AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION	A. PRIMARY	Agriculture
	B. SECONDARY	Water Management

2. TITLE AND SUBTITLE

Water conservation practices for dryland farming

3. AUTHOR(S)

Brengle, K.G.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1975	32 p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Department of Civil Engineering, Colorado State University, Fort Collins,
Fort Collins, Colorado 80521

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)

9. ABSTRACT

A discussion of methods of conserving water in soil of semi-arid farming regions such as those in the Great Plains area of the U.S. For regions that have summer rainfall and no irrigation systems, these are farmlands that receive 500mm or less of annual precipitation. The most common practice in semi-arid regions of the U.S. is to leave the land fallow--unplowed and unplanted--for a period long enough for it to store enough water. To retain the water, the soil must be deep enough and have enough water-holding capacity. This practice is called "summer fallow," but actually the land may be left fallow for 14 or 15 months, with the moisture buildup occurring mainly during the fall and winter months. To protect fallow land against wind erosion, water erosion, and water evaporation, stubble mulching is practiced. The crop residue is undercut with a subsurface instrument, and left in the ground. This decreases surface water runoff and reduces the rate of evaporation of moisture from the subsurface of the soil. If the soil grows weeds during the fallow period, these must be tilled, because the weeds will use up the moisture in the subsoil. Other methods of conserving moisture include shaping the soil surface into water-conserving structures. These include ridge terraces, level-bench terraces, parallel-bench terraces, level pans, and the practice of pitting. Those practices are described. Still other methods involve strip-cropping, wind breaks, and particular crop rotations. Depending on particular temperature and precipitation conditions in various regions of the U.S. Great Plains, various practices are used: wheat-fallow, wheat-sorghum-fallow, or wheat-millet-fallow. Fallow is generally not used with corn or oats. If land that has lain fallow has conserved or accumulated enough moisture, nitrogen fertilizer will

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAB-669	

12. DESCRIPTORS	
Comparison Conservation Dry farming USA	13. PROJECT NUMBER 14. CONTRACT NUMBER CSD-2460 211(d) 15. TYPE OF DOCUMENT

AID 590-1 (4-74)

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increase yields of wheat or grain sorghum. Applications vary, depending upon how much nitrogen has built up in the soil during the fallow period. Applications in the Great Plains of the U.S. vary from 34 to 90 kg/hectare.

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WATER CONSERVATION PRACTICES FOR DRYLAND FARMING

BY

K.G. Brengle
Associate Professor
Soils Department of Agronomy
Colorado State University

Paper developed under support from U.S. Agency for International Development under contract AID/csd-2460 and the Colorado State University Experiment Station. All reported opinions, conclusions or recommendations are those of the authors and not those of the funding agency or the United States Government.

Department of Civil Engineering
Colorado State University
Fort Collins, Colorado

September, 1975

211(d)

WATER CONSERVATION PRACTICES FOR DRYLAND FARMING

by

Kenneth G. Brengle

Abstract

The practices used in dryland agriculture in semi-arid regions are designed to conserve or concentrate adequate water for stable crop production. Summer fallow is one of the best known methods of water conservation for crop production. Where fallow is not adaptable due to low annual precipitation, unfavorable annual distribution of precipitation or high potential evaporation, water concentrating methods offer some promise of increased crop production. This paper describes water conservation and dryland farming practices in the semi-arid regions of the United States.

WATER CONSERVATION PRACTICES FOR DRYLAND FARMING

K.G. Brengle

INTRODUCTION

"Dryland Farming" is a catchall term often used to describe any type of farming that is not irrigated. It is necessary to put climatic limitations on the term in order to define the type of agriculture being discussed. The first limitation must, of course, be precipitation.

Usually dryland farming is considered to exist in semiarid regions, but again this term is used to describe widely different areas. In general, a limit for maximum annual average precipitation can be set at about 500 mm for areas receiving summer precipitation, it is less for most winter precipitation areas. This maximum is strictly arbitrary, but there is some justification in selecting this value since, in most summer rainfall areas receiving 500 mm or less annual precipitation, cultural practices primarily designed for semiarid crop production become prevalent. All regions receiving 500 mm annual average precipitation are not equally capable of producing dryland crops. As the annual average precipitation decreases from 500 mm, the differences in productivity between areas become more pronounced.

Johnson, et al. (17) use the Thornthwaite P-E index line of 32 as the boundary between subhumid and semiarid zones. The P-E index was designed to take into account the temperature factor in precipitation effectiveness.

In reality, the amount of precipitation received annually is not the most important factor in temperate zone, dryland areas. Annual distribution, i.e., winter precipitation vs. summer precipitation, largely affects the stability of crop production at a given precipitation level. The type of primary precipitation, snow vs. rain, and rainfall intensity also have an effect on the stability of agricultural production in these areas.

The mean annual temperature and the amount and velocity of wind are other climatic factors that can have a controlling influence on crop production. The crop season temperature is probably more important than the annual average, but temperatures during other parts of the year have an influence on water conservation. Wind is of importance in both evaporation and evapotranspiration. The former affecting the efficiency of soil water storage and the latter affecting the water use efficiency of the crop.

These climatic factors and the interactions between them are the principal factors that determine the "effective precipitation." The effective precipitation can be defined as the percentage of the annual rainfall available for plant use.

The dryland farming areas of the United States will be used in this discussion for comparison of different types of dryland areas and cultural practices (Figure 1). It should be kept in mind that these are temperate zone regions and direct comparison with dry subtropic or tropic regions will not be applicable. A brief description of some of these regions is necessary in order to understand both the problems encountered in crop production and the practices applied to overcome these problems.

