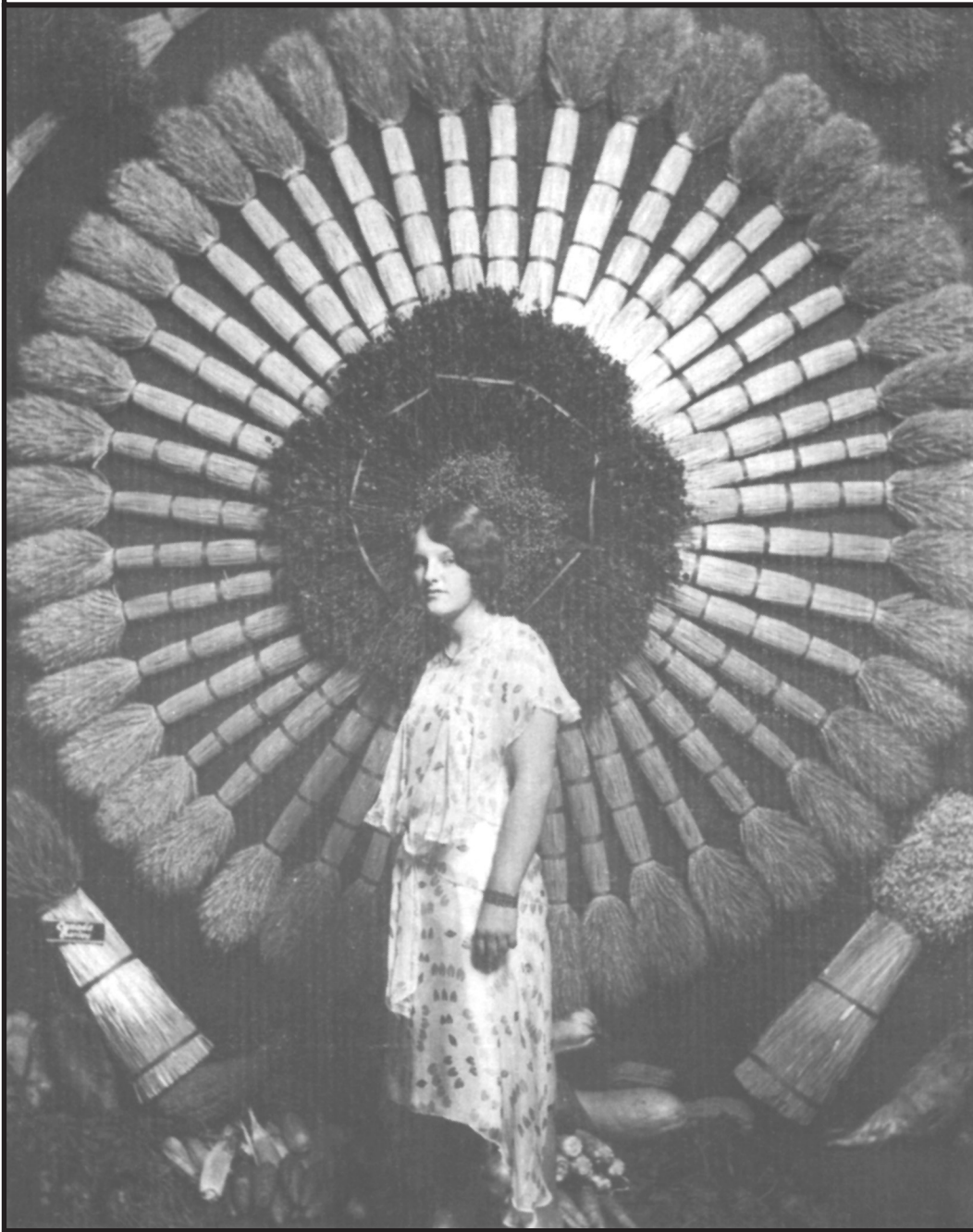


DRYLAND FARMING IN THE NORTHWESTERN UNITED STATES

A Nontechnical Overview



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About the Author and Project

David Granatstein is Project Coordinator for the Northwest Dryland Cereal/Legume Cropping Systems Project, based in the Department of Crop and Soil Sciences, Washington State University, Pullman, Washington. Work for this publication was conducted there with cooperators from Oregon, Idaho, Montana, Wyoming, and Utah, under project numbers 3481 and 4481.

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Cover photo: An artistic display of wheat sheaves at an agricultural exposition in the early 1900s. Photo courtesy of Historical Photograph Collections, WSU Libraries.

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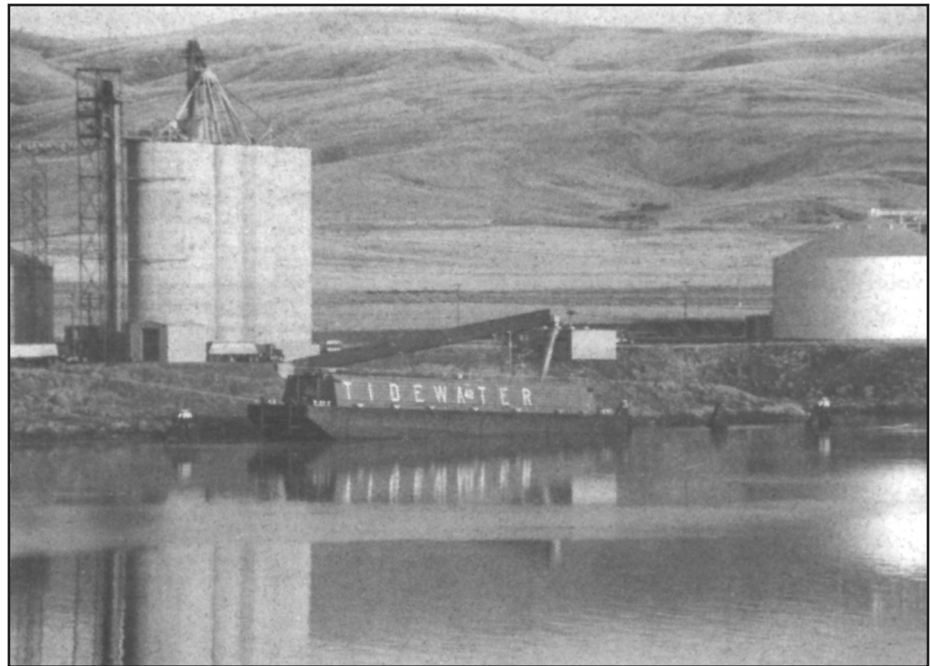
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INTRODUCTION



Most of the region's grain is exported

The staff of life. Our daily bread. Amber waves of grain. All these references evoke images of wheat, the most prominent grain in the American diet. Yet images of the Dust Bowl, deserted farm houses, and silt-choked rivers are also associated with wheat farming, especially in the drier, more marginal farming regions.

Today, more people than ever throughout the world rely on American wheat farmers to provide a steady and affordable supply of grain. At the same time, public concern about the viability of our food system is growing as part of an expanding environmental awareness. Many people feel that the enormous successes of farm productivity have not come without a cost. In the brief history of farming in our nation, more soil has been eroded than in many civilizations a thousand years old. Rural populations and communities have disappeared because of changes created by using new technology and by the world marketplace. The loss of prairies and wetlands has reduced biological diversity. Thus, sustainability is crucial to agriculture to maintain food production and the natural and human resources that support it.

In the northwestern states of Washington, Oregon, Idaho, Montana, Utah, and Wyoming, wheat and other drought-tolerant crops

are raised on over 10 million acres of land using dryland farming techniques (Table 1; Figure 1). Dryland farming generates significant economic revenues for the region and provides large amounts of food and feed commodities for both domestic and foreign markets. Farming activities also greatly impact the land, air, water, and biological resources of the region.

Table 1. Wheat Acreage and Average Yields in the Northwest, 1987-1989. Includes irrigated Acreage.

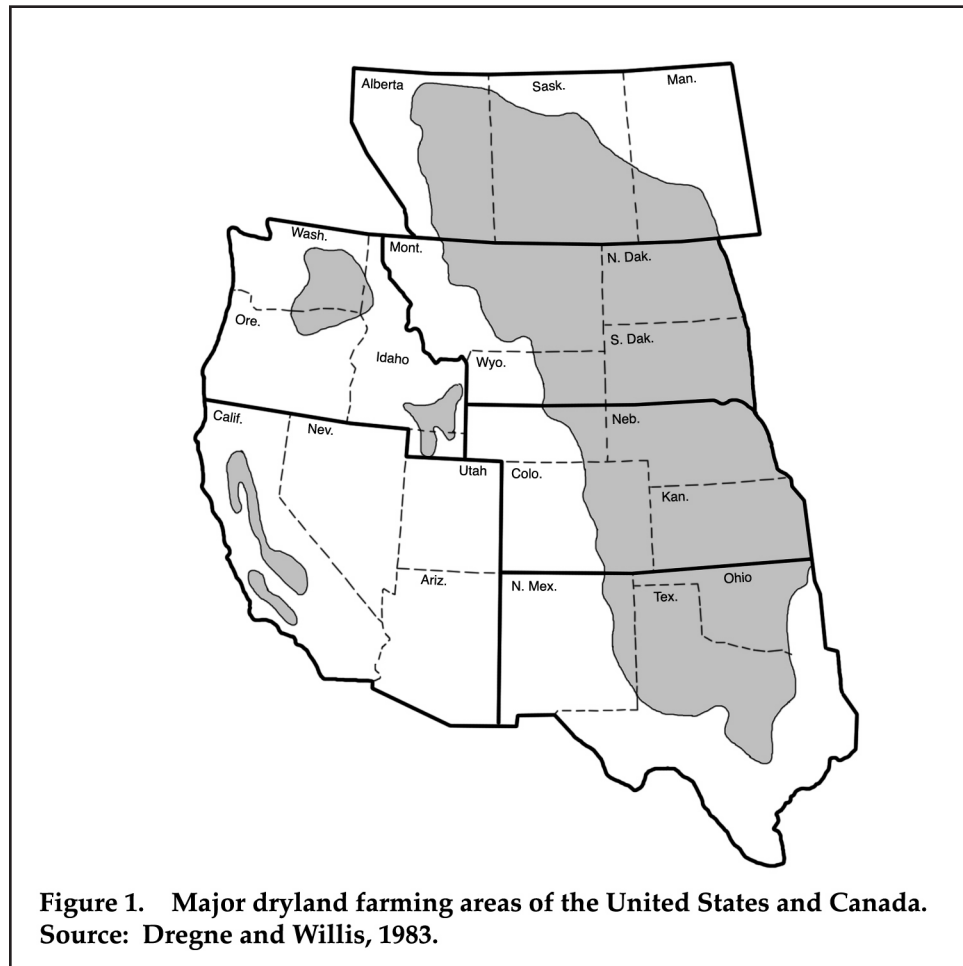
State	Planted Area (1000 ac)	Average Yield (bu/ac)
Montana	5322	25.2
Washington	2457	55.3
Idaho	1297	69.1
Oregon	865	64.1
Wyoming	268	25.4
Utah	195	38.9

Source: USDA, 1990

In 1988, a group of researchers, extension workers, farmers, and private agricultural organizations initiated the Northwest Dryland Cereal/Legume Cropping Systems project to

explore sustainable dryland farming options in the six-state region. This publication provides an overview of sustainable dryland farming in the region. It defines and presents the history of dryland farming and the concept of sustainable agriculture. A companion publication, XB1025 *Amber Waves: A Technical Sourcebook for Sustainable Dryland Farming in the Northwest-*

ern United States, contains detailed research information on moisture management, crop rotations, and soil quality. It is intended for use by growers, researchers, and other agricultural professionals. It also has a resource guide to sources for technical information and assistance about dryland farming in the six states.



What Is Dryland Farming?

