Amber Waves

A Sourcebook for Sustainable Dryland Farming in the Northwestern United States

Washington State University
College of Agriculture and Home Economics Research Center
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All photos were provided by David Granatstein.

Cover photo: Researchers are comparing soil properties on these adjacent fields from two farms near Colfax, Washington. The farmer of the left field uses a soil-building rotation that includes alfalfa, grass, and green manure at various points, while the farmer of the field on the right uses a cash-crop rotation of wheat, barley, and peas.

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by David Granatstein

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Dryland cereal farming has been practiced for more than a century in the northwestern United States. In that time, phenomenal changes have occurred in terms of increased yield, new technology, and labor productivity. Yet several serious problems persist: extensive soil degradation, dependence on export markets, and crop drought stress. Farming has become increasingly reliant on petroleum-based inputs to maintain productivity. And no alternate crop has appeared to complement or challenge the dominance of wheat. Concerns about the sustainability of agriculture are being raised in the Northwest and around the world.

To address these concerns, a group of researchers, extension workers, farmers, and private agricultural organizations initiated the Northwest Dryland Cereal/Legume Cropping Systems project in 1988 to explore sustainable dryland farming options (see Appendix for project description). The project, based at Washington State University in Pullman, covered dryland farming in Washington, Oregon, Idaho, Montana, Wyoming, and Utah.

Dryland farmers face steadily increasing management challenges. They need more information to cope with new production problems, government policies, and market forces. And new information can often exceed their ability to digest and manage it. This publication identifies and helps to interpret key information on sustainable agriculture for dryland cereal/legume systems. It focuses on three topics: moisture management, crop rotation, and soil quality. This publication was written for use by farmers and farm support personnel who have a good knowledge of dryland farming in the region. Most of the information is technical and citations are included for further reference. A companion publication, Overview of Dryland Farming in the Northwestern United States (Granatstein, 1992), presents an in-depth history and description of dryland farming for a nontechnical audience.

A tremendous body of knowledge about dryland agriculture exists to help search for ways to make farming in the region more sustainable. This knowledge comes from numerous studies by land grant institutions and government agencies, from the experiences of farmers and farm support personnel, and from dryland agriculture in other parts of the world. Current research and farmer innovation are having a positive impact on dryland agriculture in the region. Use of conservation tillage systems, including no-till, is steadily increasing, reducing soil degradation. The search for alternate crops continues, with canola showing promise across the region. Other potential new crops include lupin, lentil, and medic. Increased awareness and use of longer crop
rotations is helping to reduce disease losses and fertilizer and pesticide use. Strategies to reduce the frequency of summer fallow are being developed and successfully field tested, leading to better soil protection and more efficient water use. All these changes help create a more sustainable system.

During the past few decades, research has shifted away from the long-term studies of whole farm systems done earlier in the century to short-term studies of components and single production practices. As a result, new research results are continually generated, but they are often difficult to integrate into a real-world farming situation. More systems research and on-farm experimentation are needed to address this problem. On-farm testing by growers themselves is an effective way to bridge the gap between research results and commercial application.

The discussion of variable agroclimatic conditions in the six-state dryland region presented in Chapter 2 is intended to help growers and farm support personnel better select research information suitable to their specific conditions. Chapters 3-5 present in-depth reviews of the research data, both historical and current, relating to moisture management, crop rotation, and soil quality in dryland farming. These three interrelated topics formed the core of the Northwest Dryland Cereal/Legume Cropping Systems project. The chapters include many citations to allow readers to follow up on specific points of interest. As this publication only highlights three main topics, readers are encouraged to use the references listed in the resource section to pursue more detailed information on other key aspects of dryland farming.

Crop rotation, particularly with legumes, was chosen as a project focus because of its potential to improve the sustainability of dryland farming. Rotations and legumes can help improve soil quality, a broad term used to describe the interrelated physical, chemical, and biological properties of a soil which determine its productivity and its resilience to environmental and management stresses. Both crop rotation and soil quality influence moisture management, the ultimate controlling factor in dryland farming.

Dryland farming is in essence a form of water harvesting. The ability of a farmer, with Mother Nature’s cooperation, to provide water to a crop in a moisture-limited environment largely determines productivity, profit, and preservation of the agricultural resource base. Moisture, the climatic endowment and its management, also affects crop rotation and soil quality. The purpose of these three chapters is to better understand the interactions of these three components of a sustainable dryland agriculture.

Chapter 6, the resource guide, lists people and places to contact for more information and help regarding dryland agriculture.

References
CHAPTER 2.
AGROCLIMATIC CONSIDERATIONS

Farmers continually adapt new technology from other agroclimatic areas to their own conditions

While the six northwestern states all have considerable land areas of dryland agriculture, these areas differ widely in climatic, topographic and soil conditions. These conditions greatly influence the dryland farming techniques in a local area. Several systems were developed in the past to help classify the climate of the region (Shantz and Zon, 1924; Dregne and Willis, 1983). Researchers today are developing systems for delineating agroclimatic zones in the Northwest to help select and interpret experimental and experiential results from the many research sites throughout the area. No one classification scheme exists to cover the entire region. Several currently available systems are discussed below, with suggestions for their use in local areas.

Major Factors

Climatic factors are the dominant influence on farming practices in the region. Average annual precipitation, seasonal (or monthly) precipitation distribution, temperature extremes, and potential evapotranspiration are the most important considerations overall. Two distinct climatic regimes exist: the Mediterranean or maritime conditions generally found west of the Rocky Mountains, and the continental climate found east of them. This is the simplest agroclimatic division for the region, and it is reflected in the rainfall distribution and climatic extremes. The maritime areas (eastern Oregon and Washington, northern Idaho) receive the bulk of their precipitation during the winter and typically have little or no summer rainfall. Temperatures tend to be moderate in the winter and summer. In contrast, areas with a continental climate (Montana, Wyoming) receive most precipitation during the summer, and temperatures tend to be more extreme in both summer and winter. Intermountain areas (southeast Idaho and northern Utah) are transitional between the two climates.

The different precipitation patterns have important implications for dryland farming. Summer rainfall in the continental climate may quickly evaporate under the intense heat, giving the crop little benefit. Summer fallow systems in this region typically store only 20-30% of the incoming precipitation for crop use. Stored soil moisture on the Great Plains is considered to be 4-5 times more useful to a crop than warm season rainfall. Rainfall under intense thunderstorms may occur faster than the soil's ability to absorb it. Where winter precipitation predominates, there is typically greater storage of moisture in the soil, and the efficiency of moisture storage with summer fallow is often 30-50%. Lack of summer rainfall necessitates the use of summer
fallow to maintain seed zone moisture for timely fall planting in drier areas. This limits the possibilities for alternate crops and rotations.

Throughout the region, average annual precipitation changes dramatically over time and distance (Figure 1). East of the Cascades, it generally increases from west to east in the Pacific Northwest and is highest on the lee side of mountain ranges. Local precipitation patterns are influenced by proximity to the many mountain ranges throughout the region.

Figure 1. Mean annual precipitation (inches) in the western United States (USDC, 1968).
Variability of precipitation from year to year limits the usefulness of annual averages, and the probability of very dry years must be considered to manage risks. Variability tends to be greater in the continental climate and is often more extreme in the drier areas. Farming practices have evolved to cope with the uncertainty of water, the key limitation to crop production in the region. Little can be done to influence the amount or timing of rain or snow, but growers can determine how much moisture they capture for their crops and how effectively it is used.

Winter temperature minimums prevent winter wheat production in parts of the region such as eastern Montana. This has substantial economic implications, as winter wheat generally yields 20-40% more grain than spring wheat. Elevation, landscape position, and latitude influence temperature extremes. Unusual weather conditions such as chinook winds can dramatically alter local growing potential. In eastern Washington and north-central Oregon, winter rainfall on frozen soil results in serious soil erosion and significant moisture losses to runoff.

In parts of the region, topography is an important influence on agroclimatic conditions. This is especially true in the Palouse hills area. Wheat yields on a single hill can range from 100 bu/ac on a fertile bottomland to less than 40 bu/ac on a summit. A north slope may have agroclimatic conditions more similar to a site 60 miles north than to the other side of the same field on a south slope. This local variation is important to consider in farm management, but it is difficult to account for in agroclimatic classification systems.

Current Classification Systems

Three classification systems, developed recently, help identify local changes in agroclimatic conditions. One system was developed by researchers at Pendleton, Oregon (Douglas et al., 1988), for the dryland Pacific Northwest (Oregon, Idaho, Washington). A second system is a computer database for Montana called MAPS (Montana Agricultural Potentials System), developed at Montana State University. The third system called FARMS (Farm and Research Center Matching System) is an extension of the MAPS system that lists 13 agroclimatic characteristics for 48 research stations in the Northwest.

Pacific Northwest. The Oregon system uses three defining criteria: average annual precipitation (>16 in., 14-16 in., 10-14 in.), soil depth (deep, shallow), and growing degree days (cold, cool to warm, hot). These criteria are based on the growth requirements of winter wheat. Six separate zones are then defined from combinations of these criteria. These zones have been mapped for the three-state region east of the Cascades, with each map unit representing an area that is relatively uniform in agronomic characteristics. But variability within a mapped zone can be high, and a single field could contain more than one zone. The system is described in extension bulletin PNW354 (Douglas et al., 1990), which also contains a color map of the agroclimatic zones.

This system was developed to help growers and farm support personnel adapt new technology, especially for conservation farming, from one part of this highly diverse region to another. Given the actual variation on the ground within a mapped zone, the map must be used for a first level of assessment. From there, the specific farm or field of interest should be evaluated according to the criteria, and then compared to the agroclimatic conditions at the information source. Potential soil moisture storage is the key element in this classification system. This criterion can be used to evaluate the suitability of agronomic crops and practices from other similar areas for a target site. The soil depth criterion helps to evaluate the moisture conservation value of summer fallow on shallow soils that cannot store two seasons of precipitation.

Montana. The MAPS system is a computer geographic information system (GIS) containing information on 150 environmental attributes for the state of Montana (Caprio et al., 1990). In the system, the state is divided into geographic cells of 8 square miles. Data for the attributes of each cell are entered. These include information about precipitation, temperature, evapotranspiration, elevation, geology and soils, and vegetation. Even biological indicator data are included, such as mean date of lilac bloom and mean date of grain ripening. With this vast amount of information, the
entire state can be searched for all areas meeting any combination of agroclimatic criteria. Growers and farm support personnel can use this to determine the adaptability of a new crop or to find other areas in the state that could use a new technology developed at a single location. A computer map can be generated from the system to illustrate the search results. This system does not delineate fixed agroclimatic zones. Instead, it allows definition of a zone specific to the question at hand, and the system then produces a custom map for each search.

The MAPS concept has been extended to form another system called FARMS (Farm and Research Center Matching System). This helps farmers, researchers, and other agricultural workers locate agricultural research centers with growing conditions similar to their own (Jacobsen et al., 1989). This can help evaluate new varieties as well as alternative crops. It can also be used to determine the potential area of suitability for information from on-farm tests. Research locations are included from Montana, Idaho, North Dakota, South Dakota, Wyoming, Saskatchewan, Alberta, and British Columbia. FARMS contains data matching 13 environmental factors to 48 research centers for 25 crops. The system is being expanded in 1992 to include other Western states. More information about the MAPS or FARMS system can be obtained by calling the Montana State University Plant and Soil Science Dept. at (406) 994-5075.

Practical Applications

The first step in screening information from other agroclimatic areas for appropriateness is to determine the key environmental factor(s) relating to a new practice. For example, Montana researchers have found that legumes for fallow replacement do not significantly deplete stored soil moisture. But they will dry out the seed zone, making the timely establishment of winter wheat difficult in winter rainfall climates such as eastern Oregon. Thus, potential users first need to assess this practice for its sensitivity to seasonal precipitation distribution. In Montana, summer rainfall usually replenishes the seed zone moisture. But autumn rains normally come too late for optimum winter wheat germination in eastern Oregon. Precipitation distributions from representative dryland areas of the six-state region are presented in Figure 2. These are useful in evaluating source and target areas for the transfer of research results or farm practices.

Where precipitation distribution is not a critical factor, then other more localized criteria such as annual precipitation, temperatures, or soil types will be primary. For example, the nitrogen value from a green manure crop should be similar in areas of similar growth potential and soil type. Soil texture and temperatures may be critical factors for evaluating tillage and residue management systems.

The use of agroclimatic information is spreading rapidly with the development of new technologies. Personal computers can now handle the large data sets required for geographical information. New geographic information systems (GIS) software allows individuals to process field and landscape images that were once the sole domain of NASA engineers. Remote sensing data from airplanes and satellites can be obtained. Soil surveys are now being computerized. Fertility maps of fields are being made. All these advances allow farmers to more precisely manage the variable landscapes present in their fields.

Variable landscape management is quickly becoming a practical option for growers (Veseth and Miller, 1992). The development, refinement, and commercialization of the technologies to apply variable fertilizer rates and mixes, to measure soil nitrate or organic matter on the go, or to continuously map yields at harvest with a combine are proceeding rapidly. A yield-mapping system will enable a farmer to easily identify individual management units in a field. Variable management (e.g., fertilizers, crop varieties, pesticides) could begin with the next crop, and the results would be recorded at harvest. Such a system would optimize production practices for different agroclimatic conditions on a field or farm. This approach promises to improve farm profitability and environmental protection at the same time.

The increased interest in agroclimatic information and the new tools for its use support the development of sustainable agriculture in the dryland region. New ideas can be more easily exchanged and initially evaluated. For example, the MAPS database is
Figure 2. Seasonal precipitation distribution for selected Northwest dryland locations (USWest, 1988). MAP=mean annual precipitation; SD=standard deviation.
Figure 2 continued.
Figure 2 continued.
helping Montana researchers identify the most suitable areas for canola production in the state. This oilseed crop could provide needed crop diversification, and the agroclimatic information will reduce the risk of failure by focusing development on the most favorable areas. Variable landscape management addresses agroclimatic changes on a much smaller scale. Technologies such as yield mapping help farmers improve their current management, and offer them a convenient and accurate way to expand their on-farm testing of the new ideas that will be needed for farming in the future.

References


CHAPTER 3. MOISTURE MANAGEMENT

Moisture is the ultimate limiting factor on agriculture in most dryland areas. This subject is covered in depth in other sources (Dregne and Willis, 1983; Haas et al., 1974a; Unger et al., 1989). This chapter focuses on research results from the northwestern United States.

Little can be done to increase precipitation, aside from prayer, rain-dancing, or cloud seeding. In contrast, worldwide desertification illustrates the ability of humans to dramatically reduce the likelihood of precipitation over large areas through improper land use. Long-term reduction in annual precipitation due to overgrazing and deforestation has been documented (Mollison, 1988). Human-induced climatic changes due to atmospheric CO₂ accumulation are not understood well enough at present to predict the consequences on moisture relations in dryland areas. Thus, growers and resource managers in dry regions must rely on historic climatic data as their primary guide in developing management choices. With the help of computers, precipitation probabilities can be determined to assign a level of risk to a management choice.

In many dryland areas, adequate precipitation occurs to support crop production, but proper management is either not available or not used to convert the water into food or fiber. Without good moisture management, both farm profitability and natural resources are likely to suffer in dryland regions.

Infiltration

Once moisture hits the ground in the form of rain or snow, growers can dramatically influence its fate. Figure 3 illustrates the possible paths for moisture moving through a dryland farm. Under most situations, growers seek maximum infiltration of moisture into the soil. Climatic circumstances can inhibit full infiltration, including high intensity rainfall, sublimation of snow, or frozen soil conditions. Water that does not move into the soil will be lost to runoff, evaporation, or snow blow. In those regions where mild winters or frequent chinook winds allow multiple freeze-thaw cycles, surface sealing and frozen soil layers are major barriers to infiltration. Surface residue helps slow runoff, thus reducing soil erosion and increasing the chance of infiltration. In the Northern Plains, winter precipitation is generally in the form of snow on frozen ground, and trapping of the snow in fields with standing stubble or other practices is crucial for eventual infiltration into the soil.
Soil types vary in their natural infiltration rates. Sandy soils have higher infiltration than silts or clays. For example, in eastern Washington, the infiltration rate (in/hr) for three different soils is as follows: Winchester loamy fine sand - 0.80, Palouse silt loam - 0.35, and Cusick silty clay loam - 0.20. A sharp change in soil texture from one layer to the next will slow movement of moisture through the soil, as will compacted or cemented layers. Undecomposed layers of straw buried by plowing can also act as a barrier to water movement.

The condition of the soil surface affects infiltration rates. Surface roughness generally improves infiltration, and can be achieved through rough tillage, contour deep furrows, surface pitting, and crop residue condition. Dry plowing after harvest in the annual crop areas of the Pacific Northwest leaves large clods on the surface which resist soil sealing over the mild, wet winters. The use of overwinter standing stubble or infield grass barriers has led to greater snow retention and water infiltration in areas where snow loss due to wind can significantly lower stored moisture and crop production. In Montana, the use of double rows of tall wheatgrass at 48-foot intervals led to overwinter storage of 40-55% of the precipitation, compared to the normal 10-30%. This extra moisture allowed successful annual cropping and higher net returns (Aase and Reitz, 1989). Over time, the soil condition also benefits from the reduction of summer fallow. The water infiltration rate on bare fallow and stubble mulch was 0.30 and 2.26 in/hr, respectively, in a Wyoming study (Barnes and Bohmont, 1958).

Chisel plowing to a depth of 17 inches increased water movement through the surface horizon of a silt loam at Pendleton, Oregon, but the rate was still slower than in the subsoil below (Allmaras et al., 1976). Researchers speculated that declining surface pH may be causing silica cementation below the plow zone. The use of lime or gypsum may increase hydraulic conductivity under such conditions.

The presence of earthworm tunnels and root
channels can greatly increase the infiltration and movement of water through soil. South Dakota researchers found that a plot under no-till management for six years absorbed 5 in/hr of rainfall compared to 0.6 in/hr on a plowed plot. They attributed the difference to greater earthworm activity under no-till (Beck, 1990).

Aggregate stability is another factor to consider. When soil aggregates are stable, adequate macropores remain open and connected from the soil surface downwards, allowing good movement of water into the soil. This characteristic is influenced by the soil type and organic matter content, but management practices can greatly affect aggregate stability and porosity. In a Great Plains study, stubble mulch tillage led to more water-stable aggregates than moldboard plowing (McCalla and Army, 1961). Where residue levels were low, stable dry clods left after plowing were considered more beneficial to infiltration and erosion control than stubble mulching. At Pendleton, Oregon, winter water infiltration rates on wheat stubble under undisturbed, chisel plow, and paraplow treatments were 0.36, 0.90, and 0.93 in/hr, respectively. Overall, the paraplow, a deep tillage tool that loosens soil without inversion or surface mixing, led to the best infiltration and water transmission (Pikul et al., 1988). Farmers and researchers continue to explore the value of deep tillage practices.

Soil organic matter is an important ingredient in aggregation, although a surface mulch from residues may be more important than organic matter in increasing infiltration (McCalla and Army, 1961). Intensive summer fallow tillage physically destroys aggregates and lowers organic matter levels over time. Perennial grasses are known for their value in improving soil aggregation, and this is one benefit from their inclusion in rotations. Rapeseed/canola appears to have a similar effect.

Tillage is the most common practice used by dryland farmers to influence water infiltration. The choice of tillage system directly affects the amount and position of crop residues after harvest. Many tillage and residue combinations have been devised and tested over the past 50 years. No single system is universally beneficial for dry farming areas. The suitability of a specific system for an individual farm will depend on the agroclimatic conditions, pest problems, labor availability, financial resources for new equipment, tradition, and water conservation concerns.

In general, standing cereal stubble leads to the best overwinter moisture storage throughout the Northwest's dryland region. Fall tillage can improve infiltration in areas subject to rainfall on frozen soil conditions. Untilled standing stubble is essential for snow-trapping in the Northern Plains. In Montana, stubble sculpting by alternating 20-foot wide strips of tall and short stubble (cut by the combine) increased snow depth and stored 30% more water than uniform stubble height (Unger et al., 1989). A chem-fallow no-till system stored the most winter precipitation in a northern Utah study (Rasmussen and Newhall, 1989). Where fallow is used in the Pacific Northwest, long-term studies indicate no significant difference between moisture storage during the winter under undisturbed stubble versus other fall tillage and residue combinations, except for lower storage with stubble burning (Ramig and Ekin, 1991). When frozen soils are a barrier to infiltration, fall chiseling will be a benefit. The crop residue acts as an insulator against freezing, and thus there is a tradeoff with tillage. In one study, frost penetrated three times deeper into soil and remained twice as long with fall plowing compared to no fall tillage (Greenwalt et al., 1983).

Research from southeastern Idaho showed that fall chiseling aided infiltration of melting snow and increased winter precipitation storage (Massee, 1983). When fall tillage is needed, implements that minimize stubble disturbance are preferable. Where slopes are steep or rainfall is higher, contour chisel plowing will slow runoff and soil erosion during a winter with frozen soils. (Lindstrom et al., 1974). More aggressive tillage may be warranted to help decompose higher amounts of residue in areas with low erosion potential.

Farmers and researchers are evaluating several types of implements for postharvest tillage to improve water retention. In the high precipitation zone of the Pacific Northwest, a slot-mulch device maintained good infiltration during frozen soil conditions. This machine gathers residue from a combine swath which is then stuffed into a 3-inch wide by 12-inch deep continuous slot dug on the contour. The slots are repeated every 10-
20 feet downslope and act as infiltration channels when the soil is frozen. Several deep tillage implements show promise in aiding water movement into the soil. The paraplow, various shank subsoilers, the Dammer-Diker, and the subsoiler/ridge are all being tried in the field by farmers to reduce runoff and increase water infiltration.

Overall, the best strategy for maximizing water infiltration is that of maintaining maximum surface or standing residue after harvest. This will be a benefit both to farm profitability and soil conservation.

**Soil Moisture Storage**

Once precipitation infiltrates into the soil, proper management is needed to keep it there until crop roots can use it. Water in the soil may move downwards, sideways, or upwards. Loss of stored moisture will lower crop production potential. Both downward and lateral water movement can carry agrichemicals, particularly nitrates, away from the rooting zone. The evaporative potential in a dryland environment during the growing season is high and can deplete up to two inches of stored soil moisture. Transpiration losses through weeds are equally large. The following formula describes the relationship of these processes:

\[
\text{Soil water content} = \text{Precipitation} - \text{Runoff} - \text{Drainage} + \text{Upward flow} - \text{Evapotranspiration}
\]

Summer fallow can sometimes capture more moisture than a soil can store. Routine use of summer fallow has led to saline seep in certain areas of the Northern Plains. Excess moisture moves downward, picking up salts as it goes. In susceptible soils, the moisture hits a restrictive layer which forces lateral movement and eventual seepage downslope on the soil surface. The salts are deposited there and productivity declines. A grower thus suffers a double loss - impaired soil and wasted moisture.

Various combinations of tillage, residue management, and weed control have been developed to limit moisture loss. Alternating crop-summer fallow is currently the most widespread cropping system used in the dryland Northwest. But new production tools and improved knowledge of moisture management provide opportunities to reduce the use of summer fallow.

The moisture storage capacity of soil is dictated by several physical characteristics. Soil texture determines the storage capacity of a given depth of soil, with silt loams typically storing the most moisture available for crops. Increasing levels of soil organic matter also increase storage capacity, as organic matter can hold several times its weight in moisture. Soil depth influences the total storage capacity and the likelihood of full recharge over one or two seasons. Restrictive soil layers inhibit water movement and storage deeper in a soil. They also slow root growth and retrieval of deep moisture. Topography influences storage ability. A ridgetop position, with excessive drainage or limited rooting depth, is likely to be more droughty than a bottomland.