The Great Plains of North America is one of the largest dryland agricultural regions in the world, comprising about 450,000 square

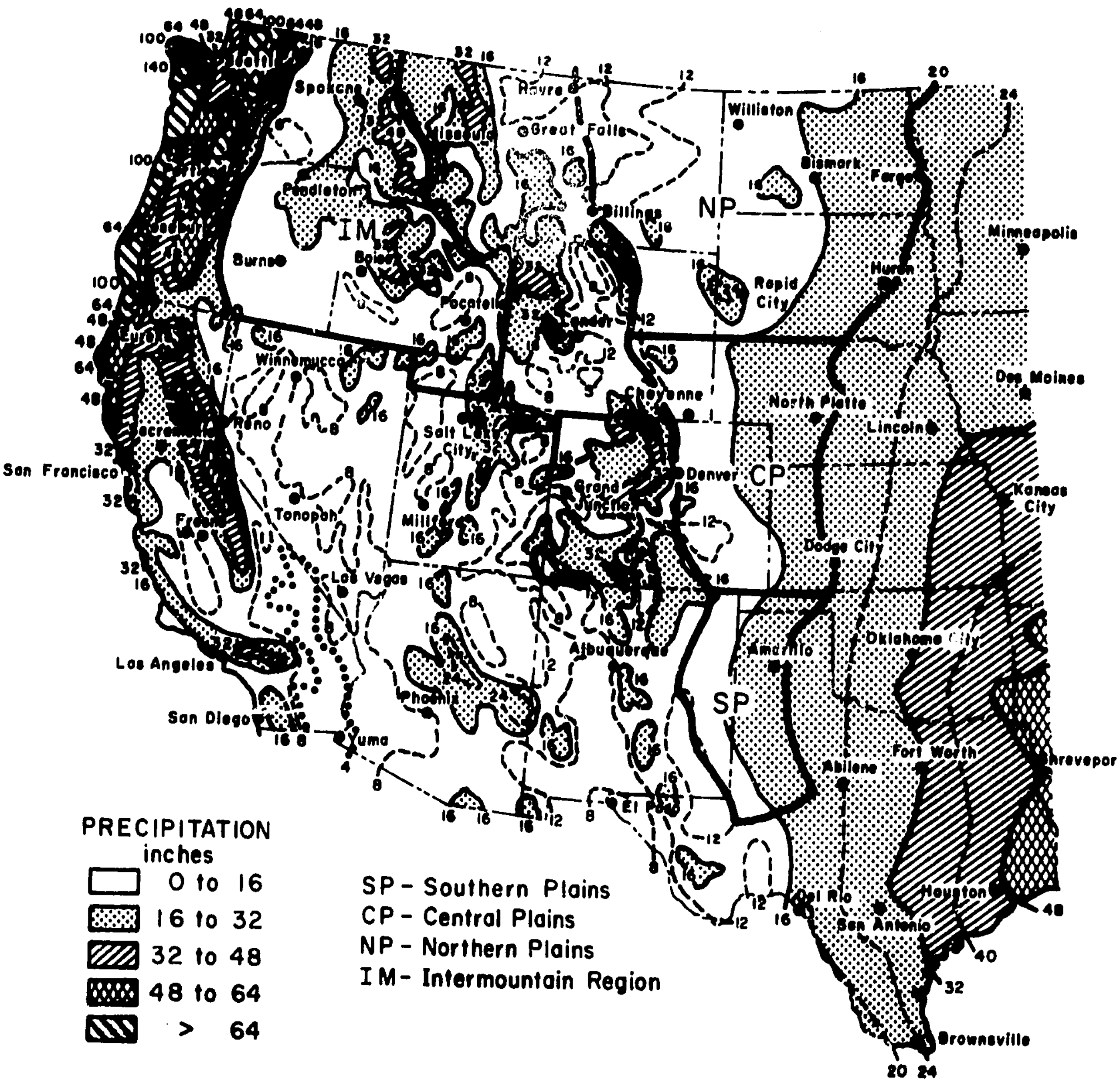

Fig. 1 Mean annual precipitation, in inches, in the 17 western states, 1931-1960, with approximate regions of dryland agriculture. (Adapted from "Summer Fallow in the Western United States" USDA-ARS Conser. Res. Rept. No. 17).

miles. Within the continental United States it extends from Texas to the Canadian border with its eastern limit at approximately the 98th meridian and its western edge bordering on the Rocky Mountains.

Great Plains agriculture is often referred to in general terms, however, there are actually several distinct regions insofar as agricultural production is concerned. The arbitrary division of the southern, central and northern Great Plains regions is based primarily on moisture-temperature relationships. Differences in altitude from east to west affect crop adaptability due to the effect on the length of the frost free season within a given region, especially in the central and northern regions. These differences in longitude, latitude and altitude are accompanied by differences in soils, type and amount of precipitation and evapotranspiration rates. About 70-75 percent of the precipitation occurs from April to September in all sections of the Great Plains. The annual average precipitation increases from west to east in all Plains regions with the western sections receiving an average of about 305 mm.

Agricultural production in the Great Plains is subject to great annual fluctuations in precipitation and the occurrence of high intensity summer rainfall events. These high intensity storms result in high runoff, thereby reducing the effectiveness of the precipitation.

Dryland farming in the intermountain region of the U.S. differs from that of the Great Plains in that it is not a large continuous farming area, but consists of smaller regions which receive about 50 percent or more of the annual precipitation from November to April. The Pacific Northwest region of eastern Washington, eastern Oregon and adjacent northern Idaho is the largest and best known dryland area of the region, but for the purposes of this discussion other areas in these states as well as Utah and western Colorado are included as part of the intermountain region. The frost free period ranges from 80 to 200 days (20). The principal difference between the areas is the form of the winter precipitation, either snow or rainfall, and the extremes between summer and winter temperatures. The Pacific Northwest region tends to have less climatic variability than the other regions.