Dryland regions are those geographic areas in which biological productivity is normally limited by available moisture. They occupy an estimated one-third of the earth's land surface. Through irrigation, the moisture limitation has been overcome for many dryland sites. But for large geographic areas, limited water resources prevent irrigation development. Thus, strategies that improve moisture conservation will continue to be crucial to agriculture in dryland areas.

Most rain fed dryland agriculture occurs in semiarid and subhumid zones. These are typically grassland ecosystems in their native state. The moisture characteristics of drylands, as reported by UNESCO (1977), are presented in Table 2.

Land resources in dryland regions may suffer irreversible losses of productivity if careful management is not practiced. In much of the world, poor management has led to desertification, which poses a growing threat to the livelihoods of people reliant on dryland

farming. Canadian researchers estimated the annual cost of soil degradation in their prairie region to be 622 million dollars in lost agricultural productivity in 1984 alone (Dixon et al., 1990). Thus, sustaining the resource base is a crucial issue for drylands in developed as well as developing countries.

Table 2. Dryland Moisture Characteristics.

	Semiarid	Subhumid
MAP/PET	0.20-0.50	0.50-0.75
MAP range (in.)	12-32 s 8-20 w	20-32 --
Rainfall variability	25-50%	<25%

(MAP=mean annual precipitation; PET=potential evapotranspiration; S=summer rainfall regime, W= winter rainfall regime)
Source: UNESCO, 1977.

Dryland wheat farming has been practiced in many parts of the world for centuries, but it is only about 100 years old in the northwestern United States. In that short period, dryland farming techniques have undergone much change due to a steady flow of new equipment, research, and farmer experience. A number of practices and tools are unique to dryland regions. The widespread practice of summer fallow stores moisture from two years for use by a single crop. Farmers alternate a crop and noncrop year, and control weeds during the noncrop year with tillage and/or herbicides. The desire to conserve as much of the moisture as possible has spawned creative technology. For example, the rodweeder is a tool unique to dryland regions; it is used to maintain a moisture-conserving dust mulch during the summer fallow period in a crop-fallow system.

Successful dryland farming requires favorable soils that can store moisture, adapted crops that can withstand the climatic extremes, and innovative farmers who can tailor a management system to fit their local environment. Many dryland farms cover thousands of acres in order to form a viable economic unit, due to low per acre yields and profits. The weather and soils can vary dramatically across an individual farm, further complicating farm

management. The variability of the dryland environment often makes it difficult to extrapolate research results or farmer experience from one location to another a short distance away. Many dryland farmers rely on their own experimentation and innovation to develop a successful management system.

Government farm programs have played a large role in shaping dryland agriculture during this century. Price supports for wheat help keep many dryland farmers in business during periods of depressed grain prices. At the same time, the programs have influenced farm management in ways that often contradict resource conservation goals. Thus, in addition to climatic uncertainties, dryland farmers have had to cope with policy issues more than most other farmers.

What is Sustainable Agriculture?

The Northwest Dryland Cereal/ Legume Cropping Systems project explored prospects for sustainable agriculture on the region's dryland farms. Sustainable agriculture is best understood as a concept or goal, rather than a specific set of farming practices. It focuses on agriculture's long-term viability, particularly concerning the use of natural resources. Ideally, a sustainable agriculture is profitable, environmentally sound, and socially beneficial, both in the short and long term. Presently used indicators of agricultural success, such as crop yields or annual profits, do not accurately measure the sustainability of our farming systems.

The current interest in sustainable agriculture is the result of public concern about the environmental impacts of modern agriculture, and grower concern about farm profitability. While simple solutions are lacking, a growing number of profitable, efficient, productive and environmentally friendly farms that embody the goals of sustainable agriculture provide positive examples. The results from these farms refute claims by critics of sustainable agriculture that the only alternative to our present agriculture is a return to horses and hoes. The sustainable agriculture concept draws on all possible options, ranging from historical farming techniques to the use of modern biotechnology.

A number of terms are used to describe approaches to developing more environmen-

tally sound agricultural methods, including alternative, ecological, regenerative, organic, and biodynamic. The term “organic farming” specifically implies a system that uses no synthetic fertilizers or pesticides. Production practices are often defined by public or private certification programs. The term “low input” refers to reducing purchased, external, or nonrenewable inputs. Low input does not mean doing nothing while magically maintaining crop productivity. Farmers successful in reducing purchased inputs such as chemical pesticides may intensively scout fields for pests, release biological controls, and apply botanical pesticides more frequently. This approach requires a greater knowledge of the biological relationships present in farming systems.

Sustainable agriculture as a concept encompasses all these approaches to more environmentally sound farming. For example, both sustainable agriculture and organic farming encourage rebuilding of soil organic matter. But organic farming prohibits the use of synthetic fertilizer, while sustainable agriculture does not.

Sustainable agriculture represents a continuum of diverse farming practices. There are no firm standards by which a farm might be judged “sustainable,” in contrast to strict standards set for organic farm certification. However, a number of principles and strategies are common to farms striving to be more

sustainable. Key principles include enhancing biological diversity, recycling nutrients and waste products, increasing reliance on renewable and internal production inputs, information-intensive and site-specific management, and recognition of both long- and short-term costs and benefits of farm practices.

Sustainable agriculture is not a cure-all and it is not a new concept. The term “permanent agriculture” was used by Oregon wheat farmers in the early 1900s. Many similar concerns were expressed during the Dust Bowl era. But problem solving in agriculture has often been narrowly focused. Eliminating one concern frequently created new ones. Sustainable agriculture stresses problem solving in a broader context, with new partnerships across academic disciplines, among all sectors of agriculture, and between urban and rural populations. It emphasizes a greater role for knowledge and use of biological processes on the farm than in the past several decades.

Wendell Berry, a noted writer and Kentucky farmer, points to the need for “agricultural solutions to agricultural problems.” He feels that many of our approaches over the past century have been “industrial approaches,” more suited to factories than to farms. He defines an agricultural solution as one that “creates more solutions, not more problems.” That may be a good guidepost in the search for a more sustainable agriculture.

HISTORY OF DRYLAND FARMING IN THE NORTHWESTERN STATES



Alternate wheat-fallow strips help control wind erosion

The dryland regions of the northwestern United States were considered a part of the “Great American Desert” throughout much of the nineteenth century. The reports of Lewis and Clark did not offer encouragement about the agricultural potential of the vast expanses of dry country they passed through. But farming did find its way to the northwestern states by two routes—the Columbia River, and the Oregon Trail. Each route has its own history, as well as a common one. The small grains which have been the cornerstone of dryland farming in the region, especially wheat and barley, came with the European settlers and replaced the perennial grasslands that had been building fertile soils for thousands of years.

The Columbia River Country¹

The early white explorers throughout the Northwest were fur trappers who had little in interest or time for agriculture. As part of the geopolitics of the early 1800s, the Hudson Bay Company decided to initiate food production in the region to bolster their strategic hold and to cut costs. Large gardens were started at several of the Company forts, and in 1826, what was probably the first wheat crop in the dryland Northwest was planted at Fort Colville (Washington). By the 1840s, settlers flocked to the fertile Willamette Valley in Oregon from the

eastern states over the Oregon Trail. Most settlers passing through the dry country were in a hurry to reach the moister climate west of the Cascade Mountains. But several missions were founded in eastern Washington and northern Idaho, where both irrigated and dry farming were practiced. In 1843, Henry Spalding speculated that the rolling hills of the Palouse region might be able to produce wheat. By 1846, he had raised several grain crops without irrigation near Lapwai, Idaho.

Isaac Stevens, later governor of Washington, recognized the agricultural potential of the Columbia Basin prairies in the mid-1850s and compared them to the famous steppes in Russia. Walla Walla became a major center for dryland grain production, with the first threshing machine arriving in 1861. White wheat was first planted in fall 1863, and yields of 33 bu/ac were harvested from upland benches. As wheat production expanded around Walla Walla in the 1860s, the price dropped from \$1.25/bu to \$0.30/bu. In 1867, about 1000 barrels of wheat flour were exported to San Francisco, and then exports to New York and London began. By 1870, gang plows and steam threshers were in use around Walla Walla, and wheat production exceeded 100,000 bu/yr.

In the early 1870s, dryland farming expanded to other parts of the Columbia prairies. Some settlers moved to dryland areas from the

Willamette Valley as word of the successful crops spread. The first railroad in the Pacific Northwest was built in the late 1870s to carry wheat from Walla Walla to the Columbia River at Wallula Gap. Average wheat yields of, 35-40 bu/ac were convincing evidence that the hills offered tremendous farming opportunities. By 1880, 50,000 people had settled in the dry region of the territory and were producing 1.5 million bushels of wheat from some 360,000 total cultivated acres.

As the more productive areas of the Palouse were claimed, settlers moved into drier areas. By 1884, transcontinental and ocean railroad connections were completed. This opened the area to a flood of settlers, improved access to technology from the East, and provided transport routes to markets for farm products. The railroads themselves initiated promotional campaigns to convince settlers of the virtues of dryland farming. This was especially true in Montana. The "dry farming" movement sponsored a number of large conferences, including the 5th International Dry Farming Congress held in Spokane, Washington, in 1910.

Initially, spring-planted wheat predominated. Fall sowing gradually increased as better management practices and varieties became available. The principal wheat variety in the late 1800s was Little Club, introduced from California. It had poor cold tolerance and fall plantings often died. Wheats from North Dakota, such as Scotch Fife, were then introduced. Farmers soon recognized the need for many varieties to suit the diverse conditions of the region. For example, Pacific Bluestem, an Australian wheat suited to the drier areas, was reported to have raised yields by 25% at Ritzville, Washington.

Farmers began to consider crop diversification during the 1890s. They grew barley for stock feed, for export, and to supply Northwest breweries. Oats and hay were grown for horses. Both spring oats and barley tended to yield better than a second successive crop of wheat. Orchards, rootcrops, and livestock were all promoted and tried. About 1400 acres of dryland sugarbeets were planted in 1899 near Waverly, Washington. But the more intensive management required by diversification was not well received by growers accustomed to wheat farming.

At this time, investment groups began to develop large farms of several thousand acres in the interior drylands. These were patterned after the "bonanza" farms of the Red River Valley in North Dakota and the Sacramento Valley in California.

New farm equipment has always interested dryland grain farmers. Various cultivating tools were tried as the use of summer fallow expanded. The first combine was brought in from California in 1888, with the first side hill model available in 1891. In 1893, steam tractors were tried at Harrington, Washington, and Umatilla, Oregon. The first gasoline-powered "caterpillar" farm tractor was marketed in 1906.

Agricultural experiment stations were established at Pullman, Washington (1891), Moscow, Idaho (1892), and Moro, Oregon (1899). Variety improvement was a priority from the start. New varieties were recommended for the low (Bluestem, Turkey Red), intermediate (Little Club, Red Chaff, Jones Fife), and high (Fortyfold, Red Russian) rainfall zones. Wheat breeding began at Pullman in 1899 under the direction of W.J. Spillman. Problem weeds at the time were wild oat, Russian thistle, china lettuce, Jim Hill mustard, and morning glory.

Scientists at the experiment stations began to express concern about soil erosion around 1910. Their critical remarks about farming practices drew considerable farmer resentment, and pointed out that the soil was not inexhaustible. But one scientist likened Palouse soils to those in Sicily which had grown wheat for over 2000 years; farmers were reassured by the idea that the soil could "fertilize itself."

Over the next 20-30 years, changes in farming practices led to a dramatic increase in soil erosion. The use of summer fallow greatly increased, both in the drier and wetter areas. It was essential for moisture conservation in the drier areas, and also accumulated nitrogen released from the soil organic matter and provided weed control. In the wetter areas, the latter two benefits of summer fallow were substantial, but the increased tillage and higher levels of residual soil moisture increased the erosion hazard. The intense tillage hastened the loss, of soil organic matter and the breakdown of soil structure, which left the soil more



Combines revolutionized wheat production

erosive. Erosion then stripped off the topsoil with the highest organic matter content, thus accelerating the erosion cycle. Farmers began using a wheat-pea rotation in the wetter areas as a way to avoid summer fallow. Intensive tillage often accompanied peas, as did the burning of crop residues and the introduction of many new weeds. Technological advances in farming were just able to compensate for the declining soil productivity. From 1900 to 1935, the winter wheat yield from dryland acres in Washington averaged a relatively constant 23 bushels per acre.

