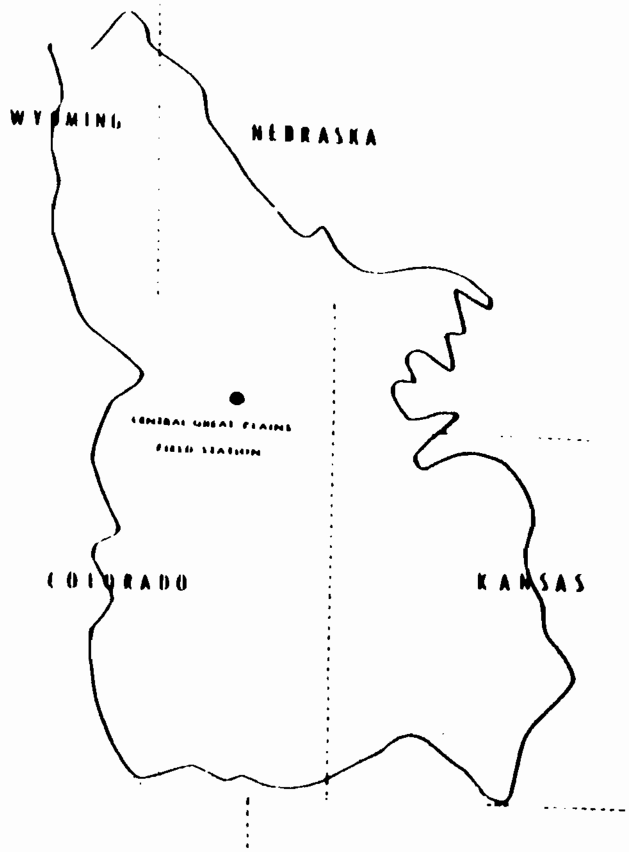
U.S. CENTRAL GREAT PLAINS

RESEARCH CENTER

Akron, Colorado



The field station serves a 55-million-acre empire in the west central Great Plains.

Land Use	Million Acres
Wheat	9.0
Fallow	8.5
Other Dryland	5.5
Irrigated	7.0
Rangeland	25.0
Total	55.0

SIGNIFICANT RESEARCH FINDINGS AND OBSERVATIONS

from the

U.S. CENTRAL GREAT PLAINS RESEARCH STATION &

COLORADO STATE UNIVERSITY EXPERIMENT STATION COOPERATING

AKRON, COLORADO

HISTORICAL SUMMARY 1900-1981

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PREFACE

A hundred years ago, the semiarid Central Great Plains of United States was an agricultural wilderness only a few years removed from a landscape of grass, buffalo herds, and Indian wars. This region is comprised of western Nebraska, western Kansas, eastern Colorado, and southeastern Wyoming. As pioneers came to settle, they were face-to-face with a harsh climate. The Central Great Plains was much drier and with much greater evaporation rates than the midwestern and southeastern regions of United States from where the pioneer's had emigrated. Additionally, the climate was sometimes windy to the extreme, temperature variations were high, and devastating blizzards and hail storms occurred with little warning. The severity of the climate defeated many pioneer efforts to establish a safe and prosperous agriculture based on cultivated crops. All too often the farmers were planting poorly adapted crops such as oats and corn, and cultivated the land with inadequate and ill-designed tillage implements. As late as the 1930's, the culmination of drought and land management mistakes resulted in an enormous "dust bowl" that threatened to empty the region of future farming enterprises. The land demanded winter wheat, adequate horsepower, and subtillage machinery.

Today, thanks to technical innovation, the semiarid Central Great Plains is a stable and profitable "breadbasket" producing over 200 million bushels of wheat per year alone. Other crops such as millet, barley, grain sorghums, and various feed crops have been worked into rotational and cultural systems that are usually successful. Many of the technical innovations that made this success story possible were originated at the U.S. Central Great Plains Research Station at Akron, Colorado. Most of this effort involved improvement of water intake, elimination of weeds, reduction of evaporation, and improved water-use efficiency by plants. A listing of significant research findings for the Akron location is hereby given.

BACKGROUND (1900-1911)

"Can a man make a living on the Plains?
It depends upon the man".

J. E. Payne 1903

Unirrigated Land in Eastern Colorado (J. E. Payne, 1903)

Soils	-	Quite fertile in native state. Texture ranges from sandy loam to silty clay loam.
Rainfall	-	Varies from 12 to 19 inches annually. Below 15 inches is marginal for cultivated crops.
Wind	-	Seldom calm, usually 4 to 40 mph.
Sunshine	-	Over 300 days per year.
Hail	-	Averaging about one per year. Can be very damaging to crops, shrubs, and young trees.
Topography	-	Mostly level to gently rolling land. Some steep breakland adjacent to major drainages. Extensive sandy soils are in Phillips, Yuma, Baca, Weld, El Paso, and Prowers counties.

Early Misconceptions Concerning Dry Farming (adapted from E. L. Chilcott, 1911)

1. Rainfall follows the plow.
2. That any definite "system" of dry farming will be applicable to all portions of the semiarid Great Plains.
3. That deep tillage necessarily or invariably increases the water holding capacity of the soil.
4. After initial plowing, that water in the soil can best be saved by utilizing a dust mulch.
5. That hard and fast rules can be adapted to govern the methods of tillage, or time and depth of plowing.
6. That a corn-hog economy could be superimposed in the semiarid Central Great Plains as in the humid midwest.

Natural Vegetation as an Indicator of the Capabilities of Land for Crop Production in the Great Plains (adapted from H. L. Shantz, 1911)

- Short grass species such as buffalo and blue grama dominate the level to gently rolling loam to silt loam soils (Hardland). Adaptable for small grains in areas receiving 15 to 19 inches annual precipitation.

- Sagebrush, yucca, and tall to medium height bunch grasses dominate the sandhills. Good for livestock grazing only.

- Some sage but mostly tall and medium height bunch grasses cover level to gently rolling sandylands. Can grow row crops in areas above 15 inches annual precipitation.

- Heavy clay "adobe" lands in southeastern Colorado are vegetated by scattered colonies of short grasses, prickly pear cactus, and some soap weed. Average precipitation 11 to 15 inches. Only limited livestock grazing.

- Breakland vegetation involves a mixture of short grass, medium height bunch grass, some yucca, and weed colonies. Adapted to limited grassing.

RESEARCH FINDINGS (1911-1920)

Determination of the Wilting Point in Soils

This is one of the most fundamental aspects of the soil-plant world. It sets up the basis for measuring water use and water-use efficiency by plants. Some water in the soil is held so tightly by clay particles that plant roots cannot extract anymore. At this point the plant wilts. It was found that the wilting point for sandy soils would vary from 2 to 5% water content of soil weight, for loams and silt loams the wilting point ranges from 6 to 9%, and for silty clay loams and clay loams the wilting point varies from 10 to 14%.