PRACTICES FOR WATER CONSERVATION

Summer Fallow

The practice most common to crop production in semiarid regions of the U.S. is summer fallow. This is the practice of leaving the land free from growing vegetation during a crop season. This practice requires tilling the land during the normal growing season to prevent water loss through weed growth. Several factors determine whether the practice of fallow will be beneficial; (a) the annual average precipitation should not be sufficient to wet the soil throughout the root zone, (b) the soil should be deep enough and have an adequate water holding capacity to retain the water made available for storage during the fallow period, and (c) the crop to be grown should have sufficient root development to utilize the stored water. In general, the 500 mm limitation previously discussed for summer rainfall areas is the boundary where fallow becomes feasible. However, the efficiency of fallow differs greatly due to the other factors involved.

The purpose of summer fallow is to store soil water and accumulate nitrate nitrogen for the succeeding crop. The term is somewhat misleading in that the actual storage of water does not occur during the summer period. Summer fallow as practiced for the production of winter wheat encompasses a 14 to 15 month period starting with the harvest of one crop, usually in June or July, and continuing until planting during September of the next calendar year. Kuska and Mathews (19) reported that with spring wheat at Colby, Kansas, the greatest water storage occurred during the first fall and winter with lesser amounts the following spring and summer and still less during the second winter. Unpublished data from Colorado, and the data reported by Mathews and Brown (22) show that significant amounts of water are stored during the summer period only when greater than average rainfall is received. Only an average of 1.45 cm was stored during the May to September period in Colorado, while in Kansas it was found that 10 cm of rainfall was required during the July to September period before any water was stored. Large losses of stored soil water can occur if weed control is poor during the summer tillage period but usually evaporation accounts for most of the losses during this period. More water is stored during the first winter of the fallow season due primarily to drier soil as a result of a crop being harvested the previous summer and to less evaporation losses during the winter.

Fallow Efficiency

Water storage efficiencies reported for the Northern, Central, and Southern Great Plains reflect the effect of increased mean annual temperature on the efficiency of fallow in summer rainfall regions (3) (14) (17). An average of 71.4 percent of the over winter precipitation and 5.9 percent of the summer precipitation were stored during the fallow year in the Northern Great Plains. The average for the entire fallow period was 27.6 percent. This figure reflects the effect of annual distribution of precipitation with only about 25 percent of the precipitation being received during the period of greatest storage. Storage efficiency for the fallow period in the Central Great Plains has been reported to be 20 to 25 percent (14). Higher efficiencies, due to improved practices on experimental plots have been reported to be about 35 percent (13). Historical data compiled by B.W. Greb [1/] shows increased average yields in the Central Great Plains since 1965. These increased yields are due, at least in part, to increased fallow efficiencies but the greatest average increases have occurred in the higher rainfall areas. The water storage efficiency for the Southern Great Plains has not been significantly improved since reported at about 16 percent by Mathews and Army in 1960 (23).

Smika (29) reports no crop failures with winter wheat after fallow at North Platte, Nebraska. However, the practice of fallowing the land does not insure the production of an economical crop every year in all parts of the Great Plains. Brengle and Greb (4) reported crop failure with both continuous wheat and wheat after fallow in northeastern Colorado. The annual variability of precipitation and temperature is so great that it is possible to obtain high yields in given years without fallow and to have complete crop failures some years when the crop is planted after fallow. Army, et al., (1) reported that wheat yields in a wheat-fallow system at Bushland, Texas could be expected to be more than 672 kg/ha 80 percent of the time. In the lower precipitation areas of eastern Colorado, 380 mm or less, the percentage of crop failures increases considerably above this, but in the higher precipitation

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[1/] Data compiled by B.W. Greb, Research Soil Scientist, Central Great Plains Field Station, Akron, Colorado.

area of northeastern Colorado with about the same precipitation as Bushland, 455 mm, the percentage of years in which crops exceed 672 kg/ha is probably closer to 95 percent

Figures 2 and 3 are included to illustrate the variability encountered in a relatively small portion of the Central Great Plains. Figure 2 shows the precipitation zones of eastern Colorado (7). The precipitation varies from less than 330 mm to 483 mm. Figure 3 [1/] shows the planted and harvested acre yields, and percent abandonment of winter wheat in the principal wheat producing counties of the area. These data are old, but although average yields have increased for each of the counties in recent years, the same relationships remain. Winter wheat production in the 330 - 381 mm precipitation zone is marginal, but it is more stable in this zone in the northern part of the state. Average yields are higher and percentage abandonment is lower. Differences in soils contribute to somewhat better conditions in the northern part of the state but largely, differences in evaporation and evapotranspiration rates affect the efficiency with which soil water is stored and utilized.

The increased water storage efficiency, and consequently, the greater stability of crop production in winter precipitation areas such as the Pacific Northwest is demonstrated in the data reported by Leggett, et al., (20). Fifty to 75 percent of the precipitation received over the first winter of the fallow period is stored in the soil. During the summer period, when small amounts of precipitation are received, there is a net loss of stored water. When fallow is continued

