water limited production of the subsequent wheat crop. With N fertilizer, crops received adequate nutrition without drawing from their normal water supply. Discernible increases in dryland wheat grain yields and increased water use efficiency due to N fertilizer were seen from the early 1950s and onward (Fig. 2), whereas previously wheat crops could not take full advantage of grain yield potential during years of high precipitation (Fig. 2).

Selective herbicides, mainly 2,4-D (2,4-dichlorophenoxyacetic acid), provided in-crop broadleaf weed control, and thus increased available water and nutrients for wheat. Moreover, they were somewhat effective in spring wheat to control Russian thistle.

A deep-furrow split-packer drill invented in the early 1960s by a wheat farmer named Robert Zimmerman enabled late summer planting of winter wheat seed to a depth of 18 cm below the soil surface to reach water for germination and emergence (Fig. 16a, 16b). This implement markedly changed the way of WW-SF farming to what it is today. In addition to deep placement of the seed, the drill kept dry surface soil from diluting the seed zone by positioning the seed opener between split packer wheels. The seed opener penetrates the dry soil layer, whereas the packer wheels keep dry soil from cascading into the opener slot, and simultaneously at their base, pack moist soil firmly against both sides (not above) of the seed row to ensure seed contact with moist soil (Fig. 16b). This unique development made it possible for farmers to plant winter wheat into carry-over water in late August to early September, well in advance of fall rains, with a high probability of achieving successful stands



**Fig. 16.** (a) Development of the deep-furrow split-packer John Deere HZ drill in the mid-1960s was a major advancement for winter wheat–summer fallow farming because seed could be placed up to 18 cm below the surface into moist soil. This allowed farmers to establish wheat early (late August to early September) for optimum grain yield potential. (b) Deep furrows spaced 41 cm apart help minimize the soil cover over the seed, but winter wheat seedlings still have to elongate through 10 to 15 cm of soil to reach the surface. The drags behind the drill are sometimes used to help stabilize the furrow and reduce the thickness of soil covering the seed. Photos by W.F. Schillinger.

in 8 to 12 d. Moreover, the deep furrows created by the drill provided for snow catch and protection to seedlings from cold, desiccating winds. Despite the greater incidence of fungal root diseases such as fusarium foot rot caused by *F. culmorum* and *F. graminearum*, late August to early September planting increased wheat yields by 30% and was adopted by essentially all dryland farmers within a few years of the invention of the Zimmerman drill. The patent to the drill was purchased by John Deere & Co. and was manufactured with the logo John Deere HZ. A competitor for this drill, the International Harvester Co. Model 150, was developed soon thereafter.

The dominant tractor during the 1950s–1960s was the track-type diesel crawler with 30 to 80 horsepower for tillage and planting that performed well on the soils and topography of the region (Fig. 10). Farms had increased to an average size of 500 to 650 ha and continued to be mostly single-family operations with as few as one or two additional individuals hired for wheat harvest.

## WHEAT CULTIVAR DEVELOPMENT

‘Pacific Bluestem’ and ‘Little Club,’ soft white spring types, were introduced from Australia and Chile, respectively, in the 1880s. Some farmers experimented with planting in the fall, but both cultivars lacked cold tolerance and were often killed during the winter. Beginning in 1890, small hectares of winter-hardy ‘Michigan Bronze’ and ‘Martin Amber’ were planted and survived the winters, but up to 50% of the grain was lost to shattering before harvest, and as a result they were soon abandoned (Anonymous, 1983).

The first true winter wheat suitable for the region was ‘Jones



**Fig. 17. Farmers gather to harvest ‘Moro’ winter wheat in July 1971 for a neighbor who is sick, has passed away, or otherwise unable to harvest his crop. Wheat farmers have a long tradition of helping each other in time of need. These combines had 6 to 7 m wide headers and could harvest 20 ha d<sup>-1</sup>. Moro was the number one wheat grown in the low-precipitation zone from 1966 through the 1970s due to its excellent ability to emerge from deep planting depths in summer-fallowed soils. Photo from Northwest Museum of Arts and Culture, Spokane, WA, L93-62.24.**

Winter Fife’, a soft red cultivar that originated in New York. A train car load of Jones Winter Fife arrived in the Inland PNW in 1896 and farmers were soon convinced that the best grain yields could be achieved by planting this cultivar in the fall with little danger of winter kill.