By the 1930s, the dramatic shift from animal traction to machine power was well under way. As the ground speed of tillage implements increased, an individual farmer could manage more land and do more cultivations. This increased soil pulverization and magnified the problem of tillage erosion.

National attention was focused on the problems of soil erosion during the Dust Bowl years. A Soil and Water Conservation Experiment Station was established near Pullman, Washington, in 1930 to research the erosion problems in the region and develop conservation farming practices. The research results were used by the Extension Service and the Soil Conservation Service to spread the adoption

of conservation farming techniques. Many improvements were made, including stubble mulch farming, contour strip-cropping, rotations with perennial grasses and legumes, and combine straw spreaders to eliminate the need for stubble burning. But adoption of these practices was minimal and soil erosion continued to diminish the soil resource.

After World War II, commercial fertilizers became widely available and affordable. The use of nitrogen fertilizer dramatically boosted dryland grain yields, as low soil nitrogen levels often limited

production. Chemical herbicides and insecticides helped reduce crop losses from weeds and insects. These materials, along with various government commodity programs, shifted cropping away from diversified rotations to more intensive cash-cropping. Although erosion continued at serious levels, crop yields increased steadily due to the numerous technological advances.

One of the most important advances in modern wheat production was the development of semidwarf wheats. The first semidwarf variety, Gaines, was released in 1963 by Orville Vogel, a USDA wheat breeder at Pullman, Washington. This variety did not lodge and thus could be fertilized for higher grain yields. Vogel's work has made a lasting contribution to increased food production worldwide.

The new technologies produced several troubling side effects. Farm size has steadily increased, made possible by the technology and often made necessary to afford the technology. This impacted rural communities and played a part in the widespread farm insolvency of the 1980s. Cumulative use of ammonium-based nitrogen fertilizers has been implicated in significant reductions in soil pH in the higher rainfall areas. Heavier farm machinery

has compacted the soil. Weed resistance to certain herbicides has been documented. The impacts of current farming on the groundwater resource are largely unknown, but degradation of surface waters from agricultural lands continues.

Nonetheless, significant improvements are being made with regard to soil conservation, efficient fertilizer use, and improved handling of pesticides. Potential exists for new crops such as canola or small red lentils. An increased research emphasis on biological processes and whole systems in agriculture will help reduce environmental impacts and enhance sustainability.

The Oregon Trail and Northern Plains²

The trappers and explorers of the early 1800s eventually found an overland route across the Rocky Mountains that was passable to wagons, later known as the Oregon Trail. Thousands of people followed it through the Great Desert to the promised land of the Oregon Territory. Virtually all migrating pioneers on the Oregon Trail passed by Fort Laramie in Wyoming. This strategic point was often relied upon for provisioning, and early farming efforts were made in the 1830s to grow some food locally. This included dryland grain, probably the first production in the Northern Plains. Southeastern Wyoming remains the primary dryland wheat producing area in that state today, where a winter wheat-summer fallow system predominates in the dry, cool climate.

One group, the Mormon followers of Joseph Smith and Brigham Young, deliberately headed for a different destination, the isolated area now known as Utah. The first Mormon settlers reached



Subsoil packing was suggested at the turn of the

the Salt Lake Valley in Utah in the summer of 1847. Creeks were immediately diverted to wet the land for plowing, and crops were planted. Irrigated farming has been the backbone of a productive Utah agriculture, but dryland farming began in 1863 and was developed on considerable acreage during the late 1800s, particularly for wheat. Many doubted that crops could be grown without irrigation. In fact, one farmer near Nephi was indicted for perjury after testifying about his good yields of dryland wheat. Dryland acreage peaked between 1910 and 1920 due to the high wartime prices. Of the total land area in the state, about 3.3 percent is tilled, and about one-third of all cropland is not irrigated. Northeastern Utah has the largest concentration of dryland farming, with other small areas occurring throughout the state.

Early dry farming successes in Utah helped pave the way for its expansion to other parts of the Northern Plains. The oldest dryland experimental farm in America, located at Nephi, Utah, was established in 1903. In 1911, Professor John Widtsoe published a classic volume entitled *Dry Farming: A System of Agriculture for Countries Under a Low Rainfall*, which outlined the scientific principles developed at that time. One of the first county agricultural agents in the Northwest was hired in Utah in 1913.

Soil erosion on dryland acres has caused serious damage in many areas of Utah. The Salt Lake series, perhaps the most credible

agricultural soil in the state, has been particularly vulnerable. In many cases, only a few inches of topsoil cover the widespread Salt Lake formation, an unproductive calcareous material. Exposure of this formation on dryland grain fields has increased 250% since 1930, and productivity of wheat often drops from 30 to 3 bushels per acre. Thus, development of suitable conservation farming systems has been a priority, both for soil and water.

As early trappers moved into Montana, they established routes that were later used by prospective settlers. The number of farms grew slowly during the 1800s and then rapidly increased at the turn of the century (Table 3). The major influx of settlement occurred once the northern railroads were open, and people emigrated west through the already settled lands of Minnesota and North Dakota. A “back to the land” movement emerged in the 1890s, as did a concern with food scarcity, and both contributed to expanded crop production in unsettled areas such as Montana. Favorable weather, high grain prices, and relatively cheap land all enhanced the rapid expansion of dry farming in the early 1900s.

Table 3. Number of Montana Farms.

Year	Number of Farms
1870	851
1880	1519
1890	5603
1900	13097

Source: Hargreaves, 1957

The railroads actively promoted dryland farming in Montana in hopes of luring settlers who would then be reliant on rail transport to get their harvest to markets. Much propaganda extolled the virtues of fertile land and nutritious crops, but failed to mention the droughts, grasshoppers, and isolation that hampered farming efforts. M.W. Hargreaves (1957), in her book *Dry Farming in the Northern Great Plains*, contends that this propaganda itself was a major innovation of the dryland farming movement in the early 20th century. A series of Dry Farming Congresses were held throughout the West, often with financial support from railroads. Promoters such as H.W. Campbell devised “systems” for dry farming, many of which were at odds with the recommendations of scientists. These propaganda efforts attempted to dispel the negative concepts of semiarid lands, and did so with considerable success.

The promotional period was followed by one in which the general principles of sound

farming practices for dry lands were discussed in hopes of creating an enduring agriculture. The fragile nature of dry lands and the high risks of farming there were stressed. Thomas Shaw, a former professor and agricultural agent for the Great Northern Railroad, brought much credibility to dryland farming practices. He stressed adapted crops and varieties with drought resistance and early maturity, promoted winter wheat, and emphasized the value of legumes and livestock in the system. Crops such as durum and spelt were brought in by Russian immigrants and proved to be drought resistant. A number of educational efforts were undertaken, including model farms, “Better Farming Trains,” and local agricultural education programs. Dryland farming in Utah and large-scale wheat farming in the Red River Valley provided the foundations for dryland farming practices in Montana. Alternate crop-fallow was reportedly common in the Red River Valley during the 1860s. The first use of summer fallow on the Northern Plains is attributed to Angus McKay of Indian Head, Saskatchewan. In 1885, he apparently was unable to sow his wheat due to a local uprising that drew away all the laborers. He did plow one field and kept it weed-free for the summer. Wheat seeded the following year on that field yielded 35 bu/ac compared to an adjacent field which yielded only 2 bu/ac.

Summer fallow expanded slowly at first, in part due to warnings about its danger from agricultural scientists. The increased yields and reduced risk associated with summer fallow were verified during drought periods. But wind erosion was soon evident wherever soil was pulverized. Farmers were encouraged to keep low-yielding lands as permanent pasture. In 1918, the Koole brothers tried using alternate narrow strips of crop and fallow that were perpendicular to the wind to reduce wind erosion on their Alberta farm. It worked. Strip farming spread rapidly and was a crucial practice for farm survival during drought cycles.

Due to the great variability of conditions in Montana, scientists cast doubt on the development of any one “system” of dry farming that could ever be broadly applied. Yet by 1907, they were endorsing dryland farming and recommending many of the practices sug-

gested by the maverick Campbell, such as deep fall plowing, subsoil packing, dust mulching, and summer fallow. But long-term research results were sorely lacking. The first state funding for specific dryland studies in Montana came in 1905. Demand for information grew with the expanding farm population. In 1914, the first four county agricultural agents were hired, and by 1917, this service was expanded to most Montana counties. Summer tillage clubs were formed in the early 1920s, as was the Montana Farm and Loan Bankers Association. The latter group issued rules dictating production practices to growers as a condition for a loan.

Plant exploration efforts by the USDA yielded many promising crops suited to dry lands in Montana and in neighboring states. Crested wheatgrass, brome grass, several alfalfas, and hard winter wheat varieties are some examples. Kharkov wheat was introduced in 1900. Early crop breeding often had conflicting goals of high yield versus drought resistance. The best-yielding wheat varieties ranged from 10 to 40 bu/ac, depending on location.

Large dryland farms were commonplace in Montana during the early 1900s. As gasoline-powered mechanization became available in the 1920s, further expansion of both farm size and total dry farm acreage occurred. The drought of 1917-1920 caused numerous bankruptcies, but it again illustrated the value of summer fallow.

The drought of the 1930s confirmed the early warnings about tillage-intensive summer fallow. The conservation programs of the federal government helped spread the strip farming practice and introduced stubble mulch

fallow to protect the soil with crop residues. Ironically, loss of organic matter from summer fallow increased the soil's susceptibility to erosion and made summer fallow more necessary in order to store sufficient water and release nitrogen for a crop. Saline seep was another problem caused by continual use of a crop-fallow system over large land areas. Excess water stored in the soil leached below the root zone. In soils with an impermeable layer, it moved laterally to a seep point downhill, carrying high concentrations of dissolved salts which accumulated on the soil surface after evaporation. This problem became evident in the 1940s, and by the late 1970s, saline seep was estimated to have removed some 200,000 acres from crop production.

Continued research has provided new options for dryland farmers in Montana, Utah, and Wyoming to tackle soil erosion and moisture conservation. Improved snow management can dramatically increase soil moisture storage, as can reduced tillage. Recent research indicates that continuous cropping can be more productive and profitable than a crop-fallow system. The flex-cropping approach was developed to reduce saline seep and improve moisture use. It suggests that decisions about planting or fallow be based on available soil moisture in the spring, but federal commodity program rules generally discourage flex-cropping. The use of legumes in rotation with cereals is being explored as a way to increase soil organic matter and reduce summer fallow. New crop choices such as spring canola offer further diversification for dryland farming and potential rotation benefits.

1. The material for this section came primarily from the following sources: Meinig, 1968; McGregor, 1982, and Jennings et al., 1990.

2. The material for this section came primarily from the following sources: Widtsoe, 1911; Utah State, 1941; Hargreaves, 1957; Haas et al., 1974; and Ford and Krall, 1979.