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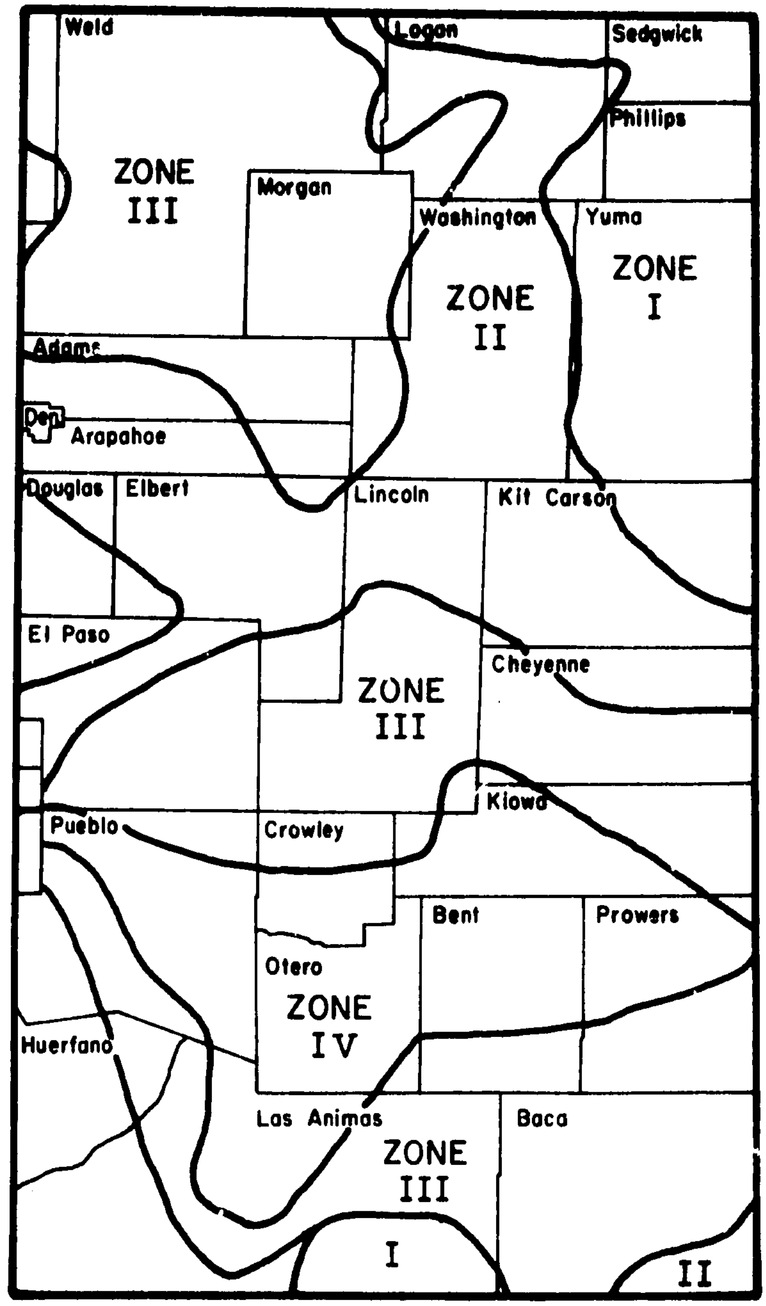
[1/] Data compiled by B.W. Greb, Research Soil Scientist, Central Great Plains Field Station, Akron, Colorado.



ZONE	EFFECTIVE RAINFALL
I	17-19 inches
II	15-17 inches
III	13-15 inches
IV	< 13 inches

Fig. 2 Precipitation zones in eastern Colorado (7).

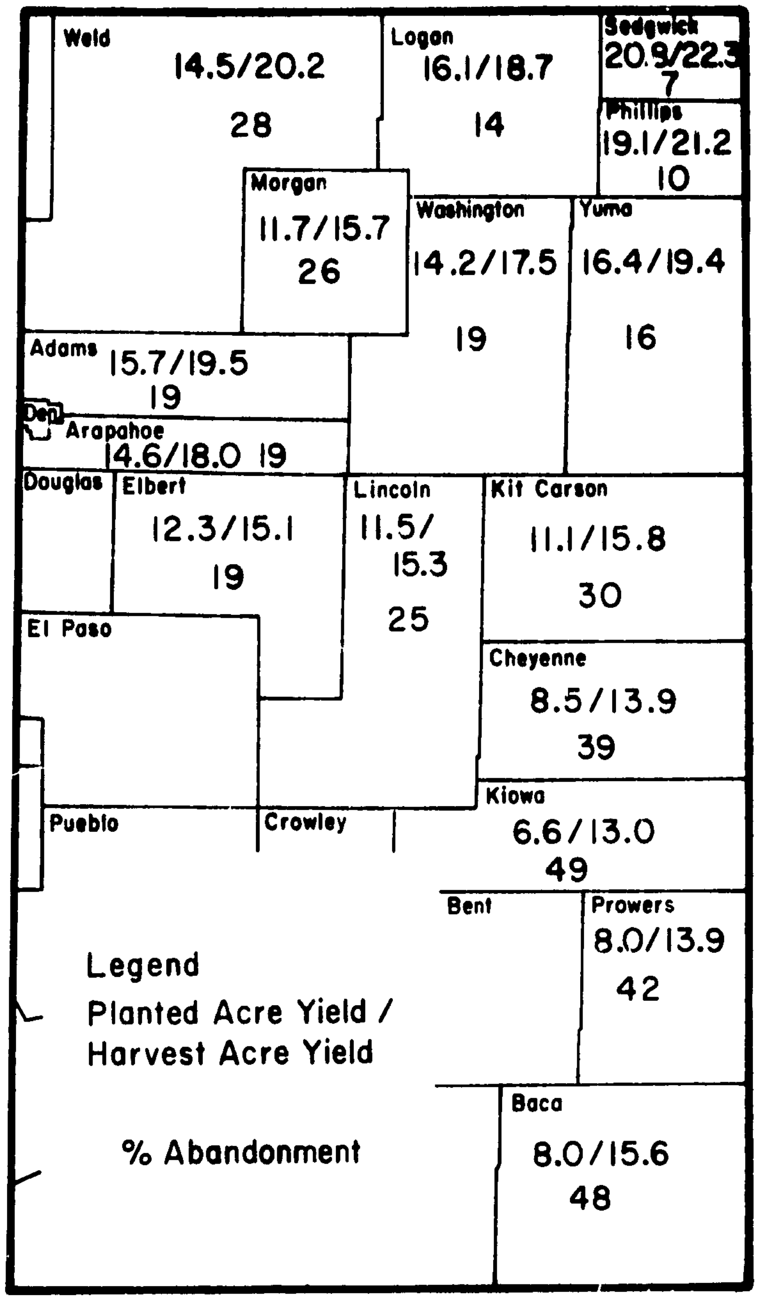


Fig. 3 Average yield per planted and harvested acre, and percent abandonment in eastern Colorado, 1939-1958.

over the next winter, for the production of spring grains, additional water is stored in the soil although it is less than that stored the first winter. This storage occurs at locations where the annual average precipitation is 250 to 380 mm. At these precipitation levels in the summer rainfall areas, crop production becomes submarginal.