Knowledge of the water storage capacity of a soil in relation to the weather patterns can help improve the efficiency of moisture use by cropping systems. For example, regular use of fallow may be inappropriate on shallow soils that typically are fully recharged over one winter. This is the case for a considerable area in the Pacific Northwest, where summer fallow provides little water storage benefit in the 10-16 inch annual precipitation zone on soils less than 40 inches deep to bedrock or a restrictive layer (Douglas et al., 1990). Other considerations may favor the continued use of fallow, such as risk management, government set-aside requirements, or the need to maintain seed zone moisture for late summer planting.

The crop-fallow system was developed for a number of reasons earlier this century. Capturing two years of precipitation for use by a single crop has enabled grain production on millions of dry acres in the Northwest. Prior to the availability of nitrogen fertilizer, fallow allowed accumulation of available nitrogen over two seasons as well. Summer fallow helped control weeds without herbicides. The fallow system also allowed a more even distribution of workload, which was important with horse farming.

The efficiency of crop-fallow systems in storing precipitation has been extensively studied across this region. Storage efficiency is strongly influenced by the climatic patterns. Winter precipitation is stored more
Amber Waves

efficiently than spring and summer precipitation, good news for the Pacific Northwest climatic area. But reliable rainfall at a critical crop development period may dramatically affect yields. For example, long-term research from Utah indicates that wheat yields are most influenced by precipitation in the March-May period (Bennett et al., 1954).

For the Northern Plains continental climate, stored soil water is worth 4-5 times as much as growing season rainfall for potential crop productivity. For example, about 65% of snowmelt moisture is utilized by a crop compared to 0-15% of the rain from a July storm (Greb et al., 1967). Fallow becomes less effective from north to south on the Great Plains, due to higher evapotranspiration demand in warmer areas (Black et al., 1974). For every three-inch increase in pan evaporation, an additional one-inch increase in precipitation is required for equal crop growth (Haas et al., 1974a).

In the Pacific Northwest, water storage under several tillage and residue management systems was studied extensively in two different climates of northeastern Oregon (Ramig and Ekin, 1991). Precipitation storage during the first winter after harvest (a 6-7 month period) ranged from 50-85%, with 70% suggested as an average (Tables 3.1 and 3.2). Efficiency was higher with increasing snowfall percentage and with increasing precipitation. During the first summer (fallow, no crop), there was no water storage and about one inch of stored moisture was lost from a 7-foot soil profile. During the second winter, with the crop planted, about 50% of the precipitation was stored. There was no storage during the second summer.

Over the 18-month fallow-crop period, water storage efficiency was 37% and 33% at Moro and Pendleton, Oregon, respectively. Tillage or residue treatment had no significant effect, except for higher losses with straw burning. Fall chiseling improved water storage only one year in ten. The best chance to improve water storage appears to be during the second winter, after the crop is planted. Seedbed preparation for the crop reduces infiltration and increases frozen ground potential. Practices such as surface pitting or a chisel behind the drill may help increase storage.

Table 3.1. Five-year Average Precipitation Storage During a Crop-Fallow Cycle at Moro, Oregon.

<table>
<thead>
<tr>
<th>Fallow Tillage</th>
<th>Crop-Fallow Period</th>
<th>C</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Precipitation Storage (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring plow</td>
<td>78</td>
<td>-23</td>
<td>56</td>
</tr>
<tr>
<td>Fall fall</td>
<td>77</td>
<td>-20</td>
<td>55</td>
</tr>
<tr>
<td>Fall burn</td>
<td>65</td>
<td>-6</td>
<td>54</td>
</tr>
<tr>
<td>Fall disk</td>
<td>79</td>
<td>-24</td>
<td>51</td>
</tr>
<tr>
<td>Fall chisel</td>
<td>74</td>
<td>-17</td>
<td>59</td>
</tr>
<tr>
<td>Spring sweep</td>
<td>79</td>
<td>-22</td>
<td>51</td>
</tr>
<tr>
<td>LSD(.05)</td>
<td>8</td>
<td>10</td>
<td>NS</td>
</tr>
<tr>
<td>Precip. (in)</td>
<td>9.5</td>
<td>7.1</td>
<td>6.5</td>
</tr>
</tbody>
</table>

A=6-month fallow winter; B=6-month fallow summer; C=4-month crop winter. (Ramig and Ekin, 1991)

Table 3.2. Five-year Average Precipitation Storage During a Crop-Fallow Cycle at Pendleton, Oregon.

<table>
<thead>
<tr>
<th>Fallow Tillage</th>
<th>Fallow Winter (7 months)</th>
<th>Total (18 months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Precipitation Storage (%)</td>
<td></td>
</tr>
<tr>
<td>Spring plow</td>
<td>69</td>
<td>35</td>
</tr>
<tr>
<td>Fall fall</td>
<td>65</td>
<td>32</td>
</tr>
<tr>
<td>Fall burn</td>
<td>58</td>
<td>31</td>
</tr>
<tr>
<td>Fall disk</td>
<td>65</td>
<td>33</td>
</tr>
<tr>
<td>Fall chisel</td>
<td>63</td>
<td>34</td>
</tr>
<tr>
<td>Spring sweep</td>
<td>68</td>
<td>34</td>
</tr>
<tr>
<td>LSD(.05)</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

Precipitation (in) 12.2 28.4
(Ramig and Ekin, 1991)

Strict chemical fallow systems have had limited success in maintaining adequate seed zone moisture in the Pacific Northwest (Unger et al., 1989). Evaporative losses from an undisturbed soil, even with a good residue cover, can be large during hot weather due to capillary action in the silt loam soils of the region. Use of an herbicide in the spring can delay tillage until May, which conserves both water and soil and reduces the number of tillage operations (Ramig, 1987).
Oregon researchers also studied water storage under annual cropping. About 2.5 inches more water was stored over winter where wheat stubble was left standing compared to fall plowing. The additional moisture raised average green pea yields 600 lb/ac (20%) in the next crop, and also carried over to the subsequent wheat crop for a 2 bu/ac increase (Ramig and Ekin, 1976; Ramig and Ekin, 1978). In the higher rainfall zones of the annual cropping region, winter precipitation is often greater than that needed to recharge the soil, thus necessitating a focus on runoff and erosion control rather than water storage efficiency.

In the intermountain region of northern Utah and southeastern Idaho, precipitation is evenly distributed throughout most of the year, with snow accumulation occurring during the winter and high evapotranspiration during the growing season. Long-term studies done earlier in the century in Utah found that 32% of precipitation was stored during the fallow-wheat cycle (Bennett et al., 1954). The choice of tillage system did not affect moisture storage, although adequate weed control was crucial. More recent results with modern no-till systems show promise. A chem-fallow no-till system stored one to two inches more water than several tillage systems, and all systems were equally cost effective (Rasmussen and Newhall, 1989). The chem-fallow no-till is suggested for steep lands for better erosion control. As the cost of broad-spectrum herbicides decreases, the profitability of chem-fallow no-till will improve.

Water storage efficiency in the Northwest is lowest on the Northern Plains due to the lower percentage of precipitation that occurs during winter. Generally, 60% of average annual precipitation occurs during the May-August growing season. But research indicates substantial opportunity to increase crop productivity despite this handicap. Fenster (1988) reported that wheat yields in western Nebraska increased 250% from 1950 to the 1980s, and he attributed a third of this increase to improvements in soil water storage.

Two cropping systems are common in the Northern Plains: spring wheat-fallow (areas too cold for winter wheat), and winter wheat-fallow. The majority of water is stored during the first winter in both systems. Storage efficiency over the crop-fallow period for spring wheat averages 18-24%, compared to 30% for annual cropping in that same environment (Haas et al., 1974b). However, more total inches of water are stored with fallow. Improved snow management could make annual cropping much more feasible in these areas.

With fallow-winter wheat, about 28% of the precipitation over 14 months is stored, with 71% of this being captured during the first winter (Black et al., 1974). Stored water increases about 6% during the first summer, but in some years a loss of up to 10% can be expected. Fallow efficiency declines about 3% for each inch increase in fallow period precipitation over 13 inches.

On the Northern Plains, one or more tillage passes are needed to break the capillary movement of water that creates evaporative losses. Thus, strict chem-fallow does not provide the maximum water conservation (Black et al., 1974). But maximizing surface residues does aid in water storage (Table 3.3). The evaporative loss of soil water over a 16-week period was reduced 57% by straw applied to the surface and 19% by straw buried one inch, according to a Montana study (Fenster, 1977). Stubble mulch systems have been widely adopted in the region. These leave standing stubble over the first winter and use sweep tillage to maximize surface residues. Wheat yields have generally been

| Table 3.3. Effect of Straw Mulch on Soil Water Storage During Summer Fallow. |
|---------------------------------|-----------------|-----------------|
| Applied Straw (lb/ac)          | Net Gain Soil Water (in) | Fallow Efficiency % |
| Sidney, MT                     |                 |                 |
| 0                              | 2.2             | 16              |
| 1500                           | 2.6             | 19              |
| 3000                           | 3.1             | 22              |
| 6000                           | 3.9             | 28              |
| North Platte, NE               |                 |                 |
| 3000                           | 7.5             | 29              |
| 6000                           | 8.0             | 31              |
| 9000                           | 8.8             | 34              |

Fallow efficiency % = (Net gain / fallow precipitation) x 100. (Greb et al., 1967)
higher with stubble mulch compared to bare fallow management in areas where annual precipitation is less than 20 inches (Fenster, 1977).

Today, modern machinery, improved crop varieties, fertilizers, and herbicides all reduce the need for summer fallow in many instances. The risk associated with climatic variability is still minimized with summer fallow. But in years with good moisture, fallow may be an unnecessary practice, one that lowers water use efficiency. To address this problem, the flexcropping approach was developed, where crop or fallow decisions are based on the amount of stored soil moisture and the probability of further precipitation (Ford and Krall, 1979). For example, in the spring wheat region of Montana, planting is suggested if soil is wet to at least 24 inches (3 inches of available water). Otherwise fallow is recommended. This approach has proved to be very successful for improving water use efficiency and for reducing saline seep problems. Unfortunately, the crop base provisions of the federal commodity programs make it difficult to use this sound agronomic and environmental approach.

As mentioned above, increased water retention due to conservation practices can allow annual cropping, with more grain produced per unit of precipitation (Table 3.4). But increased costs associated with annual cropping, along with farm program restrictions, impede use of this practice. Experience in the central Great Plains indicates that wind erosion under annual cropping can actually be higher than under a stubble mulch wheat-fallow system, since straw production is considerably lower with the former (Black et al., 1974).

In a four-year research study in northeastern Oregon, grain production per acre per year on soils less than 40 inches deep was 38% higher with annual cropping than with the traditional wheat-fallow system (Table 3.5). A risk management strategy was proposed for this approach that calls for reduced tillage, planting flexibility, and a planting decision rule based on seven inches of stored soil water (Ramig and Ekin, 1987).

As mentioned above, increased water retention due to conservation practices can allow annual cropping, with more grain produced per unit of precipitation (Table 3.4). But increased costs associated with annual cropping, along with farm program restrictions, impede use of this practice. Experience in the central Great Plains indicates that wind erosion under annual cropping can actually be higher than under a stubble mulch wheat-fallow system, since straw production is considerably lower with the former (Black et al., 1974).

Researchers feel that the opportunity for annual cropping would be increased in many areas with a 25% increase in water conservation (Dregne and Willis, 1983). Water storage efficiency is generally higher under annual cropping than with fallow (Table 3.6), but improved technology and management of fallow systems have raised water storage efficiencies to 28%, 37%, and 38% in Montana, Utah, and Idaho, respectively.

Other innovative techniques for coping with moisture deficits in dryland cropping are being examined. Pre-moisturizing seed and water injection in the furrow may help overcome the problem of inadequate seed zone moisture at planting time (Noori-Fard and Bolton, 1982). Reflectant material on the soil surface to reduce evaporation has been tested (Rosenburg, 1981). The keyline system developed in Australia several decades ago to capture and spread water across a landscape may offer new approaches for dryland farming (Yeomans, 1981). While rainmaking is not feasible, opportunities abound to make better use of
the precipitation that does occur in dryland regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Storage Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teton, ID - spring wheat</td>
<td>36</td>
</tr>
<tr>
<td>Northern Plains - spring wheat</td>
<td>19</td>
</tr>
<tr>
<td>Northern Plains - winter wheat</td>
<td>18</td>
</tr>
</tbody>
</table>

(Haas et al., 1974a)

### Water Use Efficiency

Once water is stored in the soil, various factors influence how effectively the water is utilized by a growing crop and converted into yield. Water use efficiency is a widely used measure of the output of harvest per unit of water consumed. Grain crops require a threshold amount of available soil water to produce a viable plant, after which additional water can be used for grain production. In the Northwest, wheat requires about four inches of water to complete vegetative development (Leggett, 1959; Black et al., 1974; Willis et al., 1983). Above this threshold, reported yield increases per unit of additional water vary from 5-6 bu/in (northeastern Oregon), to 7 bu/in (eastern Washington), to 3-6 bu/in (southeast Wyoming), reflecting differences in potential evapotranspiration.

Water use efficiency (WUE) is commonly calculated by two approaches. One method divides the harvested yield by the evapotranspiration during the crop's growth period (Eastin et al., 1983). Some researchers first subtract out the moisture needed to reach initial grain production (Brown, 1971). Since a measurement of total evapotranspiration is difficult to obtain, the other approach simply divides yield by the harvest-to-harvest precipitation. WUE is an important indicator for dryland farmers and can be improved by increasing crop yield faster than evapotranspiration, or by decreasing evapotranspiration while holding yield steady.

Farm management practices significantly influence WUE. Fertilization, residue cover, crop rotation, variety selection, and timing of operations can have a positive, or negative, effect on moisture use by a crop. Researchers in Saskatchewan recently reported that the moisture needed for initial grain production under current management was about 2.7 inches and 1.8 inches for spring wheat seeded on stubble and fallow, respectively (Campbell et al., 1988). This is much less than the 5.5 inches reported earlier this century, and the difference is ascribed to improved cereal varieties and crop management. Fertilization in this same study did not affect the grain threshold moisture requirement, but it did raise the yield increase per increment of additional moisture used.

In nitrogen-limited soils, the addition of N fertilizers has resulted in consistent improvements in WUE. A doubling or tripling of yield with a smaller increase in total water use is common (Willis et al., 1983; Jackson et al., 1983). High N rates may still increase yield but reduce WUE (Table 3.7), and excess N applications can reduce yields if luxuriant vegetative growth leads to excess evapotranspiration, resulting in insufficient moisture available during grain fill. This potential penalty must be balanced against the opportunity to take advantage of any additional precipitation that may occur. "Burning" of a wheat crop by excess N from green manures was reported earlier this century as well (Pawson et al., 1961). Moisture stress induced by excess N fertilization also increases potential yield loss from Fusarium foot rot (Cook and Veseth, 1991).

<table>
<thead>
<tr>
<th>N Rate (lb/ac)</th>
<th>Yield (bu/ac)</th>
<th>WUE (bu/ac-in)</th>
<th>Total H₂O Use (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24</td>
<td>5.1</td>
<td>8.7</td>
</tr>
<tr>
<td>60</td>
<td>46</td>
<td>6.7</td>
<td>10.6</td>
</tr>
<tr>
<td>240</td>
<td>54</td>
<td>6.4</td>
<td>12.4</td>
</tr>
</tbody>
</table>

(Brown, 1971).

The higher levels of surface residues found under conservation tillage affect WUE. Evaporative losses are reduced, and the soil is kept cooler.
Researchers in eastern Oregon reported higher wheat yields with no-till planting compared to conventional tillage. They ascribed the difference to slightly smaller plant size caused by the cooler soil under no-till, which reduced straw yield and increased WUE (Ramig and Ekin, 1976). These same conditions can favor a number of soilborne diseases that will severely damage crop roots and reduce their ability to utilize stored soil moisture and nutrients, thus lowering WUE.

Crop evapotranspiration can be reduced by physical practices such as field windbreaks. According to the Soil Conservation Service (1990), up to 10% of a field can be planted to a windbreak and still produce an economic benefit. Yield increases for cereal crops protected by windbreaks typically range from 10-25%, while forage yield increases are often higher.

**Opportunities and Constraints**

Farmers and researchers will continue to seek and find improved methods to capture, store, and utilize moisture in dryland farming systems. New farming implements to improve infiltration are constantly being designed. Practices that increase soil organic matter also increase the water storage capacity of the soil and improve infiltration. Crop breeders can use both classical breeding and genetic engineering to improve the water use efficiency of crops. Perhaps the biggest challenge in making dryland farming more sustainable is to develop cropping systems that make full use of the limited moisture resources while limiting risk in a drought-prone environment.

**References**


CHAPTER 4.
CROP ROTATIONS
IN DRYLAND
FARMING

Crop rotation is widely regarded as a key way to improve agricultural sustainability. Rotation primarily increases the biological diversity in a cropping system, which leads to reduced pest problems, improved nutrient cycling, and better use of natural resources and production inputs. In dryland regions, the potential for crop rotation is limited by moisture constraints. Only a few crops are well adapted to the semiarid conditions and economically competitive with wheat. Despite the obstacles, farmers and researchers are testing a variety of crops to help diversify dryland cereal rotations and their efforts are showing promise.

When discussing crop rotations, many people consider a legume crop to be an important component. Legumes have the unique ability to convert atmospheric nitrogen into a form usable by plants. This is done in association with rhizobial bacteria which develop nodules in the legume roots. Grain crops typically need more nitrogen than any other soil nutrient, and lack of nitrogen commonly limits the productivity of dryland crops. Legumes are in a different plant family than cereals. This is beneficial for breaking pest and disease cycles. Thus, the development of dryland cereal/legume cropping systems can improve the sustainability of farming in semiarid regions.

Extensive research has been done on the use of legumes in dryland farming in the northwestern United States. Historically, legumes utilized moisture that could be more profitably used by cereals. In higher rainfall areas, such as the eastern Palouse, peas and lentils have been common in rotations for decades. With improved management techniques, particularly conservation tillage and better weed control, more moisture is now being conserved in the drier areas. This has prompted a reevaluation of legume use in traditional wheat-fallow cropping.

One drawback of most common legumes is their poor water use efficiency compared to cereals. Oilseeds such as safflower and sunflower have been studied and used to some extent, and now canola is receiving much attention. Safflower is very well adapted to semiarid conditions, but its expansion is slowed by limited markets. Results with canola are more encouraging, since established markets exist domestically and in the Pacific Rim nations. The search for alternative crops continues, but nothing has yet matched the performance of wheat in the dryland region.

Adoption of more complex crop rotations is not just constrained by the dry climate. Government program restrictions have favored cereal-intensive cropping, and the 1990 Farm Bill continues the trend. With the subsidy of wheat, few other crops can compete
in terms of profitability. Alternative crops typically lack the large, relatively stable markets that wheat can access, thus slowing their widespread adoption.

The choice of crop rotation on a dryland farm has implications for soil fertility, soil conservation, moisture use, machinery and labor, information needs, and profitability. In the summary of research on dryland rotations that follows, the role of legumes and other potential alternative crops and the effects of various rotation choices on soil quality and moisture management are emphasized.

**Rotation Effects**

Many crops, such as wheat, corn, and soybeans, exhibit higher yields when grown in rotation versus continuous monocropping. This phenomenon, called the "rotation effect," is defined as the effect of moving away from monoculture on crop yield. The effect can be positive or negative, and often changes with increasing nitrogen fertilization (Pierce and Rice, 1988). In the dryland cereal region, continuous wheat or continual wheat-fallow are the monoculture situations. Both legumes and nonlegumes can be effective break crops in a rotation and elicit a yield benefit to the following crop (Randall, 1988). Rotation effects are due to a combination of factors, including better nutrient cycling (especially N), reduced pest problems, and improved soil physical properties (especially water-holding capacity and aeration).

Soil fumigation has been used as a research tool in the Pacific Northwest to identify potential rotation effects due to soilborne disease organisms (Table 4.1).

The percent yield increase due to fumigation is usually larger in monoculture than in rotation, indicating that rotation is a healthier system.

The benefits of crop rotation in dryland cereal production were recognized earlier in this century, but experimental results from that period are difficult to interpret (Ingham, 1924; Pieters, 1927; Severance et al., 1930). Tall wheat varieties were used, not the semidwarf varieties grown today. Often, no nitrogen fertilizer was used in a comparison of wheat in continuous culture or fallow with wheat in rotation with peas or green manure. Thus, nitrogen deficiencies and soil moisture differences confounded any potential rotation effects. For example, Severance et al. (1930) studied the effect of the preceding crop on winter wheat yields at Pullman, Washington, and Moscow, Idaho (Table 4.2). The yield differences appear to be mainly due to nitrogen.

<table>
<thead>
<tr>
<th>Preceding Crop</th>
<th>Wheat Yield (bu/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow</td>
<td>33</td>
</tr>
<tr>
<td>Peas</td>
<td>30</td>
</tr>
<tr>
<td>Sweetclover - 1st yr</td>
<td>35</td>
</tr>
<tr>
<td>- 2nd yr</td>
<td>30</td>
</tr>
<tr>
<td>Alfalfa - 1st yr</td>
<td>28</td>
</tr>
<tr>
<td>- 2nd yr</td>
<td>32</td>
</tr>
<tr>
<td>- 3rd yr</td>
<td>28</td>
</tr>
<tr>
<td>- 4th yr</td>
<td>31</td>
</tr>
</tbody>
</table>

(Severance et al., 1930)

Baker and Klages (1938) examined crop yield trends at Moscow from 1915-1937. The average wheat yield and the long-term yield trend were higher in rotation, and with the application of manure (Table 4.3). At the high elevation dryland Tetonia, Idaho, research station, they studied the influence of the forecrop in rotation. Surprisingly, yields of most crops after potatoes were higher than after any other forecrop.

Rasmussen et al. (1989) have recently summarized the past 55 years of research at Pendleton and associated eastern Oregon research stations.
Average winter wheat yields at Pendleton from 1972-1987 are summarized in Table 4.4. Wheat yields were seven bu/ac higher after unfertilized peas than after continuous wheat with fertilizer. Wheat in the wheat-pea rotation received 60 lb N/ac, while continuous wheat received 80 lb N/ac. In a wheat-wheat-fallow rotation, wheat yields were 26-37% lower than in a wheat-barley-fallow or wheat-peas-fallow rotation. Spring barley and spring peas appeared to have a similar rotation effect.

More recent studies of the rotation effect included modern wheat varieties and nitrogen fertilizer. Kirby (1987) measured winter wheat response after a number of legume forecrops used as green manures at Pullman (annual cropping, 21 inches annual precipitation) and Dusty, Washington (fallow every third year, 15 inches annual precipitation). Yield response of wheat to preceding green manure crops ranged from 50-200%, indicating that significant rotation effects were occurring. Normally, as little as 10-20% of the N from a legume green manure is taken up by the subsequent grain crop.

The effects of several legume forecrops on cereal yields at Pullman, Washington, and Bozeman, Montana, are compared in Table 4.6. The rotation effect appeared more significant in Washington than Montana, while the N response after legumes was greater in Montana. A drier climate may reduce the magnitude of the rotation effect. Also, crop differences undoubtedly exist, such as wheat compared to barley. In another study, Bezdicek et al. (1987) measured the N fixed by several legume forecrops and compared it to the wheat yields the following year (Table 4.7). Red clover appeared to have a greater positive rotation effect than either pea crop.

Elliott et al. (1988) compared several rotations, including two with continuous cereals. They found higher N fertilizer efficiency and a lower N rate needed for maximum yield with a spring wheat-winter wheat-spring wheat-spring wheat-winter wheat rotation compared to a simpler spring wheat-winter wheat rotation. When winter wheat was preceded by green manure peas, the yield was 21 bu/ac higher than when spring wheat was the forecrop.
In an experiment at Pullman, Washington, hard red spring wheat yields were lower after winter wheat than after Austrian winter peas harvested for seed at all N rates (Huggins et al., 1989). The total rotation effect was about nine bu/ac (Fig. 4). Similar results were reported by Mahler and Auld (1989) at Moscow, Idaho, where winter wheat yields after spring barley were 23-30% lower than wheat after fallow or Austrian winter peas. The highest N rate used in this study did not overcome the yield difference.