‘Turkey Red’ was a well-adapted hard red winter (HRW) wheat that was first introduced in Kansas in 1873 by Mennonite German immigrants who had obtained seed from the Crimea. Turkey Red was the dominant HRW cultivar in Washington and Oregon from its introduction in the late 1890s until 1959, occupying up to 25% of total planted wheat hectares in both states from 1920 to 1950 (USDA-ARS, 1959).

The first wheat breeding program in the PNW was initiated in 1894 by W.J. Spillman at State College of Washington in Pullman. In 1907, the soft white winter (SWW) club ‘Hybrid 128’ was released, the first cultivar developed through hybridization in the PNW. The release of this cultivar was an important milestone in the establishment of symbiotic ties between farmers and scientists. Hybrid 128 remained a major wheat until the availability of the SWW club cultivars ‘Alicel’ in 1919 and ‘Elgin’ in 1932, both released by Oregon Agricultural College. Elgin was susceptible to common bunt caused by either *Tilletia caries* or *T. foetida*, the first major disease faced by wheat farmers beginning in the 1920s (R.E. Allan, USDA-ARS retired, Pullman, WA, personal communication 2006).

Elgin proved to be an important parent for many future SWW club cultivars, including: (i) ‘Elmar’, released in 1949 with resistance to common bunt; (ii) ‘Omar’, developed by USDA-ARS and WSU in 1955; and (iii) ‘Moro’, a 1966 Oregon State University (OSU) release with improved resistance to stripe rust caused by *Puccinia striiformis* compared with Omar. Stripe rust, a previously minor disease, devastated the highly popular Omar in 1961 (Line, 2002).

The release of Moro (Fig. 17), which had excellent emergence ability from deep planting depths, coincided with the development of the John Deere HZ deep-furrow drill (see “Progress in the 1950s and Later” section, Fig. 16a, 16b) to help revolutionize WW-SF production practices by allowing farmers to plant into stored soil water in late August to early September for optimum grain yield potential. Moro immediately became the

number one wheat cultivar in the dry region and remained so through the 1970s (Washington Agricultural Statistics Service, 1972–2006). Moro is still planted today by some farmers due to unequalled emergence ability, despite (by today’s standards) poor disease resistance, modest yield potential, weak straw that causes lodging, and marginal grain quality.

Club wheat is a type of SWW that has less protein and more compact spikes than common SWW. Japan and other Pacific Rim countries prize a special mixture of club and common SWW called ‘Western White’ for making sponge cakes and other confections. No other area of the United States produces club wheat like the Inland PNW.

In 1961, famed USDA-ARS wheat breeder O.A. Vogel released ‘Gaines’, and soon after ‘Nugaines’, the first semidwarf common SWW cultivars that could tolerate high levels of N fertilizer without lodging. Gaines and Nugaines set new grain yield records in the PNW intermediate and high precipitation zones (Jones, 2002), but were not widely planted in the low precipitation zone due to poor seedling emergence from deep planting depths.

In recent times, two common SWW cultivars in particular, ‘Stephens’ and ‘Eltan’, released by OSU in 1978 and by WSU/USDA-ARS in 1990, respectively, continue to be planted on thousands of hectares in areas that receive >230 mm annual precipitation. Hard red winter wheat cultivars dominate where annual precipitation is <230 mm because they have equivalent grain yield to SWW cultivars but higher market value. The 12% protein required for optimum HRW grain price can generally be obtained in <230 mm precipitation areas without undue N inputs because plants are water stressed throughout much of their development and particularly from anthesis to maturity (Donaldson, 1996). There is evidence that HRW production may shift toward higher precipitation areas due to market price advantage compared with SWW and due to the recent release of HRW cultivars that are competitive with SWW cultivars for grain yield.

Today, extensive winter and spring wheat (as well as barley and grain legume) breeding programs are operated by numerous scientists and extension personnel from OSU, WSU, and the University of Idaho, in conjunction with the USDA-ARS. Advanced numbered lines undergo rigorous screening for disease and insect resistance, winter hardiness, grain quality, grain yield, test weight, wide adaptation across a range of environments, and other factors before they are released to the public. Farmers tax themselves through state wheat commissions with most of the revenue going directly to the universities and USDA-ARS to support breeding efforts. Further details on past and present wheat breeding efforts in the PNW are provided by Jones (2002).