Soil type affects the fallow efficiency in that the soil must have adequate water holding capacity to benefit from the additional water provided during the fallow period. As a rule, soil that is light sandy loam or loamy sand texture throughout the profile does not provide an adequate reservoir to benefit as greatly from fallow as heavier textured soils.

Methods of Summer Fallow

The practice of summer fallow came about in the semiarid regions of the United States through necessity. Annual crop production was so unstable that early farmers sought ways to improve it and fallow was the best practice developed. Nearly all of the early fallow was accomplished with plows that turned the soil, thus burying the crop residue. This practice, generally referred to as clean tilled or black fallow, is practiced today to a greater extent than is desired. Clean tilled fallow leaves the soil surface exposed and susceptible to erosion. The early use of a dust mulch, which was relatively effective in retarding evaporation, was discarded principally due to the wind erosion hazard presented by the practice. This practice involved pulverizing the upper 5 cm of the soil, thereby breaking the capillary continuity of the soil and retarding water movement to the evaporating surface.

The practice of stubble mulch was developed primarily to reduce the erosion hazard encountered in the summer fallow program. Stubble mulching is effective in the control of both wind and water erosion. The practice requires undercutting crop residue with some type of subsurface implement, usually a V-shaped sweep varying in width from 45 to 176 cm.

Data reported on water storage with stubble mulch has been variable and in most cases, the increases over black fallow have not been great. Theoretically, water storage should be increased with stubble mulch since surface runoff is reduced and evaporation should be decreased due to decreased radiation and wind velocities at the soil surface. Actually, the decrease in evaporation is principally a decrease in rate. If the evaporative demand remains high over a sufficient length of time, the total evaporation will amount to about the same as occurs from bare soil. The increased fallow efficiency reported for the Central Great Plains is based on measurements with high rates of wheat straw applied to the soil surface (13). These tests indicate that it is desirable to retain as much residue as possible on the soil surface to increase the available water supply.

Timeliness of tillage in the fallow period is extremely important if water losses from weed growth are to be prevented. Most locations in the Great Plains have reported that there is no advantage to fall tillage in the fallow system. Greb, et al., (14) reported increased storage at Akron, Colorado and North Platte, Nebraska with fall weed and volunteer grain control. Experiments at Springfield, Colorado[1/] have disclosed that fall tillage is of little value in this area. Several investigators have found the first tillage operation in the

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[1/] Unpublished data Colorado State University Experiment Station.

spring to be the most important. It is necessary to obtain good control of weeds at this time in order to prevent large losses of water. Tillage in the fall of the fallow year is desirable in most areas receiving winter precipitation in the form of the snow. Legget, et al., (20) report additional water storage in eastern Idaho by fall chiseling, and Brengle, et al., (6) found fall plowing necessary for the optimum production of dry fieldbeans (Phasolus vulgaris L.) in southwestern Colorado.

The type of implements used in the stubble mulch system depend primarily on two things; (a) the amount of stubble anchored in the soil at the first tillage operation, and (b) the amount of stubble desired at seeding. Many farmers prefer to have all residue turned under at planting time in order to have a clean seed bed, however, there are advantages to having at least 1200 to 1800 kg of straw per hectare left at planting. In areas where blowing snow can be trapped, a rough surface with residue is an advantage. In areas where wind erosion is a serious hazard, such as in all sections of the Great Plains, residue cover in the spring is advantageous to prevent wind erosion damage to the crop. Kroll, et al., (18) and Fenster (11) have reported the effect of various implements on the destruction of residue.

The principal disadvantages to stubble mulch are: (a) weed control with stubble mulch may be less effective than with plowing under certain conditions, (b) operation of the tillage equipment is critical in that correct implement adjustment and speed of tillage are necessary if tillage is to be satisfactory, and (c) seedbed preparation and planting with surface stubble requires the correct type of implement and more care by the operator. Downy brome (Bromus tectorum) can become a serious problem with stubble mulch in most areas where wheat is produced. In western Colorado, this weed presents a serious problem when subtillage is used in the production of annually cropped wheat (4). Seedbed preparation with a rod weeder or skew treader is necessary for the most desirable results. The skew treader is most desirable where large amounts of straw remain at seeding. This impiement is effective in knocking down and spreading straw.

Chemical control of weeds has been tried in most dryland areas of the United States with varying degrees of success. Swan et al., provide a good literature review of chemical use in a fallow program in their recent publication (31). In general, the results of tests with chemicals have been contradictory. It is necessary to have sufficient available water for active plant growth for chemicals to be effective. Most of the reports of good weed control and minimal residual damage to subsequent crops have been from higher precipitation areas of the Great Plains and the Pacific Northwest. Some reports, such as that of Black and Power (2), stress the necessity of mechanical tillage with the use of chemicals. Soil type and rainfall largely control the need for mechanical tillage and the residual damage to the following crop. The more common herbicides that have been used in chemical fallow are 2,4-D ((2,4-dichlorophenoxy) acetic acid), atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-5-triazine), and amitrole (3-amino-5-triazol).

Winter wheat (*Triticum aestivum* L.) is the crop occupying the greatest acreage of land that has been fallowed. The 14-month period of fallow for this crop is the most efficient for most areas. Some areas of the Northern Great Plains and the Intermountain Region find it profitable to fallow for the production of spring wheat. In the Central and Southern Great Plains, summer fallowing for spring planted crops is generally not economical.