The above determinations were made using the sunflower as an indicator plant as best suited for this purpose. Sunflower were grown in greenhouse pots until they no longer recovered leaf wilt in a humidity chamber. The percent of soil water remaining is the wilting point.

Water Requirements of Plants (Literature Review)

A comprehensive review of the methods and results obtained from Europe and North America of experiments to determine water use by plants including small grains, legumes, weeds, root crops, millets, row crops, and oil seed crops. In most cases the plants were grown in large size greenhouse pots (garbage cans) and weighing lysimeters.

Water Requirements of Plants (Akron, CO. 1911-1917)

The term "water requirement" indicates the ratio of the weight of water absorbed by a plant during its growth to the weight of plant dry matter produced. This can include vegetative material and/or grain. At Akron, a large number of plant types (see above list) were tested during 1910-1917. Some of the findings are listed below.

Alfalfa had a high water requirement of 1,000 to 1,200 pounds water per pound of tissue grown. Other plants with high water requirements were buffalo and blue grama grass.

Legumes such as sweet clover, clovers, beans, peas, etc. had water requirements ranging from 700 to 850 pounds water per pound of tissue produced.

Small grains (wheat, oats, rye, barley) were intermediate in water requirements which ranged from 500 to 600 pounds.

Corn, sorghum, and millet were quite low at 260 to 350 pounds with millet the lowest. Corn and sorghums, however, have a high total water use to reach the reproductive grain formation stage.

Other plants having low water requirements include a number of annual broadleaf weed species.

It was found that in poor soils, the water requirement of plants may be reduced by one half or even two-thirds by the use of fertilizers. Similarly in field cropping, the water requirement has been increased as the result of previous cropping. This would follow because of the consumption of available plant nutrients by the first crop.

The overall conclusions were that small grains, wheat in particular, plus millet would be the most adapted crop in areas below 18 inches annual precipitation. Secondly, these crops could expect competition from weeds where allowed to proliferate.

ESTABLISHMENT OF FIELD TESTING (1908 →)

During the early years there were four major areas of investigation established at the station. These included (i) long-term crop rotations, (ii) an elaborate shelterbelt plant material study, (iii) crop variety trials in cooperation with the Colorado State Experiment Station, and (iv) a first class weather station.

Long-Term Crop Rotations (1909-1954)

The primary crop types included in these rotations were winter wheat, spring wheat, barley, oats, winter rye, corn, millet, forage sorghum, grain sorghum, peas, and beans. Each crop type was grown in continuous cropping situations and succeeding fallow. Tillage preparation variables included early fall plow, late fall plow, and spring plow in one series of tests and fall listed, spring plow and spring listed in another. The more notable findings from the long-term rotations are listed below:

Under continuous cropping the crop types tested showed considerable year-to-year yield variation as dependent upon favorable or unfavorable precipitation. In most years, however, there was insufficient available water (soil water + crop season precipitation) to produce bumper crops. The average grain yields were low, ranging from about 7 to 13 bushels/acre. Corn and grain sorghum did as well or better than the small grains. In part this was due to having a more weed free growing environment. Cultivation for weed control between the wide rows (44 inches) of corn and sorghum was possible whereas small grains are grown in narrow rows (8 to 10 inches) where cultivation is not possible.

It was sometimes difficult to get a stand of winter wheat and winter rye because of dry seedbed conditions if insufficient rainfall occurred between late July harvest and early September planting. Forage sorghum and the millets (foxtail and proso) yielded somewhat higher and more consistently under continuous cropping in total dry matter production than did the other crops.

All crops succeeded corn better than succeeding themselves or other crops. Corn apparently left unused available soil water that succeeding crops could utilize. Although corn converts water to dry matter quite efficiently, total soil water extraction by corn is not as complete as with sorghums, winter wheat, and winter rye.

Such legumes as field beans and peas were marginal in performance. Both of these crops are shallow rooted with little stress tolerance for drought. Additionally, both have very little plant stubble after harvest as needed to catch snows and to protect the soil from wind erosion.

Using beans, peas, and sweet clover as green manure did not improve the yield of other crops.

There was little average difference in crop yields grown continuously as influenced by fall versus spring plowing. In some seasons of heavy snowfall, the spring plow system was best because undisturbed crop stubble trapped snow. In other years of heavy fall weed growth and little snowfall, then fall plow was best.

Minor crops tested included sweet clover, alfalfa, soybeans, sudangrass, flax, and sunflower. There was insufficient available precipitation to maintain sweet clover and alfalfa. Flax and soybeans were poorly adapted. Sunflower yields were generally lower in grain and straw than grain sorghum and corn. Sudangrass total dry matter yields was only about 60% of forage sorghum yields. When cut in the boot stage, sudangrass made fairly palatable livestock feed. However, if sudangrass was allowed to mature, it lacked calcium and phosphorus, and was only little more palatable than winter wheat straw.

All crops responded to fallow at a ratio of about 1.3 to 2.6 over continuous cropping. Winter wheat yields were dramatically increased from an average 7.2 bushels/acre under continuous cropping to an average 18.5 bushels/acre succeeding fallow in rotation. Grain sorghum responded second best under fallow with yields more than double in those years when grain sorghum could mature ahead of frost.

Oats, spring wheat, barley, and corn did not respond as well to fallow as did winter wheat or grain sorghum. In the case of oats, spring wheat, and barley, rooting depth was too shallow to take advantage of stored soil water deeper than 3 feet in the soil profile. Corn not only needed fallow, but much above average summer rainfall to produce yields above 30 to 40 bushels/acre.

The second disadvantage of spring planted oats, spring wheat, and barley was their later date of maturity as compared with winter wheat. The grain heads are in flower or soft dough stage about the time hot winds arrive about June 20th. Hot winds cause moisture stress on these heads, thereby causing grain shrinkage.

There was little difference in yields of winter wheat in a tillage comparison of moldboard plowed (fall and spring) shallow cultivated plots (fall and spring) and fall and spring listed plots. From 1928 to 1938 yields averaged about 12.5 to 14.1 bushels/acre for the various tillage treatments above. Some of the years tested were quite droughty.

For all years tested on the long-term rotations, the results definitely favored a two-year rotation of fallow-winter wheat, or a three-year rotation of fallow-winter wheat-millet (or forage sorghum).