Goldstein (1986) studied three rotations at Pullman, beginning in 1983: spring barley-winter wheat-winter wheat; medic-winter wheat-winter wheat; medic-winter wheat. These plots were preceded by lentils in 1982 and winter wheat in 1981. The barley was unfertilized. Weeds were controlled with herbicides in barley and by clipping in medic. Wheat in rotation with forage legumes was more competitive with weeds than wheat preceded by barley in a cereal rotation (Table 4.8). This was attributed to healthier root systems of wheat in the legume rotation which were able to outcompete weeds for moisture and nutrients. Soils from the respective rotations and an alfalfa rotation were used in a greenhouse experiment where light and moisture were not limiting. The same results occurred. Wheat after alfalfa produced the greatest root biomass and the healthiest appearing roots, followed by wheat after medic. Both wheat after wheat and wheat after grass had discolored roots that were restricted to surface soil layers.

Several Canadian researchers have studied crop rotation influences in dryland cereal production in Saskatchewan. In one study, barley yields were 21% higher after green manure than after barley (Wright and Coxworth, 1988). Wheat in a green manure-barley-wheat rotation exhibited 15% greater dry matter yield, grain yield, and N uptake than wheat after 2 years of barley. These researchers estimated that a rotation of field peas-barley-wheat used 59% of the production energy (fuel, fertilizer, herbicides) of that needed in a barley-barley-wheat rotation. Zentner et al. (1987) reported...
that unfertilized wheat in rotation with legumes often yielded as well as fertilized wheat after fallow. Slinkard et al. (1988) found that 40 lb N/ac from a green manure crop increased subsequent wheat yields more than wheat stubble with 54 lb N/ac from fertilizer.

More research is needed to further understand and take advantage of rotation effects. In areas with full soil moisture recharge each year, an alternative rotation crop might be used solely as an internal resource to boost output of the following cereal. For example, net returns from peas and lentils are erratic and often low. Profits might be improved by replacing them with a crop that exhibits large positive rotation effects on wheat yields. Nonlegume crops have potential, as each yield increment increase from rotation effect will return far more to the producer than each increment of N fertilizer replaced by a legume.

The value of a legume rotational crop will increase whenever fertilizer prices rise. Also, regulatory pressures may encourage the adoption of more diverse rotations that increase fertilizer use efficiency in an effort to reduce movement of nutrients to water supplies. Growers considering potential rotational crops should be careful to choose ones that will not be a host for predominant soilborne pathogens, as disease suppression is certainly a major factor in the rotation effect in the dryland regions of the Northwest.

Both research results and farmer experience show that soil-building rotations, such as those that include green manures and perennial grasses, do improve soil conditions. Improvements include increases in soil organic matter, better soil aggregation and water-holding capacity, more favorable soil pH, less erosion, and increased nutrient cycling. These rotation benefits are hard to measure and do not always get considered in short-term economic analysis. But their importance in sustaining profits and health of the soil needs to be recognized and promoted.

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**Figure 4.** Effect of previous crop and nitrogen rate on spring wheat yield at Pullman, WA. (Huggins et al., 1989)
Legume Green Manures

A green manure refers to a crop grown for the sole purpose of soil incorporation to improve fertility and physical conditions. The crop can be mechanically killed and worked in, as with a plow, or killed with an herbicide or frost and left as a surface mulch. Termination of a green manure crop can be timed according to several criteria, including maximum plant biomass or N content, minimum water use, carbon-to-nitrogen ratio, or weediness. Since there is no direct cash return from a green manure, minimal inputs are used to grow it. Often legumes are a favored green manure because they can fix atmospheric N and add it to the soil. Nitrogen is often the primary limiting nutrient to grain production. Other crops are being examined for their ability to accumulate soil nutrients, such as P or S, for their pest suppression potential, or for their effect on soil physical conditions (e.g., strong taproot or fibrous root system).

The best summaries of the green manure research done prior to widespread nitrogen fertilizer use may be found in the work of Pawson et al. (1961), Horner et al. (1960), and Stephens (1944), which covered the dryland areas of the Pacific Northwest. Bennett et al. (1954) summarized more than 50 years of dryland research in Utah, and Army and Hide (1959) described green manure research for dryland cereals in Montana.

Montana.

In the low rainfall areas of eastern Washington, the first crop of wheat after a green manure often yielded less than wheat after fallow. The same was true in the intermediate rainfall areas, except after green manure peas. Both moisture depletion by the green manure and excess N from its breakdown contributed to the problem. Wheat after green manure typically yielded well in the high rainfall areas. In all areas, yields of the second and subsequent wheat crop were usually larger where legumes had been grown. A legume-grass mix gave better results than a pure legume stand in the low rainfall areas (Horner et al. 1960).

At Nephi, Utah, field peas incorporated were 6 inches to 12 inches high improved wheat yield compared to fallow. Other green manure treatments depressed wheat yields, apparently from nitrogen tie-up by the green manures. But over 50 years, the fertility in all green manure plots increased considerably, and the larger the green manure crop was allowed to grow, the greater the increase in fertility. A small addition of nitrogen fertilizer with the green manure was suggested as a strategy to avoid nitrogen tie-up (Bennett et al. 1954).

After 38 years of research in Montana, Army and Hide (1959) reported that green manure treatments either had no effect or a yield depression on the subsequent cereal crop (Table 4.9). Apparently, native soil nitrogen was not yet depleted, while moisture was limiting. Poor green manure management, inefficient water storage, and weed problems occurred during these studies. The primary effect of the green manures was reduction of stored soil moisture.

Suitable green manure crops for the extremely dry areas have proven elusive. Jacklin (1936) suggested grass for these areas, as no suitable legume was available. He promoted soil-building rotations that were 4-7 years in length. Early work at Moro, Oregon, failed to find enough benefit from green manures to justify the
expense (Stephens, 1924). But later research indicated that a spring wheat-pea rotation was more productive than the typical wheat-fallow system (Stephens, 1944). To date, net returns from a cereal-green manure system appear to be lower than for wheat-fallow where the annual precipitation is less than 17 inches in the Pacific Northwest (Rasmussen et al., 1989).

Table 4.9. Average Wheat Yield After Green Manure and Fallow in Montana, 1915-1951.

<table>
<thead>
<tr>
<th>Previous Crop</th>
<th>Missoula Yield % Over Fallow</th>
<th>Huntley Yield % Over Fallow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow</td>
<td>15.3</td>
<td>21.3</td>
</tr>
<tr>
<td>Field pea</td>
<td>16.0</td>
<td>15.1</td>
</tr>
<tr>
<td>Sweetclover</td>
<td>14.6</td>
<td>11.1</td>
</tr>
<tr>
<td>Rye</td>
<td>15.9</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Ave. ann. precip. = 15 in.

The benefits from a green manure or soil-building rotation may take a number of years to become evident. The nitrogen benefit was often obvious where fertilizer was not used, but significant soil erosion by water was reported after sweetclover plowdown. Studies by Kent (1957) in eastern Washington showed much less soil loss after two cycles of a legume/grass rotation than after only one.

Historically, sweetclover and alfalfa were the most widely used green manures in the region. They were often seeded with a spring crop, such as peas or barley. With barley, an alternate row seeding was common. At Tetonia, Idaho, sweetclover had no adverse effect on the yield of the companion crops (Siddoway and McKay, 1955), while at Pendleton, Oregon, sweetclover reduced pea yields by about 20% (Rasmussen et al., 1989). Yellow-blossom sweetclover was recommended over white, due to its finer stems and shorter growth. Some sweetclover selection and breeding occurred during the 1950s in an attempt to match varieties to specific environments. Pumphrey and Koehler (1958) found similar levels of total N, winterhardiness, and rooting patterns among a number of sweetclover varieties.

Sweetclover, a biennial (except for Hubam), was used for forage as well as green manure on some farms. Hay yields the first year were usually less than 1 ton/ ac, and from 1-2 ton/ac the second year. Grazing the growth with sheep was another strategy. Clipping the sweetclover in the first year increased the overall hay yield, but reduced the second year hay yield and total N added per acre. Unclipped stands also had less erosion (SCS, 1938). In one long-term study at Pullman, Washington, yields of winter wheat after sweetclover increased over time parallel to increases in the biomass of the preceding sweetclover crop (Fig. 5). Over the same period, yields of winter wheat after fallow steadily declined (Stephens, 1944).

Pawson et al. (1961) examined a tremendous amount of information on the economics and soil impacts of various cropping systems in the Palouse region. They found alfalfa in rotation to be an excellent choice at that time. With no nitrogen fertilizer, a three-year stand of alfalfa for green manure substantially increased the succeeding wheat yields for at least 10 years. The best-paying green manure rotation at the time was as follows: Plant alfalfa with peas in year 1. Cut alfalfa in years 2 and 3, leave for green manure. Plow under alfalfa in July of year 3. Seed to cash crops (wheat-peas) for 5-8 years. This rotation entailed less capital, less labor, and less risk than harvesting the alfalfa for hay.

Soil losses after alfalfa green manure were the lowest of any of the systems (Pawson et al., 1961). A three-year stand of alfalfa provided extended benefits up to seven years in reducing erosion. A three-year rotation of wheat-peat-alalfa-alalfa green manure had the highest increase in soil organic matter, with or without nitrogen fertilizer.

In a 16-year rotation (4 yr alfalfa hay, fallow-wheat for 6 cycles) at Pendleton, Oregon, the first wheat crop had depressed yields, while crops 2-6 yielded 2-7% higher than the wheat after fallow control (Rasmussen et al., 1989). The alfalfa influence declined over time. Gross returns were 21% lower under the alfalfa rotation than the wheat-fallow system.
Crop Rotations

Smith (1948) felt that alfalfa provided more nitrogen to a crop than sweetclover, but sweetclover was easier, faster, and cheaper to establish. The sweetclover weevil and sensitivity to 2,4-D herbicides have discouraged the use of sweetclover, and soil acidification makes legume establishment and N fixation more difficult.

Neither sweetclover nor alfalfa alone adds organic matter or controls erosion as well as legume/grass mixes (McKay and Moss, 1949). Mountain brome or slender wheatgrass were good mixes with sweetclover at Tetonia, Idaho (Siddoway and McKay, 1955). Tall and pubescent wheatgrass gave the highest forage yields at Nephi, Utah, while crested wheatgrass was a more dependable seed producer (Bennett et al., 1954). At Weston, Oregon, a 1:1 mix of sweetclover and grass had a higher N uptake (122 lb/ac) than sweetclover alone (98 lb/ac) (Rasmussen et al., 1989). Legume/grass mixes produced higher root biomass than either one alone (Kent, 1957).

More recent green manure studies have focused on legumes other than alfalfa and sweetclover. For generalized use, the ideal legume for green manure has yet to be identified, particularly for the drier areas. The Soil Conservation Service (1938) proposed studying new materials such as Astragalus (milkvetch) species, big-headed clover (native to eastern Washington), medic, sainfoin, Montana goldenpea, lupins, and vetches. Winter annual legumes, such as Austrian winter pea and winter lentil, have generated some interest.

At Moscow, Idaho, Auld et al. (1983) found that Austrian winter peas take up substantial amounts of N from the soil in addition to fixing N. Total vine N at flowering ranged from 225-240 lb/ac for most varieties, except Melrose, which contained 278 lb N/ac. Mahler and Auld (1989) found wheat yields to be similar whether the preceding Austrian winter peas had been used as a green manure or harvested for seed. The seed pea-winter wheat-spring barley rotation was the most economically efficient, with a cash crop each year. Pea...
Amber Waves

vines decompose rapidly and the released N appears to remain in the upper 24 inches of soil, where it is available to young winter wheat plants in the spring. This apparently helps boost yields.

An average green pea crop at Pendleton, Oregon, (about 2 tons/ac) supplies about 40-50 lb N/ac to the next crop from the decomposing vines. This is comparable with the N-supplying ability of sweetclover at that location (Rasmussen et al., 1989).

Saskatchewan researchers compared Indianhead lentil with Tangier flatpea as green manures preceding hard red spring wheat (Slinkard et al., 1988). Wheat yields were always higher after the annual legume than after continuous wheat plus N, especially on drier sites (Table 4.10). Seed cost of the lentil was $9/ac, versus $20/ac for the flatpea, or fababean. The Indianhead lentil appeared to return more value in fixed N than the seed cost.

Table 4.10. Hard Red Spring Wheat Yields from Various Rotations in Saskatchewan.

<table>
<thead>
<tr>
<th>Previous Crop</th>
<th>Relative Yield %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow</td>
<td>100</td>
</tr>
<tr>
<td>Legume green manure</td>
<td>85</td>
</tr>
<tr>
<td>Wheat + 54N</td>
<td>77</td>
</tr>
<tr>
<td>Wheat</td>
<td>68</td>
</tr>
</tbody>
</table>

(Slinkard et al., 1988)

In another Saskatchewan study, the inclusion of a grass/legume forage or a legume green manure in rotation increased unfertilized wheat yields 15-24% after fallow, and 33-71% after stubble. These yields were often similar to or higher than those on wheat-fallow rotations with fertilizer (Zentner et al., 1987).

In Wyoming, barley preceded by uncut hairy vetch, Austrian winter peas, or cut or uncut alfalfa had yields greater than or equal to those with 90 lb N/ac (Abernethy and Bohl, 1987). Alfalfa was the best legume choice, as it enhanced barley yields even with the removal of 1.65 tons/ac of forage. Hairy vetch was the best green manure in a North Dakota study (Meyer, 1988). Barley yields were 7-10% higher after hairy vetch than after fallow. Unfertilized barley yields after green manure legumes were higher than after legume forages or pulses, but not at nitrogen rates of 67 and 133 lb/ac.

Recent research in Montana and Wyoming (Sims et al., 1991) examined over 25 legume choices for possible use as a green manure replacement for summer fallow. Dry matter yields ranged from a low of 168 lb/ac (arrowleaf clover at Huntley, Montana, in 1989) to a high of 14,200 lb/ac (subterranean clover at Bozeman, Montana, in 1989), with large variations among locations and years. Annual clovers appear better adapted to the wetter, cooler environments, while the annual medics are superior under drought conditions. A legume management strategy that dictates green manure incorporation based on a set amount of legume water use or biomass production is being formulated. For
example, Montana researcher Jim Sims proposed that 900 lb/ac legume dry matter (about 40 lb N/ac) is the threshold level to supply the nitrogen needs of a subsequent cereal crop in the drier, lower yielding areas. Related studies are examining the amount of biomass produced per unit of water used, and initial results indicate that Austrian winter pea is most efficient. Large-seeded legumes have generally performed better than small-seeded species, since the former can be planted deeper and are more likely to successfully germinate.

Montana researchers have attempted to adapt the Australian ley farming system to their environment. The ley system alternates wheat or another cash crop with an annual forage legume. The legume provides nitrogen for the cash crop, and it is often grazed by sheep to produce income as well. Hard-seeded legumes are commonly used so they reseed themselves during the cereal rotation, thus cutting costs. Medic species and subterranean clover varieties are the most common legumes used for the ley system in Australia. A number of medics were tested in Montana, with black medic looking particularly promising (Table 4.11). There was no significant difference in stored soil moisture after the medics compared to after fallow. All legume treatments increased the nitrate-N level of the soil compared to fallow, with levels increasing by 2.5 times under black medic (data not shown).

A ley system for the annual cropping area of the Palouse region was tested by Goldstein (1986). He used a three-year spring pea/black medic-medic green manure-winter wheat rotation. Once established, the medic volunteered in each pea crop to provide green manure for the wheat. Unfertilized cereal yields after medic were generally equal to fertilized cereals after cereals (Table 4.8). The medic appeared to induce strong rotational effects in addition to its nitrogen contribution. Economically, the ley system showed higher net returns under both high and low yield conditions at market prices, while returns from a conventional counterpart were only higher in the high yield environment with government price supports.

Other researchers in the annual cropping area of eastern Washington (Kirby, 1987; Bezdicek et al., 1987) found red clover and a sweetclover/rose clover mix to have potential as green manures. The red clover was successfully overseeded into spring wheat, and subsequent winter wheat yields were higher after red clover than after Austrian winter peas or hairy vetch. Unfertilized winter wheat yield after the clover mix was higher than after any other legumes, but was 14% lower than wheat after fallow. All yields following a legume still responded positively to added N fertilizer (Table 4.12).

<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Previous Crop</td>
<td>Grain Yield</td>
<td>Nitrate-N (lb/ac)</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Fallow</td>
<td>31.8</td>
<td>99</td>
</tr>
<tr>
<td>Clover mix</td>
<td>33.1</td>
<td>86</td>
</tr>
<tr>
<td>Fababeen</td>
<td>33.3</td>
<td>81</td>
</tr>
<tr>
<td>Pea</td>
<td>32.6</td>
<td>35.8</td>
</tr>
<tr>
<td>Rose clover</td>
<td>35.6</td>
<td>78</td>
</tr>
<tr>
<td>Medic mix</td>
<td>35.6</td>
<td>78</td>
</tr>
<tr>
<td>Sweetclover</td>
<td>35.6</td>
<td>78</td>
</tr>
<tr>
<td>Lentil</td>
<td>35.6</td>
<td>78</td>
</tr>
<tr>
<td>Chickpea</td>
<td>35.6</td>
<td>78</td>
</tr>
<tr>
<td>Barley</td>
<td>35.6</td>
<td>78</td>
</tr>
</tbody>
</table>

(Sims, 1982)
Legume green manures can provide a substantial portion of the nitrogen needs of a subsequent cereal crop. In dryland areas, competition for water represents a roadblock to their expanded use, as does the loss of income if the green manure replaces a cash crop. It is difficult to accurately assess the potential economics of green manure systems without going through several rotation cycles. Often all the benefits of such systems cannot be predicted in advance. Positive interactions within alternative rotations can lead to improved crop health, weed control, soil and water conservation, and reduced production costs, such that net returns over the course of a rotation can equal or exceed those with a cash crop every year.

Recent economic studies in the region have examined cereal/legume rotations on commercial farms (Matheson et al., 1991; Painter et al., 1992). In the Palouse region, a winter wheat-spring barley-clover green manure system had the lowest variable cost of any rotation studied. Its returns over variable costs were slightly less than a winter wheat-spring barley-spring pea rotation, the most profitable one in this study (Young and Painter, 1991). On several case study farms for which enterprise budgets were developed (Matheson et al., 1991), production costs were low and gross margins were positive. One farm using a green manure every fifth year reported higher than average yields for all crops and the elimination of fungicides on wheat after green manure.

Good green manure options do not exist for the drier areas of the Pacific Northwest. The primary constraint is the depletion of seed zone moisture by the green manure which prevents timely planting of a subsequent winter wheat crop. Switching to spring wheat would address this problem. But spring wheat yields are at least 20% lower than winter wheat yields. Planting alfalfa/grass for a period of years, such as in the CRP, is a good agronomic possibility. Also, planting grass and harvesting the seed is an option when the grass seed market is strong.

East of the Rockies, the greater likelihood of growing season rainfall minimizes the seed zone moisture problem. Field-scale success with green manures in Montana, even in very dry areas, indicates a real potential for green manure use that does not compromise grain yield.
Grain Legumes in Dryland Rotations

Grain legumes, or pulse crops, have been grown by dryland farmers in the Northwest for many years. These include spring pea (dry, freezing, and canning), winter pea, and spring lentil. More recently, researchers have studied the adaptability of chickpea, fababean, lupin, dry bean, and winter lentil. Most dry peas and lentils are produced in the annual cropping regions of eastern Washington and northern Idaho. Montana growers raise limited acreage of nonirrigated dry beans, as well as some fababean, particularly in the northwestern part of the state. Chickpeas are produced commercially to a limited extent in eastern Washington, and lupin production is being explored. The greatest increase in grain legume production in recent years has been across the border in Saskatchewan, Alberta, and Manitoba, where pea and lentil production have grown enormously (Slinkard and Blain, 1988). While the acreage planted to grain legumes in the region is small in comparison to cereals, it currently covers several hundred thousand acres.

Grain legumes are of interest to dryland farmers for several reasons. First, they help diversify the crop rotation. Second, they fix nitrogen and require no N fertilizer inputs. Third, typical dryland cereal production equipment is well suited to growing grain legumes. Their large seed size helps ensure adequate germination by enabling deep planting into moist soil. Research indicates potential benefits to soil structure. A grain legume also offers the flexibility of using it as a cash crop or green manure, depending on market conditions.

Drawbacks to grain legume production include limited and volatile markets, weed problems (due to poor competitiveness and limited herbicide options), and numerous disease and insect pests. But grain legumes have help control certain cereal diseases (e.g., Take-all, Cephalosporium stripe) and grass weeds (Papendick et al., 1988; White, undated). Many parts of the northwestern United States that currently rely on a wheat-fallow system receive enough moisture to produce grain legumes. Grain legumes have successfully replaced fallow in Turkey and Saskatchewan. Both small red lentil and chickpea have replaced fallow in Turkey in areas that receive 14 inches or more annual precipitation (Muehlbauer, 1990). Crops which show promise for the Northwest include desi-type chickpea, spring sown small red lentil, winter lentil, and Austrian winter pea. Sizeable potential export markets exist for both the desi chickpea and small red lentil. Kabuli-type chickpeas (also called garbanzo beans) must compete with Mexican and Californian production. Chickpeas are susceptible to serious Ascochyta blight disease problems, although resistant varieties are being developed. Lupins can replace up to 25% and 100% of the soybean meal in nonruminant and ruminant livestock rations, respectively (Granatstein, 1988). Domestic demand for peas and lentils has been stable but low. The increasing emphasis on vegetable fiber for human health offers opportunities to expand their use.

Seed yields of most grain legumes have been relatively flat during the past several decades. In part this is due to a much smaller breeding effort compared to cereals, as well as inadequate weed control options. But grain legumes have a lower potential yield due to the fact that they accumulate high levels of protein in the seed. This requires more energy expenditure by the plant, as does nitrogen fixation in the root nodules. Grain legumes often yield more protein per acre than a high-yielding cereal, and clearly require far less fossil fuel energy due to the absence or minimal use of nitrogen fertilizer. Examples of grain legume yields in the northwestern states are given in Table 4.13. Yields of minor grain legumes include 1-3 cwt/ac for pinto beans and 1-14 cwt/ac for lima beans at Pendleton, Oregon; 12 cwt/ac for fababean and 18 cwt/ac for dry beans at Bozeman, Montana; and 15-27 cwt/ac for Miranda protein peas at Logan, Utah.

Prices for peas and lentils have become more volatile since the early 1970s. Prior to that time, dry peas sold for $4/cwt and lentils sold for $7/cwt for many years. More recently, prices have fluctuated from $7-11/cwt for peas and $11-20/cwt for lentils (Washington Agricultural Statistics Service, 1991). Prices for black peas are often slightly higher than green or yellow peas, but markets are limited. Chickpea prices have been favorable for high-quality kabuli types under contract to processors ($20-40/cwt).

While the water use efficiency of grain legumes is generally lower than cereals, they use less total water.
than cereals. Water depletion is typically limited to the upper three feet of soil. Moisture stored below this is available to a subsequent cereal crop, and may account for some of the favorable rotation effects. Chickpeas (desi-type) are generally considered to be most drought tolerant and the fababean least tolerant, with peas and lentils being intermediate (Papendick et al., 1988). The small red lentil appears more drought tolerant than larger seeded varieties. Lupin is grown under very dry conditions in Australia, and is being tested for its adaptability to low rainfall areas of eastern Oregon and Washington. Estimates of consumptive water use for pea, lentil, and fababean are 14-20, 5-9, and 4-27 inches per year, respectively (Farah et al., 1988).

Since grain legumes fix nitrogen in their root nodules when properly inoculated, nitrogen fertilizer is seldom needed. During early growth prior to nodulation, residual soil N is normally sufficient to supply the needs of the crop. High levels of residual soil N will depress nitrogen fixation, since the plant uses less energy taking up soil N than fixing N. Thus, a grain legume will fix the most N when it follows an N-depleting crop such as wheat or barley. Fababeans are more tolerant of high soil N than other grain legumes (White, undated). Any stress on a legume crop that reduces its growth rate also reduces N fixation.