Ridge Terraces

Terraces have been used in dryland areas principally as water conservation structures. Ridge type terraces constructed on the contour have been used to retain water on the field. With these terraces the water is confined to a relatively narrow strip immediately behind the ridge and does not provide any great benefit to the large area between ridges. Crop yields are usually reduced in the terrace channel during wet periods. The extent of damage depends on the length of time the crop is subjected to standing water and to the stage of growth of the crop. During periods when precipitation is deficient, the ridge is often too dry to produce good crops. Terraces of this type have not actually performed the function for which they were intended and their use has decreased. The need to farm fields with these terraces on the contour has probably had as much to do with their lack of acceptance as the poor water distribution which is an inherent characteristic of their design.

Level Bench Terraces

The conservation bench terrace was first initiated by A.W. Zingg at the Southwestern Great Plains Field Station at Bushland, Texas in 1955. This terrace is designed to catch runoff water and spread it over a leveled area that is to be intensively cropped. The basic idea is not new but it had not been applied to modern agriculture as it is known today.

These terraces require leveling an area on the contour about 30 meters wide with a contributing area on sloping land above the bench to provide runoff. The contributing slope is farmed to some suitable crop, either an annually grown spring crop or possibly a fallow winter wheat rotation.

Mickelson (25) (26) did considerable work in evaluating these terraces and the ratio of level bench to contributing area most efficient for eastern Colorado conditions. He first reported a 3/1 ratio of contributing slope to bench width to give the best results but later reported a contributing area to bench ratio of 2/1 to be the more efficient. Haas, et al., (15) found that runoff from wheat or grass contributing area had minor effect on water storage and yields on bench terraces in the Northern Great Plains with a ratio of contributing area to bench area of 1/1. They stated that the principal advantages of level bench terraces appear to be collecting snow, preventing runoff of snow melt and torrential rains, reducing erosion, and increasing crop yields through water conservation. In the Central Great Plains, Mickelson reported that in a four-year period the average increase in water storage on the benches was about 5 cm and annual sorghum production increased about 120 kg/ha.

There are several problems associated with the use of conservation bench terraces. The crop grown on the contributing area must be managed in such a way that runoff events will not present an erosion hazard and at the same time especially in areas where snow collection is not adequate to supply significant amounts of water, provide some additional water to the bench area. The period of the year when runoff is received largely determines the crop to be grown. Failure to establish winter wheat on conservation bench terraces at Akron two out of four years restricts their effectiveness for this crop when grown annually. The yield of grain sorghum grown annually on benches receiving runoff was 448 kg/ha greater than biannual yields on fallow.

The collection of water on the bench area has presented some problems in that during light runoff events distribution across the width of the terrace has been poor and during large runoff events farming operations have been delayed or prevented and growing crops have been damaged.

Parallel Bench Terraces

The use of parallel level benches is also being studied by Mickelson (Figure 4)[1/]. This system is designed to transport water from a 913 hectare, grassed watershed by a diversion terrace to a waterway along the ends of each of three level benches, 0.7 hectare in size. Gates constructed in the waterway are used to measure runoff onto the bench or they are closed to allow runoff to enter the adjacent bench. In this study, one level bench does not receive runoff. The benches receiving runoff produced 393 kg/ha more dry matter than the level check and 1333 kg/ha more than the unleveled check.

Level Pans

Leveled areas have been placed in a broad natural drainage at the Central Great Plains Field Station at Akron, Colorado (Figure 5) (25). These areas, referred to as level pans, ranging in size from less than one hectare to about 3.5 hectares, are designed to trap

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[1/] Personal Communication. R.H. Mickelson, Agricultural Engineer, Central Great Plains Field Station, Akron, Colorado.

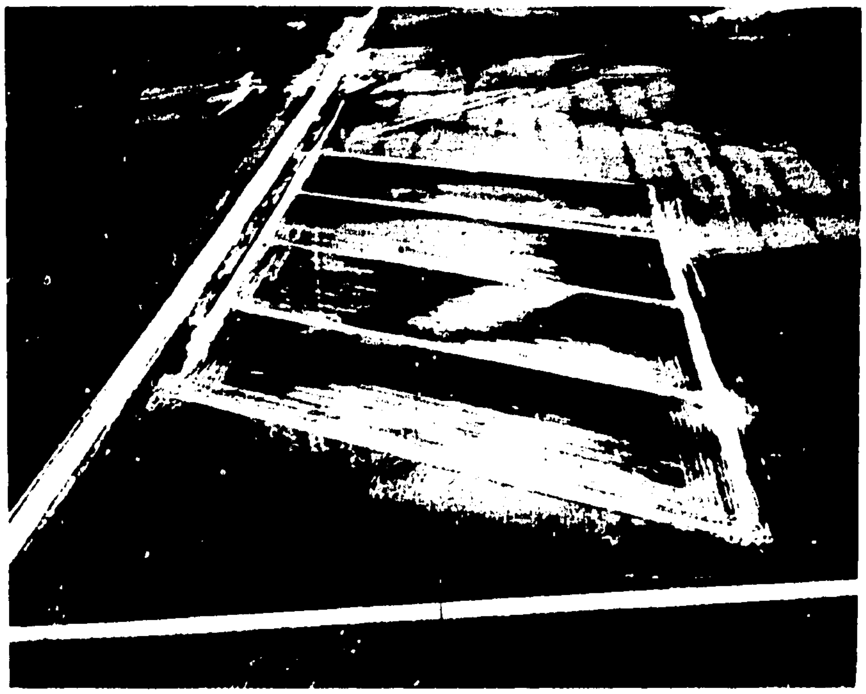

Fig. 4. Parallel level terraces at Central Great Plains Field Station, Akron, Colorado.