Since the late 1880s, spring wheat (SW) has played a relatively minor role in the low-precipitation region due to yield advantages of winter wheat and the agronomic and economic stability of the 2-yr WW-SF system. However, SW is sometimes planted in lieu of summer fallow after wet winters when adequate water is stored in the soil and/or to allow control winter annual grass weeds such as downy brome or jointed goatgrass (*Aegilops cylindrica* Host.). In the intermediate and high precipitation regions of the PNW, 3-yr rotations of WW-SW-SF



**Fig. 18.** A modern Flexi-coil no-till drill delivers seed and fertilizer in one pass through the field. This 11 m wide drill has an attached tank cart that carries seed in one section and granular starter fertilizer in the other section. Aqua  $\text{NH}_3\text{-N}$ , carried in the 3800-L tank at the end, is pumped forward and delivered slightly to the side and below the seed. Photo by W.F. Schillinger.

and WW-SW-SW (or spring barley) or WW-SW-grain legume are standard (Schillinger et al., 2006).

### FARMING IN RECENT TIMES

With the invention of the deep-furrow split-packer drill, research attention was turned to maintaining seed zone water during the hot, dry summer for late August to early September planting of winter wheat. Papendick et al. (1973) showed that increasing the depth of the tillage mulch from 6 to 11 cm at Lind, WA, reduced summertime seed zone drying sufficiently to benefit winter wheat emergence. The dry mulch not only restricted evaporation by cutting off capillary flow of water from the seed zone but also thermally insulated the moist subsoil. These workers concluded that water in the seed zone was best conserved by an overlying tillage layer that has good thermal insulation properties simultaneous with resistance to upward vapor and liquid water flow. In addition, the seed zone must maintain good capillary continuity with the moist subsoil below. Interestingly, the rotary rodweeder (Fig. 10) produces stratification with these properties (Papendick et al., 1973).

Along with the interest in seed zone water, farmers in the 1970s questioned whether fall tillage could increase water storage from runoff on frozen soils that frequently occurred in the northerly areas, and whether type of secondary spring tillage affected over summer water retention. A study at Lind, WA, during a cold winter with considerable soil freezing showed that fall chiseling to a depth of 25 cm increased water storage markedly and disking 12 cm deep to a lesser extent compared with no-tillage (Lindstrom et al., 1974). However, tillage had no effect on water storage during a mild winter with little soil freezing. The increase in storage during the cold winter was attributed to improved infiltration properties of the frozen soil associated with tillage. Although type of spring tillage had no effect on over-summer water loss, the increase in water storage due to fall tillage during the cold winter carried through the fallow season. Seed zone water increased with total water conserved and was higher with spring tillage compared with chemical fallow. Today, many farmers routinely fall chisel winter wheat stubble in areas where there is a high probability of frozen soils.

The downside to tilled fallow is wind erosion, even with the additional residue produced by wheat planted early in late August or early September. After the broad spectrum herbicides paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) and glyphosate [*N*-(phosphonomethyl)glycine] became commercially available in the 1970s, there was interest in no-till or chemical fallow as an alternative to improve erosion control and conserve energy

in WW-SF farming. Although research showed that over-summer water loss in the 180-cm soil profile from chemical and tilled fallow were about equal, less water was retained in the top 15 cm of soil with chemical fallow (Oveson and Appleby, 1971; Lindstrom et al., 1974). Simulations with a numerical water/heat flow model using measured meteorological inputs confirmed that water loss from the seed zone of a silt loam soil was greater from no-till than from tilled fallow, resulting in seed zone water contents that were too low for successful stand establishment in chemical fallow (Hammel et al., 1981). Field trials and experiences since indicate that for the climate and soils of the region, some tillage during the spring and summer of the fallow period may be necessary for retention of adequate seed zone water for late summer establishment of winter wheat.

With the majority of farmland in a tilled WW-SF system, the concern with wind erosion intensified when air quality issues surfaced. Driven by environmental and economic issues, farmer and research interests in the 1990s turned to re- or flex-cropping in no-till systems (Fig. 18) with winter and spring crops as alternatives to traditional WW-SF (Thorne et al., 2003). The soil water status in early spring would dictate whether to spring crop or to summer fallow. The objectives were to control wind erosion, improve water use efficiency, and increase farm profits. The advantage of annual cropping with no-till vs. WW-SF is year-round cover for maximum erosion control and improved water use efficiency.