Grain legumes vary widely in their ability to fix N (Smith et al., 1987). Lupin and fababean have been found to fix the highest amounts under favorable conditions, followed by pea and lentil, chickpea, and soybean (White, undated). In a Canadian study, fababean fixed the most N under wetter conditions, while pea and lentil fixed the most under drier conditions (Bremer et al., 1988). Dry beans are generally poor N fixers. A number of studies in the region have examined grain legume crops to determine their potential nitrogen inputs into the system and their economic performance (Bezdicek et al., 1987; Smith et al., 1987; Speilman, 1984). In many cases, more N was exported in the harvested grain than was fixed. In pea, lentil, and chickpea, the amount of N fixed is generally equal to that removed in the seed, while lupin and fababean will normally leave a net gain in soil N after harvest. Nitrogen returned to the soil from the tops and roots can become available quickly after harvest if conditions are favorable, and care must be taken to avoid N losses from the legume residue.

Grain legumes have mixed impacts on soil physical conditions. Farmers and researchers have noticed that the surface soil is more friable and erosive after a pulse crop such as peas (Baker and Klages, 1938). Soybeans mellow the soil to the extent that erosion can be quite severe following this crop (Zhu et al., 1989). In contrast, Australian researchers describe the lupin as a "biological plow" because of this crop's ability to alleviate soil compaction (Henderson, 1989). Poor soil physical conditions can seriously impair grain legume production. Soil compaction can lead to poor root growth, increased root diseases, and waterlogging. The latter problem was found to reduce winterhardiness in Austrian winter peas in Idaho (Kephart and Murray, 1989). At Pendleton, Oregon, chiseling under the pea row increased yields by 40-50% where the compaction zone was fractured (Wilkins et al., 1984). While effective, this practice may not be economical on a large scale.

Grain legumes are susceptible to several soilborne and foliar diseases. Pathogens include Fusarium, Pythium, Rhizoctonia, Ascochyta, Aphanomyces, and Sclerotinia species (Kraft, 1982). Resistant varieties offer the best protection, followed by sound crop rotation practices. Grain legumes should be used in rotations where 3-4 year intervals separate their

<table>
<thead>
<tr>
<th>State</th>
<th>MAP (in)</th>
<th>Pea (cwt/ac)</th>
<th>Lentil (cwt/ac)</th>
<th>Chickpea (cwt/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oregon</td>
<td>15-17</td>
<td>10-40</td>
<td>5-11</td>
<td>1-3</td>
</tr>
<tr>
<td>Washington</td>
<td>20-22</td>
<td>24-32</td>
<td>16-21</td>
<td>28</td>
</tr>
<tr>
<td>Idaho</td>
<td>22-24</td>
<td>31-35</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>Montana</td>
<td>15-20</td>
<td>32</td>
<td>26</td>
<td>23</td>
</tr>
</tbody>
</table>

MAP = mean annual precipitation
(F. J. Nuehlbauer, pers. comm.)
production in the same field. Sunflowers are an alternate host for many grain legume diseases. In contrast, cruciferous crops such as canola appear to be a favorable forecrop for grain legumes. For example, the sulfur-containing compounds produced during the breakdown of brassica crop residues have significantly reduced Aphanomyces root rot in peas (Chan and Close, 1987). Any practice that avoids stress for the pulse crop will help reduce disease. Soil compaction, low soil pH, and lack of necessary plant nutrients all favor certain diseases. Diseases carried by insects from other host crops can devastate grain legumes, as occurred during 1990 when aphids carried viral diseases from distant alfalfa fields into pea fields in the Palouse region.

Grain legumes appear to have potential in many dryland farming areas of the Northwest. Lack of markets and affordable, effective weed control are two hurdles to overcome. Development of new varieties will help to address production problems and match legumes with the varied agroclimatic conditions of the region. For example, a "leafless" pea is being bred that will have quicker maturity, more drought tolerance, and less incidence of Sclerotinia (Muehlbauer, 1982), but may be less competitive with weeds. Innovative practices such as intercropping can help integrate grain legumes into a rotation. Researchers in northern Idaho found that a 25% winter wheat/75% winter pea mixture seeded together yielded 30% more than an equal area with monocrops of wheat and peas (Murray and Swensen, 1984). The intercrop was less subject to lodging and disease. A farmer near Spokane, Washington has been successfully intercropping spring barley and peas for several years.

Grain legumes can contribute to a more sustainable dryland cropping system, but they require adept management to cope with the high economic risk. The dramatic effect of farm conditions and management on pulse production is illustrated in Table 4.14, where the best performing 25% of farms was compared to the worst 25% surveyed in the Palouse region (Wiese, 1982). The rotational value of grain legumes to other crops, particularly wheat, needs to be better quantified to more fairly evaluate their economic impact. While grain legumes may be considered a minor crop compared to wheat, they will continue to be an important component of crop rotation in Northwest dryland agriculture.

| Table 4.14. Differences in Spring Pea Production on High and Low Yielding Farms in the Palouse Region. |
|----------------------------------------|-----------------|-----------------|
|                                       | Top 25% | Bottom 25% |
| Seed yield (lb/ac)                    | 3716    | 1907          |
| Vine yield (lb/ac)                    | 3635    | 2268          |
| Seeding date                          | Apr. 10 | Apr. 25       |
| Days to maturity                      | 114     | 104           |
| Weeds (% total DM)                    | 2       | 7             |
| Aphids (per 16 sweeps)                | 64      | 362           |

(Wiese, 1982)

Other Alternate Crops for Dryland Farming

Once settlers discovered that wheat could be successfully grown in the dryland Northwest, they tested the adaptability of many other crops. Few have been able to compete with wheat during the past century, but the search for potential crops continues. Crops that did grow well often faded due to economic or market constraints. For example, early in this century, Elberton, Washington (near Pullman) was the prune capital of the nation. This once-thriving town was surrounded by plum orchards on the rolling Palouse hills, but it is virtually abandoned today. Most dryland farms regularly grew forages to fuel horses and other livestock prior to machine traction. The advent of tractors greatly impacted crop rotation and diversity in the region.

Early research reports from agriculture experiment stations in the region indicate active efforts in testing potential new crops. In a 1919 research report from Pullman, Washington, a photo shows a field of Jerusalem artichokes that produced 11 tons/ac silage and 14 tons/ac roots. Over time, oilseeds and various grain crops have shown the most promise. Adapted species and varieties can grow in the often harsh climate, and these field crops are well matched with the management and equipment resources of grain farmers (Table 4.15).
Table 4.15. Yields of Alternate Crops in the Northwest Dryland Region.

<table>
<thead>
<tr>
<th>Crop</th>
<th>OR</th>
<th>WA</th>
<th>ID</th>
<th>NT</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Rapeseed/canola</td>
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</tr>
<tr>
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<td>10-24</td>
<td>17-24</td>
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<td>20-30</td>
</tr>
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<td>6-10</td>
<td>6-20</td>
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<tr>
<td>Triticale</td>
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<td>Buckwheat</td>
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</tbody>
</table>

(Kephart et al., 1989; Smith et al., 1989a, 1989b, 1989c, 1989d)

Oilseeds. Both safflower and sunflower have been commercially produced for many years on the Northern Plains. They have also been tested in eastern Oregon (Rasmussen et al., 1989), eastern Washington, and northern Idaho (Auld, 1978; Auld, 1981). Further production has been deterred by lack of a nearby processing facility. Safflower is probably the most drought and heat tolerant of all the commercially viable alternate agronomic crops within the region (Kephart et al., 1989). Seedlings can also withstand a hard frost. Its taproot can extract water from soil depths of 7-10 feet, making it a good crop to combat saline seep and increase water infiltration deeper into the soil (Smith et al., 1989b). Recommended rotations for Montana include wheat-safflower-barley-fallow or wheat or barley-safflower-fallow. Due to the deep moisture depletion, winter wheat should not follow safflower. Standing stubble from safflower provides good snow capture and soil protection.

Safflower and sunflower need a long growing season to mature (e.g., 120-150 days). Selection of shorter-season varieties is important in cooler areas. Sunflower silage has shown promise in northern Idaho where temperatures are too cool for seed maturity (Kephart et al., 1989). Several Montana growers are producing confectionery sunflowers for that specialty market. Sunflowers are more subject to insect and bird damage than safflower, and both crops are susceptible to diseases such as rust, verticillium wilt, and sclerotinia wilt.

At present, the most promising alternate crop in the region is rapeseed/canola (Prato, 1988). This crop appears suited to a large portion of the region. Approximately 57,000 acres were planted in Montana, Washington, Oregon, and Idaho in 1991. Domestic demand for the oil is growing due to its minimal saturated fat content and its high cooking stability. Canola oil currently contains about 6% saturated fat, the lowest of any common vegetable oil. Oil from industrial rapeseed is also in demand for its unique chemical properties for use in manufacturing and industry.

There are two species of rapeseed - *Brassica napus* and *Brassica campestris*. The *B. napus* varieties are taller, later maturing, and higher yielding under good conditions than *B. campestris*. In general, rapeseed is less drought resistant than cereal grains and uses more water (Smith et al., 1989d). Traditional rapeseed varieties contain high levels of undesirable compounds for human and animal consumption (erucic acid and glucosinolates). Canola refers to varieties of rapeseed that have been selected to contain <2% erucic acid in the oil and low levels of glucosinolates in the oil-free meal. The latter is economically important so the oilcake can be sold for livestock feed.

Industrial rapeseed and canola will cross-pollinate, leading to an oil that is unacceptable to either market. Therefore, minimum distances of 0.25-1.0 mile should be maintained between fields. *B. campestris* is more prone to this problem than *B. napus*. In the Pacific Northwest, specific rapeseed districts have been established to minimize this problem. Contact local agricultural officials to determine the regulations for a specific area.

Rapeseed appears to be a good rotation crop for dryland farmers. It produces chemical compounds that seem to suppress certain soilborne pests. Growers report yield increases in subsequent crops and improved soil tilth. But rapeseed generally should not be grown on the same field more than once in four years due to the potential for diseases such as *Alternaria* leaf spot,
production in the same field. Sunflowers are an alternate host for many grain legume diseases. In contrast, cruciferous crops such as canola appear to be a favorable forecrop for grain legumes. For example, the sulfur-containing compounds produced during the breakdown of brassica crop residues have significantly reduced Aphanomyces root rot in peas (Chan and Close, 1987). Any practice that avoids stress for the pulse crop will help reduce disease. Soil compaction, low soil pH, and lack of necessary plant nutrients all favor certain diseases. Diseases carried by insects from other host crops can devastate grain legumes, as occurred during 1990 when aphids carried viral diseases from distant alfalfa fields into pea fields in the Palouse region.

Grain legumes appear to have potential in many dryland farming areas of the Northwest. Lack of markets and affordable, effective weed control are two hurdles to overcome. Development of new varieties will help to address production problems and match legumes with the varied agroclimatic conditions of the region. For example, a "leafless" pea is being bred that will have quicker maturity, more drought tolerance, and less incidence of Sclerotinia (Muchlbauer, 1982), but may be less competitive with weeds. Innovative practices such as intercropping can help integrate grain legumes into a rotation. Researchers in northern Idaho found that a 25% winter wheat/75% winter pea mixture seeded together yielded 30% more than an equal area with monocrops of wheat and peas (Murray and Swensen, 1984). The intercrop was less subject to lodging and disease. A farmer near Spokane, Washington has been successfully intercropping spring barley and peas for several years.

Grain legumes can contribute to a more sustainable dryland cropping system, but they require adept management to cope with the high economic risk. The dramatic effect of farm conditions and management on pulse production is illustrated in Table 4.14, where the best performing 25% of farms was compared to the worst 25% surveyed in the Palouse region (Wiese, 1982). The rotational value of grain legumes to other crops, particularly wheat, needs to be better quantified to more fairly evaluate their economic impact. While grain legumes may be considered a minor crop compared to wheat, they will continue to be an important component of crop rotation in Northwest dryland agriculture.

| Crop Rotations |

<table>
<thead>
<tr>
<th>Table 4.14. Differences in Spring Pea Production on High and Low Yielding Farms in the Palouse Region.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield Percentile</strong></td>
</tr>
<tr>
<td>Seed yield (lb/ac)</td>
</tr>
<tr>
<td>Vine yield (lb/ac)</td>
</tr>
<tr>
<td>Seeding date</td>
</tr>
<tr>
<td>Days to maturity</td>
</tr>
<tr>
<td>Weeds (% total DM)</td>
</tr>
<tr>
<td>Aphids (per 16 sweeps)</td>
</tr>
</tbody>
</table>

(Wiese, 1982)

Other Alternate Crops for Dryland Farming

Once settlers discovered that wheat could be successfully grown in the dryland Northwest, they tested the adaptability of many other crops. Few have been able to compete with wheat during the past century, but the search for potential crops continues. Crops that did grow well often faded due to economic or market constraints. For example, early in this century, Elberton, Washington (near Pullman) was the prune capital of the nation. This once-thriving town was surrounded by plum orchards on the rolling Palouse hills, but it is virtually abandoned today. Most dryland farms regularly grew forages to fuel horses and other livestock prior to machine traction. The advent of tractors greatly impacted crop rotation and diversity in the region.

Early research reports from agriculture experiment stations in the region indicate active efforts in testing potential new crops. In a 1919 research report from Pullman, Washington, a photo shows a field of Jerusalem artichokes that produced 11 tons/ac silage and 14 tons/ac roots. Over time, oilseeds and various grain crops have shown the most promise. Adapted species and varieties can grow in the often harsh climate, and these field crops are well matched with the management and equipment resources of grain farmers (Table 4.15).
Oilseeds. Both safflower and sunflower have been commercially produced for many years on the Northern Plains. They have also been tested in eastern Oregon (Rasmussen et al., 1989), eastern Washington, and northern Idaho (Auld, 1978; Auld, 1981). Further production has been deterred by lack of a nearby processing facility. Safflower is probably the most drought and heat tolerant of all the commercially viable alternate agronomic crops within the region (Kephart et al., 1989). Seedlings can also withstand a hard frost. Its taproot can extract water from soil depths of 7-10 feet, making it a good crop to combat saline seep and increase water infiltration deeper into the soil (Smith et al., 1989b). Recommended rotations for Montana include wheat-safflower-barley-fallow or wheat or barley-safflower-fallow. Due to the deep moisture depletion, winter wheat should not follow safflower. Standing stubble from safflower provides good snow capture and soil protection.

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seedling blight, and blackleg. Rapeseed should not be grown next to or in close rotation with sunflower, field beans, field peas, potatoes, mustard, or other cruciferous crops (Smith et al., 1989d).

Both winter and spring rapeseed/canola varieties are available. This gives growers more flexibility in using the crop. Winter varieties must usually be planted on summer fallow land to allow early planting (mid-August to mid-September) and good germination. Complete ground cover is generally achieved by late fall, effectively controlling weeds and soil erosion. Spring rapeseed must be planted as early as possible to maximize growth during cool, moist conditions and avoid flowering during very hot temperatures. This latter situation will abort flowers and reduce yields. B. campestris varieties are more frost tolerant than B. napus and can be planted earlier. Growers near Pendleton, Oregon, are experimenting with aerial seeding of winter canola into unharvested wheat to allow recropping. Success of this practice is subject to timely summer and fall rains.

The nutrient requirements of rapeseed are similar to small grains (Premier, 1990), except that rapeseed needs 25-50% more sulfur and sometimes will respond to higher N rates. It is also very sensitive to boron deficiency. Growers in eastern Washington are successfully shanking nitrogen into a growing winter canola crop in the spring and thus minimizing overwinter losses. The nitrogen in rapeseed residue appears to be quickly released after harvest.

A number of companies are contracting for canola acreage in the region. In Montana, most seed is crushed in Canada. Whole seed from eastern Washington is exported to the Pacific Rim. Several companies have indicated interest in a processing plant in the region, once the supporting acreage can be assured. Development of custom oil varieties for specific end uses (e.g., potato processing) is under way. Overall, the markets for rapeseed/canola oil look brighter than for other alternate crops. Researchers are exploring the use of rapeseed as a cover crop to control specific pests, breeding varieties for just this purpose. Also, several brassica species can be grown for mustard seed used in making condiments by the food industry.

Other oilseed crops include flax, crambe, and castorbean. Flax is grown commercially in the Northern Plains. The other crops are experimental for the region.

Grains. Many grains are adapted to dryland conditions, but few have the large markets and government support that wheat enjoys. Barley is widely grown throughout the region, and will not be considered here as an alternative crop.

Triticale, a cross of wheat and rye, received much attention during the 1960s. It has a higher lysine content than other feed grains and more feed value than either corn or wheat, making it desirable for livestock rations (Smith et al., 1989c). Triticale also makes high quality forage and silage. Many production problems dampened the early enthusiasm, but progress is being made in improving the crop (National Research Council, 1989). Both winter and spring varieties are available, with winter varieties producing more grazable forage than other small grains. It may be especially suited to drought-prone areas with poor soils that are marginal for wheat production (Belcher and Withers, 1981). Triticale plantings are affected by farm program regulations, and the grain is generally priced below barley (McClintic, 1990). Thus, this crop faces large economic hurdles to further expansion.

Various relatives of wheat are being grown for specialty markets. Spelt is a winter annual popular in Europe. It has a hulled seed and low test weights of 32-36 lb/bu. Yields in humid temperate areas range from 80-120 bu/ac. Health food companies are interested in the product since it can be used as a substitute grain by people allergic to wheat. Similarly, kamut, a large-seeded relative of durum wheat, is hypo-allergenic. This crop was developed by a Montana farmer who has exclusive rights to it (Matheson et al., 1991). It is higher in lipids and minerals than common wheat and is used as a substitute for durum in pasta. Yields average 25 bu/ac in Montana (12-14 inches precipitation), but the crop commands a premium price.

Buckwheat is a fast-growing summer annual crop that produces edible seed made into flour. Domestic demand is not great, but Pacific Rim markets appear to be expanding. Buckwheat grain has a high lysine content and is considered a very high quality protein source. The crop is adapted to many
environments and soils, and may yield better on poor soils than many other grains (Smith et al., 1989a). Buckwheat is adapted to a warm growing season, and is easily killed by frost. It does not tolerate moisture stress due to its small root system. A crop can mature in 10-12 weeks under favorable conditions. Buckwheat is produced commercially on Montana, Idaho, and Washington dryland farms. About 14,000 acres were planted in Montana in 1991, with most of the crop destined for export. Buckwheat did not respond to N fertilizer on soils with too little N for spring barley (Auld, 1986). The crop is reputed to have the ability to accumulate phosphorus in soils with low available P (Kourik, 1986), and a current study in Montana is examining this. It also provides a good cover crop to smother weeds. One grower near Lewiston, Idaho, reports substantial yield increases in winter wheat following buckwheat green manure.

Quinoa, a domesticated relative of lambsquarters, was a staple grain for the Inca people in the Andes mountains (Johnson and Croissant, undated). The amino acid profile of quinoa is similar to milk, making it an ideal protein source. It is well adapted to high elevation, cool environments, and poor soil. Maturity ranges from 90-125 days in Colorado. Temperatures above 90°F inhibit growth and yield. Quinoa requires 10-15 inches of water. It responds well to nitrogen. Yields of 1200 lb/ac have been recorded in Colorado. No information is available from Northwest dryland locations.

Grasses. As native grasses were the dominant vegetation on much of the Northwest drylands prior to cultivation, it may sound ironic to call them alternate crops today. Grasses are certainly an alternative to wheat production, and they can provide seed, forage, and excellent soil conservation (USDA, 1957; McClure et al., 1958; Renney et al., 1967). They are seldom a competitive alternative if immediate cash income is a critical concern. Many of the grasses now grown are not native to the region. The majority of grass production is on land enrolled in the USDA Conservation Reserve Program (CRP). Growers receive a "rent" in lieu of cash income from crops for a period of 10 years. The CRP has been an economically attractive alternative to wheat on the more marginal lands in the region.

A number of grass seed crops are produced by dryland farmers in the region (Morrison and Law, 1978). These include wheatgrasses, fescues, bromegrasses, and Kentucky bluegrass. Grass seed prices are extremely volatile and markets are often limited. Successful grass growers in the Pacific Northwest have kept grass as an integral part of their rotation, with acreage fluctuating somewhat with price. The benefits for soil conservation and tilth have thus accrued over the years, despite periods of poor prices. Grass is often kept in a field for 6-8 years, followed by 10-20 years of annual cropping. Burning grass straw after harvest remains an important production practice, but the air quality implications are forcing a search for alternatives (Wirth et al., 1977). No-till planting of cash crops into chemically killed grass sod is a viable practice that reduces costs and can eliminate soil erosion for several years (Schirman and Canode, 1979).

An established grass seed field requires relatively few production inputs (Painter et al., 1992). Growers generally apply nitrogen fertilizer each year, with some rates exceeding 100 lb N/ac. Herbicides are seldom needed. Charges for machinery are the major variable expenses. With tighter regulations regarding field burning, production costs are expected to rise, and yields may suffer until alternative practices can be found.

A Conservation Reserve Program grass planting
Researchers at Nephi, Utah, found several promising grass crops earlier this century (Bennett et al., 1954). Tall and pubescent wheatgrass were the best forage/pasture producers. Crested wheatgrass was the most stable seed producer. More recently, several forage legumes have been tested for their adaptability to marginal and degraded wheatlands in Utah. Sainfoin was superior to alfalfa or cicer milkvetch in establishment and forage production, with enough potential production to justify livestock grazing (Rasmussen and Newhall, 1991). Combinations of legumes and grasses have generally outperformed monocrops in the Pacific Northwest and are a good choice for soil improvement.

Grass species tested at Pendleton, Oregon, in the 1950s had seed yields between 200-600 lb/ac for perennials and 800-1000 lb/ac for annual canary grass. They were not considered economically promising alternate crops at the time (Rasmussen et al., 1989). A study of grass seed production on southern Idaho dryland farms in the 1960s indicated yields of 100-400 lb/ac for several species. With grass, a crop was produced three out of four years compared to two out of four years in a wheat-fallow system. At least 12 inches of precipitation was needed (Windle et al., 1966). Current dryland grass seed yields range from 200-600 lb/ac.

Baker and Swanson (1952) studied three pairs of dryland farms in eastern Washington (18-22 inches precipitation) over five years to examine the benefits of rotations with grass. One farm in each pair used a wheat-pea rotation, while the other farm included a grass/legume crop on about 20-30% of the land each year, in addition to wheat and peas. With the grass/legume rotation, wheat and pea yields were 17% higher, net crop income was 38% greater (despite higher costs), and soil losses from erosion were 60% lower, compared to the wheat-pea rotation. The benefits from the grass/legume phase were greater with increasing frequency in the rotation.

The Soil Conservation Service has championed the benefits of grass for soil conservation and soil improvement in the dryland regions for many years (USDA, 1948; Renney et al., 1967). But grass has seldom been a viable economic alternative to cereals. Over the past decades, the yield potential on selected portions of the landscape has been lowered by soil erosion in many areas. As the current on-site and off-site costs of erosion are quantified, these marginal areas may be more economically used for grass production. One farm in eastern Washington rotates grass across all fields (Thorn, 1991). The susceptibility of an individual field to erosion determines the grower's decision on the length (10-30 years) and the use of the grass (seed, forage, or conservation). Changes in soil quality due to grass and other management practices must be better quantified to help growers best maintain current income while also investing in their soil "bank account."

Nitrogen and Water Relations in Dryland Cereal/Legume Rotations

In a crop field, nitrogen is a very dynamic element. It can come from numerous sources, including the air, rainwater, crop residues, synthetic fertilizers, manure and other organic wastes, decomposing soil organic matter, and subsurface water flow. Nitrogen can leave the field by leaching, soil erosion, surface and subsurface runoff, crop removal, denitrification, and volatilization. The balance between potential inputs and outputs changes over the growing season, and is also influenced by the nitrogen cycling in the soil, consisting of immobilization (N made unavailable in organic form), mineralization (N converted to inorganic, available form), and nitrification (N converted from ammonium to nitrate) processes.