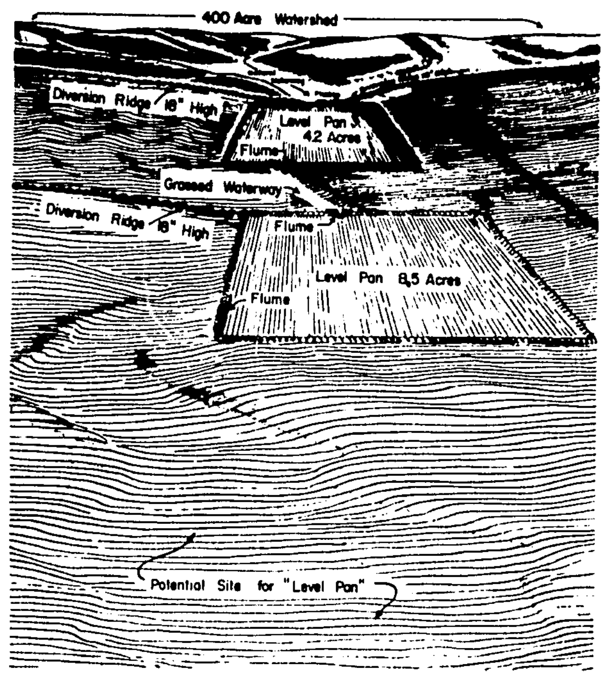

Fig. 5. Schematic representation of level pan system for intercepting, spreading and storing runoff from a contributing watershed. (25)

runoff from a watershed of about 200 ha. Standing water will collect in one pan to the desired height and then drain the excess water so that it may collect in the next pan. The runoff water in the drainageway may be diverted from the pans at times when excess water would be detrimental to farming operations or growing crops. The additional water collected in these pans permits annual crop production.

The amount of water collected in the pans depends on the number and type of runoff events and the location of the pan in relation to the other pans. The total available water in the soil profile was 10 to 18 cm greater on some pans than on corresponding check areas which were annualy cropped (24). In 1966, Mickelson (25) reported the data for a four-year period which showed improved water use efficiency from level pans with an increase in yield of 115 to 278 kg of grain sorghum per additional inch of water. The value of these level pans in the Great Plains is probably in the production of supplemental feed where land is suitable for their installation.

Pitting

Pitting and ripping are practices that have been tried in the Great Plains to trap and hold water. Pitting is used principally on cultivated land and ripping on rangeland. Pitting is generally performed with some specially made implement that systematically digs out soil leaving pits in which water can collect. This is a practice which is accepted in some localities but has not gained wide acceptance throughout the dryland regions. It is difficult to conduct meaningful research on the practice of pitting and very little work has been done on it.

Strip Cropping

Alternate strips of crop and fallow are used to some extent to control soil erosion. Strips used to control wind erosion are straight strips situated as nearly as possible at right angles to the prevailing wind. The width of these strips depends on soil texture in a given area. Strips on light textured, highly erosive soil should be narrower than strips on heavier soil types. There is no evidence that use of wind strip cropping promotes better soil water storage or water utilization by plants. The acceptance of strip cropping for wind erosion control has not been great by farmers, although the wind erosion hazard is quite high.

The use of contour strip cropping is even more limited than straight strip cropping in dryland areas since it is a practice designed primarily to reduce water erosion. Water erosion is probably a more serious problem in the areas receiving winter precipitation and the topography of many of these areas is too irregular for contour strips to be practical.

Wind Breaks

Windbreaks or field shelter belts have been used to varying degrees in the Great Plains. Shelter belts may consist of one or more rows of trees and they are designed principally to reduce wind velocity and prevent soil erosion. However, in areas that receive substantial amounts of snow they may have a favorable effect on soil water storage. In Canada, a net increase in wheat yields of only .84 kg/ha was reported (30). The net increase was due to higher water storage, and yield, adjacent to the shelter belt.

A report from Russia claimed that a field protected by a shelter belt had increased water 30 to 40 percent in the spring resulting in increased crop yields of 150 to 200 percent (8). At Akron, Colorado soil water is decreased adjacent to old, well established windbreaks since snow accumulation is not adequate to supply all of the water required by the trees. Broadleaf trees are the heaviest users of water and can decrease the available water up to a distance of 20 meters from the shelter belt.

Annual vegetative barriers to trap snow have been investigated at Akron, Colorado and Sidney, Montana. These barriers are double rows of grain sorghum (*Sorghum vulgare* Pers.) or tall wheatgrass (*Agropyron elongatum*) spaced at 10 to 20 meters. Black, et al., (3) report that during the over-winter period at Sidney, snow trapped within double barriers of tall wheatgrass increased soil-water recharge enough to equal 14 to 21 months of fallow.

CROPS AND CROPPING SYSTEMS

Crop Adaptability

Hard red wheat has traditionally been the principal crop of the temperate semiarid regions. The milling and baking quality of hard red winter and hard red spring wheats grown under dryland conditions is generally superior to that of similar wheat grown under higher precipitation.

Hard red winter wheat has been the principal crop of the southern High Plains and the central Plains areas since the early 1940's. Hard red spring wheat is the crop grown on the largest acreage in the Northern Great Plains but the production of winter wheat has increased greatly over the past few years, particularly in Montana. The development of more winter hardy varieties and improved management practices has been responsible for the increase in winter wheat in this region. Crops of less importance in the northern plains are barley (Hordeum vulgare L.), durum wheat (Triticum durum Desf), oats (Avena sativa L.), and corn (Zea mays L.). Grain and forage sorghums are the principal secondary crops in the Southern and Central Great Plains. Relatively small acreages of corn are grown in the Central Great Plains, generally on sandier soils. Proso millet, (Panicum milaceum) and foxtail millet (Setaria italica) are also grown on limited acreages in northeastern Colorado (16). The proso millets are grown for grain and are used in mixed livestock feed. Foxtail millet is grown principally for hay. Grain yield of proso averaged 1177 kg/ha for the 1965-69 period in northeastern Colorado.

Wheat is also the principal crop of most of the dryland areas of the intermountain region. In the Pacific Northwest, winter and spring wheat and winter and spring barley and peas are the crops primarily grown. In the San Juan Basin of southwestern Colorado and southeastern Utah, dry fieldbeans is the principal crop, with winter wheat being the secondary crop.