DRYLAND FARMING: PRINCIPLES AND PRACTICES



Microbial control of weeds being tested near Pullman, WA

The Semiarid Environment in the Northwest

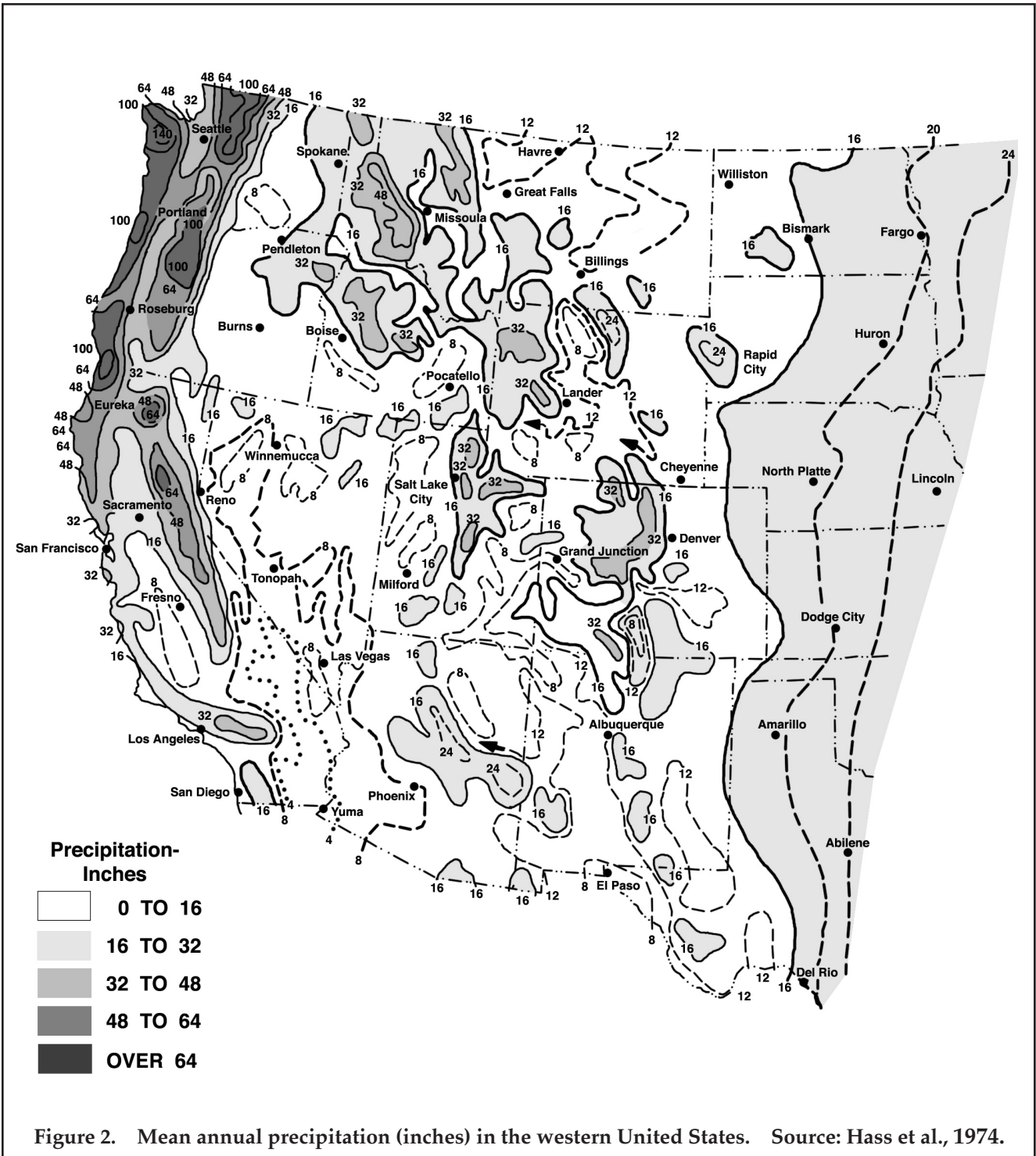
The geoclimatic character of the northwestern United States is shaped by one overriding influence—mountains. Since the prevailing winds are from the west, those lands east of mountain ranges typically fall in a rain shadow, and thus are arid or semiarid. Most mountains in the region run north-south, but many minor ranges exist which often are not contiguous with the predominant chain. Thus, the climatic patterns of the farmlands are highly variable over short distances but are generally moisture deficient (Figure 2).

The relatively warm currents of the Pacific Ocean have a moderating effect on most of the region, despite the northerly latitude. This effect diminishes as one travels east, but is still evident in north-central Montana. The moderating effect allows winter wheat production in many areas. Where winter precipitation predominates, farmers can make more efficient use of the moisture, since summer rainfall is often ineffective due to high evaporation. Potential evapotranspiration (PET) decreases farther north and at higher elevations, leaving more moisture for crops.

Three general climatic regions exist in the dryland Northwest. West of the Rocky Mountains (eastern Washington and Oregon, and northern Idaho), the climate is a modi-

fied Mediterranean type in which most of the precipitation falls in the winter with little rainfall during the summer. Temperatures tend to be moderate year round due to the moderating maritime influence East of the Rockies (Montana and Wyoming), a continental climate dominates and most precipitation occurs during summer. Temperatures tend to be more extreme in both summer and winter. Southeast Idaho and northern Utah have an intermountain climate that is transitional between the other two with relatively even precipitation throughout the year. These climatic differences have shaped the farming practices found in various parts of the dryland region.

The soils of the region, while highly diverse, share several common traits. The low rainfall conditions limit the weathering and leaching processes, thus favoring soil fertility. Many of the soils are young, due to their formation after the last glaciers some 10,000 years ago. The widespread loess deposits of the Palouse region were formed from wind-blown glacial dust. Other fertile soils formed from sediments under glacial lakes. The silt loam texture of these soils is ideal for storing plant-available soil moisture. This has been a decisive factor in the success of dryland farming in the region. But these soils are also easily eroded by wind and water.



Deep-rooted perennial grasses and shrubs are well adapted to the semiarid conditions. Most of today's wheat lands were covered with perennial grasses in the native condition. This native vegetation led to the development of high levels of soil organic mat-

ter and good soil structure. The organic matter contained a substantial reserve of nitrogen and other plant nutrients. Early grain farming drew down this reserve in the absence of fertilizer inputs and reduced organic matter levels by 30-50%. This caused the breakdown of soil

structure or tith, which increased the erosion potential and the need for more tillage power. Loss of organic matter also lowers the potential of soils to store moisture. **Fortunately, the semiarid environment is conducive to soil improvement when it is well managed.**

The low humidity and infrequent rainfall of semiarid climates inhibit many foliar diseases of crops in the region. This climate favors the maturing and field-drying of crops, making harvest easier. A dry climate also provides more suitable days for field work with machines because the soil is not too wet. But temperature extremes that commonly occur can damage crops through frost or extreme heat at sensitive growth stages.

Cropping Systems of the Region

Early white settlers used the semiarid lands primarily for livestock grazing, since the lands were considered generally unfit for cultivation. Small areas, especially flat lands along watercourses with subirrigation, were first used for crop production. But inquisitive individuals soon began to experiment with crop production on the drier lands. As word of their success spread, other landowners began to plow and plant cereals on parts of their farms to test out the idea, and dryland farming expanded rapidly.

The early cropping systems were relatively crude, often no more than a transplant of Midwest practices into an unsuitable environment. A field was normally planted every year, with grain crops predominating. Most grain crops were adapted to the dry conditions. The grain was relatively nonperishable and easily shipped, an important consideration in a sparsely populated region far from markets. The native soil fertility generally produced good yields if there was adequate moisture, weed control, and plant stands. Weeds were not a problem at first, but the increased influx of settlers, livestock, seed, and feed rapidly infested the region. The newly plowed fields were relatively resistant to erosion, with their high organic matter levels and good soil structure. This deteriorated during the first 10-20 years of farming and erosion was then recognized as a serious problem.

The dry and variable climate led farmers to eventually replace annual cropping with

a crop-summer fallow system. Fallow greatly dampened the wide swings in moisture conditions and reduced the risk of crop failure. Farmers used fallow for weed control, and additional nitrogen accumulated in the soil during fallow that countered declining fertility. Fallow also spread out the peak demands for field work. The wheat-fallow system was constantly refined over the years and remains as the cornerstone of dryland farming in the region today.

The introduction of tractor power greatly altered cropping systems on dryland farms. When horses provided farm power, a portion of the farm needed to remain in forage and pasture production. This use protected vulnerable lands from erosion and could be rotated through fields to improve their fertility. The smaller farms of the horse era often had livestock enterprises such as cattle, sheep, or hogs, for diversification and home use. These livestock further justified the use of perennial grasses and legumes in the cropping system. When tractors replaced horses, the forage acreage was converted to grain cropping on most farms. The loss of the soil-building rotations, and the annual cultivation of fragile lands added to the soil erosion problems of the region.

Rotations in the wheat-fallow area. A wheat-fallow rotation is still used on the largest acreage of dryland farms in the region. Where the winter is not too severe, farmers plant winter wheat. Winter wheat generally has a higher potential yield than spring wheat due to greater use of stored soil moisture and because flowering occurs before periods of excessive heat. But unusually cold weather can kill a winter wheat crop, requiring farmers to replant in the spring. Winter wheat is almost universally used by farmers in the Pacific Northwest, Utah, southeast Wyoming, and north-central Montana, while spring wheat is more common in eastern Montana and at higher elevations in all states.

The wheat-fallow system stores two seasons of moisture for use by one crop. This has been the key strategy for raising crops in dry areas, especially in areas with winter precipitation. Where soils are shallow (e.g., 18-24 inches deep in the Pacific Northwest), the profile may be normally recharged each year even under low precipitation; some farmers

use annual cropping in these areas. But fallow does maintain moisture near the soil surface, which allows for timely planting and germination of fall crops such as winter wheat.

Farmers and researchers in Montana and Wyoming are experimenting with rotations that reduce or eliminate summer fallow. One system is modeled after the ley farming system used in Australia, where an annual legume (medic or clover) is alternated with wheat. The legume fixes nitrogen, provides ground cover, and can be used for pasture and green manure. In Montana, over twenty legumes have been evaluated for their potential use in such a system. The legumes are mostly annuals with shallow roots and low water consumption. Initial results indicate that soil moisture in the spring following legumes is no different than after fallow.

In moving away from a wheat–fallow system, Montana farmers are trying rotations that include spring barley, lentil, several types of pea, flax, buckwheat, and oilseeds. The rotations are typically complex and are continually adjusted to reflect current weather and market conditions. Farmers who raise cattle as well as crops can incorporate perennial grasses into the rotation. Farmers using more diverse rotations must search out markets for minor crops and may find conflicts with government commodity programs. But they report favorable changes in terms of lower weed pressure, lower costs for fertilizer, better soil tilth, and less soil erosion.

In general, modern farming practices have improved moisture conservation to the point where an alternating crop–fallow system is not always necessary. For example, planting decisions are based on the presence of adequate soil moisture with the flex-cropping system. Practices such as grass barrier strips and stubble retention over

the winter capture more snow and can increase moisture storage enough to allow more annual cropping.

There are fewer opportunities to modify the wheat–fallow system in the drier areas of the Pacific Northwest than in the Northern Plains. While mean annual precipitation may be similar, the distribution pattern is very different. With the winter rainfall pattern, Pacific Northwest farmers must be sure there is enough seed zone moisture in the early fall to allow timely planting of winter wheat. Since the probability of summer precipitation is low, summer fallow is crucial for keeping soil moisture near the surface. Crops that replace fallow, such as the legumes used in Montana, may not greatly affect total moisture available for the wheat crop, but they will dry the soil to a depth below that needed for fall seeding.

Researchers at Pendleton, Oregon, have proposed a strategy similar to the flex-crop system. They encourage annual cropping, with the choice of winter or spring planting dependent on soil moisture conditions. A farmer near Walla Walla, Washington, has been experimenting with continuous no-till hard red spring wheat in an 8-10 inch rainfall area with sandy soils. He compared net returns from this system to



The rodweeder is an important moisture conservation tool

his normal wheat-fallow rotation over several years and found the continuous cropping to be more profitable. Any system that relies on continuous wheat or cereal cropping faces many potential problems, but periodic use of this approach within a wheat-fallow system offers possibilities.