Shelterbelt Materials Study (1912-1963)

Various type trees and shrubs were planted between 1912 and 1946. In nearly all cases the plantings were too close together which required periodic thinning for survival. Trees planted too close together quickly exhaust sparse available water and threaten to all die within a given planting. The original evergreen planting of ponderosa pine, Austrian pine, Rocky Mountain juniper, and eastern red cedar were planted in a 5' x 5' spacing. Periodic thinning brought a survival spacing of 10' x 15' for larger tree types and 10' x 10' for smaller type such as juniper. Thinning was conducted by two methods: (a) removal of every other tree in a row or (b) removal of every other row.

Shelterbelts trap blowing snow and in this manner receive supplemental water beyond that of rainfall alone. In fact, one reason shelterbelts are less successful in the southern Great Plains of Oklahoma, Texas, and New Mexico is the absence of sufficient snow.

In young stages, shelterbelts need periodic cultivation to remove competition from weeds, particularly tap rooted broadleaf types. Cheatgrass (downy brome) can also be an invader that saps water and is a fire hazard after maturity.

Some of the more adapted species for shelterbelt purposes in the semiarid Central Plains include Chinese elm, Russian olive, black locust, honey locust, hackberry, American elm (marginally), ponderosa pine, Austrian pine, Rocky Mountain juniper, Siberian pea (Caragana), chokecherry, wild plum, and squaw bush.

Roots are shallow and plantings must get available water by horizontal root extention up to 4 and 5 times their heights. Root extension, as measured at the Akron Station, has reached 125 ft. in one direction from deciduous trees 24 to 26 feet in height.

Those trees occupying outside rows or at the corners of multiple row plantings were about double the size of those trees occupying inside positions. This is an example of competition and availability of water.

American elms, although adapted to the Central Plains, tended to be quite ragged in appearance as compared to American elms grown in the more humid midwest. Hackberry, also adaptable, are very slow growers and do not attain good height.

Shelterbelts are more useful around farmsteads and livestock pens than across cultivated fields. Tree root extension into planted fields can reduce crop growth up to 100 ft. on each side of the shelterbelt.

One maintenance problem with shelterbelts is the trapping and accumulation of tumble weeds. When very thick, tumble weeds can smother younger plantings as well as being a fire hazard.

Windbreaks in this area composed of two or three rows of a combination of ponderosa pine and Rocky Mountain juniper appear to be the most successful. At best these species will average 6 to 8 inches height per year until the ponderosa reaches 25 ft. and the juniper 12 to 15 ft. at which time the growth tends to level off. Chinese elm grow fast, but are not long lived because of slime flux and other diseases.

Pine needle mulch under a ponderosa planting 26 years old was measured at 13 tons/acre. Under a ponderosa planting 50 years old the needle mulch weighed 25 tons/acre. An artificial rain simulator at 3 inches water/hour application under both plantings showed no water runoff after 6 inches of water was applied. This is an excellent example of the capability of mulch to absorb high intensity rainfall. During periodic drought some of the older ponderosa die out. This seems to occur more frequently during a dry windy April after it has been droughty all winter.

Siberian pea (Caragana) and Russian olive grow well for about 15 years after which time they begin to deteriorate with dead branches and ragged top growth.

Tests are underway at the Station on rates of drip irrigation on the survival and growth of a number of established shelterbelt species.

When used wisely, shelterbelts are worth the effort. Shelterbelts moderate immediate climate, has an esthetic value, and acts as a harbor for wildlife.

Crop Variety Trials and Plant Breeding Efforts (1910-1981)

Crop varieties have been monitored at the Station since the beginning. Nearly all the crop types mentioned in rotational studies have undergone crop variety testing. Crop types receiving the most intense and longest test period were winter wheat, sorghums (grain and forage types), and both the hay type foxtail millet and grain type proso millet.

In winter wheat the characteristics most sought included early maturity, shorter height, good tillering, strong protein, tough stems (anti-lodging), and relatively free of diseases and insects. As of today, improved winter wheat varieties now yield 30% higher than the original parentage of "Turkey Red" and "Kharkof". The leading varieties now include "Baca", "Scout", "Scout 66", "Centurk", and "Vona". The leading varieties 15 to 25 years ago were "Wichita" a good early wheat, "Warrior" high quality; and "Comanche" also high quality.

The objectives in sorghum selection were similar to that of wheat. That is, shorter height, better tillering, nonlodging, and early maturity. Unfortunately, the Akron area has been consistently too dry and too cool to grow grain sorghum satisfactorily. The Akron Station has an average rainfall of 16 inches with an average annual temperature of 48.5°F. It is felt that sorghum is better adapted where the rainfall exceeds 18 inches with an average temperature 52°F. The Akron area is good for forage sorghum and a number of good varieties have been recommended for local use. These include "Fremont", "Leota Red", "Black Amber", and "Coes".

"Brunker" oats, "Vance and Otis" barley were bred and released from the station. However, most spring grains at Akron do poorly for reasons already given.

In recent years large scale nursery tests have been conducted on alfalfa, and vetch. There is still a search for a legume that can thrive under pasture conditions in the semiarid Great Plains. On sandy soils, thin stands of alfalfa mixed with various wheatgrasses has provided better weight gains on cattle than with wheatgrasses alone.

An active breeding and selection program on proso millet since 1963 has been quite productive with the release of "Leonard", "Cope", and "Abarr" varieties. Proso millet is planted on about 150,000 acres annually in northeastern Colorado.

"Leonard" is a taller leafier type proso that matures in about 85 days and has a straw-grain ratio of about 1.6/1. "Leonard" can be harvested for hay or for grain. "Cope" and "Abarr" are 70-75 day maturity prosos as selected from "Common White". Both "Cope" and "Abarr" have high yield potential of 60 B/A, high water-use efficiency, and a low straw-grain ratio of 1.2/1 or less.

Weather Station Data (1910-1981)

From the very beginning of the Akron Research Station to the present day, the weather station has been an invaluable source of data on such items as precipitation, storm intensity, daily maximum and minimum temperatures, day degrees above 40°F, open pan evaporation, and average and peak wind velocities. Average annual values for the Akron Station include 16.25 inches precipitation, 33 inches snowfall, 48.5°F temperature, 4750 day degrees March to November, open pan Type A evaporation of 69 inches, and 6.6 mph wind velocity.

Since 1950, there has been a drastic shift in annual precipitation. From 1910 to 1949 annual precipitation averaged 17.27 inches. From 1950 to 1981, however, average annual precipitation has been only 15.12 inches. Much of this precipitation deficit has occurred from April 1 to May 10 and to some extent from August 1 to September 10.

During the period 1920 to 1967, the contribution of annual precipitation during the late fall and winter (Oct. 21 to Mar. 31) progressively dropped from 20% to 10%.