When a legume is introduced into a cropping system, a common expectation is a net gain of nitrogen into the system. Whether this actually occurs will depend on the amount of nitrogen fixed and the availability of that nitrogen to the following crop. Also, legumes can increase subsequent crop yields beyond an actual nitrogen contribution due to rotation effects. These are often translated into "nitrogen fertilizer equivalent" values for various legume forecrops. These considerations will be discussed below in the context of dryland cereal cropping in the Northwest.

Nitrogen Fixation. Legumes vary greatly in the maximum amount of atmospheric nitrogen they can fix during a given time period. The first requirement is to achieve good nodulation of legume roots by the proper
Rhizobium species. This can be accomplished by inoculation of the seed with a high-quality Rhizobium product, or by a high population of suitable Rhizobium bacteria in the soil. In dryland environments, moisture conditions affect how much nitrogen fixation will be expressed. Greater plant growth typically results in greater N fixation, but requires more moisture. This is perhaps the key trade-off in the use of legumes in areas that do not experience annual soil moisture recharge.

Nitrogen fixation is also inversely related to levels of residual soil nitrogen. In the Palouse region, nitrogen fixation in chickpeas was reduced by 2.5 lb/ac for each lb/ac of available soil N (D.F. Bezdicek, pers. comm.). Legumes expend less energy in using available soil N than in fixing it. Thus, in order to maximize N fixation in a cropping system, a legume should be preceded by a crop that takes up most of the available soil N.

<table>
<thead>
<tr>
<th>Legume</th>
<th>Location</th>
<th>N Fixation (lb/ac/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring pea</td>
<td>Pullman, WA</td>
<td>15-67</td>
</tr>
<tr>
<td>Winter pea</td>
<td>Pullman</td>
<td>72-101</td>
</tr>
<tr>
<td>Lentil</td>
<td>Pullman</td>
<td>51-125</td>
</tr>
<tr>
<td>Dusty, WA</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Chickpea</td>
<td>Pullman</td>
<td>6-93</td>
</tr>
<tr>
<td>Dusty</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Faba bean</td>
<td>Pullman</td>
<td>47-126</td>
</tr>
<tr>
<td>Dusty</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Lupin</td>
<td>Pullman</td>
<td>52-56</td>
</tr>
<tr>
<td>Hair vetch</td>
<td>Pullman</td>
<td>96</td>
</tr>
<tr>
<td>Annual</td>
<td>Pullman</td>
<td>20</td>
</tr>
<tr>
<td>sweet clover</td>
<td>Dusty</td>
<td>14</td>
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<tr>
<td>Biennial</td>
<td>Moscow, ID</td>
<td>160</td>
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<tr>
<td>sweet clw</td>
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<td></td>
</tr>
<tr>
<td>Red clover</td>
<td>Pullman</td>
<td>55</td>
</tr>
<tr>
<td>Moscow</td>
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<td>140</td>
</tr>
<tr>
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<td>Pullman</td>
<td>19</td>
</tr>
<tr>
<td>Dusty</td>
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<td>7</td>
</tr>
<tr>
<td>Black med</td>
<td>Dusty</td>
<td>11</td>
</tr>
</tbody>
</table>

Estimates of nitrogen fixation in various legumes from experimental data in the Northwest are reported in Table 4.16. The large variation in estimates can be attributed to different years, environments, management, and measurement methods. The variability in actual fixation is a major drawback in relying on legumes to supply the bulk of a crop’s nitrogen needs. Determinations of legume dry matter yield and percent N are necessary to estimate the total N contribution (fixation plus soil uptake) to the system. Nitrogen fixation also varies with landscape position. Mahler et al. (1979) found N fixation by spring peas to be 61, 20 and 15 lb N/ac/yr for bottomland, south slope and ridge sites, respectively, near Pullman.

Substantial amounts of N are removed when legume pulses and forages are harvested. Smith et al. (1987) estimated net N contributions to be +62 lb/ac from lentil and -43 lb/ac from chickpea near Pullman. Another study (D.F. Bezdicek, pers. comm.) estimated that pulses generally fixed 50-100 lb N/ac/yr, but that more N was removed in the harvested seed than was fixed. Residual soil N was higher after pulses than after forage legumes, presumably due to greater uptake of soil N by the forages.

Nitrogen Recovery from Legumes. Studies with the isotope $^{15}$N, a form of nitrogen used as a tracer in research, have provided an idea of how nitrogen is released from legumes and recovered by a following crop. Australian researchers (Ladd et al., 1986) found that 20-27% of the N added by medic residues was recovered by the subsequent wheat crop, and about 4% by the second wheat crop. At Pullman, wheat plants recovered 6-8% of the N from the residue of a preceding spring pea crop (Veseth, 1989). Recovery was similar for the plow, disk, and chem-kill residue management treatments. A Nebraska study estimated that 5-10 lb N/ac were lost as ammonia when sweetclover was left on the surface after subtilling (Walter, 1988). Subtilling also retarded immediate legume N release, a consideration in managing the timing of N availability.

At Moscow, Idaho, 50-80% of the Austrian winter pea residue N was mineralized during the next growing season (Mahler and Auld, 1989). The N from the pea residue where seed had been harvested was used more efficiently by wheat than the N from the pea green
manure residue. North Dakota researchers found that N use efficiency in wheat was higher following forage legumes (21 lb grain/lb N) than after wheat (20) or fallow (18) (Badaruddin and Meyer, 1989). Nitrogen transfer may also occur from a growing legume to a nonlegume. In a Minnesota study, as much as 65% of the N in reed canarygrass was from alfalfa or trefoil when planted in a 3:2 or 2:3 ratio of grass:legume (Heichel, 1988).

**N Fertilizer Equivalent.** Crop yields after a legume are often greater than what can be attributed to the nitrogen contribution. The N fertilizer equivalent is calculated as the amount of fertilizer N needed on a cereal crop after a nonlegume to equal the yield of the same crop without fertilizer N after a legume. Factors such as root diseases in cereal-intensive rotations can account for a large part of the apparent crop response to legumes. The experimental values from the Northwest are summarized in Table 4.17.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Barley</td>
<td>81</td>
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<tr>
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</tr>
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<td>Lentil</td>
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</tr>
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<td>Field pea</td>
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</tr>
<tr>
<td>AM pea</td>
<td>30</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Fallow</td>
<td>--</td>
<td>0</td>
<td>34</td>
</tr>
</tbody>
</table>

(5% Max. Barley Yield (bu/acre) 103 116 55 56)

When a legume is used to substitute for fallow, or to provide a harvestable crop, N fertilizer equivalent and relative yield data can help determine the best choice of legume. In many cases, it is not profitable to attempt to replace all N fertilizer with legume N, since fertilizer N is inexpensive. The cost of a foregone cash crop or of grain yield loss due to legume moisture depletion will most likely exceed the savings on N fertilizer. The real advantage of green manure rotations comes when rotation effects boost grain yields, since an additional bushel of wheat has a greater economic benefit than a saved pound of N fertilizer. For example, growers in northern Idaho use spring peas in the rotation to help maintain winter wheat yields, even though peas are often unprofitable. If another forecrop could be found that boosted subsequent wheat yields more than peas, it might be a more profitable choice even if it was a green manure that produced no cash income.

**Legume Water Use.** The feasibility of diversifying dryland grain cropping with legumes will largely depend on the potential for water competition among the crops.
and how it compares to fallow. Historical data from the Northwest indicate that in many areas moisture was more limiting than nitrogen prior to the use of fertilizers. Thus, grain yields after legumes were typically lower than after fallow. Wheat yields were often depressed in the first crop after a green manure legume in the low and intermediate rainfall zones of eastern Washington, except after green manure peas (Horner et al., 1960). It was common to summer fallow after a green manure crop to help recharge soil moisture, but this practice often led to excessive available soil N, which also reduced yields.

In areas that experience full soil moisture recharge each year, moisture competition is not a problem. Legumes can substitute for a fallow period if their moisture use is limited by early incorporation, and if there is a high probability of seed zone moisture recharge prior to planting the following grain crop. With the winter rainfall and dry summers west of the Rocky Mountains, such a strategy may work for a spring crop, but it is risky for a fall-seeded crop. East of the Rockies, summer rainfall is generally adequate to recharge the seed zone prior to fall seeding.

Water use by legumes has been estimated by measuring the actual soil moisture depletion, or the remaining soil moisture after legume harvest or incorporation. Experimental results are presented in Tables 4.19 and 4.20. Generally, cereals use more water than forage legumes, which use more water than pulse legumes. In eastern Washington, moisture depletion by legumes was not correlated with the growth or yield of the following winter wheat crop at Pullman (21 inches precipitation), while there were significant negative correlations at Dusty (15 inches precipitation), indicating inadequate moisture recharge (Kirby, 1987).

When both the soil moisture depletion and N fixation rates are known for a legume, a ratio can be calculated to evaluate which species or variety fixes the most N per unit of water used. This index needs to be compared with the relative grain yield information for actually determining the best legume in a given system. Kirby (1987) found no correlation between water use and nitrogen fixation at Pullman.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Soil Moisture Depletion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pullman</td>
</tr>
<tr>
<td>Fallow</td>
<td>2.8</td>
</tr>
<tr>
<td>Lentil</td>
<td>5.5</td>
</tr>
<tr>
<td>Fababeans</td>
<td>5.9</td>
</tr>
<tr>
<td>Chickpea</td>
<td>5.9</td>
</tr>
<tr>
<td>Field peas</td>
<td>6.3</td>
</tr>
<tr>
<td>Black medics</td>
<td>7.1</td>
</tr>
<tr>
<td>Rose clover</td>
<td>7.5</td>
</tr>
<tr>
<td>Annual</td>
<td>8.7</td>
</tr>
<tr>
<td>Sweet clover</td>
<td>9.4</td>
</tr>
<tr>
<td>Clover mix</td>
<td>6.7</td>
</tr>
<tr>
<td>Barley (O-N)</td>
<td>6.7</td>
</tr>
<tr>
<td>Mean</td>
<td>6.7</td>
</tr>
</tbody>
</table>

(Kirby, 1987)

<table>
<thead>
<tr>
<th>Legume</th>
<th>Residual Moisture (in/3 ft soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red clover</td>
<td>7.0</td>
</tr>
<tr>
<td>hairy vetch</td>
<td>7.0</td>
</tr>
<tr>
<td>Winter pea</td>
<td>7.7</td>
</tr>
<tr>
<td>Spring pea</td>
<td>8.4</td>
</tr>
</tbody>
</table>

(Bezdecek et al., 1987)

Currently, several researchers are examining low water use legumes and strategies for limiting their water use. Previous work in Idaho indicated that sweetclover incorporation at 14-16 inches height did not greatly reduce the total nitrogen contribution, but did save a considerable amount of soil moisture (Table 4.21). Canadian researchers are studying new legumes such as Indianhead lentil, Tangier flatpea, Sirius feedpea, and chickling vetch as possible fallow substitutes (Biederbeck, 1989). They propose to kill the legumes after a specified amount of moisture has been depleted,
preferably with sub-tillage that leaves residue on the surface. In their study, legume inoculation increased the water use efficiency of these legumes by 230%. The feedpea and chickling vetch were the most efficient water users.

After two years, Montana researchers have found the following relative legume water use efficiency: Austrian winter pea > black medic > Cahaba white vetch = sweetclover > Indianhead lentil (J. Sims, pers. comm.). Austrian winter peas were also superior to Indianhead lentils in Wyoming studies. In Montana, winter wheat yields were highest after an Indianhead lentil green manure with an intermediate water consumption compared to high or low consumption, fallow, or continuous cropping. This system of controlled legume water use appears to be successful in replacing fallow, based on two cycles of the green manure-cereal rotation at several Montana locations.

Table 4.21. Effect of Sweetclover Height on Residual Soil Moisture and N Contribution at Teton, Idaho.

<table>
<thead>
<tr>
<th>Height at Plowing</th>
<th>Residual Moisture (in./6' soil)</th>
<th>Total Plant N (lb/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fellow</td>
<td>7.88</td>
<td></td>
</tr>
<tr>
<td>6&quot;</td>
<td>7.11</td>
<td>69</td>
</tr>
<tr>
<td>14-16&quot;</td>
<td>6.11</td>
<td>109</td>
</tr>
<tr>
<td>22-24&quot;</td>
<td>4.65</td>
<td>119</td>
</tr>
<tr>
<td>34-36&quot;</td>
<td>1.48</td>
<td>123</td>
</tr>
</tbody>
</table>

(Siddoway and McKay, 1955)

Austrian winter peas for green manure or seed on a Montana dryland farm
Conclusions

The value of crop rotation is a well-established agronomic fact. In dryland areas, alternative rotation crops must not diminish the moisture supply for the cereal crop unless they can return a greater overall value (e.g., income, nitrogen input, rotation effect) to the system. The use of legumes as an alternative to fallow shows promise in the Northern Plains. Improved farming practices are increasing water storage enough to allow annual cropping in many traditional crop-fallow areas. Past research shows that grass/legume periods in a wheat-fallow system can increase the yield potential over time by increasing water retention and storage. But short-term economics prevent most growers in the wheat-fallow areas from choosing this prudent long-term investment in their land resource. Subsidized programs like the CRP do allow for this option. Unfortunately, such efforts are often limited to the least productive land. The rotation options discussed above can help sustain productivity and resource conservation on all cropland regardless of production potential.

References


Ingham, I.M. 1924. Effect of legumes in rotation upon the nitrogen content of the soil. M.S. thesis. Washington State College, Pullman, WA.

Jacklin, A.W. 1936. Crop rotations. USDA-SCS Agronomy - Range Meetings, Pullman, WA.


Cooperative Extension, Pullman.


other forage legumes in Montana. *Montana AgResearch* 8(1):4-10.


Stephens, D.E. 1944. Conservation practices on wheatlands of the PNW. USDA-SCS.


White, J.G.H. undated. Grain legumes in sustainable cropping systems. Unpublished manuscript from Plant Science Dept., Lincoln University, New Zealand.


CHAPTER 5. 
SOIL QUALITY

Sampling for earthworms near Pullman, Washington

Farmers, researchers, consumers, and policy makers increasingly recognize the crucial role of the soil resource for food production and environmental protection. In the past few years, the term "soil quality" has received credibility in scientific circles as researchers attempt to measure soil properties that farmers have often monitored with their senses. Soil quality refers to the complex interactions of physical, chemical, and biological properties that support the enduring productivity and integrity of a soil. Soil quality is often equated to soil "health" since soils function as living systems. According to folklore, a healthy soil produces healthy plants which support healthy animals (including people). Researchers are now attempting to examine these relationships.

For the dryland farmer, soil quality revolves around two central issues: crop productivity and resource conservation. Productivity is influenced by moisture-holding capacity, nutrient-supplying power, rooting conditions, and the absence of toxic conditions (e.g., salinity, acidity). Soil erosion control is the primary resource conservation concern, since erosion removes the most productive part of the soil. Erosion also contributes to off-site problems such as sedimentation and agrichemical contamination. Both current productivity and resource conservation are essential in sustaining dryland farming.

Productivity can be evaluated from several aspects. Absolute yield is a widely used indicator of soil condition, but is of limited value. For example, in the Palouse region of eastern Washington, average winter wheat yields have steadily increased from 25 to 60 bu/ac over the past 50 years, despite the fact that erosion has stripped 50-100% of the topsoil from ridgetops, upper slopes, and other erodible landscape positions. Current yields require high levels of inputs and thus do not directly reflect the soil's inherent productivity. Thus, yield per unit of input may better measure the productivity aspect of soil quality. Similarly, yield stability over time under varying weather patterns may reveal more about the soil condition than absolute yield levels.

The effects of soil degradation are obvious on severely eroded sites and saline seep areas, where crop productivity has declined markedly. A large body of research and experience exists about the impact of various dryland farming practices on soil condition. Soil quality can be improved with currently available management options. But this may require a short-term economic sacrifice to realize production and environmental benefits in the long run.

Soil quality is best viewed in a relative sense. In
many agricultural areas, soils have been dramatically altered from their native state by farming activities. For example, comparing soils under native vegetation and cultivation (e.g., rain forest vs. rice paddy) may have little value. Fortunately, in the semiarid regions, soils under the native grass vegetation do provide a good reference point for soil quality when examining changes due to dryland cereal cropping systems.

Of all the possible approaches to measuring soil quality, the best indicator at present is soil organic matter. For the soils of the region, an increase in organic matter generally leads to improved soil quality attributes, such as increased biological activity, improved soil structure, greater water-holding capacity and fertility, and decreased erodibility. Organic matter influences the physical, chemical, and biological activity of a soil, and is an important integrating component. From an analytical perspective, measurements of total soil N are more precise than measurements of soil carbon, and both are better than a measurement of soil organic matter (Rasmussen and Collins, 1991). The discussion that follows attempts to briefly address the physical, chemical, and biological aspects of soil quality in separate sections while recognizing that most agricultural actions affect more than one aspect.

Long-Term Studies

Many soil quality attributes change slowly over time and require long-term studies to determine the influence of farming practices on them. Several research stations in the region have conducted long-term studies that provide valuable insights into the effects of farming systems on soil quality (Bennett et al., 1954; Rasmussen et al., 1989; Campbell et al., 1990). Replicated long-term plot studies have been conducted at Pendleton, Oregon; Nephi, Utah; Lethbridge, Alberta; and Swift Current, Saskatchewan.

While long-term studies were common earlier this century in cropping systems research, they are now rare because they require stable funding over the years. Paired-farm comparisons offer one alternative approach to long-term studies for investigating soil quality changes. Farms with known contrasting historical management need to be identified with side-by-side fields on the same soil and landscape position. A "snapshot" of current soil quality then provides inferences about the effects of various management schemes. These studies are typically confounded by many factors, making it difficult to determine specific cause-and-effect relationships. But they do illustrate the often large influence that a farming system can have on soil quality (Reganold, 1988). The documentation of contrasting management systems may be the best approach to examining long-term soil quality changes in an era of shrinking fiscal resources.

Physical Aspects

Loss of soil organic matter through cultivation and erosion has greatly degraded soil quality. Historical accounts seldom mention soil erosion from wheatlands in the first years after the sod was broken, due to the very stable soil structure. Intense cultivation physically deteriorated structure and accelerated organic matter oxidation. Organic matter loss decreased structural stability of the soil, leading to increased runoff and erodibility of soil particles. Erosion removed the topsoil, which contained the highest organic matter levels, and thus the soil became more erosive. This is illustrated in the data from Table 5.1, where organic matter, runoff, and erosion were measured over time on plots that had been continuously cropped for 60 years versus land that had been virgin grass until the experiment began (Stephens, 1944; Kent, 1957). Jacklin (1936) reported that soils that were originally high in organic matter but that had lost much of it were more erosive than soils originally low in organic matter.

Long-term studies throughout the Northwest have shown livestock manure to be one of the best treatments for maintaining organic matter levels (Baker and Klages, 1938; Rasmussen et al., 1989). At Pendleton, Oregon, wheat-fallow plots with manure had 2.62% organic matter compared to 1.93% with wheat-fallow plus nitrogen fertilizer (Table 5.2). Burning the wheat straw led to the greatest decline in soil organic matter (Fig. 6). At Moscow, Idaho, straw burning increased soil losses 300% over the treatment where straw was plowed in. Nitrogen fertilizer maintained organic matter levels in Idaho, but erosion was higher (14 tons/ac/yr) compared to soil fertilized with manure every third year (<5 tons/ac/yr). Several years of
perennial grass cover were also effective for erosion control (Baker and Klages, 1938).

Table 5.1. Effect of Historical and Current Management on Water Runoff and Soil Loss at Pullman, Washington.

<table>
<thead>
<tr>
<th>Current Cover (inches)</th>
<th>Runoff Soil Loss T/ac</th>
<th>Organic Matter %</th>
<th>Organic C Added (lb/ac)</th>
<th>Organic N Added (lb/ac)</th>
<th>Total Nitrogen (lb/ac)</th>
<th>pH (H2O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin land</td>
<td>0.06</td>
<td>0.03</td>
<td>3.9</td>
<td>5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter wheat</td>
<td>0.04</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass</td>
<td>0.01</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultivated land</td>
<td>2.97</td>
<td>8.99</td>
<td>2.3</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter wheat</td>
<td>0.05</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass</td>
<td>0.20</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Broken out of sod in 1935 and cropped to wheat-fallow. Average yield 40 bu/ac.
* Cropped for the past 60 years. Average yield 25 bu/ac.

(Stephens, 1944)

Table 5.2. Soil Changes from Long-Term Cropping Systems at Pendleton, Oregon.

<table>
<thead>
<tr>
<th>Cropping System</th>
<th>Organic C Added</th>
<th>Organic Matter</th>
<th>Total Nitrogen</th>
<th>pH (H2O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP</td>
<td>3.83</td>
<td>0.20</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>WP</td>
<td>2.69</td>
<td>0.13</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>WA</td>
<td>2.59</td>
<td>0.12</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>WF SM</td>
<td>2.62</td>
<td>0.10</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>WF S+N</td>
<td>1.93</td>
<td>0.09</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>WF S-N</td>
<td>2.07</td>
<td>0.08</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>WF FB</td>
<td>&lt;550</td>
<td>0.07</td>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

GP - grass pasture; improved varieties, grazed, occasional fertilizer and irrigation
WP - wheat-pea rotation; N fertilizer on wheat, straw returned
WA - annual crop wheat; N fertilizer, straw returned
WF SM - wheat-fallow; manure (10 T/ac/crop), straw returned
WF S+N - wheat-fallow; N fertilizer, straw returned
WF S-N - wheat-fallow; no fertilizer, straw returned
WF FB - wheat-fallow; no fertilizer, fall-burned straw

(Rasmussen et al., 1989)

Figure 6. Change in soil organic matter (1 ft depth) under a wheat-fallow rotation at Pendleton, Oregon, 1881-1986. Includes residue management treatments from 1931-1986. (Rasmussen et al., 1989)
In eastern Washington, wheat after peas in a rotation with alfalfa had about 60% less runoff and erosion than wheat after peas in a wheat-pea rotation (Horner et al., 1960). Baker and Klages (1938) reported that peas in rotation modified the surface soil structure and made it more subject to erosion. A similar phenomenon is reported to occur after soybeans in the Midwest (Zhu et al., 1989). Pawson et al. (1961) measured higher erosion after Austrian winter peas than after summer fallow. In contrast, an alfalfa stand for three or more years showed an effect in reducing erosion for seven years after it was plowed down.

On sites degraded by erosion, a grass/legume mixture has consistently been the most effective remediation (McKay and Moss, 1949). The grass roots effectively add below-ground stable organic matter (Kramer and Weaver, 1936) and restructure the soil, while the legume adds fixed nitrogen to the system to support the grass. Also, strong taproots (e.g., alfalfa) can penetrate compacted layers. The large contribution of root biomass by grasses is illustrated in Tables 5.3 and 5.4. In a study at Tetonia, Idaho, soil organic matter levels under perennial grass increased to levels similar to or even greater than those in a native condition (Kent, 1957). Nebraska researchers found that significant increases in soil N and C only occurred in plots with grass for more than six years compared to plots under continuous cultivation (McHenry et al., 1946).