The use of perennial grass in a wheat-fallow system is another option. Many farmers use the Conservation Reserve Program (CRP) as a way to maintain income from a perennial grass stand. A farmer near Waitsburg, Washington, in a 14-16 inch rainfall zone includes three years of intermediate wheat grass after three or four wheat-fallow cycles. He finds yield benefits of 7-10 bu/ac in the following three wheat crops. He harvests the grass seed for sale when the market is good, or for his own use in replanting other acres. Drought-tolerant oilseeds such as safflower and canola fit well in a wheat-fallow rotation. Farmers replace small acreages of wheat with oilseed in a crop-fallow system. The oilseeds have beneficial rotation effects by increasing the interval between wheat crops. Production practices are very similar for winter canola and winter wheat, and markets for canola are expanding.

Areas in the Pacific Northwest receiving 14-18 inches of annual precipitation are considered to be transitional between strict wheat-fallow and annual cropping. Many growers have shifted from a wheat-fallow system to winter wheat-spring barley-fallow. This reduces the amount of fallow land by one-third, which benefits soil conservation. This rotation also helps control problem weeds and diseases. Other crops with potential for this zone are small red lentils, winter lentils, and desi chickpeas. They are relatively drought tolerant, but a lack of weed control options and firm markets are slowing their expanded use.

Rotations in the annual crop area. Annual cropping is standard practice in the Inland Pacific Northwest where annual precipitation exceeds 18 inches. Growers still use summer fallow, primarily on set-aside acres. Fallow is not needed for moisture conservation since the soil is normally recharged every year. The most common rotation is winter wheat-spring pulse (pea or lentil). But researchers and farmers have found benefits in yields, disease control,

weed suppression, and profitability in moving to a three-year rotation such as winter wheat-spring barley-spring pea. In certain areas, lentils are traditionally grown more frequently than peas. Chickpeas are also being tried as another legume cash crop.

Earlier this century, rotations that included a soil-building phase were common. Biennial sweetclover was a popular choice that only removed a field from grain production for one year. Several years of alfalfa provided the greatest benefit to the soil, and some income could be derived from hay production. Perennial grasses were used on the more fragile lands and they were grain-cropped only for short intervals.

A few growers continue to use these rotations, and recent economic analyses indicate that they perform comparably to the standard rotations, with fewer potential environmental problems. One grower near Lewiston, Idaho, uses a rotation of winter wheat-spring pea-winter wheat-spring pea seeded with red-clover red clover green manure. Austrian winter pea is another popular green manure crop that can be planted in the fall. Other farmers use a winter wheat-spring grain-green manure rotation.

Continuous wheat systems are being tested by farmers and researchers. No-till continuous wheat controls erosion very well and can be profitable. But farmers find it necessary to burn the wheat stubble to avoid serious problems with diseases and weeds. Future restrictions on field burning will discourage the use of no-till continuous wheat.

A number of farmers in the annual crop region produce grass seed. It is a premier crop for soil conservation, but volatile prices make it economically risky. Growers using grass keep a stand for 7-10 years, and then raise grain crops for 10-20 years. By killing the grass with herbicides, growers can no-till plant into the dead sod and minimize soil erosion associated with plowed sod.

Canola (or rapeseed) is another rotation option. Winter canola must be preceded by summer fallow in order to achieve germination with an August planting. A few growers are experimenting with recropping canola right after a grain, and they have even tried aerial seeding canola into wheat just prior to harvest. Timely

rains are critical to the success of this practice. Weed control and erosion control are both excellent with winter canola. Spring canola yields considerably less than winter canola, but its use helps diversify spring crops. Growers report that soil structure and tilth are improved from the root system of canola.

Government programs. The federal government has instituted a steady stream of commodity programs and rules over the past 50 years. These programs have attempted to regulate the supply of major farm products, including grains, and to help stabilize farm income in the process. The programs have impacted the nature of dryland cropping systems in the region. They have encouraged the intensive production of subsidised crops, and discouraged many resource-conserving practices such as flex-cropping, perennial grasses, and alternative rotations in general. Cropping systems in Canada, where government programs are not based on historic acreages and yields, are often more diverse and innovative than their counterparts across the border.

Legislators are now being encouraged to design commodity programs more in concert with conservation programs. This has not been the case in the past. Many farmers feel frustration with the conflicting messages they receive from the government, and they cite commodity programs as a major barrier to further resource conservation. In discussing sustainable agriculture for dryland regions, the role of commodity programs must be addressed since wheat, the primary crop, is included in the program. The programs chosen by Congress directly impact the cropping systems that farmers choose, and are a powerful force that affects farm income, resource conservation, and rural communities.

Organic farming. Organic farming is one possible approach to increasing agricultural sustainability. Organic systems are strictly defined by the types of inputs they can and cannot use. Both state and private organic certification programs exist to regulate the farms and guarantee the product to consumers. Synthetic fertilizers and pesticides are excluded, and use of diverse crop rotations, animal and green manures, and mechanical and biological pest control are required. Interactions among

all parts of the farm are considered to be as crucial as individual practices, and recent research supports this idea.

The dryland environment poses many challenges to organic farmers due to the moisture constraint. Yet a number of large, commercial organic grain farms exist in the region. The geographic distribution is not uniform, however. The Pacific Northwest has only a small acreage of commercial dryland organic grain production. No dryland farm is entirely under organic management. Typically, growers manage selected fields for several years according to the certification rules, and then rotate them back into conventional production. Weed control and nitrogen fertility are two major constraints. In contrast, a growing number of dryland grain farmers in the Northern Plains are succeeding with organic management. Their farms range from 200-3000 acres in size. These farmers follow practices that meet certification requirements so they can capture premium prices for their products, where possible. Their rotations are very complex with minimal summer fallow, while neighboring farmers continue to rely on a wheat-fallow system.

As with conventional farming, organic farmers cite crop rotation as one of the key elements for success. A suitable crop rotation helps maintain soil fertility, suppresses weed, disease, and insect pest problems, lowers risk through diversification, maximizes biological interactions, and minimizes production expenses. Soil fertility is enhanced with legumes, nutrient accumulator plants such as buckwheat, ground rock minerals, and foliar sprays. Soil-building rotations increase organic matter levels, which adds fertility and water storage capacity. Tillage, rotation, and crop competition suppress weeds. Purchased inputs are minimal, and budget analyses have shown variable costs for organically grown wheat to be as low as \$30/ac, compared to about \$68/ac for a conventional farm.

Organic farms are a valuable information resource for all farms in the region. Certain aspects of organic farm production can be readily adapted to other farms. For example, conventional farmers can adopt the rotations and green manures used by organic farmers without other changes. More importantly, organic farms are living laboratories. They



Federal farm program agencies

pose numerous questions for further research and contain biological interactions not found on conventional farms. For example, unique insights on weed dynamics and control can be gained from farms which have not used herbicides for many years, but have used other weed control strategies.

Organic farming is not a panacea for sustainable agriculture. It requires a high level of commitment and management, including marketing activities. Like other farms, organic farms can suffer soil erosion unless proper conservation measures are taken. The markets offering premium prices are small, but production costs for cereals are also low. The diversity of experience among organic growers further contributes to the possibilities for making dryland farming more sustainable.

Tillage and Equipment

Tillage has always been an essential component of dryland farming. It serves several purposes, including seedbed preparation, moisture conservation, weed control, and modification of soil physical conditions. Plows were needed to kill the native grasses and expose the soil for planting. Prior to herbicides, tillage was the primary tool for weed control. Tillage implements such as subsoilers attempt to improve water infiltration and storage by

breaking up compacted or impermeable layers. This can also decrease soil erosion potential. And in a wheat-fallow system, conservation of stored soil moisture has been achieved through numerous surface tillage operations.

But there are several undesirable consequences of tillage. It is probably responsible for more soil degradation in the region than any other human activity. Each tillage operation exposes more of the soil to accelerated decomposition of soil organic matter. This lowers the inherent soil fertility and makes the soil more susceptible to erosion. Tillage normally breaks down and buries surface crop residues and degrades soil structure, again increasing the erosion potential. On sloping lands, most tillage operations move soil downhill, accelerating

soil loss from hilltops through tillage erosion. Thus, it is not surprising that both researchers and farmers have focused much of their attention on reducing the negative impacts of tillage in dryland agriculture.

The moldboard plow has been the standard primary tillage tool for over a century. It was crucial for breaking up the native sod. It buries crop residues, making seedbed preparation and seeding easier, but leaving bare soil exposed to erosion. The burying action helps minimize certain diseases and weeds. When the furrow is thrown downhill, the amount of soil moved by tillage erosion can be large. But many growers who still use a moldboard plow throw the furrow uphill, and they contend it is the only tool other than a dump truck that can reverse downslope soil movement.

Another key tillage implement that is unique to dryland farming is the rodweeder. This device consists of a rotating square metal rod that is pulled at a shallow depth through the soil to uproot weeds and create a dust mulch which breaks the capillary action of the soil. Silt loam soils in particular can lose tremendous amounts of moisture to evaporation through capillary action. Weeds also extract much stored soil moisture if left unchecked. Thus, the practice of "dust mulching" in a wheat-fallow system was developed to con-

serve moisture, and the rodweeder was invented to do the job. But repeated rodweeding pulverizes soil structure and increases erosion potential during summer fallow and in the subsequent wheat crop.

As farm equipment has become larger and heavier, the potential for soil compaction has increased. The greatest problem occurs on wet soils, conditions more common to spring crops. Tillage will alleviate compaction in the tillage zone. But the extent of compaction deeper than that, and the impact on crop growth, is not well established.

Conservation tillage. In the 1930s, concern over soil erosion captured national attention. Soil conservation research was greatly expanded, and it continues today. The development of conservation tillage systems was a major result. Conservation tillage refers to a broad set of farm practices, singly and in combination, that maintain agronomically suitable conditions for a crop while reducing the potential for soil erosion and water contamination. Two dryland farms seldom have identical systems, but growers increasingly use some common principles and practices to conserve soil and water.

Conservation tillage relies on several basic ideas. Minimizing the number of tillage operations helps retain soil structure, organic matter, and surface residues. Operating costs for the farmer are generally lower with reduced tillage. Surface residue retention is increased through less inversion tillage (e.g., moldboard plow or large disc), choice of higher residue crops, or no-till planting. Where primary tillage is needed, a chisel plow or sweep plow is preferred. Certain implements leave a rougher soil surface, which also reduces erosion.

Another practice being evaluated is chemical fallow. Nonselective herbicides such as glyphosate replace one or more tillage operations. Chem-fallow no-till systems are conserving more moisture and drastically reducing soil erosion in certain areas. But on many of the soils in the region, some tillage is needed during the fallow period to break the capillary action. Partial chemical fallow, where the initial tillage is delayed until late spring, has become a popular practice. It improves weed control, water storage, and residue retention, but still maintains seed zone moisture with tillage. As

the cost of nonselective herbicides decreases, chem-fallow systems are becoming more economically attractive. The impacts of increased herbicide use must be balanced with reduction in soil erosion when assessing its net effect on sustainability.

In certain areas, conservation tillage systems must also address special soil problems such as restrictive layers or frozen soil conditions. Farmers in eastern Washington find fall chisel plowing to be helpful. Various subsoiling tools can deeply fracture the soil to increase water and root penetration. A slot-mulch machine was invented by USDA researchers to create a straw-filled trench on the contour that remains open to infiltration when the topsoil is frozen. The Dammer-Diker implement creates surface pitting with small basins, or infiltration reservoirs, every few feet to slow runoff and erosion. The subsoil/ridger tool forms a ridge of soil mixed with straw over a deep chisel mark to improve infiltration and residue decomposition.

Through the innovation of dryland farmers, researchers, and private industry, a large number of conservation tillage tools and systems are available today. These include no-till drills, one-pass drills, and shank and seed systems. And new options are still being developed.

Research in the Northwest dryland region clearly shows that **those practices that minimize soil erosion tend to maximize water conservation.** The additional stored moisture increases the potential productivity. Conservation tillage systems achieve this by reducing the number and severity of tillage operations and maximizing the surface residue, thus benefitting both farm profitability and environmental protection.