Long-term cropping systems experiments with annual no-till spring wheat, spring barley, yellow mustard (*Brassica hirta* Moench), safflower (*Carthamus tinctorius* L.), and occasional winter wheat near Ritzville, WA (300 mm average annual precipitation), showed that although they perform well in years of normal or above normal precipitation, grain yield is more variable and they do not consistently achieve the profitability of WW-SF (Schillinger et al., 2007). A decision-making model to predict spring wheat grain yield based on available soil water (minimum of 125 mm available water is recommended) at time of planting in March combined with expected growing season (April, May, June) rainfall for any given location is presently under development. This model will allow farmers to better determine the likelihood of producing a profitable spring wheat crop or if they should instead make conservation tillage summer fallow. The present effort is a follow up on previous research on the relationship between available water and wheat grain yield at numerous field sites during the 1950s by Leggett (1959).

Beginning as early as 1917 (Stephens et al., 1936), researchers and farmers have experimented with a wide array of other spring-planted alternative crops such as pea (*Pisum sativum* L.), condiment mustard (*Brassica* spp.), sunflower (*Helianthus annuus* L.), corn (*Zea mays* L.), and flax (*Linum usitatissimum* L.). An alternative crop has not yet been revealed that can compete agronomically or economically with WW-SF in the low-precipitation zone. Winter canola (*Brassica napus* and *B. campestris*) and camelina (*Camelina sativa* L.) presently show potential as alternative crops and research is underway to test their suitability, driven by the need to develop biofuels to reduce U.S. dependence on oil imports.

Today, WW-SF continues to be the dominant cropping system in the low precipitation zone. It surpasses alternative systems so far tested because it is less risky and more profitable



**Fig. 19. (a)** A modern 375-horsepower Caterpillar 85E crawler tractor pulls a 3800-L tank filled with aqua  $\text{NH}_3\text{-N}$ , and a Haybuster undercutter during primary spring tillage plus N fertilizer injection near Lind, WA. The 11 m wide implement is operated at  $10 \text{ km h}^{-1}$  and covers about  $75 \text{ ha d}^{-1}$ . The tank needs to be refilled with aqua  $\text{NH}_3\text{-N}$  every hour. **(b)** The wide, narrow pitch, and overlapping V-blades on the undercutter implement slice below the surface with little soil lifting or disturbance of surface residue, but completely sever soil capillary continuity to halt upward movement of liquid water to maintain seed-zone moisture in summer fallow. Note the standing stubble that is much more effective than flattened stubble for wind erosion control. This represents the best technology currently available for profitable and environmentally sound winter wheat–summer fallow farming in the low-precipitation zone of the Pacific Northwest. Photos by W.F. Schillinger.

for farmers. The down side to intensively tilled fallow is risk of accelerating wind erosion. Recent research by WSU has led to the introduction of the “V-sweep undercutter” system to the Inland PNW drylands, a modification of an earlier sweep cultivator technology that poses as major advancement in fallow tillage for erosion control and energy savings (Schillinger, 2001). After application of glyphosate herbicide to the standing stubble to control grass weeds, the undercutter management system uses 80-cm wide, overlapping narrow pitch V-sweep blades that operate 10 to 13 cm beneath the soil during primary spring tillage to disrupt capillary continuity with the subsoil while causing minimal disturbance of surface cover (Fig. 19a, 19b). Nitrogen and often sulfur fertilizer is applied with the undercutter during primary spring tillage. Tillage operations are reduced from the usual six or more with the traditional fallow system to two or three with the undercutter system without detrimental effects in conserving seed zone water for early planting of winter wheat. Advantages with the undercutter system translate to significant short- and long-term environmental and economic benefits for farmers (Zaikin et al., 2007) and the public. The economics of the undercutter system is particularly favored by the increase in diesel prices and corresponding reduction in the cost of glyphosate herbicide in recent years. The USDA regards the undercutter system as a significant advancement in conservation farming and in 2006 made a \$1.8 million cost-share grant available to eligible wheat farmers to demonstrate and encourage the adoption of the undercutter



**Fig. 20.** A new John Deere 9760 level-land combine with 10-m header unloads wheat on the go near Ritzville, WA, in July 2006. The grain yield of soft white winter wheat in this field averaged  $3220 \text{ kg ha}^{-1}$ . The combine operated at a speed of  $8 \text{ km h}^{-1}$  and harvested  $6.7 \text{ ha h}^{-1}$ . Farm machinery costs have skyrocketed in recent decades. This combine was rented from an equipment dealer for  $\$150 \text{ separator h}^{-1}$ . The price of a new machine is  $\$250,000$ . Photo by Derek Schafer.

method of WW-SF farming throughout the entire dry region of the Inland PNW.