### Table 5.4. Yields of Roots and Tops in Alfalfa/Grass Mixtures at Pullman, Washington.

<table>
<thead>
<tr>
<th>Plant Biomass</th>
<th>Alfalfa</th>
<th>Grass</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/ac</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard fescue</td>
<td>3840</td>
<td>11328</td>
<td>15168</td>
</tr>
<tr>
<td>Crested wheatgrass</td>
<td>3356</td>
<td>8896</td>
<td>12352</td>
</tr>
</tbody>
</table>

(Kent, 1957)

Soil compaction is becoming recognized as a widespread problem in many dryland areas. Contributing factors include loss of soil structure and organic matter, increasing weight of farm machinery, field operation on wet soil, and the use of tillage implements that create tillage compaction zones (e.g., moldboard plow and disc). Compaction inhibits root penetration, increases the tillage draft requirement, encourages certain diseases, and reduces air and water infiltration which can increase erosion potential. In a Whitman County,
Washington study, north slopes of fields had the least compaction of any landscape position, and compaction was greater in a spring barley field than in a winter wheat field (Tangren, 1979). Bulk density decreased as organic matter levels increased, indicating the benefit of organic matter in resisting compaction.

The actual impact of compaction on crop production is not well defined. But farmers and researchers are experimenting with various tillage implements, such as subsoilers, to alleviate compaction. In one study of pea fields, tillage pans were found at a 10-inch depth at a Pendleton, Oregon, site and at 7- and 15-inch depths near Walla Walla, Washington. Chisel plowing to 14 inches under the pea row increased pea yields by 40-50% at Pendleton, but decreased yields at Walla Walla since the lower tillage pan was not fractured. Chiseling did not appear to influence root disease incidence on peas in this study (Wilkins et al., 1984).

After 50 years of various tillage treatments at Pendleton, researchers found little difference in water infiltration (Fig. 7). In contrast, infiltration increased dramatically where a higher rate of N fertilizer had been used, probably reflecting higher crop residue additions and more organic matter (Rasmussen et al., 1989). Soil compaction was greatest in plots with straw only and straw burn treatments. Earthworms were always uncovered in the livestock manure treatments and never in the N fertilizer treatments, perhaps due to the higher organic matter levels and soil pH with the manure (Pikul and Allmaras, 1986). Earthworms may help to increase subsoil water movement.

Earthworms are receiving greater respect for their role in improving soil physical characteristics (Smith, 1990). Their action can help reverse compaction, improve water infiltration, and increase soil aggregation (Dutt, 1948). No-till systems appear to favor earthworms much more than other tillage systems.
The use of no-till systems can lead to changes in soil physical condition. In a 10-year Idaho study, soil bulk density increased under reduced tillage systems compared to conventional tillage systems (Hammel, 1989). The three crop rotations compared (wheat-pea; wheat-barley-pea; wheat-pea-alfalfa/clover) had no effect on physical properties. In contrast, soil physical conditions were significantly better under no-till versus cultivated in a nine-year study in southern Alberta, again with no effect from rotation (Dormaar and Lindwall, 1989). One reason for such conflicting results is the relationship between soil texture and farming practices concerning soil physical properties.

The physical condition of soils can be improved by including a legume in the crop rotation, according to researchers from Saskatchewan (Bowren, 1986). They measured the tractor power needed for tillage on plots with and without a legume in the rotation. The power requirement was significantly less with legumes at three out of four locations (Table 5.5).

<table>
<thead>
<tr>
<th>Location</th>
<th>Power Requirement (ft-lb) Legume</th>
<th>Power Requirement (ft-lb) No Legume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scott'</td>
<td>139</td>
<td>215</td>
</tr>
<tr>
<td>Loon Lake'</td>
<td>96</td>
<td>173</td>
</tr>
<tr>
<td>Melfort'</td>
<td>478</td>
<td>658</td>
</tr>
<tr>
<td>Indianhead</td>
<td>254</td>
<td>229</td>
</tr>
</tbody>
</table>

The effect of rotations on soil quality can be studied using paired farms with a history of contrasting management. This approach was used on two adjacent farms near Spokane, Washington (Patten, 1982; Bolton et al., 1985; Reganold, 1988). Both farms were broken out of sod around 1908 and farmed similarly until the 1950s. At that time, one farm (conventional) began to use commercial fertilizers and a more intensive cash crop rotation. The other farm (low-input) continued to use legume green manures and grass in rotation and never used any commercial fertilizer. After 30-40 years of contrasting management, significant differences in a number of soil properties were measured (Table 5.6). The most striking difference was depth to the clay-rich subsoil layer, or the thickness of remaining topsoil, which was six inches greater on the low-input farm. Microbial biomass and enzyme activities tended to be greater on the low-input farm as well.

<table>
<thead>
<tr>
<th>Table 5.6. Influence of Long-Term Management on Soil Properties on Paired farms near Spokane, Washington.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-input</td>
</tr>
<tr>
<td>Avg. wheat yields (bu/acre)</td>
</tr>
<tr>
<td>Moisture content (%)</td>
</tr>
<tr>
<td>Polysaccharides (g/kg soil)</td>
</tr>
<tr>
<td>Organic matter (%)</td>
</tr>
<tr>
<td>Depth to clay (in)</td>
</tr>
<tr>
<td>Estimated erosion (T/acre) 10-yr avg.</td>
</tr>
<tr>
<td>Palouse average erosion = 12.7 T/acre/yr</td>
</tr>
</tbody>
</table>

(Reganold, 1988)

Chemical Aspects

Soil chemical properties have been determined for decades to help manage fertility and irrigation. Many routinely-measured properties, such as pH, salinity, and organic matter, are important indicators of soil quality. The paired farm study mentioned above (Reganold, 1988) examined several chemical aspects of the two soils, including total N, total P, extractable P, and extractable K. While the low-input farm had never received any fertilizer additions other than green manures, the levels of soil nutrients were the same or greater than on the conventional farm which received N, P, and S in commercial fertilizer. Other studies in the Midwest are confirming the increased nutrient supplying power of soils that are managed to improve biological activity compared to those reliant on commercial fertilizer (Steel, 1990).

Many studies have examined nitrogen relations in long-term plots, as nitrogen is a crucial nutrient element for dryland grain production. Total N generally increases or decreases in tandem with changes in soil
organic matter and is the most precise measure of organic matter status. Biological activity then determines how much N is released from the organic matter each year. While crop-fallow accelerates the release of N, it also diminishes the total N supply of the soil compared to continuous cropping. Canadian researchers examined the potential N mineralization from 30-year plots in Saskatchewan (Campbell et al., 1991). They developed a parameter called the initial potential rate of N mineralization which was sensitive to changes in organic matter due to various rotation treatments. Annual cropping systems had a greater initial rate than crop-fallow systems. Fertilizers were as effective as legumes (green manure or hay) in increasing the quantity and quality of organic matter and nitrogen.

Wheat yields on this northern Utah field have declined from 30 to 3 bu/ac over the past several decades due to soil degradation.

In most situations, an input of nitrogen from fertilizer, legumes, or manure is necessary to maintain organic matter levels. Sievers and Holtz (1926) found C/N ratios to be fairly constant in Palouse soils, generally falling between 10:1 to 12:1. Cropped soils near Pullman, Washington (22 inches precipitation) always contained less N and C than the virgin soil, and C was lost more rapidly than N. At Lind, Washington (10 inches precipitation), the amount of crop residues returned to the soil was more important than N in maintaining soil organic matter (Horner et al., 1960).

Most nitrogen supplied to dryland crops is in the form of ammonium-based fertilizers. In much of the region, an undesirable side effect of the use of these materials has been a decline in soil pH. The decline in a given soil is in direct proportion to the total cumulative amount of N fertilizer applied over time (Rasmussen and Rohde, 1989). The effect is less pronounced in the driest areas since the native soil pH tends to be higher and fertilizer rates are lower. At Pendleton, Oregon, acidification was more rapid under stubble mulch tillage (pH 4.81) than under a moldboard plow system (pH 5.08). N applications were more concentrated in the top three inches with the stubble-mulch tillage, which may create a problem in the seed zone more quickly (Rasmussen and Rohde, 1989). Increased acidity also led to greater release of soluble silica, which moved below the plow zone where it may be precipitating in the higher pH soil and forming a restrictive cemented layer (Douglas et al., 1984).

In the dryland cereal region, soil organic matter (SOM) is the most simple measure of soil quality. Climate, vegetation, and landscape all influence native SOM levels. Thus, care must be used when comparing SOM in soils from various locations. Change in SOM can be used as an indicator of the impact of management practices on soils that formed under similar conditions. Also, the SOM under various management schemes can be compared to that under nearby native vegetation. The difference roughly reflects how much soil quality has changed due to agricultural activities. New analytical tools become available, researchers are looking beyond simple SOM levels to see if changes in the quality of SOM can also be linked to management actions. In a recent Canadian study, the SOM quality was considerably different under no-till versus conventional tillage (Arshad et al., 1990). The no-till soil was higher in aliphatic C (paraffins) and lower aromatic C than the conventional soil, and these organ
organic matter and is the most precise measure of organic matter status. Biological activity then determines how much N is released from the organic matter each year. While crop-fallow accelerates the release of N, it also diminishes the total N supply of the soil compared to continuous cropping. Canadian researchers examined the potential N mineralization from 30-year plots in Saskatchewan (Campbell et al., 1991). They developed a parameter called the initial potential rate of N mineralization which was sensitive to changes in organic matter due to various rotation treatments. Annual cropping systems had a greater initial rate than crop-fallow systems. Fertilizers were as effective as legumes (green manure or hay) in increasing the quantity and quality of organic matter and nitrogen.

Wheat yields on this northern Utah field have declined from 30 to 3 bu/ac over the past several decades due to soil degradation.

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matter fractions may be more sensitive indicators of soil quality than the SOM alone.

Investigators are proposing many possible approaches to measuring soil quality. Some of the methods, such as humus fractionation and oxidation-reduction potential, have a sound research base but have not been used for this purpose. One advantage of chemical methods for soil quality determination is the analytical precision and repeatability. Many of the biological and physical methods are fraught with poor repeatability and lack of rigorous methodologies. Thus, a view of soil quality from the chemical perspective may offer more promise than other approaches.

**Biological Aspects**

The focus on soil quality has grown out of a long-standing interest in the "living soil" held by farmers and researchers alike. But describing the biological status of soil is extremely difficult. Most of the life is microscopic. Efforts to measure microbial life often involve shocks to the system (drying, grinding, extractants, etc.) to which the organisms can be very sensitive. Therefore, it can be difficult to know whether the ultimate measurement reflects the original comparison or the effect of the analytical process.

Given this difficulty, measurements of soil biological characteristics are best used in a relative sense to compare treatments. The biological status changes considerably throughout the year, and thus the choice of sampling times must reflect the questions being asked.

Multiple sampling dates are necessary in most cases. But since the microbial system is highly dependent on soil carbon for its existence, the SOM differences between treatments can provide a reference point in judging the validity of biological test results.

Probably the best investigation of soil biology in the region comes from research on the long-term plots at Pendleton, Oregon (Rasmussen et al., 1989). These cropping systems have been in place 30-50 years, and include grass pasture, wheat-wheat, wheat-pea, and several wheat-fallow systems. The lowest levels of microbes and organic matter were found in the wheat-fallow systems. Within the fallow system, livestock-manured plots were similar to those under annual cropping, while straw burning resulted in the lowest levels of C and N. Manure was apparently able to counteract the effect of increased tillage on soils under summer fallow management. Researchers estimated that about 17% of the carbon added by wheat residue was stabilized in the soil under wheat-fallow cropping. The rest was lost by microbial respiration during decomposition. At Pendleton, microbial biomass varied seasonally in all systems (Collins et al., 1992). Microbial C increased from September to February, and then decreased. Microbial N followed a similar pattern, but peaked in November rather than February. The microbes appeared to capture a substantial portion of fertilizer N in the soil during the fall, thus reducing the potential for its loss. The population of bacteria and fungi showed wide seasonal variation, while actinomycete levels were relatively stable (Table 5.7).

Microbial levels were higher in plots with growing crops compared to those with fallow. This is due to the rhizosphere effect, in which plant roots provide a sizeable food source for soil microbes.

The long-term rotations at Pendleton also influenced the severity of several wheat diseases. Straw-breaker footrot (Pseudocercospora herpotrichoides) was most severe in continuous wheat plots, intermediate in wheat-fallow, and least in wheat-
pea. Take-all and Cephalosporium stripe were not affected by rotation. Damage from a root rot complex (Rhizoctonia and Pythium spp.) was greater in wheat-fallow than in wheat-wheat or wheat-pea. In wheat-fallow, this root rot complex was most prevalent in plots with N fertilizer and straw returned. Straw burning reduced the incidence of root rot, but not to the level in the livestock manure treatment.

Other studies in the region indicate that soil microbes benefit more from a reduction in tillage than from a shift in crop rotation (Dormaar and Lindwall, 1989; Granatstein et al., 1987). Application of manure or sludge is consistently beneficial to the soil biology as well (Dick et al., 1988).

The interest of farmers in soil life reflects their observations about the effects of their management practices on such aspects as residue decomposition, disease, and crop yield. They are interested in more quantitative measurements of soil quality to help them evaluate the economic impacts and to work with regulators on issues such as soil conservation compliance and water quality protection.

Summary

Based on the long-term research in the region, the following management principles will help maximize soil quality on dryland farms:

- minimize the use of summer fallow
- minimize tillage
- maximize crop growth and residue return
- add manure or other carbon sources when feasible
- include perennial grasses in the system
- minimize use of acid-forming fertilizers

Increasing the level of soil organic matter appears to be one of the best overall strategies for improving soil quality. Incorporating perennial grasses into the rotation is very effective in restructuring the soil, and the use of crops with a strong taproot (e.g., alfalfa, rapeseed) can help fracture hardpans. The Conservation Reserve Program can help growers use grass to rehabilitate many degraded acres. It also provides an opportunity to study the dynamics and time-frame of the process of soil improvement in the various rainfall zones of the Northwest.

The management options for maintaining and improving soil quality are well known. But their use is constrained by short-term economic considerations and government farm policy. As soil quality is further defined, studied, and linked to production and environmental concerns, the economic benefits of soil quality improvement will become better quantified. Future government farm programs that encourage and perhaps subsidize soil-building practices can help increase their adoption. Farmers would benefit from the increased inherent productivity of the land and the public would reap the environmental benefits of reduced soil erosion and water quality improvement.
References


Jacklin, A.W. 1936. Crop rotations. USDA-SCS Agronomy - Range Meetings, Pullman, WA.


Stephens, D.E. 1944. Conservation practices on wheatlands of the PNW. USDA-SCS.


CHAPTER 6.
RESOURCE GUIDE TO SUSTAINABLE AGRICULTURE IN THE DRYLAND NORTHWEST

As society moves towards the 21st century, the Information Age is becoming a reality. Agriculture has not escaped this revolution, and people involved in agriculture must have greater access to information and the ability to manage and interpret it. Sustainable agriculture relies heavily on intensive information management, where knowledge about the intricacies of the biology of agroecosystems can be used to replace some of the production inputs that are costly to both the farmer and the environment. The following section will help guide growers, consultants, agricultural agency personnel, and others interested in dryland farming to the information sources they need. Obviously, any such listing will be quickly out of date, but the institutions and programs will remain even if the people change.

RESEARCH RESOURCES

Idaho
Idaho Agricultural Experiment Station University of Idaho (UI) Moscow, ID 83843 (208) 885-7173 Ongoing Projects: Conservation tillage - Roger Veseth Yield mapping - Charles Peterson Nitrogen management - Robert Mahler On-farm testing - Stephen Guy Economics of reducing inputs - Ed Michelson STEEP Program - Roger Veseth

UI SW Idaho Research and Extension Center 29603 U of I Lane Parma, ID 83660 (208) 722-6701

UI Tetonia Research and Extension Center Box 1231, Star Rt. Newdale, ID 83438 (208) 456-2879
USDA-ARS Small Grains and Potato Germplasm Research Unit
P.O. Box 307
Aberdeen, ID 83210
(208) 397-4162

USDA-ARS Soil and Water Management Research Unit
3793 N. 3600 E.
Kimberly, ID 83341
(208) 423-5582

USDA-SCS Plant Materials Center
P.O. Box AA
1693 S. 2700 West
Aberdeen, ID 83210
(208) 397-4181

Montana

Montana Agricultural Experiment Station
Montana State University (MSU)
Bozeman, MT 59717
(406) 994-3681

Ongoing Projects:
Legumes for fallow replacement - Jim Sims
Managing green manures - Mal Westcott, Jim Sims
Nutrient accumulator plants - Jim Sims
Nonchemical weed control strategies - Peter Fay
Weed ecology - Bruce Maxwell
Variable landscape management - Jeff Jacobsen
Grain legume adaptability - Ron Lockerman
Specialty crops - Allen Bjergo

MSU Central Agricultural Research Center
HC 90, Box 20
Moccasin, MT 59462
(406) 423-5421

MSU Eastern Agricultural Research Center
P.O. Box 1350
Sidney, MT 59270
(406) 482-2208

MSU Northern Agricultural Research Center
Star Rt. #36, Box 43
Havre, MT 59501
(406) 265-6115

MSU Northwestern Agricultural Research Center
4570 Montana 35
Kalispell, MT 59901
(406) 755-4303

MSU Southern Agricultural Research Center
748 Railroad Hwy.
Huntley, MT 59037
(406) 348-3400

MSU Western Agricultural Research Center
580 NE Quast Lane
Corvallis, MT 59828
(406) 961-3025

MSU Western Triangle Research Center
P.O. Box 1474
Conrad, MT 59425
(406) 278-7707

USDA-ARS Cereal Crop Improvement Research Unit
Leon Johnson Hall
Montana State University
Bozeman, MT 59717
(406) 994-3344

USDA-ARS Range Insect Control Research Unit
Rangeland Insect Lab
Montana State University
Bozeman, MT 59717
(406) 994-3344

USDA-ARS Biological Control of Weeds Research Unit
Culbertson Hall, 4th Floor
Montana State University
Bozeman, MT 59717
(406) 994-6850

USDA-ARS Soil and Water Management Research Unit
Northern Plains Soil and Water Research Center
P.O. Box 1109
Sidney, MT 59270
(406) 482-2020

USDA-SCS Plant Materials Center
Rt. 1 Box 1189
Bridger, MT 59014
(406) 662-3579
Oregon

Oregon Agricultural Experiment Station
Oregon State University (OSU)
Corvallis, OR 97331
(503) 737-4251

Ongoing projects:
Soil fertility dynamics - Richard Dick
Soil microbiology - Richard Dick
On-farm testing - Russ Karow
Alternate crops (canola, meadowfoam) - Russ Karow

OSU Columbia Basin Agricultural Research Center
P.O. Box 370
Pendleton, OR 97801
(503) 278-4186

Ongoing Projects:
Conservation tillage systems - Don Wysocki
Alternative crops (canola, lupin, lentil) - Tom Chastain
Managing cereal diseases - Richard Smiley
Resistance to Russian wheat aphid - Pam Zwer
On-farm testing - Don Wysocki
STEEP Program - Don Wysocki

USDA-ARS Soil & Water Conservation Research Unit
Columbia Plateau Conservation Research Center
P.O. Box 370
Pendleton, OR 97801
(503) 276-3811

Ongoing projects:
Tillage and residue management - Paul Rasmussen
Nitrogen management - Paul Rasmussen
Wheat growth modeling - Ron Rickman
Subsoiling - Dale Wilkins
Agroclimatic zones - Clyde Douglas

USDA-ARS Forage Seed and Cereal Research Unit
National Forage Seed Production Research Center
3450 SW Campus Way
Corvallis, OR 97331-7102
(503) 757-4824

USDA-SCS Plant Materials Center
3420 NE Granger Ave.
Corvallis, OR 97330
(503) 757-4812

Utah

Utah Agricultural Experiment Station
Utah State University (USU)
Logan, UT 84322
(801) 750-2207

Ongoing projects:
Conservation tillage systems - Phil Rasmussen
Alternative crops - Phil Rasmussen
Reduced input rotations - Phil Rasmussen

Washington

Washington Agricultural Research Center
Washington State University (WSU)
Pullman, WA 99164-6240
(509) 335-4563

Ongoing projects:
Soil quality - David Bezdicek, John Reganold
Rhizobium for legumes - David Bezdicek
Variable landscape management - Baird Miller, David Mulla, Bill Pan
Crop rotations - Peggy Chevalier
Spring canola - Baird Miller
Grass seed production - Bill Johnston
Fertility management - Bill Pan
Crop and soil modeling - Gaylon Campbell, David Mulla
Nutrient/pesticide movement in soils - David Mulla, Larry King
Economics of alternative rotations - Douglas Young
Biological control of weeds - Gary Piper
Russian wheat aphid biocontrol - Lionel Tanigoshi
On-farm testing - Baird Miller
Conservation tillage systems - Roger Veseth
STEEP Program - Roger Veseth

WSU Dryland Research Unit
P.O. Box B
Lind, WA 99341
(509) 677-3671

USDA-ARS Wheat Genetics, Quality Physiology, and Disease Research Unit
Johnson Hall, Rm. 209
Washington State University
Pullman, WA 99164-6420
(509) 335-3632
USDA-ARS Plant Germplasm Introduction and Testing
Research Unit
Johnson Hall, Rm. 59
Washington State University
Pullman, WA 99164-6402
(509) 335-1502

Ongoing projects:
Introduction and distribution of new plant species and varieties. Germplasm maintenance and evaluation of the following collections: forage and turf grasses; forage legumes (medics, alfalfa, Astragalus, sainfoin); food legumes (pea, lentil, chickpea); oilseeds (safflower); some spice plants and medicinal plants. Contact Richard Johnson.

USDA-ARS Grain Legume Genetics and Physiology
Research Unit
Johnson Hall, Rm. 215
Washington State University
Pullman, WA 99164-6421
(509) 335-9521

Ongoing projects:
Grain legume breeding (winter and spring pea, winter and spring lentil, chickpea) - Fred Muehlbauer

USDA-ARS Land Management and Water Conservation
Research Unit
Johnson Hall, Rm. 215
Washington State University
Pullman, WA 99164-6421
(509) 335-1552

Ongoing projects:
Soil and water conservation - Robert Papendick
Soil erosion measurement - Don McCool
Soil microbiology and biological control - Ann Kennedy
Nitrogen management - Jeff Smith
Tillage and seeding equipment - Keith Saxton

USDA-ARS Root Disease and Biological Control
Research Unit
Johnson Hall, Rm. 365
Washington State University
Pullman, WA 99164-6430
(509) 335-1116

Ongoing projects:
Disease management with crop rotation, tillage and biological control - James Cook

USDA-ARS Nonirrigated Agriculture Weed Science
Research Unit
Johnson Hall, Rm. 215
Washington State University
Pullman, WA 99164-6421
(509) 335-1551

Ongoing projects:
Crop rotation studies - Alex Ogg
Integrated weed management - Frank Young
Nonchemical weed control - Alex Ogg

USDA-ARS Western Wheat Laboratory
E202 FSHN Facility East
Washington State University
Pullman, WA 99164-6394
(509) 335-4062

USDA-ARS Plant Materials Center
257 Johnson Hall
Washington State University
Pullman, WA 99164-6428
(509) 335-7376

CENEX/Land O'Lakes Agronomy, Inc.
W. 11202 McFarlane Rd.
Spokane, WA 99202
(509) 924-3561

Ongoing projects:
Variable fertilizer management, nutrient and pesticide movement - Max Hammond
On-farm testing - Craig Walter

The McGregor Co.
Research and Development Division
P.O. Box 740
Colfax, WA 99111
(509) 397-4355

Ongoing projects:
Conservation farming equipment, nutrient/pesticide movement in soil - Steve Reinertsen

Spectrum Crop Development Corp.
P.O. Box 541
Ritzville, WA 99169
(509) 646-3213

Ongoing projects:
Canola, lupin - Andrew Thostenson, Curtis Hennings
Wyoming

Wyoming Agricultural Experiment Station
University of Wyoming
Laramie, WY 82071
(307) 766-3667

*Ongoing projects:*
- IPM for small grains and sugar beets - D. Legg
- Alternative forage crop evaluation - D. Koch, R. Delaney, A. Gray
- Intercropping forages for pest control - F. Gray
- Spoke-wheel injection for fertilizer - A. Blaylock

UW Torrington Research and Extension Center
Rt. 1 Box 374
Torrington, WY 82240
(307) 532-7126

*Ongoing projects:*
- Legumes for fallow replacement - J. Krall, S. Miller
- Conservation tillage systems - J. Krall
- Dryland production survey - J. Krall

UW Powell Research and Extension Center
747 Road 9
Powell, WY 82435
(307) 754-2223

Other

Surrounding states and provinces, such as Colorado, North Dakota, Saskatchewan, and Alberta, have active research programs relating to sustainable agriculture in dryland regions. Also, much Australian research is relevant to Northwest conditions. Contact universities and governmental agencies in these places.