Fertility Management

Most of the soils of the Northwest dryland region were very fertile when the first settlers plowed up the sod and began to farm. Soil organic matter levels as high as 8% were reported. Gradually, the effects of tillage, erosion, and crop harvest depleted the native fertility, and farmers and researchers explored strategies to provide more crop nutrients. In the 1920s and 1930s, green manure crops, such as sweetclover, became commonplace and led

to substantial improvements in wheat yields where moisture competition was not a problem. Once fossil-fuel based nitrogen fertilizers became widely available and inexpensive after World War II, green manure use faded. Over time, research and experience indicated a need to add sulfur and phosphorus to many soils.

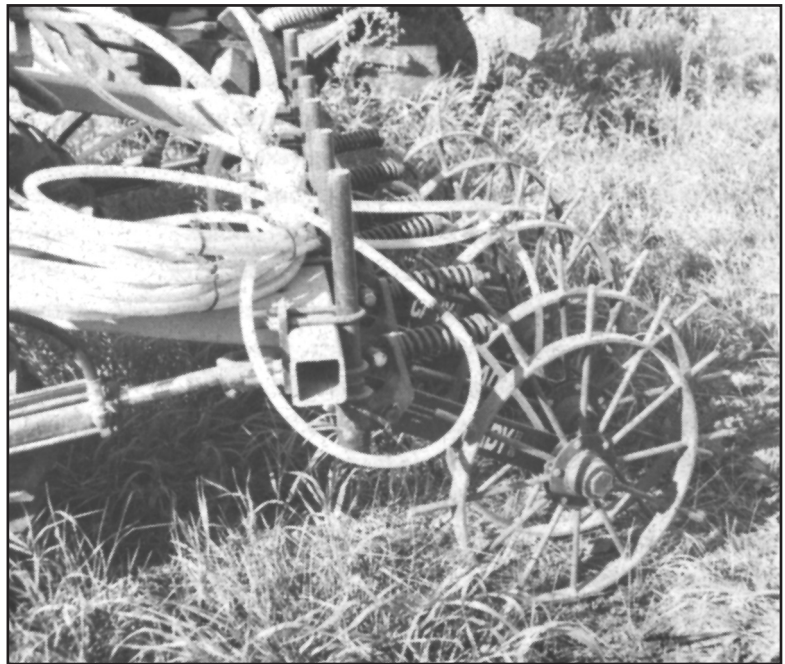
Fertilizer has been one of the best investments for a dryland grain farmer over the years. However, rising fertilizer prices in the 1970s and increasing concerns about water quality have spurred a closer examination of fertilizer use. Many fertilizers are also produced from nonrenewable resources. While it is unlikely that fertility inputs can be eliminated in a cropping system that exports large quantities of nutrients, fertility management can be improved through more efficient application, better soil testing, and return of more organic residues to the soil.

Organic matter management. Soil organic matter (SOM) plays a major role in the physical, chemical, and biological nature of a soil. SOM helps to create and maintain favorable soil structure. This benefits water infiltration, soil aggregation, root penetration, tractor fuel economy, and erosion control. The water-holding capacity of a soil increases with increasing SOM levels. About 95% of the nitrogen in the soil is stored in SOM, and 2-4% of this is made available to plants each year by soil microbes. SOM also can release significant amounts of phosphorus and sulfur for crop use. SOM adds to the cation exchange capacity of a soil, which affects the nutrient-supplying power. The biological activity of the soil is directly linked to SOM levels, influencing residue decomposition, nutrient availability, disease problems, and other factors.

Intensive tillage stimulates the loss of organic matter. Thus, reduced tillage slows the loss of organic matter and even reverses it when more plant or animal residues are retained or added. According to results from long-term plots at Pendleton, Oregon, annual cropping conserves more SOM than fallow systems due to greater

residue additions, while burning straw accelerates SOM decline.

Nitrogen. As the native soil fertility declined in the region, cereal crops began to suffer from nitrogen (N) deficiency. Cereals demand more N than other plant nutrients for high yields, as it is a major component of the protein in grain. Crop yields respond to N fertilization on most soils in the region. The N can come from organic (manure, green manure) or inorganic (commercial fertilizer) sources. Most commercial N fertilizers require substantial amounts of fossil fuel (usually natural gas) for production. But they are relatively inexpensive and widely available. The N fertilizers most commonly used are ammonium-based materials, especially anhydrous ammonia (82% N). These fertilizers are quickly converted to the plant-available nitrate form by soil microbes if the soil is moist and warmer than 45°F. Plants can use either the ammonium or nitrate form, and may actually prefer a mixture of both. Nitrate is very mobile in the soil and easily leaches out with water moving downward or laterally in a field. Slow-release formulations of N and split fertilizer applications can help reduce leaching and N losses.



A point injector for improving N efficiency

Unfortunately, ammonium-based fertilizers make soils more acid. The soil pH in the dryland Pacific Northwest has declined in direct proportion to the cumulative amount of fertilizer N applied historically. Since the higher rainfall areas have a higher yield potential, they have received the highest N applications. This, coupled with the lower native soil pH, has significantly acidified the soil. Wheat can generally tolerate pH to about 5.4, but legumes such as peas, lentils or clover need a pH greater than 5.6. Liming is not considered economical, but the subtle side effects of a lower pH, such as more disease and weed problems, may cost more than is now realized.

Since N fertilizer is relatively cheap, farmers have been rewarded for using an "insurance" approach to their N management. They have often fertilized for their best yields rather than their average yields, hoping for good moisture conditions. Without more precise weather prediction for a growing season, it is difficult to dramatically improve the precision of fertilizer rates. But high residual soil levels indicate that much fertilizer is being wasted, and studies are examining the movement of N to streams and groundwater. Setting realistic yield goals, based on soil moisture and historic precipitation, would help achieve improved N fertilizer management. This, coupled with better fertilizer placement, formulations, and timing, can increase fertilizer efficiency and help prevent environmental problems due to excess N.

Legumes fix their own nitrogen from the atmosphere and are a renewable source of N. The term "green manure" refers to a crop grown solely for its soil fertility benefit. Legumes are often used as green manures because they add new nitrogen to the system. In annual cropping areas, a cash crop is sacrificed when a green manure is grown. But in wheat-fallow areas such as Montana, farmers and researchers are exploring the use of green manures to replace fallow. This cuts fertilizer costs while improving soil conservation. The biggest problem is moisture use by a green manure that can reduce yields in the subsequent crop. While green manures are often a more expensive source of N than fertilizers, they do more than add N. They can improve soil structure, increase SOM, and inhibit certain

weeds or diseases. Assigning economic values to these benefits is difficult. However, those farmers still using green manures find them to be a profitable practice in the long run.

A green manure can often replace most or all of the N fertilizer normally used by a cereal crop, despite the fact that no more than 10-20% of the N in the green manure is actually used by the cereal the first year. The N replacement value of the green manure exceeds its actual N contribution due to "rotation effects." These loosely refer to biological or physical benefits to the cereal crop from the green manure that improve yields.

Other nutrients and soil amendments. The soils in this region generally contain sufficient levels of most nutrients, other than nitrogen, for crop production. One exception is the widespread need for phosphorus (P) on Montana soils. Crop responses to added sulfur (S) are also now common, as this nutrient is used with nitrogen to make protein. Canola needs high S levels. Phosphorus deficiency is showing up on eroded areas in the Pacific Northwest. Substantial amounts of P are lost in the organic matter of topsoil, and the lower biological activity in the remaining soil further reduces P availability.

Most soils contain adequate potassium, calcium, and magnesium. There is debate about the importance of the ratios of calcium and magnesium. Certain soil testing services recommend achieving a specified balance. Researchers are currently trying to verify farmer reports about the positive benefits from this balancing.

Fertilizer companies and consultants increasingly suggest that farmers use micro nutrients, which are applied in small amounts as foliar sprays. Growers are exploring the need for zinc on wheat and boron on canola. Several seed treatments containing micro nutrients are also available. While micronutrient deficiencies are well documented for legumes (e.g., molybdenum), less is known about their importance in cereals. Other products are often applied with micronutrients to enhance plant growth. These may be seaweed materials, wetting agents, enzymes, or other formulations. Several farmers report a significant reduction in the use of commercial fertilizer and some pesticides

where they have used nontraditional fertility products. Growers are encouraged to carefully evaluate any new products in replicated on-farm tests for several years to determine their effectiveness.

Improving management. Researchers have intensively studied fertilization practices, especially for N, for decades. Yet the actual management of soil fertility is relatively crude. One problem lies with soil testing. A recent survey of dryland farmers in the Palouse region indicated that about half of them did regular soil testing and based their fertilization on the results. But many farmers report frustration with soil testing, complaining that the reports are hard to read and understand. Results can be highly variable from year to year in the same field. Fertilizer recommendations for the same test results can differ dramatically. Soil testing should be used along with a grower's experience. But when regular tests are taken from a field, and the results kept on file, this history can be used to improve fertility management.

Another problem faced by farmers is the great soil variability within many fields that are fertilized uniformly. An eroded ridgetop has quite different yield and fertility needs than a fertile bottomland. The concept of variable field management, especially for fertility, is receiving much attention. As the appropriate knowledge base and tools are developed, farmers will be able to vary fertilizer rates to match soil conditions while in the field. This may reduce fertilizer costs and the potential for contamination from excessive fertilization on certain parts of the landscape.

Other diagnostic tools can be used to refine fertility management. Tissue and grain analysis can help determine if nutrient levels are in the optimum ranges. Excess protein in soft white wheat is often due to over fertilization with N. Novel tools such as the refractometer are being tested by growers for monitoring plant "health." Infrared aerial photos can help spot crop stress and different yield potentials within a field. But our ability to improve fertilizer management will ultimately be limited by our inability to predict the moisture supply for a crop in the highly variable dryland climate.

As long as farm products are exported from the region, nutrient inputs will be needed

by dryland farmers. For example, an 80-bushel wheat crop at 10% protein will remove 77 pounds of N per acre in the harvested grain. Long-term nutrient removal without fertility inputs can degrade the soil. Dryland cereal farming can become more sustainable by improving the three "R's" of fertility management—reduce (erosion, leaching, over fertilization), recycle (crop residues, soil nutrients), and renew (organic matter, fertilizer, nitrogen fixation). More and more growers are doing just that.

Pest Management

Dryland farmers face significant pest problems from weeds, diseases, and insects. Average precipitation and annual weather patterns both influence pests. Certain pests thrive in dry conditions while others prefer a moist environment. But a healthy, vigorously growing crop is the universal first line of defense. Pest-resistant crop varieties are the second line of defense. A healthy crop can crowd out weeds and outgrow many insect and disease pests. Management practices that prevent plant stress due to moisture or fertility problems also help control pests.

Weeds. Weeds are usually highly competitive invasive species well adapted to disturbed conditions. The greatest threat to a crop from weeds is generally in the first 30-60 days of growth. If a crop can be kept relatively free of weeds during this period, it will out compete them.

All weeds were not created equal. Thus, weed control strategies should consider the individual nature of each species. Some weeds are very well adapted to the typical dryland cereal cropping system (e.g., wild oat, kochia, Russian thistle) and will lower crop yields, while others may be present but pose little economic threat. Others can become a problem very quickly (downy brome) or are very tough to control once established (field bindweed). Jointed goat grass is a weed that is genetically similar to winter wheat. It thrives under conditions where wheat thrives, and will only be killed by herbicides that also kill wheat. Constant monitoring of weeds is crucial to a successful weed management program.