Although precipitation expectancy for 66% of the year decreased since 1950, the rainfall contribution has tended to increase during late spring to mid-summer (May 11 to July 31). Sixty percent of all rainfall now occurs during this 22% length of the year.

The rainfall pattern during late spring and early summer since 1950 suggests a higher frequency of torrential type storms capable of inducing runoff.

Dormant season (Oct. 15 to Mar. 31) air temperatures increased by 0.5°F per decade beginning in 1911-1920 through 1961-1970.

Crop losses to hail is a realistic risk in the Central Great Plains. Since 1956, hail destroyed 100% of late summer crops of corn, millet, and sorghum at the Station in 1956, 1966, and 1978. A 100% hail loss also occurred on winter wheat and other spring grains in 1959, 1965, and 1966.

Implications of Rainfall Shift

Success of early spring plantings of barley, oats, or spring wheat will be seriously handicapped by lack of seedbed soil water needed for plant germination and development.

Because of higher rainfall frequency in late spring, the growth of weeds within winter wheat tend to increase. This poses a spray problem prior to harvest and also after harvest with unwanted live vegetation.

Reduced late summer rainfall makes it more mandatory that wheat planters be able to go through 4 to 5 inches of dry soil to reach wet soil to germinate wheat seed.

There is little point in beginning spring fallow tillage until May 1st for three reasons. First, cultivating the soil during a dry April merely increases water evaporation losses. One exception to this rule would be a winter carry over of volunteer wheat and cheat grass. Secondly, the soil is usually already receptive for water in April because of freezing and thawing during the winter. Lastly, most deep rooted broadleaf weeds in wheat stubble do not activate strong growth until after April 25th.

With nearly 60% of the rainfall occurring in the late spring and early summer, the concept of stubble mulch fallow becomes more important to (a) decrease runoff of torrential storms (b) increase water infiltration, and (c) reduce evaporation.

In any continuous cropping program, the growing of millet appears as well favored as any other crop. This would be especially true in northeastern Colorado.

One use of long-term weather data can be shown in the means of daily air temperatures and daily wind velocities to study the effect on daily open water pan evaporation. Evaporation constitutes the largest single loss of water in semiarid climates around the world. At Akron, our data shows that a shift of air temperature from 40°F up to 75°F increases evaporation by 0.15 inches per day. Similarly, increasing wind velocity from 4 mph to 10 mph increases evaporation by 0.14 inches water per day. What this data tells us is that if we can find a canopy that will cool the soil surface by even 5°F and keep it wind free, a significant savings of water is possible over a period of time. It so happens that a heavy weed free mulch of wheat straw will accomplish this purpose. It is for this and other reasons that we believe in stubble mulch fallow for the semiarid Central Great Plains.

Other Weather Phenomena

In 1946 the greatest amount of precipitation was received at 26.49 inches and the lowest at 9.93 inches occurred in 1939 and 1974. This spread of 16.56 inches between the lowest and highest precipitation years is really quite narrow as compared with most locations in the Great Plains. Nearly all other locations such as Burlington, CO, Colby, KS, Garden City, KS, Springfield, CO, and Amarillo, TX show about 25 to 30 inches spread between their record high and low precipitation seasons. Although the climate goes "dry" for several months duration at Akron, it has never been truly droughty in terms of effective precipitation for more than a single year. In terms of wheat farming with fallow this is an almost ideal situation in that effective precipitation is received with a high probability during any two year wheat-fallow cycle.

Daily air temperatures have ranged from 107°F down to -29°F. Temperatures 100°F and above have averaged 3.5/year with the highest at 19 days in 1939. Extreme winter conditions prevailed in the seasons of 1916-17, 1929-30, 1936-37, and 1972-73. Yet the hardier strains of winter wheat have never been killed because of extreme cold. In general, air temperatures warm up quickly about June 20th, just in time to ripen winter wheat. Air temperatures are not warm enough (67°F) until late May and early June to plant sorghum and millet. Wheat is planted in September after the soil cools to 65°F.

Day degrees (over 40°F) have ranged from 4,038 in 1912 to 5,682 in 1934. Most season day degrees are within the 4,600 to 4,900 range. It is warm enough to mature corn quite consistently.

The average wind velocity of 6.6 mph at Akron is quite low as compared with 9.2 mph at Colby, KS, 10.2 mph at Garden City, and 13.5 mph at Amarillo. Wind velocities for given storms can be severe, however, as exemplified by +80 mph gusts occurring on Feb. 23, 1977 during a dust storm and Mar. 10, 1977 during a blizzard. Akron is situated far enough north and west that hot dry winds in June from the southwest direction seldom occur.

Evaporation rates at Akron are 33% less than in southern locations such as Springfield, CO, Amarillo, TX, and Woodward, OK. This is one of the reasons summer fallow is so much better adapted in northeastern Colorado, southwestern Nebraska, and northwestern Kansas than other parts of the Central and Southern Great Plains.

A section on snow and snowfall phenomena is given later in this report.

SOIL FERTILITY STUDIES (1952-1981)

During the years of the long-term rotation studies (1908-1954) at the station, it was found that addition of 7 tons/acre manure usually caused an increase in straw and stover production of crops such as wheat and corn, but also a slight decline in grain production. In some cases the stimulated plant growth exhausted the available water supply too early. In years of abundant rainfall, manure did not decrease or increase yields. Manure tended to be a source of weed seeds.

In 1952, an outstate testing program was initiated in eastern Colorado on the effect of low rates of N and P on dryland winter wheat, corn, and grain sorghum. Some of the results and observations are given below:

Yield responses of 4 to 9 bushels/acre of wheat, corn, and sorghum were obtained from the application of 30 lbs/acre nitrogen on nearly all sandylands where the organic matter in the surface soil was less than 1.1%. The same type of response was also obtained on these crops grown on eroded hardlands (loam to silt loam texture) when the organic matter was less than 1.2%. Straw or stover also increased at about 1.5 to 2.0 pounds for each 1-pound of increased grain yield.

There was little difference in N responses to winter wheat when the N was applied in the fall shortly after germination or early in the spring up to April 10th.

Nitrogen applied after May 1st was too late for maximum benefit. In fact nitrogen applied after May caused new green tillers to form which tended to stay green at harvest causing a double layer of grain heads.

Rates of nitrogen application above 30 lbs/acre gave only 1 to 3 bushels/acre additional yield than 30 lbs/acre alone. However, the protein content of grain was usually increased about 1% per extra 25 to 30 lbs/acre of added N.

The protein content of winter wheat was increased about .5 to 1.5% by applying 25 to 30 lbs/acre of nitrogen. The response to protein tended to increase as the date of applying N was delayed during the spring.

There was very little yield response to N applications on wheat grown after fallow on noneroded hardlands in which the organic matter content of surface soils exceeded 1.4% (1952-1954 data).