The Soil Conservation Service has four National Technical Centers that support the field operations with research information. One is located in Portland, Oregon.

SCS West National Technical Center
511 NW Broadway, Rm. 248
Portland, OR 97209
(503) 326-2826

The Soil Conservation Service conducts research on various plants for conservation use through the Plant Materials Centers, listed above under individual states. The address for the national office is:

National Plant Materials Center
Building 509, BARC-East
Beltsville, MD 20705
(301) 344-2175

The USDA Sustainable Agriculture Research and Education program (formerly LISA) has a western region program. More information about ongoing projects and funding opportunities can be obtained from the following:

Dr. David Schlegel
University of California
Division of Agriculture and Natural Resources
300 Lakeside Dr., 6th Floor
Oakland, CA 94612-3560
((510) 987-0029

Several international agricultural research centers are heavily involved in dryland agriculture. While they tend to focus on problems in regions warmer than the Northwest, some of their findings may still be applicable.

CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), P.O. Box 6-641, Mexico 06600, D.F. Mexico. Major responsibility for wheat, corn, barley, and triticale.

ICARDA (International Center for Agricultural Research in the Dry Areas), P.O. Box 5466, Aleppo, Syria. Major grain legume responsibility (chickpea, lentil, fababean) and regional responsibility for barley and wheat.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru P.O., Andhra Pradesh 502 324, India. Crop mandate includes millet, sorghum, and chickpea.
EDUCATIONAL AND SERVICE RESOURCES

Cooperative Extension Service

The Cooperative Extension Service is a partnership among federal, state, and local entities that provides educational opportunities and materials to the public. Most counties have an extension office, where various types of agricultural information can be obtained. Local extension agents are supported by specialists at the colleges of agriculture and/or at outlying research and extension centers. Individuals can request a catalogue of extension and research publications available from land-grant institutions.

Idaho Cooperative Extension System
University of Idaho
Moscow, ID 83843
(208) 885-6639

Montana Extension Service
Montana State University
Bozeman, MT 59717
(406) 994-3681

Oregon Extension Service
Oregon State University
Ballard Extension Hall
Corvallis, OR 97331-3613
(503) 737-2713

Utah Cooperative Extension Service
Utah State University
Logan, UT 84322
(801) 750-2200

Washington Cooperative Extension
Washington State University
Pullman, WA 99164-6230
(509) 335-2811

Wyoming Cooperative Extension Service
University of Wyoming
Laramie, WY 82071
(307) 766-5124

Soil Conservation Service

Idaho State SCS Office
3244 Elder St., Rm. 124
Boise, ID 83705
(208) 334-1601

Montana State SCS Office
Federal Bldg., Room 443
10 E. Babcock St.
Bozeman, MT 59715-4704
(406) 587-6842

Oregon State SCS Office
Green Wyatt Federal Bldg., Rm. 1640
1220 SW Third Ave.
Portland, OR 97204
(503) 326-2751

Utah State SCS Office
P.O. Box 11350
Salt Lake City, UT 84147
(801) 524-5050

Washington State SCS Office
W. 316 Boone, Suite 450
Spokane, WA 99201-2348
(509) 353-2336

Wyoming State SCS Office
Federal Bldg., Rm. 3124
100 E. B St.
Casper, WY 82601
(307) 261-5201

Private, Nonprofit Organizations

AERO (Alternative Energy Resources Organization)
44 N. Last Chance Gulch
Helena, MT 59601
(406) 443-7272
AERO has had a sustainable agriculture program for more than eight years. Activities include regional surveys, farm case studies, conferences, farm tours, and on-farm testing projects.

Alberta Sustainable Agriculture Association
P.O. Box 1063
Nanton, Alberta T0L 1R0 Canada

Bio-Integral Resource Center (BIRC)
P.O. Box 7414
Berkeley, CA 94707
(415) 524-2567
One of the best sources of information on biological
control of pests. They publish the *IPM Practitioner* and *Common Sense Pest Control Quarterly*.

Great Northern Botanicals Association  
P.O. Box 362  
Helena, MT 59624  
(406) 227-5237  
This group specializes in producing and marketing herbs and other high-value crops.

Idaho Grain Producers Association  
Suite 315 Owyhee Plaza  
Boise, ID 83702  
(208) 345-0706

Idaho Rural Council  
P.O. Box 236  
Boise, ID 83701  
(208) 344-6184  
This group is actively involved in farm policy and family farm issues that affect the region.

Montana Ag Producers, Inc. (MAGPI)  
Box 212  
Harrison, MT 59735  
(406) 685-3376  
A grower group exploring alternative crop and market development. Crops of interest include canola, specialty crops, grain, forage, and green manure legumes.

Montana Grain Growers Association  
P.O. Box 1165  
Great Falls, MT 59403  
(406) 761-4596

Northern Plains Sustainable Agriculture Society  
Box 36  
Maida, ND 58255  
(701) 256-2424  
This grassroots grower organization is involved in research, education, and networking for sustainable agriculture in the Northern Plains region of the United States and Canada. They publish a practical monthly newsletter.

Northwest Coalition for Alternatives to Pesticides  
P.O. Box 1393  
Eugene, OR 97440  
(503) 344-5044  
NCAP is an advocacy group interested in reducing the use of pesticides in forestry, agriculture, and the home. Their quarterly publication *Journal of Pesticide Reform* discusses pesticide policy, toxicology, and alternatives to current pesticide use.

Oregon Wheat Growers League  
P.O. Box 400  
Pendleton, OR 97801  
(503) 276-7330

Oregon Tilth  
P.O. Box 218  
Tualatin, OR 97062  
Oregon Tilth is a statewide group interested in sustainable agriculture and organic farming. Their main focus is on cropping systems in the Willamette Valley.

Palouse-Clearwater Environmental Institute (PCEI)  
P.O. Box 8582  
Moscow, ID 83843  
(208) 882-1444  
PCEI has had a sustainable agriculture program for about two years. Initial efforts have focused on communications between farmers and consumers, and on an organic farm certification program for Idaho.

Progressive Farmers Inland Northwest (PFIN)  
Rt. 4 Box 236  
Walla Walla, WA 99362  
(509) 525-2494  
PFIN is a grassroots farmer organization that promotes on-farm testing and adaptation of sustainable agriculture practices for dryland farming in the Pacific Northwest.

USA Dry Pea and Lentil Council  
5071 Hwy. 8  
Moscow, ID 83843  
(208) 882-3023  
This is the umbrella group for the dry pea and lentil industry in the region. They work on international marketing, and also cooperate with the Idaho, Washington, and American Dry Pea and Lentil Associations.
Washington Association of Wheat Growers
109 E. First Ave.
Ritzville, WA 99169
(509) 659-4302

Washington Tilth
P.O. Box 465
Olympia, WA 98507
(206) 842-5612

Washington Tilth is a statewide group interested in sustainable agriculture and organic farming. They have been most active in western Washington and the Columbia River valley with horticultural crops.

Wyoming Wheat Growers Association
Burns, WY 82053
(307) 788-1530

National Information Services

AgriSource
CENEX/Land O'Lakes Ag Services
P.O. Box 64089
St. Paul, MN 55164
(612) 451-5151

This is a private information service for Cenex/Land O'Lakes dealers and customers. It includes crop protection assistance, crop planning, soil test results, crop variety selection, and current technical information.

Alternative Farming Systems Information Center
National Agricultural Library, Room 304
10301 Baltimore Blvd.
Beltsville, MD 20705
(301) 344-3704

This service offers brief searches of AGRICOLA (a major agricultural database), help in identifying current USDA research projects, and bibliographies on sustainable agriculture topics, including dryland farming, green manures and cover crops, and cultural and mechanical weed control. Recently, they have produced a series of videotapes featuring key proponents of sustainable agriculture, including Robert Rodale, Wes Jackson, Charles Francis, and Fred Kirschenmann.

Appropriate Technology Transfer for Rural Areas
P.O. Box 3657
Fayetteville, AR 72702
(800) 346-9140

ATTRA is a federally-funded information service available through a toll-free number. Their staff produces information packets on many sustainable agriculture subjects, and will provide custom reports for unusual requests.

Sustainable Options Hotline
Center for Rural Affairs
P.O. Box 405
Walthill, NE 68067
(402) 846-5428

This service offers advice on how growers can take advantage of new sustainable farming options in the Farm Bill. This includes the Integrated Farm Management Program Option, the Water Quality Incentives Program, and various conservation practices that impact base acreage.

Organic Farm Certification Programs

Farm Verified Organic
RR 1 Box 40A
Medina, ND 58467
(701) 486-3578

Idaho Organic Certification
Idaho Dept. of Agriculture
P.O. Box 790
Boise, ID 83701
(208) 334-2623

Idaho Organic Producers Association
11741 Bullock Lane
Middleton, ID 83644
(208) 585-6140

Oregon Tilth
P.O. Box 218
Tualatin, OR 97062
(503) 692-4877

Organic Certification Association of Montana
P.O. Box 871
Helena, MT 59624
(406) 721-4331

Organic Foods Production Association of North America
P.O. Box 1078
Greenfield, MA 01301
(413) 774-7511
PRINTED INFORMATION SOURCES

Dryland farming in the Northwest has been studied and written about for more than a century. Consequently, the volume of printed information is huge. Sources range from historical studies to current scientific articles to field day handouts. The list below highlights the outstanding sources pertinent to the Northwest.

Cooperative Extension Publications

Each state extension system operates a publications division. Catalogues of currently available resources (including computer programs) can be ordered from the addresses below. A fee is charged for many publications. For extension publications no longer in print, contact the library system at your land-grant university, or the National Agricultural Library to request a photocopy.

Extension Publications, Ag Publications Bldg., College of Agriculture, University of Idaho, Moscow, ID 83843.

Cooperative Extension Service, Publications and News Services, Montana State University, Bozeman, MT 59717

Agricultural Communications, Administrative Services Bldg. 422, Oregon State University, Corvallis, OR 97331-2119.

Extension Publications, Utah State University, Logan, UT 84322-5015

Cooperative Extension Bulletin Dept., Washington State University, Pullman, WA 99164-5912.

University of Wyoming, Bulletin Room, University Station, Laramie, WY 82071

Classic Historical Studies


This paper summarizes the results from the green manure treatments that were a part of a 38-year study (1914-1951) of numerous small grain rotations involving wheat, barley, oats, corn, and fallow in various combinations at several Great Plains experiment stations. The results indicated that rotation crops had no effect at all or a depressing effect on small grain yields the following year as compared to ordinary fallow. Possible factors leading to their failure include sufficient soil organic N supplies, poor weed control, inefficient storage of winter precipitation, late seeding, poor timing of plow down, and a lack of nodulation. The main effect of the green manures in this study was to reduce the water available to the subsequent grain crops. The results of this unreplicated study are the most likely reason that research on dryland legume-cereal rotations essentially ceased in Montana until 1978.


This is a general paper that was written to disseminate information about dryland farming to the increasing number of new farmers in Montana. Such items as equipment, moisture conservation, tillage, weeds, stubble management and crops are discussed. The recommendations include discing after harvest, harrowing after every summer rain and whenever a crust formed on fallow soil, cultivating for weeds, using press drill to pack soil around the seed, and harrowing out weeds when grain was six inches high.

The rate of water absorbed by the soil was evaluated on bare fallow, trashy fallow, and grassland. Total absorbed water in one hour was 1.55, 2.80, and 2.11 inches for the respective covers. The water intake rate at one hour was 0.3 in/hr for bare fallow and 2.26 in/hr for trashy fallow. Water intake rates associated with other tillage practices are also presented in this bulletin.


This bulletin summarizes the results of 50 years of research at the Nephi Field Station in central Utah, where the average annual precipitation was 12.65 inches. A pea green manure increased wheat yields both in the short and long term. Wheat yields were sometimes depressed by green manure, due to moisture shortage or N immobilization. Manure application increased wheat yields in all treatments, and was more beneficial in wet years. Burning straw increased yields for 30 years, but then they began to decline. A wheat-fallow system gave the highest yields and net returns, and wheat was the only crop that distinctly benefitted from summer fallow. But only 32% of the precipitation was stored in the soil during summer fallow.


This bulletin summarizes the research results from soil management experiments conducted over 40 years at six experiment stations in the region. It covers crop rotation, fertilization, and use of organic materials. Sweetclover and alfalfa were more effective than other legumes in increasing wheat yield. Yields of wheat were markedly affected by the sequences of cropping. Return of straw to the soil decreased yields slightly under low N conditions. Organic and mineral N had no effect on yields in low precipitation zones. The effects of cropping on runoff and erosion are also described.


Bulletin 112 presents the results of a seven-year dryland farming study that was conducted on six farms, in six counties of Utah. The average annual rainfall over all locations during the study was 14.8 inches. The study looked at time and depth of plowing, time and depth of seeding, fallow versus continual cropping, and crop varieties. Fall plowing to a depth of 10-18 inches, planting seed in the fall at a shallow depth of 1.5 inches, and use of summer fallow all led to the highest yields. Plowing under wheat straw enhanced the water retaining capacity of the soil compared to burning the straw.


Alfalfa was not successful as a legume in rotation with cereals over a 16-year period. The deep alfalfa roots greatly depleted soil moisture. Oat yields following two years of alfalfa were 14.7 bu/ac compared to 21.5 bu/ac oats following corn.


This is probably the most thorough examination of crop rotations and their impact on farm income and soil conservation ever done for the Palouse region. Wheat was always the most profitable crop. When grown with N fertilizer, wheat was able to maintain soil organic matter levels. Farm program provisions greatly influenced the profitability of various rotations. The authors recommended using different rotations on different land capability units. With acreage allotments, alfalfa hay rotations were profitable. On eroded upper slopes, barley and alfalfa were recommended, with wheat on the lower slopes.


This bulletin emphasizes the fact that "...soil erosion has
now increased during this (35-50 year) period until now it has become a serious menace.” Five cropping systems and several livestock systems are described in detail. Budget breakdowns for equipment, labor, and initial capital investment, schedules for operations, and marketing considerations are provided, relative to 1930.


In order to help farmers judge the agricultural value of unbroken land, a detailed study of natural vegetation was conducted in the Great Plains area. Three main associations were determined; 1) Short-grass formation, represented by the grama-buffalo grass association, 2) Wire-grass association, characterized by shallow-rooted and deep-rooted plants, and 3) Bunch-grass association of primarily deeply rooted plants. These vegetation groups were correlated with available soil moisture, with soil texture being the most determining factor.


An excellent summary of the dryland experiment station research in Washington, Idaho, and Oregon. Describes research on stubble mulching, tillage implements, crop rotations, and fallow. The use of rotations with sweetclover or alfalfa-grass were encouraged.


A summary of the early dryland farming techniques in Wyoming.


This is one of the most technically competent early books on dryland farming, written by a respected Utah researcher.

Selected Contemporary References


Alberta Agriculture’s nonchemical guide to crop protection begins with 28 pages of general advice on how to control weeds, insects, and disease in crops without chemical pesticides. This includes crop rotation, sanitation, crop competition, physical control, biocontrol, and field scouting. The rest of the book looks at specific pests and considers their life cycles, emergence, reproduction, management strategies, and control. Where available, tables of economic thresholds are included. This is an excellent reference for assessing potential alternatives to chemical pesticides for a large number of pests.


The results of interviews with 23 farmers in the Palouse region of Washington and Idaho are summarized in chapters on crop and soil management, economics and policy considerations, and social institutional factors. Farmers were chosen for their use of alternative rotations or cropping practices. The booklet illustrates some of the successful alternative practices currently used by commercial grain farmers and the economic and social motivations and consequences.


A clearly written and nicely illustrated summary of the soil benefits from legumes in rotation and recommended management of them. Examples of benefits from erosion control, increased yield, improved soil structure, reduced horsepower requirements, and nitrogen fixation are included.

This easy-to-use guide to cover crops for the United States contains much general information on cover crop species and potential applications.


This book summarizes the major findings from the various long-term experimental plots in western Canada. It focuses on dryland farming systems, and the effect of crop rotation and tillage practices on soil quality, fertility, yields and economics, energy, pests, and moisture.


Wheat Health Management was written as a thorough guide to wheat production for growers as well as researchers. It is applicable throughout most of North America and many other wheat producing areas. The book is technically complete but easy to read, and is illustrated with many excellent photos and figures. Wheat health management is discussed before planting, at planting, postplant, and postharvest. The final chapter presents the idea of holistic health for wheat.


This volume presents a thorough review of current dryland farming practices throughout the western United States and Canada. It covers water conservation, soil conservation, cropping practices, pests, and socioeconomic. The chapters are fully referenced.


A compilation of the papers presented at the 1986 STEEP Symposium, representing 10 years of research on conservation farming systems for the dryland Pacific Northwest. Major topics include tillage and plant management, erosion and runoff prediction, plant design, pest management, socioeconomic, integrated systems, and technology transfer.


This excellent publication describes the historical development of summer fallow use in dry farming in Montana and some of its consequences. The authors propose a new approach to cropping intensity, one called "flex-cropping" in which the decision to plant a crop is based on the presence of at least three inches of stored soil water at seeding time. This system would reduce some of the negative effects of summer fallow while also reducing exposure to drought risk. Federal acreage restrictions under the commodity programs pose a major barrier to this approach.


This booklet describes the benefits of a "sustainable agriculture system" on properties that reduce the impacts of drought conditions. Topics include the influence of soil aggregate size on moisture retention and crop growth, the benefits of perennial grasses in the rotation to improve soil structure, management of sweetclover for grazing and green manure, and stubble mulch tillage.


This work covers a number of dryland research areas, including white lupin as an alternative crop; the use of black medic in rotation (the PALS concept); influence of rotations, fertilization, and fumigation on winter wheat performance; rotational effects of medics; wheat interference with weeds; costs and returns of alternative systems; and comparison of agronomic effects of conventional, organic, and biodynamic management. Rotational effects appeared to suppress weeds in wheat with the medic compared to a continuous cereal system.

The available information on the use of summer fallow (as of 1974) is presented in this report. Advantages and disadvantages are presented with reference to crop yield, soil conservation, and moisture management. The chapters are organized by geographic region.


A well-written text covering all aspects of biological farming in the prairie region of Saskatchewan. Practices apply to small and large farms. It includes reports from selected farms. References are at the end of chapters.


Summarizes the talks given at the conference. Much information is from Canadian researchers in Saskatchewan who are working on low water use legumes as fallow replacements.


This easy-to-read booklet suggests numerous strategies to help protect groundwater while also maintaining profits. The strategies are organized around weed control, insect control, disease control, and nitrogen efficiency.

Kirschenmann, F. 1988. Switching to a sustainable system. Northern Plains Sustainable Agriculture Society, RR 1, Box 73, Windsor, ND 58424. 18 pp.

The author runs a crop/livestock farm of several thousand acres in North Dakota that is certified organic. He shares his insights about the key elements needed to move a farm in a more sustainable direction - crop rotation, soil-building, imagination, and time.


AERO’s survey in 1988 of farmers and ranchers practicing sustainable agriculture resulted in a demographic profile of these farmers and identified their management goals and the practices that they found successful. Their operations tend to be moderately sized for the region and include both crops and livestock. Farmers identified specific practices or techniques they are using or have used, and the farm management goals being met. The goals most frequently mentioned were soil fertility and soil conservation, closely followed by crop yield and quality, pest control, water conservation, and reducing inputs or costs.


The farm case studies presented in this book include details of the crop rotations, tillage, fertilization, and pest control practices used by the farms. Farms were chosen for their innovative or alternative practices. Partial budgets for each crop on each farm are presented to provide a reference point for the economic performance of alternative dryland cropping systems. Comparisons with more conventional systems are not made.


The agronomic practices associated with raising dry peas in the Pacific Northwest are detailed in this manual.


Methods for easily identifying the growth and development stages of wheat, barley and wild oat are presented. This will aid in proper timing of many farming activities.

This chapter summarizes the key results of long-term dryland farming studies at Pendleton, Oregon, and other similar locations. It focuses on the impacts of farming practices on soil organic matter and microbial properties.


A summary of over 50 years of plot research at Pendleton, OR. Manure maintained highest yields, highest soil organic matter, and highest pH compared to other treatments. Nitrogen fertilizer had a more marked effect on water infiltration than various tillage treatments. Green manure systems are generally not economic in the drier areas, due to competition for moisture with wheat, which is the most profitable crop. Legumes can contribute between 40 and 80 lb N/ac to the following crop. Varietal improvement over the past 50 years has been the most significant factor in increasing wheat yields. Burning straw accelerated organic matter losses from the soil and eventually reduced yields. Marginal returns have generally been lower from alternative crops than from wheat.


The book is a guide to the process of finding the most appropriate legume species and management system for a given situation. The methods rely principally on simple tools and procedures. While targeted to researchers and extension workers, many farmers will be able to perform the screening. Procedures include an initial assessment phase, a screening phase for local adaptation, screening within the cropping system, and long-term trials to assess impacts.


The ley farming system used extensively in Australia is being adapted to Montana conditions. Initial results show that legume green manures before cereals can replace some or all nitrogen fertilizer with little reduction in soil moisture available to the cereal crop.

Strand, L.L. (ed.). 1990. *Resource Guide.* The ley farming system used extensively in Australia is being adapted to Montana conditions. Initial results show that legume green manures before cereals can replace some or all nitrogen fertilizer with little reduction in soil moisture available to the cereal crop.


This publication is part of a series on major crops of California. It is a well-written volume with a wealth of information. There are many figures and pictures included to help in diagnosing pest problems. Cultural, biological, mechanical, and chemical controls are included.


Strategies for controlling weed, insect, and disease pests of wheat are described, with many photos of specific pests. A range of control methods are listed, including cultural, chemical, and biological, where available.


This proceedings covers a wide range of topics related to food legumes: international programs, gene resources, cropping systems, management and tillage, harvest and storage, processing and utilization economics, biotic limitations, IPM, nitrogen fixation, physiology, breeding and biotechnology, and regional reports.


The proceedings consists of more than 280 scientific papers on dryland farming. Subject areas include...
sustainability, soil erosion, water conservation, agroclimatology, soil fertility, residue management, socioeconomic issues, environmental issues, cropping systems, and crop/livestock systems.


The manual is a loose-leaf collection of chapters on more than 35 possible alternative field crops, including buckwheat, grain legumes, oilseeds, and grains. It is targeted to Upper Midwest conditions, but the information can be used to evaluate these potential crops for other environments.


The handbook incorporates the findings of over 15 years of research on conservation tillage systems in the Pacific Northwest dryland farming region. This research was supported by the STEEP program (Solutions to Environmental and Economic Problems), a cooperative research effort by Washington State University, the University of Idaho, and Oregon State University. The handbook contains chapters on tillage and equipment, erosion impacts, residue management, disease and weed control, fertility, and economics. It is in a loose-leaf binder format that can be updated with future issues of the Conservation Farming Update. Available from extension publication offices in Idaho or Washington for $20.


The most current guide to weeds in the region, with over 900 photos and descriptions of 350 weeds, including growth stages and habitat. Available from Cooperative Extension Publication offices for $19.50.


Over 100 diseases of wheat are described in technical terms in this authoritative reference. Figures and photos are used throughout the text, and a section of color photos is useful in identifying diseases.

Resource Lists


Magazines and Newsletters

**AERO Sun Times.** A quarterly magazine about sustainable agriculture, energy, and economic development issues for rural Montana. Contact AERO, 44 N. Last Chance Gulch, Helena, MT 59601.