While herbicides may be regarded as the most important tool for weed control today, many other cultural practices contribute to overall weed control. Farmers should use weed-free seed. Crop rotation is an effective weed control strategy when crops with a life cycle different than the weed are grown. For example, downy brome is a winter annual plant much like winter wheat. Planting spring crops such as barley in rotation can reduce downy brome problems. Farmers in eastern Washington have reduced weed problems by shifting from a wheat-pea to a wheat-barley-pea rotation in the annual cropping area, or from winter wheat-fallow to winter wheat-spring barley-fallow in the drier areas. Significant increases in weeds occur in crops that are uncompetitive or that do not have effective herbicide controls, such as peas. Several growers using green manures report decreased weed problems in those rotations.

Tillage practices can reduce weed problems by burying or exposing weed seeds. Weed seed that does not survive long in the soil can be killed by burial with a moldboard plow. But this same tillage may bring long-lived seeds to the surface where they can finally germinate. Conservation tillage systems, particularly in short or continuous cereal rotations, have been very weedy in the early years, but weed problems often diminish over time. Organic farmers who do not use herbicides may lightly till a crop after planting, sometimes with special harrows for this purpose. In erosion-prone areas, substituting more tillage for herbicides must be balanced against soil conservation needs. Summer fallow with intensive tillage is an effective weed control strategy that also increases soil erosion.

Fertilization practices affect weeds. Deep banding fertilizer near the seed row helps get more nutrients to the crop and less to the weeds. Broadcasting fertilizer increases certain weed problems, particularly grass weeds such as wild oat and downy brome. A nutrient-deficient crop is not as competitive as a well-fertilized crop, resulting in increased weed competition. Soil tilth may also be a factor. Growers report that soil compaction appears conducive to certain weed species such as bindweed.

Herbicides can be grouped according to their potential for leaching and their per-

sistence in soil. Thus, if two compounds are equally effective in controlling weeds, a farmer can choose the one with the least potential for environmental problems. Current pesticide application equipment is quite inefficient. A large percent of the material is not applied to the target pest. Improved equipment is being designed to help lower application rates, improve herbicide effectiveness, and reduce drift. Sticker/spreaders and other spray adjuvants are commonly used to increase the effectiveness of herbicides and reduce rates. Many growers are experimenting with reduced rates for cost control. Novel approaches such as spray water acidified with vinegar are being tested. By scouting fields for weeds, farmers can vary herbicide application according to the actual weed problem present. Recommendations for herbicide choice and use can be obtained from local county extension offices.

With increased environmental concerns, biological control strategies for weeds are receiving more attention. Several rangeland weeds have been successfully controlled with introduced insects that feed only on that weed, such as Klamath weed and tansy ragwort. This strategy is more difficult to implement in an annual cropping system since the habitat for the biocontrol insects is often destroyed each year. One possible solution is to leave buffer strips in fields to provide suitable habitat for the beneficial insects. Researchers are examining the potential for microbial herbicides. They first identify naturally occurring disease organisms that attack a specific weed. A spray is then made of the organisms and applied to the field to suppress or kill weeds. Much testing is needed to insure the disease affects only the target. Microbes may be useful below ground as well. Researchers have identified naturally occurring bacteria (*Pseudomonads*) in eastern Washington wheat fields that suppress downy brome in wheat. Problems with field application have not yet been resolved.

Weeds are the most obvious pest problem for dryland farmers, and control is costly. Do-nothing weed control is a recipe for disaster. Sustainable agriculture relies on internal, biological controls for both economic and environmental reasons. Long-term studies, such as the Integrated Weed Management project at Pullman, Washington, are providing impor-

tant biological and economic data on whole cropping systems. Much remains to be learned about the weed ecology in a complex cereal/legume rotation. Those farms that use little or no herbicides and successfully control weeds offer a special opportunity to learn more about nonchemical weed control mechanisms.

Diseases. Dryland farmers must contend with several potentially serious crop diseases. Some are soil borne, others spread through the air, by insects, or on seed. Some attack the foliage, others the roots. Several diseases can attack more than one crop in a rotation. Strategies that reduce the potential for one disease may increase it for another. The effects of diseases are often slow to develop and hard to recognize, so they receive less attention by many farmers than weeds. Yet their impacts can be devastating. Crop breeders have developed varieties resistant to certain diseases, notably rusts, footrot, and grain smuts. Breeding for disease resistance is an ongoing process since the diseases are constantly evolving as well. But selection of an adapted, resistant variety is a good first step in disease management. Also, for seed borne diseases, growers should only buy seed that is certified disease free.

Researchers are examining the potential for biological control of diseases. One strategy is the inoculation of seed with "friendly" organisms that prevent diseases from attacking roots. Most crop seeds are currently treated with fungicide to ward off diseases, and seed treatment with other control materials offers a convenient approach to disease control.

Crop rotation is another key element in disease control. In areas restricted to crop-fallow, periodic substitution of canola for winter wheat can have a positive effect, since canola is from a plant family that does not host many cereal diseases. A wheat-barley-pea rotation in the Palouse region has less disease problems than a wheat-pea rotation. Several farmers using green manures in rotation report minimal disease problems in the wheat after green manure, alleviating the need for fungicide.

Crop residues are an important food source for many soilborne diseases. Field burning is an effective sanitation technique for disease control, but it degrades air quality and reduces soil organic matter and long-term

soil productivity. Conservation tillage systems leave more residues on the surface and near the seed. This has exacerbated certain disease problems in short crop rotations. The residues feed the disease organisms and mulch the soil, creating ideal conditions for diseases such as Rhizoctonia root rot, Pythium root rot, and Take-all. Research has shown that no-till drills with a fertilizer shank in and below the seed row provide enough soil disturbance to minimize Rhizoctonia problems present in many no-till systems. Also, when herbicides are used to kill volunteer cereals before planting, a minimum 2-3 week waiting period is recommended to allow the proliferation and decline of disease organisms feeding on dying roots.

Soil conditions affect disease problems. Compacted soils often have more diseases due to lack of oxygen. Crop roots are weakened under these conditions, enhancing diseases such as Pythium and Fusarium foot rot. Adding animal manure in long-term plots near Pendleton, Oregon, suppressed disease. An increase in the general soil microbial population may help to out compete disease organisms. As soils become more acid, Pythium root rot and Cephalosporium stripe become more severe, while Take-all is inhibited. Thus, judicious use of acid-forming fertilizers can play a role in disease management.

Changes in disease problems should prompt closer investigation by a grower. While effective fungicide treatments are available for many diseases, they are expensive and can potentially contaminate the environment. Diseases can develop resistance to certain chemicals, such as *Pseudocercospora* (strawbreaker footrot) resistance to benomyl. A decline in disease problems may signal improved biological functioning of the cropping system, an indication of sustainability.

Insects. Compared to many horticultural crops, dryland crops are relatively free of insect pests. But as in any monoculture, once a pest settles in a field, serious damage can escalate quickly. Farmers are subject to the arrival of new pests as well. This occurred in the past decade with the Russian wheat aphid, which spread across the United States in less than two years after its initial discovery in Texas. Many alternate crops have serious insect pest

problems and require more control measures than cereals. For example, canola grown in eastern Washington is almost always sprayed with parathion to control the cabbage seed pod weevil. This highly toxic chemical is losing its registration, so alternative control measures must be developed.

Several types of aphids feed on cereals in the region. They seldom cause economic damage, although they can transmit barley yellow dwarf virus to cereals, reducing yields. The Russian wheat aphid causes the most damage to water-stressed plants, which frequently occurs with spring wheat or barley. But seasonal weather patterns markedly affect its development, and control may not be needed in wetter years.

Aphids are chronic pests of peas and can transmit several pea virus diseases as well. Weevils can damage peas and lentils. Pea growers normally treat their crop with an insecticide. Grasshoppers occasionally damage all crops as well.

As with diseases, resistant crop varieties offer one insect management strategy. Damage by the sawfly in Montana has been greatly reduced by use of resistant cereal crop varieties. Breeders are working on developing cereal varieties resistant to Hessian fly (e.g., Wakanz) and Russian wheat aphid.

The release of biological control agents shows promise, but it involves a lengthy process of testing, particularly if the agent is not native to the United States. Researchers are field-testing several parasitoids and predators for the Russian wheat aphid. *Nosema locustae*, a naturally occurring disease organism of grasshoppers, is an effective alternative to chemical insecticides.

Insect pests can be affected by crop management. Researchers have found that conservation tillage reduces the attraction of greenbug to cereal crops. This appears to be due to a difference in the light reflected from the ground when crop residue is present on the surface. A grower near Spokane, Washington, observed that aphids did not enter a field intercropped with barley and peas, while they readily fed on an adjoining pea field. In contrast, farmers near Lewiston, Idaho, are finding increases in Hessian fly damage in conservation farming systems with higher surface residues.

The shrinking number of chemical insecticide choices, particularly for minor crops, will hopefully spur the development of new biocontrols and other control practices for the insect pests of dryland farming. Biotechnology may provide opportunities to increase crop resistance and to tailor biocontrols such as *Bacillus thuringiensis* to the cropping systems of the region. In the long run, innovative redesign of our dryland cropping systems may provide the best avenue for insect management.

Resource Conservation

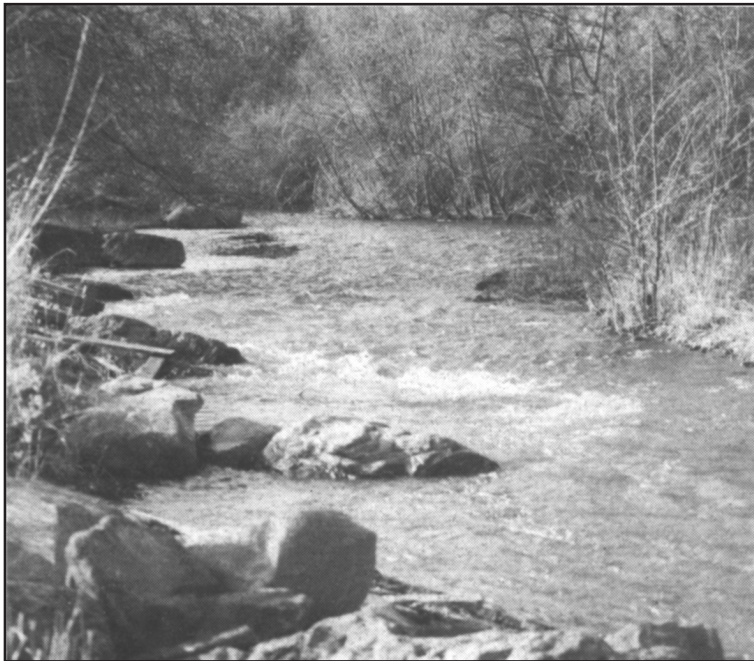
Agriculture relies on a broad resource base to remain viable, including biological, physical, and human resources. Agriculture can only be sustained by conserving and improving its resource base. Specific farming practices must be considered for their agronomic value as well as their role in sustainability.

Energy. The primary purpose of agriculture is to convert solar energy into food or fiber. At present, virtually all modern farming systems, conventional or organic, rely heavily on fossil fuel inputs to accomplish this conversion. Farmers are making great strides in improving the efficiency of fossil energy use in agriculture. Conservation tillage reduces fuel use. Legumes replace energy-intensive nitrogen fertilizers. Drip irrigation reduces electricity use by pumps. But most systems would fail if fossil energy sources were no longer available. Energy sustainability is more evident on Amish or developing country farms, but these systems are not feasible for dryland farmers in the Northwest. Nonetheless, farmers must continue to reduce their reliance on fossil fuels as much as possible.

Energy efficiency provides a better yardstick of sustainability than yield or worker productivity. Crop yields per person-year have dramatically increased due to large infusions of fossil fuels. A better indicator of the use of nonrenewable resources is the energy input per pound of crop produced. One study in eastern Washington compared similarly sized conventional and alternative dryland grain farms for their output and energy use. The alternative farms used fewer purchased inputs and more complex rotations with legumes, resulting in a 25% reduction in energy use. Soil conserva-

tion helps conserve energy since more energy (about 12 gallons of fossil fuel energy-equivalent per acre) is needed to maintain current productivity on a field for each inch of soil lost to erosion. Average wheat yields have steadily increased in the Palouse region despite serious soil losses, due in part to increasing fossil fuel inputs.