Even under drought conditions, a nitrogen deficient soil would give some crop yield response to added N.

Winter wheat grain protein content is influenced to the greater extent by total precipitation during 40 to 55 days before maturity, available soil water at seeding, total NO_3-N at seeding and maximum air temperature 15 to 20 days before maturity. By applying nitrogen fertilizer so that it moves into the soil with the water stored during fallow, high yields of high protein (>13%) wheat can be obtained.

There was no yield response to the application of phosphorus alone under any soil condition of texture or organic matter levels on winter wheat, corn, and sorghum.

Response to P did occur about 50% of the time when applied with N at 30 lbs/acre each as restricted to very coarse sandy soils and eroded hardland in which P levels were very low.

In nearly every case, regardless of soil type, the NP treatments produced lower levels of protein than did N-alone. The reduction ranged from 0.2 to 0.6%.

Observations showed that if a crop was lost on nutrient deficient soil, fertilizer carryover would show up in a succeeding crop.

Observations suggested iron chlorosis symptoms on sorghum, sudangrass, and millet on eroded high lime spots on "hardland" soils.

In more recent years the nitrogen picture on hardland soils has changed. Twenty-five years ago wheat would yield 20 bushels/acre at 14% protein. With modern water conservation of better weed control and stubble mulching fallow the yield potential has increased to 40 bushels/acre but at 10% protein. This lower protein is indicative of stretching the N supply too far and that added N would now be a desirable practice.

In summer fallow the accumulation of soil nitrate nitrogen (NO_3-N) by wheat seeding time ranged from 50 to 130 lbs/acre with a level of 70 lbs/acre as border line deficiency. This is because it takes about 2½ lbs/acre of available N per bushel of wheat produced. Thus, it takes 100 lbs NO_3-N to produce 40 bushels/acre.

The level of NO_3-N generally increased about 15% with the use of tillage or herbicide treatment in wheat stubble after harvest. The level of NO_3-N tended to decrease about 10% as the volume of stubble mulch increased from 1,500 to 6,000 lbs/acre.

Introduced grasses such as Russian wildrye, Crested wheatgrass, and Intermediate wheatgrass would respond at the rate of 300 to 500 lbs/acre dry matter production per 25 lbs/acre N application up to 50 lbs/acre usage. This assumes that soil water is reasonably sufficient during the growing period.

In general, grass response to N application was more consistent with cool season wheatgrass type species than with warm season species such as blue grama and buffalo grass. In no case did the application of P along with N give any better response than with N alone.

The addition of supplemental N did not significantly increase the extraction of soil water by the grasses tested.

There was no evidence of a potassium (potash) deficiency in any of 45 test sites of wheat, corn, and sorghum during 1952-1954.

<u>Organic Phosphorus Investigations</u> (1951-1952)

Organic P averaged 23% of total P in Colorado soils, 26% in 3 irrigated rotation soils, and 27% in 4 virgin soils.

Organic C, N, and P were highly correlated for all soil groups tested. Carbon to organic P ratios of 95:1, 72:1 and 128:1 were obtained for the three groups cited above respectively.

Alfalfa and manure treatments in rotations increased the level of C, N, and P and also C/P and N/P ratios when compared with continuous row cropping without organic residues. Alfalfa was more effective than manure in maintaining organic C, N, and P.

Nonvirgin soil contained less organic P, and much less organic C and N, and lower C/P and C/N ratios than virgin soil.

Organic P mineralized at an average 3.6 ppm P for 13 Colorado soils when incubated for 21 days at 35°C.

SUMMER FALLOW (1909-1981)

Fallowing for wheat represents the single most important cultural crop system in the semiarid regions of western United States. Fallowing implies deliberately extending the noncropped or dormant season between crops to accumulate sufficient soil water to reduce the risk of failure when the next crop is finally planted. This time lapse includes at least one winter and one crop season. In the Central Great Plains the system includes fallow-winter wheat and fallow-winter wheat-sorghum (or millet) where applicable.

The basic objectives of fallowing are:

- Maximize soil water storage
- Maximize nutrient availability (N)
- Minimize soil erosion potential
- Minimize energy and economic input

Years of research, new technological plateaus and experience suggest the following concepts for upgrading these objectives:

- Weed control for entire 14 months of fallow
- Standing stubble overwinter to capture snow
- Maintain straw mulches during the spring and summer for better water intake and evaporation suppression
- Hard soil clods 1/2 to 3 inches in diameter for wind erosion control
- Maintain soil wettness in the seedbed

Improvements in fallow tillage were slow to develop in earlier years because restrictions of horsepower and adaptable implements. In general the progression of fallow included dust mulch (1915-1930) as conducted with initial moldboard plow succeeded by frequent harrowing → conventional tillage (1931-1945) with shallow disks and harrowing → improved conventional tillage (1946-1957) with shallow disks and rodweeders → stubble mulch tillage (1957-1966) with sweeps and rodweeders → minimum tillage (1968-1977) with fall applied herbicides succeeded by spring sweeps and rodweeder → and no-tillage (1978-1981) with exclusive use of herbicides.

Fallow efficiency is the percentage of soil water gain from precipitation from wheat harvest (begin fallow) until wheat seeding 14 months later. In olden days, dust mulch stored only about 3.5 to 4.0 inches water during the fallow period or about 16 to 20% fallow efficiency. Today, minimum tillage and no-tillage average about 35% and 45+% fallow efficiency respectively. Yields of winter wheat at the Station have likewise doubled from the 18.5 bushels/acre average of 1908-1954 to 37.0 bushels/acre achieved during 1967 to 1981. Also noted was the fact that annual precipitation averaged 2-inches less during the 1967-1981 period than during 1908-1954.

Under minimum tillage fallow, soil water storage efficiency will average about 30% during the fall, 55% during the winter, 35 to 40% during the spring, and only about 10% during the hot summer. In some seasons there is an actual loss of soil water during July and August.

It was found under minimum tillage that for every 100 lbs/acre of weed suppression in the fall, there was a corresponding net gain of 60 lbs/acre wheat grain and 110 lbs/acre of straw.

The use of any tillage in fallow causes an evaporative soil water loss of 0.2 to 0.3 inches per operation. In general, deep tillage, greater than 5 inches soil depth loses more soil water by evaporation than does shallower tillage.