Farms in the dryland region today range from 600 to over 6000 ha with an average size of 1400 ha. The farm equipment used is among some of the largest in the world. Tractor size has increased to 375 horsepower or more (Fig. 19a). This power is adequate to tow a 11-m wide undercutter with attached 3800-L fertilizer cart covering  $75 \text{ ha d}^{-1}$  (Fig. 19b), a gang of deep furrow drills 15 m wide planting  $90 \text{ ha d}^{-1}$ , or a 20-m wide rod-weeder covering  $130 \text{ ha d}^{-1}$ . Harvesting is accomplished with combines equipped with headers 10 m wide having capability to thresh  $22 \text{ Mg}$  of grain  $\text{h}^{-1}$  (Fig. 20). There have been numerous advances in dryland farming since 1980 but many research challenges lie ahead; these have been outlined by Schillinger et al. (2006) and are not repeated here.

## THE ROLE OF GOVERNMENT FARM PROGRAMS IN THE ECONOMY OF THE DRYLANDS

Wheat farmers continue to survive, and in some cases thrive, due to three factors. First, their productivity per unit of inputs has increased steadily and vigorously (Fig. 21, 22). Bigger machinery improves labor productivity and better cultivars, herbicides, fertilizers, tillage management, and so forth continue to drive grain yields upward (Fig. 13). Second, farmers are expanding the size of their farms, allowing them more hectares from which to accrue profit. Third, the U.S. government has, since the 1930s, provided income support to farmers. Despite these factors, the financial structure and production efficiency of individual farmers varies widely and some farmers may suffer while others prosper. The volatile nature of farming has been particularly acute given the large year-to-year fluctuation in wheat prices since 1975 (Fig. 13).

Before 1996, government farm programs relied on hectareage restrictions to control production and safety net programs were used to protect farmers when grain prices were low. The 1996 Freedom to Farm legislation eliminated hectareage restrictions and substituted fixed payments that were to be gradually phased out.

In the 2002 Farm Bill, the government added the Conservation Security Program (CSP) that was intended to reward farmers for resource conservation and environmental



**Fig. 21. Wheat grain yields in 1975 (and in other years) exceeded elevator storage capacity. This 34,000 Mg (1.25 million bushel) wheat pile at Lind, WA, set a world record at the time for most wheat stored outside in a single pile. The wheat was destined for export and was shipped or covered before fall rains began. Photo from Union Elevator and Warehouse, Lind, WA.**

protection practices. To date, the U.S. Congress has not provided full funding for CSP and relatively few Inland PNW wheat farmers (in a few prescribed watersheds) have so far been able to participate in this program.

The main government safety net today is the Direct Payment that provides  $\$38.80 \text{ Mg}^{-1} \text{ ha}^{-1}$  ( $\$0.52 \text{ bu}^{-1} \text{ acre}^{-1}$ ) of the 5-yr proven grain yield  $\times$  85% of the farmer's hectareage base. The 5-yr proven grain yield was established for individual farms from 1981 to 1985, and the grain average from this time period is still used today as the basis for Direct Payments.

Since the 1980s, the USDA has paid farmers to remove environmentally sensitive land from crop production and grow perennial grasses and shrubs for conservation benefit through the Conservation Reserve Program (CRP). The land is under contract for 10 yr, with contracts often available for renewal. Tillage and harvest are not allowed, but vegetative cover is required. Many counties in the low-precipitation zone of the PNW have more than 25% (the maximum allowed without a legal exception) of their cropland hectares enrolled in CRP (U.S. Government Printing Office, 2006). Farmers in the region receive from  $\$75$  to  $\$150 \text{ ha}^{-1} \text{ yr}^{-1}$  to participate in the CRP. Farmers and economists (D.L. Young, WSU, Pullman, WA, personal communication, 2006) agree that CRP is more profitable than farming the land in the WW-SF region; thus, the program is very popular and competitive in the low-precipitation zone—much more than in Inland PNW cropland areas that receive more than 300 mm annual precipitation. Critics of the CRP claim the program is too expensive for environmental benefits gained, and that retiring farmland is bad for rural agricultural economies. Also, CRP makes it difficult for new farmers to enter the industry by reducing the supply of rentable land and driving up the price of farmland.