Soil conservation. In his 1937 report entitled "Conquest of the Land Through Seven Thousand Years," W.C. Lowdermilk (1975) catalogues the numerous past civilizations that fell due to deterioration of the soil. For over fifty years, our nation has worked to reduce soil erosion, but the problem is still serious. Wes



Farmers are striving to protect water resources

Jackson, a researcher studying prairie ecosystems in Kansas, talks of the problem of agriculture, rather than problems in agriculture. He implies that systems reliant on annual crops and tillage will always degrade the soil in fragile regions, such as drylands. Jackson has proposed a "perennial polyculture" as a future alternative. There is a wide spectrum of opinion about soil conservation strategy that ranges from "trying harder" to a radical redesign of how we produce food.

Many time-tested soil conservation practices are available to farmers. They include conservation tillage; rotations with high residue, green manure, or perennial crops; strip cropping; windbreaks; and conservation structures (e.g., terraces). Practices that conserve soil generally reduce runoff or blowing snow, leading to more storage of moisture in the soil for crop use. Thus, once conservation systems are working, they should pay their way in more stable or increased productivity. But adoption of these practices has been limited in the past due to their real or perceived economic costs and conflicting messages from government commodity programs. Unfortunately, **more attention has been directed toward the cost of soil conservation than toward the cost of erosion.**

The conservation compliance provisions of the 1985 Farm Bill are forcing a base level of soil conservation by farmers to maintain eligibility for commodity support payments. This has spurred innovation and adaptation of technologies and techniques in the dryland region. Major challenges include maintaining adequate surface, residue, farming with higher residue levels, and maintaining profitability where there are added costs for the soil conserving practices.

Perhaps the largest reduction in erosion has come from those highly credible fields planted to perennial grass under the Conservation Reserve Program (CRP). These fields must be in permanent grass cover for 10 years. Once established, the grass eliminates erosion in most cases and it will help restore soil structure and organic matter, leading to less future erosion. Farmers using soil-building rotations are interested in measuring improvements in soil quality that can be credited as part of their conservation program.

In the Northern Plains, some soils are susceptible to the development of saline seep. This problem is a result of the widespread use of a crop-fallow system in which stored soil moisture exceeds crop use. The excess moisture

reaches below the rooting zone, carrying salts with it, until it reaches an impermeable layer and moves laterally through the soil, eventually breaking out on the surface lower on the landscape. Salts are deposited as the water evaporates, reducing soil productivity. Seep areas are difficult or impossible to farm. Crop management strategies that increase moisture use, such as flex-cropping, are essential to prevent and control saline seep. Growing alfalfa can accelerate reclamation of saline seep areas, and is an important soil conservation measure in parts of Montana.

Water conservation. Farming practices affect both the quantity and quality of water resources in dryland regions. Since leaching below the root zone is minimal in a water-efficient dryland cropping system, impacts on surface water are probably more significant than for groundwater. But investigations into groundwater quality and nutrient arid pesticide transfer are beginning to establish baseline information for dryland farming areas. For example, a large amount of lateral flow in the subsoil appears to occur in certain soils of the Palouse region, which redistributes moisture and soluble chemicals across the landscape. Water and chemicals may move off hilltop positions and accumulate in low-lying areas where leaching may occur. Landscape position may need to be considered in future pesticide and nutrient management strategies.

Runoff from snow or rain can carry sediment, nutrients, and pesticides into streams and rivers. While the runoff water helps to maintain minimum streamflows, the contaminants can hurt fish and wildlife, recreation, and reservoirs. Economists estimate that these off-site costs of soil erosion are nearly twice the on-site costs (Moore and Miller, 1987). Where soils are not fully recharged, this lost water also reduces yields. Soil conservation practices reduce runoff and surface water contamination.

Groundwater provides the drinking water for most rural residents in the region, so protecting it is a priority. When nitrates are found in well water, it is very difficult to determine their origin. The risk of contamination depends on the geological conditions, the average precipitation, and the intensity of

agriculture. Irrigated farming appears to pose a higher contamination than dryland farming, but few studies have been done on the water quality impacts of dryland farming.

Atmospheric conditions. The role of agriculture in global climate change and the greenhouse effect is currently the subject of much debate and research. Historically, agriculture has released significant amounts of carbon into the atmosphere as soil organic matter levels have declined. Researchers are now discussing the potential of soil as a sink for CO₂ and effective agricultural practices to accomplish this. Agriculture affects other greenhouse gases, particularly methane and nitrogen compounds. The net impact of farming is not clear. Nitrogen fertilizers and cows have been implicated by several scientists as significant sources. But simple answers are elusive due to the complexity of the global system.

Other impacts of agriculture on the atmosphere are more obvious. Dust from wind erosion is a public health and safety problem. In 1991 alone, dust storms in eastern Washington darkened the sky several times, closing highways and causing numerous car accidents. The dust is acutely harmful to people with respiratory problems. Similarly, controversy surrounds the practice of field burning. Grass seed producers burn fields annually to maintain production. But more farmers are becoming interested in field burning as a production tool, especially in systems such as burn, no-till, continuous wheat, a potentially profitable and soil conserving system. The political and environmental repercussions from expanded field burning will probably limit this practice in the future.

Human resources. Human innovation and motivation are two important renewable on-farm resources that must be encouraged. Farmer innovation has made important contributions to dryland farming techniques. Motivation is tied in part to economic rewards and optimism about the future. Thus, a farming environment that is unprofitable, risky and stressful, and increasingly regulated does not encourage human talent in agriculture.

The human resources necessary to develop a more sustainable agriculture are being

undermined by several pervasive trends—rural depopulation, increased absentee ownership, and continued farm consolidation. Young people leave their rural areas as educational, social, and economic opportunities decline with the continued loss of the population base. The income goals of absentee landowners removed from the complexity of contemporary farming may conflict with stewardship goals of the farmer operator. This can strongly influence the farming practices of an area, since the average farmer in the region now leases over half of his/her farmland. As farms continue to grow in size, resource efficiency may decline. Studies by the Center for Rural Affairs in Nebraska indicate that medium-sized family farms produce the most dollar output per unit of direct resources consumed (Strange, 1988).

Agricultural research and education are under fiscal pressure throughout the region. Programs at land-grant universities are being steadily cut. Ironically, the increased urbanization in the region which reduces political support and funding for agriculture also pressures agriculture to become more sustainable. The role of private, nonprofit groups in supporting

the development of sustainable agriculture has expanded significantly, but their funding is unstable. Publicly-funded land-grant universities need to focus on the problems and practices that will not be addressed by private industry. For example, studies of crop rotation offer little promise of economic return for industry and therefore should be a university priority. In contrast, economic incentives exist for development of herbicide resistant crops.

The nonfarming public has an important role to play in the development of sustainable agriculture. Consumer buying habits are quite influential. Urban legislators represent a large vote that can support policy favorable to sustainable agriculture. New marketing strategies that bring farmers and consumers closer together can benefit both groups. Urban residents desire clean water and air and an aesthetically pleasing rural environment along with abundant, inexpensive, and unblemished food. But a sustainable agriculture cannot exist in a society that is not ecologically sound. The human resources of both farm and city must work, together to fashion a more sustainable society, a truly great challenge.

PROSPECTS FOR SUSTAINABLE DRYLAND FARMING



People, the key resource for sustainability

Sustainability is a long-term goal for agriculture. Unfortunately, a loss of sustainability is much easier to determine than a gain. The moisture constraints in dryland regions limit the options. But farmers can make changes that will increase the sustainability of their operations. Every step in that direction increases the safety margin for our food production systems in light of an unpredictable future and continuing population and resource pressures.

Wheat is the premier crop for dry farming in the region. It is well adapted to the environment, and is more consistently profitable than any other crop, in part due to government subsidies. This has led to a general lack of diversification in the region, prompting numerous studies of alternative crops. Unfortunately, none have been able to compete with wheat. Barley, peas, and lentils are grown on significant acreages, often for rotational benefits for the wheat. Canola and chickpea plantings are currently expanding, and may offer profitable alternatives. However, a crushing plant in the region is necessary to support a significant acreage of oilseed production.

Growers rely on markets outside of the region. Over 80% of the wheat from all six states is exported from Portland and Seattle. The Asian market is crucial for the soft white wheat from the Columbia River region. Pea and lentil markets rely heavily on consumption through Food for Peace program exports.

Much of the interest in oilseeds is based on potential sales to the Asian market. Thus, growers remain heavily influenced by currency exchange rates, transportation charges, foreign quality standards, and the cost of production in other exporting countries. The current loss of pea markets to Canadian producers underscores the vulnerable but crucial nature of export markets.

Sustainability can be improved by increasing the diversity of crop rotations. Farmers in all parts of the dryland Northwest are exploring new crops and combinations. Rotations have positive impacts on pest control and soil fertility. The use of fallow-replacing legumes in the Northern Plains or perennial grass in the Pacific Northwest can help reverse soil degradation. Even in the driest wheat-fallow areas, the use of oilseeds such as canola or safflower can increase the diversity of the rotation. Rotations impart both short- and long-term benefits. Government commodity program rules provide a strong incentive to grow wheat, which can discourage expanded use of more diverse rotations.

Farmers are expanding their use of conservation tillage practices and systems. These efforts pay off in several ways: reduced soil erosion, increased water storage, and lower fuel consumption. Farmers need to continue to fine-tune practices to individual situations. When a conservation farming system is

started, an adjustment period often occurs as the biology of a field seeks a new equilibrium. This poses a degree of risk that has slowed the adoption of conservation tillage in the past. But the conservation compliance mandates of recent farm legislation provide a strong incentive to adopt conservation tillage.

Given the substantial variation within many dryland fields, farmers and researchers are developing practical and cost-effective variable resource management schemes. These include variable fertilizer and pesticide rates, specific rotations and crop varieties for different landscape positions, and yield monitoring systems to identify different management units and monitor their responses to variable crop management.

More futuristic ideas for sustainable dryland farming are being pursued by several groups, with a common focus on perennial crops. Wes Jackson of the Land Institute in Salina, Kansas, has proposed the concept of a perennial polyculture that mimics the ecosystem functions of a native prairie. His researchers are testing combinations of potential food-producing perennial plants, such as cool season and warm season grasses, legumes, and sunflowers, that could be grown together in a polyculture. The goal is to eliminate annual tillage, and to choose crops that will provide natural nitrogen fertility and weed control. Other researchers at Montana State University and the Rodale Institute are exploring perennial wheat. An increase in the use of perennials in dryland farming would help sustain the soil resource.

There is a growing interest in farmer-managed experimentation. On-farm testing

can be designed and coordinated so that new information from farmer testing is scientifically valid and available for others to learn from. The Farm Improvement Club approach being used in Montana can accomplish this while also providing mutual support and hope for the future of farming. Farmer participation in the research process through new opportunities such as the federal Sustainable Agriculture Research and Education program is changing attitudes about the farmer-extension-researcher relationship. This will hopefully improve the ability of public institutions to address the needs of the farm community.

Other areas do not hold much promise at this time. Few viable alternatives exist to the heavy reliance on herbicides. While energy conservation is improving, our farms remain very dependent on fossil fuels. National and world pressures to keep food prices low create short-term, unprofitable conditions for many sustainable farming options, thus discouraging their use. Rural communities continue to lose population and services, increasing business costs for farmers and lowering their quality of life.

In summary, the prospects for a more sustainable agriculture in the Northwest region are good. Dramatic change will not happen overnight, and public policy will strongly influence the pace. Innovative farms in the region that have made significant strides towards sustainability despite all the barriers provide proof that change is possible. The resilience of dryland farmers to the adversities of climate, pests, prices, and policies is testimony to their fundamental dedication to the land.

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