Complete no-tillage fallow offers the ultimate in fallow efficiency and wheat yields within the limits of prevailing effective precipitation. With the adaptation of complete no-tillage fallow starting in 1976, winter wheat yields at the Station have averaged 53 bu/acre over the last five harvests as compared to 40 bu/acre where tillage fallow has been used. These yields represent a 25% increase in five years which prior to 1975 took 15 years to achieve. With the development of herbicides that can be applied in the growing of wheat prior to maturity to control existing and germinating weeds, soil water storage efficiencies of 70 to 75% are attainable. This, coupled with the advent of air seeders, new fertilizer techniques and new wheat varieties, make 100 bu/acre dryland winter wheat feasible in the not too distance future.

Whether using minimum or no-tillage fallow, there is a high priority need to apply contact and long-term preemergence herbicides as quickly after wheat harvest as possible. The contact herbicide suppresses weeds in the stubble when the weeds are still small and shallow rooted. Secondly, the preemergence herbicides prevents germination of new weeds and also suppresses the growth of volunteer wheat.

A thick stand of weeds can consume 0.2 inches of soil water per day.

Even if no herbicides are used, there is an advantage to undercutting wheat stubble 4-inches deep with sweeps shortly after harvest. Undercutting destroys one generation of water sapping weeds and also provides a loose cloddy soil surface which can readily absorb any late summer torrential rains without runoff. The yield advantage with fall undercutting at the Station averaged 3.2 to 6.0 bushels/acre of winter wheat depending upon whether one sweep operation was used or a double sweeping, one after harvest and a second operation a month later.

In nearly all experimental cases, the final yield of wheat has been closely correlated with the amount of soil water gained during the fallow season. Yields generally increased at the rate of 4 to 7 bushels/acre per inch of stored soil water after the minimum requirement of 8 to 8.5 inches has been satisfied. It takes about 8 to 8.5 inches evapotranspiration (soil water + precipitation) before the first bushel of grain is produced.

STUBBLE MULCH FALLOW (1957-1968)

Stubble mulching involves deliberately maintaining straw, stalks, or stover on the soil surface for the intent of reducing wind and water erosion potential, to increase the soil intake of water, and to suppress soil water evaporation. Assuming noninterference by weeds, stubble mulch really does accomplish the objectives quoted above.

Wheat that undergoes some drought stress will produce straw that is light grey in color and weak in fiber strength. Such straw is fragile and decomposes readily upon contact with soil. Wheat that matures without drought stress will have golden color straw that is tough and somewhat resistant to decomposition. Obviously, the golden colored straw is best for mulching purposes.

Studies at this Station have shown that standing stubble does not cause a wick effect that would hasten soil water evaporation. In general, for both erosion control and water conservation, standing stubble is better than leaning stubble, leaning stubble better than flat stubble, and flattened stubble much better than no stubble at all.

Studies at the Station showed that a 12 inch height wheat stubble could withstand a 13 mph wind without significant wind movement at the soil surface. With stubble 24 inches high, winds up to

35 mph were deflected from the soil surface and thereby decreased potential evaporation soil water loss considerably.

Stubble is very valuable in the catchment of winter snows.

The net gain in soil water storage has averaged 0.7 and 1.5 inches for 3,000 and 6,000 lbs/acre wheat straw mulch as compared with 1,500 lbs/acre mulch as tested over six fallow seasons. Wheat yields were increased an average 3 and 6 bushels/acre as the result of the soil water gains by mulching.

Assuming perfect distribution upon the soil, the amount of winter wheat, spring barley, and spring oats stubble needed for 100% soil cover was determined at 3,200, 2,000, and 3,200 lbs/acre respectively. The high efficiency for spring barley as a mulch is due to a much thinner stem shell. The values given here for these crops are within normal straw production when grown on fallow in northeastern Colorado. The average straw production for wheat is about 3,800 lbs/acre.

The amount of stover required for 100% ground cover for millet, sudangrass, and grain sorghum is high at 7,200, 6,000, and 14,600 lbs/acre respectively. The average production of stover for these crops is 2,200 lbs/acre for proso millet, 4,000 lbs/acre for sudangrass, and 2,400 lbs/acre for grain sorghum.

It is recommended that livestock grazing not be permitted on millet and grain sorghum stover because of low stover coverage of the soil and soil pulverizing by trampling which would increase the wind erosion potential considerably.

Straw mulches over 3,600 lbs/acre decrease the soil temperature 3 to 7°F at 2 inches soil depth during the spring and summer, and tend to increase soil temperatures about 2°F during the late fall and winter.

The organic decomposition of stubble on the soil surface increases stable soil aggregates because of added binding agents such as fats, waxes, and oils released by the decomposition process. Increasing the percentage of stable aggregates thereby decreases the wind erosion potential.

In earlier years, stubble mulching was difficult to achieve because of poorly designed machinery and lack of power. Early objections to mulches included poor weed kill, sweeps were too narrow and with insufficient soil disturbance, and low tool bar clearance. Modern sweep blades are now 5 to 7 ft. with high clearance. Additionally, weeds in stubble can be destroyed by contact and/or preemergence herbicides, thereby eliminating any tillage until or if needed for seedbed preparation.

The quantity of wheat straw in the 0-3 inch depth of soil in wheat-stubble mulch fallow rotations were determined at Sidney, MT, Akron, CO, North Platte, NE, and Bushland, TX. Quantities of straw mixed with 3 inches soil ranged from 1,160 to 6,680 lbs/acre after two or three cycles of fallow. Straw quantities were influenced by duration of rotations, amount of initial straw, and dates and type of primary tillage.

At Akron it was found that after two cycles of fallow, a total of 61, 43, and 34% of 1,500, 3,000, and 6,000 lbs/acre per cycle of fallow would be recovered. At the end of three cycles the values were about the same.

There was no evidence that application of nitrogen had any influence on straw disappearance.

There was evidence that straw would build up to a certain equalibrium and then level off.

Use of disk type implements in Texas greatly reduced mulch carryover as compared with stubble mulching with sweep. The reduction was greater than 50% on fallowed plots and in continuous wheat plots.

An analysis of surface straw on 10 commercial fields in northeastern Colorado showed an average level of 4,100 lbs/acre.

In general, more mulch can be saved under drier fallow conditions than under wetter conditions.

Winter Wheat Culture (1967-1981)

Winter wheat should be planted with a furrow drill, with furrows 4 to 5 inches deep sometime between Sept. 7 to 17th. The row width should be 12 to 14 inches and oriented east-west as much as possible. The deeper furrows and row orientation helps to trap more snow during the winter. Wide row spacing has yielded about 1 to 2 more bushels/acre than narrower spacing.

There is a double disadvantage to seeding wheat before Sept. 1 in eastern Colorado. First, early planted wheat is much more susceptible to disease such as foot rot and insects of hessian fly and green bug. Second, fall growth is likely to be excessive which thereby consumes too much soil water that is better utilized the succeeding spring for grain production. A dry matter production of 200 to 400 lbs/acre in the fall is considered optimum.