Cropping Systems

Alternate wheat and fallow is the cropping system utilized on the greatest land area in the dryland regions of the United States. Fallow is necessary for the economical production of wheat in most areas of the Great Plains that receive less than 500 mm of annual precipitation. Annually cropped wheat in years of high precipitation will produce good yields and wheat after fallow can fail in years of deficient precipitation. The practice of alternate wheat-fallow requires twice as much land as needed for annually grown wheat since there must be one hectare of fallow for each one planted to wheat. However, the yield from wheat after fallow does not need to be twice that of annually cropped wheat to be economical. Planting wheat after fallow stabilizes wheat production by eliminating some crop failures and increasing the number of economical yields produced over a period of years. Fallow also results in better quality grain as measured by the test weight.

Some fallow is used for the production of grain sorghum in the Southern and Central Great Plains. This practice is not extensive due to (a) less economic importance of sorghum, (b) to the extreme wind erosion hazard resulting from the longer fallow period, and (c) more inefficient soil water storage over the longer fallow period. The wind erosion hazard is greatest during the spring months and fallowing for sorghum dictates that the land be left without a growing crop over two spring periods, and it is almost impossible to maintain an adequate residue cover over the second winter and spring. A common practice is to use wheat and sorghum in a wheat-sorghum-fallow sequence. The fallow period is shorter in this sequence than in the wheat-fallow system but this does not appear to seriously affect the yield of wheat in areas receiving 400 mm or more precipitation. Wheat-millet-fallow rotation shows some promise in northeastern Colorado.[1/]

Fallow is used with both wheat and barley in the northern plains. Fallow is generally not used with corn or oats.

[1/] Personal Communication. G.O. Hinze, Agronomist, Central Great Plains Field Station, Akron, Colorado.

The cropping systems used in the various areas of the intermountain region depend largely on annual precipitation (20). Alternate fallow is generally used with winter or spring wheat and winter or spring barley in the northwest region where annual precipitation is less than 330 mm. The 330 to 410 mm precipitation areas of this region may or may not use fallow with crops. In the regions receiving greater than 410 mm of annual precipitation, annual cropping is practiced with wheat, barley and peas. Occasionally, these crops are used in rotation with alfalfa, (Medicago sativa L.) or fallow.

In southwestern Colorado, dry fieldbeans are annually cropped in areas of 330 to 430 mm annual precipitation. Some fallow is used for winter wheat production in the area but where wheat is produced, the more common cropping system is to follow beans with wheat. Beans may be grown any number of years before wheat is planted. Wheat following beans is planted later than desirable but yields are not seriously decreased by this practice. Dry fieldbeans to not deplete the soil water below a depth of 60 cm thereby leaving a reservoir of soil water for the following crop. Although over-winter water storage is good in this area, the production of annually cropped wheat is less stable than that of wheat following beans.

In general, the cropping sequences used in dryland areas of the continental United States are designed to utilize the existing water in the most efficient manner while providing reasonable protection to the soil. The systems using two years of crops in a sequence with fallow, favor the wheat crop while utilizing the water stored over the winter following wheat harvest for the spring planted crop. These systems also provide two cash crops in three years compared to the one crop every other year produced in a single crop-fallow sequence. The systems utilizing two crops are well adapted to strip cropping and can increase the protection needed to reduce wind erosion.

Fertilizer Use

The use of commercial fertilizers with dryland crops has been investigated in most semiarid regions of the United States (5) (9) (21) (32). Soils tests for nutrient levels are limited in their value in the Great Plains area, since the correlation between soil test value and response to fertilizer is dependent upon adequate soil moisture.

Nitrogen is the fertilizer element found to be the most beneficial in most areas. Crop responses to phosphorus have been reported in western Oklahoma and North Dakota (10) (28).

In Colorado, responses to nitrogen fertilizer occur more frequently on light textured, loamy sand and sandy loam soils. Fertilizer use with wheat grown or medium or heavy textured soils has resulted in increased yields only with annually cropped wheat or wheat grown on severely eroded areas. Nitrogen build-up occurs during the fallow period and is apparently adequate in these soils to supply the nitrogen needed by the crop at the yield levels being produced. About 34 kg/ha is the optimum rate of nitrogen for wheat grown on the sandy soils in Colorado.

Other areas in the Great Plains have reported optimum nitrogen applications to be about 45 kg/ha (9) (21). Regions with winter precipitation use higher rates of nitrogen in precipitation zones comparable to those in the plains area (27) (32). In eastern Washington, nitrogen rates up to 90 kg/ha are recommended (32).

Nitrogen applications on winter wheat will often have a greater effect on protein content of the grain than on yield. Under poor water conditions, the higher protein is the result of shriveled grain.

Commercial fertilizer is not used as extensively on crops of less economic importance. Favorable responses to nitrogen have been obtained with grain sorghum in Colorado but the probability of increasing yield is not as good as with wheat. In the regions of the Great Plains where grain sorghum production is more favorable, the nitrogen rates used are about the same as those for wheat.

SUMMARY

The practices used in dryland agriculture are designed to conserve or concentrate adequate water for stable crop production. Summer fallow, utilizing good stubble mulch practices, is the best known method of water conservation in temperate dryland areas where wheat is produced on large acreages using large farming equipment. Where soil erosion is a problem it is fortunate that this practice is also the best soil conservation practice.

In areas where fallow is not adaptable due to low annual precipitation, unfavorable annual distribution of precipitation or high potential evaporation, water concentrating methods offer some promise of increase crop production. These methods that involve land forming to provide areas suitable for cropping are dependent on collecting run-off and must be adapted to each individual situation. Water harvesting strictly for crop production may be necessary for some areas, particularly in regions adapted to farming smaller land areas. These systems limit the crop to be grown to some extent since usually the period of

plant growth must coincide with the period when runoff water is available. Considerable research is needed in these areas on water concentrating systems for crop production.

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