**American Journal of Alternative Agriculture.** A refereed scientific journal about the agronomic, socioeconomic, and policy aspects of sustainable agriculture. Contact Institute for Alternative Agriculture, 9200 Edmonston Rd., Greenbelt, MD 20770.

**Australian Grain.** A bimonthly that presents a mix of popular and technical articles on dryland farming in Australia, where many issues are similar to the Northwestern U.S. Contact Australian Grain, P.O. Box 766, Toowoomba, 4350 Australia.


**Bumper Times.** A newsletter about no-till farming for small grains. S. 4305 University Rd., Spokane, WA 99206.

**Columbia Basin Agricultural Research.** An annual publication of the current research results from the joint USDA-ARS/Oregon State University research station at Pendleton, OR. Order from CBARC, P.O. Box 370, Pendleton, OR 97801.

**Extension newsletters.** Many county extension programs publish a newsletter for their farmer clients. Contact your local extension office.

**IPM Practitioner.** An excellent technical reference on biological pest control. Contact BIRC, P.O. Box 7414, Berkeley, CA 94707.

**Journal of Pesticide Reform.** A mix of popular and technical articles about the use of toxic substances in our society and ways to reduce their impacts and use. Contact NCAP, P.O. Box 1393, Eugene, OR 97440.

**Journal of Sustainable Agriculture.** A refereed scientific journal about the agronomic, socioeconomic, and policy aspects of sustainable agriculture. Contact Haworth Press, 10 Alice St., Binghamton, NY 13904.

**Montana AgResearch.** An annual publication of the Montana Agricultural Experiment Station featuring results of current research activities. Order from Editor, Montana AgResearch, Communications Services, Culbertson Hall, Montana State University, Bozeman, MT 59717.

**The New Farm.** A bi-monthly popular magazine featuring leading farmers and researchers working on sustainable agriculture. Its focus is the eastern United States but occasional articles discuss dryland agriculture and specialty crops. Available from Rodale Institute, 222 Main St., Emmaus, PA 18099.

**Northern Plains Sustainable Agriculture Society Newsletter.** A monthly newsletter for members of NPSAS that contains research reports, marketing information, and policy articles written by farmers and researchers. Order from NPSAS, Box 36, Maida, ND 58255. Membership is $10/yr.

**Oregon Wheat.** The monthly magazine of the Oregon Wheat Grower League. It contains features on research and policy related to wheat and feed grain production. Contact OWGL, P.O. Box 400, Pendleton, OR 97801.

**Soil and Water Conservation District newsletters.** Many districts produce their own newsletters which contain information about local conservation activities. Contact your local district or SCS office.

**STEEP II Extension Conservation Farming Update.** A quarterly review of research results on conservation tillage systems in the Pacific Northwest. Dept. of Plant, Soil, and Entomological Sciences, University of Idaho, Moscow, ID 83843.

**Sustainable Farming Quarterly.** A publication of the Northwest Dryland Cereal/Legume LISA Project containing articles on historical and current research, farmer innovation, and resources for sustainable dryland agriculture. Contact AERO, 44 N. Last Chance Gulch, Helena, MT 59601.

**Synergy.** A quarterly publication covering alternative agriculture and rural issues on the Canadian Prairies. Order from Synergy, Box 97, Drinkwater, Saskatchewan S0H 1G0, Canada. Cost is $14/yr Canadian.

**Wheat Life.** The monthly publication of Washington Association of Wheat Growers. It contains features on research, economics, and policy related to wheat and barley production. Contact WAWG, 109 E. First Ave., Ritzville, WA 99169.
OTHER RESOURCES

Computer Resources

AERO Database of Sustainable Agriculture in the Northern Plains Rockies and Plains. A database containing the responses of over 180 farmers to a detailed survey about farm goals and practices, and successes and failures in developing more sustainable farming systems. Searches can be done to find other farmers using specific sustainable agriculture practices. Contact AERO at (406) 443-7272 to request a search.

AGRICOLA. The major agricultural database which is managed by the National Agricultural Library (NAL). It is accessible by phone modem, through most land-grant universities, or directly from the NAL. CD-ROM versions are available for personal computer use. Contact NAL, 10301 Baltimore Blvd., Beltsville, MD 20705.

AGSTATS. An IBM-compatible statistics program designed for use by farmers and extension workers to analyze the results of simple on-farm research experiments. Send a formatted disk and postage paid return mailer, or $5, to Russ Karow, Extension Agronomist, Crop Science Bldg. 131, Oregon State University, Corvallis, OR 97331-3002; (503) 737-5857.

CRIS/USDA. A database of current research project information for USDA-CSRS funded projects, USDA-ARS research projects, and Agricultural Experiment State projects. Other federally-funded projects are listed in the NTIS database of federal research in progress. Contact CRIS, NAL Bldg. 5th Fl., 10301 Baltimore Blvd., Beltsville, MD 20705; (301) 504-6846.

CROPSYS - Northwest Dryland Cereal/Legume Cropping Systems Database. MCP0011. A compilation of historical and current information on practices that may enhance the sustainability of dryland agriculture in the northwestern United States. The database focuses on crop rotation, legumes and grasses, and soil quality, and includes information on many other aspects of dryland farming. The program requires an IBM-compatible computer. Available in a format with a manual and more search capability (for use with a dBase-compatible database program) from Bulletin Office, Cooperative Extension, Washington State University, Pullman, WA 99164-5912 (cost $15) or in a stand-alone format from V.P. Rasmussen, Dept. of Soil Science, Utah State University, Logan, UT 84322.

CROPSYST. A simple multi-year, multi-crop daily time step simulation model intended for studying the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and loss, and erosion. Management options include cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations, and residue management. The model is written in TurboPascal 6.0 for MS-DOS, with documentation available. For more information, contact Claudio Stockle, Agricultural Engineering, Washington State University, Pullman, WA 99164-6120; (509) 335-3826.

Database of Alternatives to Targeted Pesticides. Statewide IPM Project, Univ. California, Davis, CA 95616-8621. Scientists at the University of California developed an inventory of alternatives to pesticides and specific crop uses that would be restricted under new federal and state law. Each record in the database represents one alternative to a crop/pest use of a targeted pesticide. The database works with FoxBASE or dBASE III.

FARMS (Farm and Research Center Matching System). An offshoot database of the MAPS system, FARMS contains environmental information about dryland agriculture research stations in the Northern Plains and Rockies. Users can search for those locations most similar to their own to pinpoint the best sources of research information. Contact Dept. of Plant and Soil Science, 826 Leon Johnson hall, Montana State University, Bozeman, MT 59717; (406) 994-5075.

GRAINVAR. A database of over 250 wheat, barley, oat, and triticale varieties released from public and private sources in the Pacific Northwest. The IBM-compatible program permits searches for specific varietal traits to address a particular production problem. For more information, contact Baird Miller at (509) 335-2858.

GRIN (Germplasm Resources Information Network). A database operated by the USDA National Plant Germplasm System. It allows searches of the entire national germplasm collection for species or varieties with particular traits, with the potential to obtain samples for experimental purposes. For more information, contact Manager, GRIN Database Management Unit, USDA-ARS-PSI-GSI, Bldg. 001 Rm. 130 BARC West, Beltsville, MD 20705; (301) 344-1666.
MAPS (Montana Agricultural Potentials System). A database containing 150 biophysical attributes for agricultural lands in Montana. The information is coded for cells of 8 square miles. Searches can be done to determine areas suitable for potential crops, potential for environmental problems, or many other purposes. Contact MAPS Analyst, Dept. of Plant and Soil Science, Montana State University, Bozeman, MT 59717; (406) 994-5067.

MODWHEAT. A detailed wheat development and growth simulation model calibrated for Pendleton, Oregon, but usable anywhere with local data. Can model winter and spring wheat. Minimum inputs are daily maximum/minimum temperatures and precipitation; planting data; and soil moisture data. Contact Ron Rickman, USDA-ARS, CBARC, P.O. Box 370, Pendleton, OR 97801; (503) 276-3811.

PLANTEMP. This program models crop cover and vegetative leaf development. Daily maximum/minimum temperature data are needed. Order from Agricultural Communications, Administrative Services Bldg. 422, Oregon State University, Corvallis, OR 97331-2119; (503) 737-2513.

Residue Decomposition Model. This program calculates the rate of decomposition of standing or buried crop residue. Needed inputs are daily maximum/minimum temperature, initial residue amount, tillage condition, and residue N content. The model can be used at any location. Contact Clyde Douglas, USDA-ARS, CBARC, P.O. Box 370, Pendleton, OR 97801; (503) 276-3811.

RESMAN. A residue management decision support program that helps farmers select practices that maintain surface residue for erosion control. It covers 21 crops, including wheat, barley, peas, buckwheat, lentils, and oilseeds. Contact Diane Stott, USDA-ARS National Soil Erosion Research Laboratory, Purdue University, SOIL Bldg., West Lafayette, IN 47907.

SANET. This is the electronic bulletin board developed by the Sustainable Agriculture Network to share information across electronic networks. The system requires access to INTERNET, an electronic mail system found on most university campuses. To automatically be updated by SANET, send the message (with no other words) SUBSCRIBE SANET-MG to the following INTERNET address: ALMANAC@OES.ORST.EDU. For more information, contact Jill Auburn, UC Davis, at (916) 757-3278.

SMART.FRMS. A user-interactive program to assist farmers in evaluating the agronomic, economic, and environmental impacts of various crop rotation and input scenarios. It requires certain baseline information about the farm and the farming practices being compared. For more information, contact Allen Bjergo, Montana State University Extension, 1018 Burlington, Rm. 200, Missoula, MT 59801; (406) 728-7799.

SOILOSS. A soil erosion damage model that assigns economic values to soil loss and compares the short- and long-term economic impact of current choices about soil conservation practices. Contact David Walker, Dept. of Agricultural Economics, University of Idaho, Moscow, ID 83843.

Sustainable Agriculture Network. An on-line sustainable agriculture computer network to access information sources around the country. It is currently in its developmental phase. For more information, contact Jill Auburn, Information Group, SAREP, University of California, Davis, CA 95616; (916) 757-3278.

Sustainable Agriculture Research and Education (SARE) Program Project Summaries. A database of all the project summaries for USDA SARE (formerly LISA) project summaries since the start of the program in 1988. The stand-alone program does instant searching and indexing. Contact Phil Rasmussen, Dept. of Plant, Soils, and Biometeorology, Utah State University, Logan, UT 84322-4820; (801) 750-2255.

SWIM (Soil Water Infiltration and Movement). A menu-driven model to simulate soil water balances using numerical solutions of the basic water flow equations. Contains three programs for file management, simulation, and display. Contact CSIRO Division of Soils, Private Mail Bag, P.O. Aitkenvale, Queensland, Australia 4814.

TISSUE TEST. MCUG #47. Integrated Nutrient Diagnosis and Recommendations (INDR) is an IBM-compatible program to formulate nutrient diagnoses and to recommend fertilizer applications for agronomic crops. It provides users with a second opinion that can promote more efficient fertilizer use. Order from University of Idaho, Ag Computing Services, Ag Science Bldg., Room 307, Moscow, ID 83843; (208) 885-7110. Cost is $20.

USU-LISA-BBS. An electronic bulletin board on sustainable agriculture at Utah State University. To connect, call (801) 750-2195 through a computer modem that uses standard ANSI-color emulation terminal
software such as PROCOMM. Contact Phil Rasmussen at (801) 750-2257 for further information.

Weather Wizard. A program used to generate average weather data for specific locations without weather stations. Based on 30-year average data from weather stations in eastern Oregon or Washington. Order from Agricultural Communications, Administrative Services Bldg. 422, Oregon State University, Corvallis, OR 97331-2119; (503) 737-2513; or from Bulletin Office, Cooperative Extension, Washington State University, Pullman, WA 99164-5912; (509) 335-2857. Cost is $15.

W.E.E.D.S.: Western Expert Educational Diagnostic Systems. A random access computer program that helps to quickly identify weed species using easily recognizable traits. The program requires an IBM-compatible computer. Available from Weed Diagnostic Lab, Dept. of Plant, Soil & Entomological Sciences, University of Idaho, Moscow, ID 83843 for $79.99 retail.

WHEATD. MCUG #46. An IBM-compatible program to identify diseases commonly found in Idaho wheat fields and to recommend control treatments. Order from University of Idaho, Ag Computing Services, Ag Science Bldg., Room 307, Moscow, ID 83843; (208) 885-7110. Cost is $20.

WheatPlan. An IBM-compatible program to help determine nitrogen fertilizer needs for winter wheat in wheat-fallow rotations in the 10-15 inch precipitation zones of eastern Oregon. Order from Agricultural Communications, Administrative Services Bldg. 422, Oregon State University, Corvallis, OR 97331-2119; (503) 737-2513.

In addition to the programs listed above, many other programs have been developed by researchers to model plant growth, insect development, soil conservation, water quality impacts, and economic returns. Many of these are not formally released for public use but may be available directly from the researcher. New computer software is constantly being produced and any listing will be immediately outdated.

Videos

"Conservation on Your Own." A 60-minute video on conservation compliance plans and soil conservation problems. Presents practical advice on residue management, windbreaks, terraces, and strip-cropping. Available from National Association of Conservation Districts, Box 855, League City, TX 77574. Cost is $7.50.

Montana State University videos. Subjects include alfalfa management, alternate crops, safflower, small grains, and amaranth, with film lengths ranging from 12-30 minutes. Contact Jim Sims, Plant and Soil Science, MSU, Bozeman, MT 59717-0312 for more information.


"Profitable Conservation Systems: Insights from the IPM Project." A 30-minute video highlighting the results of a six-year study comparing conventional and conservation farming systems near Pullman, Washington. The project focused on weed management and conservation compliance, and included several tillage and rotation combinations. The wheat-barley-pea rotation under conservation tillage and moderate to high weed management provided higher yields, lower risks, and greater profits than other systems. Order from Bulletin Office, Cooperative Extension, Washington State University, Pullman, WA 99164-5912. Cost is $15.

"Soil Sampling." A 5-minute video describing proper procedures for soil sampling from agricultural fields. Available from Phil Rasmussen, Dept. of Plant, Soils, and Biometeorology, Utah State University, Logan, UT 84322-4820; (801) 750-2255.

"Sustainable Agriculture." A 10-minute video discussing what this term means for Utah agriculture. Available from Phil Rasmussen, Dept. of Plant, Soils, and Biometeorology, Utah State University, Logan, UT 84322-4820; (801) 750-2255.

"Sustainable Agriculture." A 30-minute video produced by KUID-TV, Moscow, Idaho, featuring interviews with Fred Kirschenmann, Richard Thompson, and Garth Youngberg at the first Farming for Profit and Stewardship conference in Post Falls, Idaho, March 2-3, 1989. A copy may be borrowed from David Bezdicek, Dept. of Crop and Soil Sciences, Washington State University, Pullman, WA 99164-6420. Phone (509) 335-3644.

Suppliers of Sustainable Agriculture Products and Services

Biological Control of Weeds. 1140 Cherry Drive, Bozeman, MT 59715; (406) 586-5111. Biological control agents for several range and cropland weeds.
Bozeman Biotech. P.O. Box 3146, Bozeman, MT 59772; (406) 587-5891. Suppliers of various biological control agents for agriculture.

From Furrow to Fork. P.O. Box 1266, Helena, MT 59624; (406) 442-3505. An organic food consulting and marketing service.

Gallagher Power Fence. P.O. Box 708900, San Antonio, TX 78270; (800) 531-5908. Markets the Pasture Probe Mk III, a device made in New Zealand to estimate the dry matter per acre of forages and cover crops. Useful in determining a suitable time for green manure plowdown.

Grassland West. Box 489, Clarkston, WA 99403; (509) 758-9100. A supplier of grass and legume seed for conservation, forage, and green manure.

K-Hart. Box 413, Elrose, Sask. S0L 0Z0, Canada; (306) 378-2258. Manufactures a barrier seeder to plant barrier strips (flax, canola, etc.) on summer fallow for wind erosion protection and snow trapping.

Paul Brown. 1624 South 3rd, Bozeman, MT 59715; (406) 586-0411. Sells a soil moisture probe to quickly determine soil moisture to a depth of three feet.

Spectrum Crop Development Corp. P.O. Box 541, Ritzville, WA 99169; (509) 646-3213. A supplier of new barley and canola varieties. Also testing white lupin and other potentially adapted crops.

Timeless Seeds. Rt. 3 Box 461, Conrad, MT 59425; (406) 278-3384. A supplier of seed and inoculant for soil-building crops for dryland farming. Specializing in medics and other legumes.

Turner’s Welding. Box 124, Kyle, Sask. S0L 1T0; (306) 375-2363. Manufactures a barrier seeder to plant barrier strips (flax, canola, etc.) on summer fallow for wind erosion protection and snow trapping.

Information about conservation practices developed earlier this century, such as contour stripcropping, are very valuable today.
APPENDIX - Project Summary

Project Title: Options to Enhance the Sustainability of Dryland Cereal Cropping in the Northwest

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Major Cooperators:
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V. Philip Rasmussen, Utah State University, Logan, UT
R.W. Smiley, Oregon State University, Pendleton, OR
C.L. Peterson, University of Idaho, Moscow, ID
Alternative Energy Resources Organization (AERO), Helena, MT
Progressive Farmers Inland Northwest (PFIN), Walla Walla, WA

Summary: The overall goal of this project is to develop a comprehensive research and education program to help dryland producers in the Northwest implement sustainable grain and legume cropping systems that will reduce environmental impacts and external, nonrenewable production inputs while maintaining or improving profitability.

Dryland cropping regions in the northwestern United States share the common problems of economic instability and resource deterioration. Major constraints to change include chronic moisture deficits, soil degradation, export dependence, and government farm programs. The limited moisture conditions often result in poor yields and minimize the number of production options that growers can choose from. In the driest areas, summer fallow is a standard practice used to economically produce a crop, but it also plays a role in soil deterioration, erosion, and saline seep. The wetter areas have more agronomic options, but choices are often limited by the provisions of government farm programs. Finding farming practices that can maintain or enhance both profitability and natural resources is particularly difficult in dryland regions.

In addition to the biophysical constraints on dryland agriculture, growers face the loss of important production inputs, such as certain fertilizers and pesticides. The recent proposal to classify anhydrous ammonia as a hazardous substance, although rejected, threatened to greatly restrict transport of this material, which is the cheapest and most widely used nitrogen source in the region. Registration of the herbicide Dinoseb was canceled in 1987, thus limiting the weed control options in peas and lentils grown in rotation. Cases of weed resistance to herbicides have been documented. The fungus that causes strawbreaker footrot (an important cereal disease) is becoming resistant to benomyl fungicides. The lack of incentive for the pesticide industry to maintain or develop materials for use in minor crops accentuates the need for alternative pest control methods so growers can diversify their crop rotations.

For these reasons, researchers, extension workers, and growers involved with dryland farming in Washington, Idaho, Oregon, Montana, Wyoming, and Utah initiated a USDA-LISA funded project in the fall of 1988. The project has focused on identifying historical and current information on cropping alternatives in cereal-based systems, dissemination of the information to user groups, and prioritizing future research needs and
extension activities. The second phase of the project will emphasize continued regional communication, development of on-farm testing and documentation, and in-depth research into soil quality, soil biology, and the benefits of rotational systems.

A comprehensive review of the historical and current literature on dryland cropping systems alternatives was completed during the first phase of the project. This information has been used by Washington State University (WSU) cooperators to develop a computer citation database that is now available to the public. The highlights of the review are being compiled in a six-state resource guide on dryland farming. A regional newsletter called the Sustainable Farming Quarterly is published by the project and features articles on historical studies, current research, and innovative farmers.

A project publication from Oregon State University (OSU) summarizes the findings of 50 years of consistent research on plots near Pendleton, Oregon. These plots are the oldest continual dryland research plots in the Northwest, and they offer a unique chance to measure long-term changes due to crop and soil management in the region. Numerous other publications and presentations have been developed by project cooperators as part of the educational effort.

Project cooperators have been involved in several surveys. In Wyoming, a survey of dryland farmers found that 60% of farmers currently use no fertilizer, and 20% use no herbicide, indicating that many farmers in this marginal area are indeed low-input. A group of eastern Washington and northern Idaho farmers using alternative practices and rotations were surveyed through detailed interviews in an attempt to learn what alternatives were actually in use on a commercial scale. This information is summarized in a WSU publication and is being used in an associated project of economic and policy modelling.

Several major conferences have been organized by project cooperators, including a Soil Building Cropping Systems conference in Montana and four dryland Farming for Profit and Stewardship conferences in northern Idaho and eastern Washington.

Project cooperators are involved in many ongoing research efforts. Oregon scientists are examining the effects of long-term management on soil microbiology factors, including microbial diversity and soilborne plant pathogens. Management effects on soil quality factors are being studied by Washington researchers. In Idaho, a combine-mounted yield mapping system is being developed for management of variable landscapes. Montana and Wyoming cooperators are focusing on replacement of summer fallow with low water use legumes to conserve soil and reduce nitrogen fertilizer needs. Alternative rotations are being tested by Utah researchers, and expanded use of the Miranda protein pea is one significant outcome.

Project activities are expanding into on-farm testing as well. Farmer-initiated research, demonstration, and information exchange have been highly successful in the Midwest. Similar strategies have not been widely used in the dryland regions of Washington, Oregon, and Idaho. The great environmental diversity among locations in the dryland region makes it difficult to transfer information from an experiment station to a given farm.

On-farm testing is important for several reasons. Much of the historical information compiled to date was generated prior to semidwarf wheat varieties and widespread use of N fertilizer. Growers need to test this information in the context of today's practices and soil conditions. It is not possible to initiate rotational studies and generate valid results with the short-term LISA funding. But data can be collected from existing rotational systems on farms to determine some of the long-term effects. Many alternative practices are being used by farmers, and documentation of their performance is needed in order to extend the information to others. Growers are concerned about impending increases in regulation and loss of production tools, and view on-farm testing as a way for them to quicken the introduction of alternative practices.

On-farm tests supported by the project include tillage, variety, fertility, and green manure comparisons. Also,
soils from a series of paired farms with contrasting management histories are being analyzed to document any measurable differences in soil condition due to farming practices. Farm tours have been held to view alternative practices, and more are planned for the future.

To date, the project has had a significant educational impact in the dryland region. The most promising areas for enhancing sustainability include soil quality improvement, use of rotation effects, variable landscape management, and fallow replacement. At present, few options exist for weed control, and moisture management strategies are limited in many areas. Economic data for evaluating alternatives are sorely lacking as well. By continuing the research activities, maintaining a high level of farmer involvement, and emphasizing regional communication, the project cooperators are optimistic about making dryland farming more sustainable in the Northwest.

Northwest Dryland Cereal/Legume LISA Project

Major Products

1. Publications


Sustainable Farming Quarterly. AERO, 44 N. Last Chance Gulch, Helena, MT. (8 issues to date)


2. Computer Software

Northwest Dryland Cereal/Legume Cropping Systems Database. Ver. 12/90. MCP0011 Cooperative Extension, Washington State Univ., Pullman, WA. This program was upgraded to a stand-alone version by Phil Rasmussen of Utah State University.

GRAINVAR. Grain variety selection database. Extension Publications, Univ. Idaho, Moscow, ID.


AERO Sustainable Agriculture Database. AERO, Helena, MT (1989). Searches done on request.

3. Educational Activities


Farming for Profit and Stewardship/Conservation Farming Conference Series.
   Summer field tours in Washington, Oregon, Idaho, Montana, and Utah.
   Oral presentations at grower meetings, professional meetings, and national conferences.

4. Products in Progress (as of 5/1/92)

On-farm testing manual. B. Miller et al., WSU. (in review)

Alternate rotation enterprise budgets. K. Painter, D. Granatstein, and B. Miller, WSU. (in review)

Palouse grower survey. C. Beus and D. Dillman, WSU.

Yield mapping system for combines. C. Peterson, Univ. Idaho.

Decision support software for N fertilizer on winter wheat. T. Fiez and B. Miller, WSU.