Seeding rates for most wheat varieties should be 18 to 22 lbs/acre on hardland except for "Vona" which requires about 40 lbs/acre. Seeding rates on sandylands should be about 30 to 35 lbs/acre for most varieties because wheat does not tiller as well.

If fall rains occur after planting, an operator should check his fields closely for germinating cool season weeds such as mustard and wild lettuce. These should be sprayed while still small. If mustard reaches the rosette stage, it is much more difficult to kill.

Soil water in good fallow usually wets the soil to 5½ to 6 ft. depth containing 7 to 10 inches available water. Wheat roots have been found at 6 ft. depth within six weeks of fall planting. Assuming only a moderate rainfall of 1½ to 2 inches in June, wheat will exhaust nearly all available water in the soil profile by harvest time.

Wheat should be cut at maximum height that does not cause loss of yield. Taller straw is more advantageous than short straw for water conservation purposes during fallow. Unfortunately, most combine crews set the cutter bar at half height or less.

Up to about eighteen years ago, the straw/grain ratio of winter wheat in the Akron area was 2.5:1. Tall stems of these wheats consumed too much water and the yield potential suffered. Energy and water are better used when the stalks are divided into 3 shorter stems with three grain heads than into a pair of taller stems. The yield potential of new wheats has now increased 25 to 30% and the straw/grain ratio is 1.7:1.

SNOWFALL AND SNOW CONSERVATION (1955-1979)

Uncontrolled snow has long been a hazard of the northern and central Great Plains of the United States. Violent storms disrupt communication, power supply, and transportation. They also cause death and injury to human life, livestock, and wildlife. Yet, in favorable seasons, snow is a valuable water resource for stock ponds, range grasses, shelterbelts, cropland, and recharge of ground water.

In 1955 studies were initiated at the Station to monitor and characterize snowfall events, to estimate the contribution of snowmelt to crop production, and to design practical systems to trap and hold wind-transport snow for water conservation.

For all winters, measurable snowfall occurred an average 12 times per season, totaling 32 inches of cumulative snowfall, which contained 11.9 percent water and averaged 3.82 inches precipitation. Year-to-year variations were sometimes extreme.

Snowfall events ranged from 4 to 23 per season. From winters 1955-56 to 1969-70 snowfall events were reasonably consistent at 9 to 13 per season.

Annual snowfall varied from 11 to 82 inches per season. In five seasons less than 20 inches of snow was received and in three seasons more than 60 inches were received. Snowfall was less than average in 67 percent of the 24 seasons measured.

A metal core sampler was used to measure water content of snow. The sampler was 12 inches long, a 3-inch inside diameter, had depth marking at 2 inch intervals, and had narrow vertical slots to release air pressure and permit visual inspection for proper filling of snow in the tube without compression.

Water content of individual snow storms varied from 4 to 22 percent. The data revealed that water content of new snow was related to air temperatures and wind velocity. Under low wind conditions, the water content of new snow ranged from about 5.5 percent at 0°F to 17 percent at 35°F (beginning of rain). At higher windspeeds of 20 to 30 miles/hr, water content of new snow ranged from 9% at 0° to 22 percent at 35°.

Snowfall precipitation ranged from 1.42 inches to 11.73 inches per season. In five winters, less than 2-inches snowfall precipitation was received and more than 5-inches was received in 5 other years. During the last 11 winters, snowfall has averaged 4.95 inches precipitation per season.

Individual snowstorms have varied from ½ to 20 inches snow deposit. About 43 percent of all storms were of the 1-inch category. Storms of 5 inches deposit and greater occurred 13 percent of the time. These larger storms, however, contributed 39 percent of total snowfall and 41 percent of snowfall precipitation.

Snow was received in all months September through June. March has been the snowiest month averaging 7.2 inches and succeeded by November and January averaging 5.1 inches each. An average of two storms per month were received December to March.

Water content of snowfall was highly correlated with mean monthly temperatures and ranged from 9.2% during January and 10.3% in February up to 13.9% in October and 14.2% in April.

The soil at Akron is usually frozen from about December 11 to February 20. During this period, about 33% of the total snowfall is received. The drier type snow received during this period contributes only 27% of snow precipitation. Thus, about 73% of total precipitation occurs during nonfrozen conditions. This is an important factor in the recharge of available soil water. Secondly, because of the preponderence of nonfrozen soil during the snow season, soil erosion from snowmelt is minimal and soil water storage potential is high.

Snowfalls at the Station have occurred with windspeeds ranging from 0 to greater than 80 mph. Significant snow drifting involved at least 2 inches snowfall with wind velocities above 12 mph. Snowstorms causing snowdrifts greater than 12 inches deep occurred 103 times during the 1955 to 1979 test period, averaging 4.3 times per season or 36% of all snowfall events. There were two winter seasons without drifting and two had eight drifting events.

Snowfall received under drifting conditions averaged 16.5 inches per season and accounted for 52% of all snowfall. Snowfall deposited per drifting storm averaged 3.8 inches as compared with only 2 inches for nondrift storms.

Snow deposited during drifting storms averaged 13.1% water content as compared with 10.7% for nondrift types.

Newly formed snow drifts averaged 19.8% water content or 1.5 times greater density than adjacent level snow. This fact has important implications in those cases where snow drifts can be manipulated for specific water conservation purposes.

Blizzards in the Great Plains are dangerous to life and property. A blizzard as defined here is any given storm in excess of 4 inches snowfall, >35 mph wind speed, and lasting 8 hours or longer.

During the last 32 years at Akron, 27 blizzards have occurred. These blizzards averaged 7.7 inches snowfall and 0.97 inches of precipitation. There is a 65% probability that Akron will receive at least one blizzard or more per winter. Blizzards have been recorded from mid-October to early May. Of the 27 blizzards recorded, 6 have occurred in November and 5 each in January and February. The most significant and dangerous blizzards occurred Jan. 2-4, 1949, Nov. 2-3, 1956, March 27-28, 1975, and March 10, 1977.

Although of low frequency, serious ground blizzards did occur in northeastern Colorado during the winters of 1948-49 and 1972-73. In both these cases heavy snowfall buried all crop stubble, the temperatures stayed below freezing (no crust formation) and the wind could blow loose snow back and forth with few obstacles.

<u>Snowmelt Storage in Soil</u>

Water from snow can be lost by evaporation, sublimation, blowoff from fields and runoff from frozen soils. For agronomic reasons, it is hoped that greater use of snow enters the soil for crop and grass production. The efficiency of snowmelt storage in the soil is defined as the net gain in soil water within the top 6 feet of soil from a given water equivalent of snowfall.