The final government farm program of importance is the Environmental Quality Incentives Program (EQIP). In the WW-SF region of the Inland PNW, this program rewards farmers for maintaining 30% residue throughout the summer fallow period to prevent wind erosion and for no-till practices. Farmers who use the undercutter method of summer fallow



**Fig. 22. Soft white wheat is barged down the Snake and Columbia Rivers and then loaded on ocean-going ships in Portland, OR, for export to Asia and other continents. Photo by Miles Hochstein.**

farming (Fig. 19a, 19b) have been successful in winning EQIP contracts that pay up to  $\$37 \text{ ha}^{-1}$  per crop (i.e., every other year for WW-SF) for a 6-yr period. Other WW-SF farmers have EQIP contracts to employ chemical summer fallow in lieu of tillage-based summer fallow, but this is not popular with farmers, except in some areas of northeast Oregon, due to the large winter wheat grain yield reductions associated with late-fall planting with chemical summer fallow. Still a few other farmers receive EQIP funds to practice annual cropping using no-till (Fig. 18). Each county or group of counties has a local working group that decides the most important environmental problems to be addressed and funded by EQIP.

## CONCLUSIONS

The low precipitation ( $<300 \text{ mm}$  average annual) cropping region in the PNW is a dissected plateau covering 1.56 million ha in a belt across east-central Washington and north-central Oregon. The climate is Mediterranean-like with occasional high winds that cause dust storms in the spring and late summer. Most of the region was homesteaded in the 1880s by immigrants from the Midwest who arrived by wagons and later by trains. As farming took root, the drylands merged with the rest of the Inland PNW into an export-based wheat economy that continues today.

The newcomers faced many challenges in establishing a livelihood from agriculture with little precedent for guidance. These included scarcity of water and wood, need to clear native sage, unprecedented wind erosion, variable precipitation, and minimal equipment for farming. Practices imported from elsewhere often required major modification for adaptation to the PNW drylands, and until establishment of state agricultural experiment stations, farmers were forced to resort to trial and error to develop farming methods that would enable them to survive. The development of the WW-SF rotation, cold tolerant winter wheat, and an infrastructure for grain export were three major accomplishments that boosted dryland wheat farming in the first decades. Yield increases and upturns in the economy

provided capital for accessing large scale equipment by rail and expand wheat hectareage.

The introduction of the combine in 1898 was a major advancement in wheat harvesting that reduced manpower requirements and made stationary threshing obsolete by 1920. About the same time invention of the rotary rodweeder enabled efficient control of Russian thistle, a troublesome summer annual broadleaf weed. Later progress in wheat culture included the transition to gasoline powered combines, tractors replacing horses, and bulk handling replacing sacked grain in the 1930s, and in the 1950s the introduction of N fertilizer, herbicides, higher yielding wheat varieties, and self propelled combines. A landmark in dryland wheat farming was the invention of the split-packer deep-furrow drill in the mid-1960s that enabled early stand establishment of winter wheat. This technology increased winter wheat yields by 30% and was adopted region wide by farmers and still used today with updated techniques for conserving surface residue and seed zone water during fallow. Wheat cultivar improvements for deep furrow planting also enhanced yields as cultivars were developed with good emergence, winter hardiness, disease resistance, grain quality, and other values.

As tractors replaced horses, farming shifted toward surface stubble management to reduce wind erosion and conserve water. This trend continues today with the introduction of the undercutter management system for fallow that minimally disturbs the surface soil and reduces the number of tillage operations by at least one-half. This advanced system holds promise to significantly reduce wind erosion and fine particulate emissions from fallowed fields and increase farm profitability. The 2-yr WW-SF rotation survives today due to improved technologies, expansion of farm size, and government income support. Research showed that chemical fallow (no-till) could not substitute for tilled fallow in most of the low-precipitation zone because of greater loss of seed zone water that does not allow late summer establishment of winter wheat. Long-term no-till cropping systems research showed that grain yield of spring-planted crops was highly variable compared with WW-SF and that at least 125 mm of plant-available soil water should be present before planting spring wheat or spring barley in lieu of conservation-till summer fallow.

Since the late 1920s, average wheat yields have increased from 1 Mg ha<sup>-1</sup> to about 3.4 Mg ha<sup>-1</sup>, an average gain of 3% yr<sup>-1</sup> over 80 yr. Farm size today ranges from 600 to over 6000 ha for an average size of 1400 ha. Government support in the last several decades for conservation and grain subsidies has accounted for as much as 40% of gross farm income.

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