Because of much cooler and less evaporative environment, an inch of water in the form of snowmelt is about twice as efficient in recharging soil water than is an inch of water in the form of rain.

Winter wheat is harvested on 7.5-million acres per year in the semiarid Central Great Plains west of the 100th meridian. The snowmelt storage efficiency in large stubble fields at the Akron Station averaged 55% over 20 winter seasons. During this period winter precipitation averaged 4.05 inches with a net average snowmelt storage of 2.23 inches per season. This accounted for about 37% of the water gained in fallow.

Some snowmelt runoff occurred about 8% of the seasons.

Snowmelt intake efficiencies ranged from net water losses during three low snowfall years to well over 60% in 9 of 20 years tested.

It is common for snow to stockpile in wheat stubble in the north 100 feet of large fields because of snow blowing.

Stubble that is partially knockdowned or completely flattened will hold only 50% or less of the amount of snow as with undisturbed stubble.

Small isolated strips of wheat stubble will trap and hold surprising quantities of wind driven snow.

It is estimated that snowfall in fallowed stubble and on planted wheat contributes 40 to 45% of the wheat yield north of the 39° parallel in the Central Great Plains.

Snowmelt storage efficiency on ungrazed native grass pasture averaged 38% over a 12 year test period. A slight loss of water occurred in four seasons of low snowfall whereby evaporation from the soil exceeded the winter gain. The results obtained at Akron was similar to results taken at Nunn, CO.

Snowmelt efficiency averaged 66% and 70% from snowdrifts formed leeward of 48 and 24-inch height snowfences over a five year test period. For individual storms, snowmelt efficiency ranged as high as 77 to 89% from large drifts undergoing rapid melting.

There was little evidence of horizontal movement of snowmelt under various snowdrifts induced by artificial or vegetative barriers during the years of testing at Akron. This suggests that frozen soil is a negligible factor in snowmelt movement. In some instances frozen soil thawed out under snowdrifts because of upward heat flux.

Snowdrift configuration could be manipulated by variation of height and air porosity of wood-slat fences. In general, the largest volume and overall width of drifts were formed leeward of fences containing 70 to 75% air porosity. The standard highway slat fence is 58% air porosity and 48 inches tall. By pulling out every third slat, a 72% porosity fence is made and is quite efficient for managing snow for water conservation purposes.

Snowfences could be used to increase soil water at a given spot for shelterbelt (2 or 3 rows) establishment.

A 72% air porosity fence was used on a planting of Russian wildrye, intermediate wheatgrass, and crested wheatgrass which achieved 64% snowmelt efficiency. The added water storage induced from snowdrifts 55 feet wide increased grass yields remarkably and especially so with nitrogen fertilizer added to the grasses. Grass yields were highly correlated with the amount of snowmelt water produced at given distances from the fence.

Vegetative Barriers for Snow Management

A series of double row plantings of forage sorghum stubble and sudangrass stubble were installed to act as snow barriers, similar to a picket fence, for depositing snow onto a leeward crop target area. The objective was to reduce the speed of wind-transport snow and thereby induce snow deposition 12 to 15 times as wide as the barrier is tall. Criteria sought for barriers are given below:

- Strong flexible stalks greater than 20 inches in height but not so tall or top heavy that lodging of stalks would result. Good winter durability is desired.

- Double-row plantings instead of single row to eliminate possible air flow gaps.

- Stalk population to provide 65 to 75% air porosity.

- Spacing between barrier strips (the crop target area) should be from 36 to 60 feet.

- Orient the parallel barriers at right angles to the prevailing wind.

Stubble barriers of sudangrass and forage sorghum were tested in a winter wheat-fallow rotation during 1960-1964. The gain from snowmelt averaged 6 inches more snow catchment per season which contained 1.5 inches more snowmelt inside the barrier system than outside. This extra water increased average winter wheat yields by 230 and 370 lb/acre grain and straw per season respectively.

Crop barriers does involve annual installation which could be a disadvantage.

In 1972, barriers composed of tall wheatgrass were installed at Akron involving twelve parallel strips spaced 37 feet apart. The grass grew to a height of 4 to 5 feet. A relatively dense leafy growth developed to 1 foot above ground level with seed stalks extending higher. As a perennial grass it proved effective in trapping and holding snow. Air porosity ranged from 65 to 70%, about ideal for the purpose intended. Windspeeds were reduced by an average 80, 60, 40, and 30% at distances of 5, 11, 16, 23 feet respectively (Sidney, Montana data).

Winter rye, winter wheat, foxtail millet, and sudangrass were tested for forage yield production both inside and outside the tall wheatgrass barrier system for crop seasons 1974 to 1977. There was an average net gain in snowmelt of 1.93 inches during those years inside the barrier system. Forage production was increased by an average 1,075 lbs/acre. This included subtracting 10% of the yield because of the space occupied by the barrier system. By years, the net gain was 360, 620, 1,610, and 1,670 lbs/acre forage for years 1974, 1975, 1976, and 1977 in that order.

Under one very severe blizzard, occurring Mar. 10, 1977 where winds were clocked at over 80 mph, the tall wheatgrass barrier system very successfully held snow. The crop target area had tightly packed snow 15 inches deep on the north side and tapering to 9 inches across the southern portion. The snowmelt measured 3.75 inches. There was no other snow stopped or held by stubble at the Station and surrounding area because of extreme wind velocity.

In 1978, fallowed winter wheat averaged 60.9 bushels/acre inside the tall wheatgrass barrier system and 51.7 bushels/acre outside. Subsampling showed that most of the net grain in wheat yield was in the north half of the crop target areas.

In summary, vegetative barriers will efficiently trap and hold wind transport snow which can be used for crop production purposes. Barriers can protect soils from wind erosion and young crop plants from wind dessication and soil abrasion. Barriers can offer quick farmstead protection until perennial woody species become established.

Strip systems of alternate winter wheat and fallow are quite efficient in holding snow providing the strips are properly oriented across the prevailing storm winds.

There are some good strip cropping systems across northern Weld and Phillips Counties in Colorado.

EARTH MOVING FOR WATER CONSERVATION (1957-1980)

Use of engineering systems to control and efficiently utilize runoff water involves earth moving of some kind. Land leveling, lagoon enlargement, water way flood pans, and various terrace systems have all shown promise in specific water control situations. In most cases there is a tradeoff between earth moving costs and exposure of less fertile subsoil as weighed against better water utilization for higher crop yields. About 15 to 20% of dryland acreage could use some form of earth moving to increase crop production.

Land Leveling

Land leveling is generally used to spread water uniformly over fields and to increase the time of infiltration. Some zero-zero slope leveling has been done on dryland to retain all precipitation. At Akron, level benches without a contributing area has averaged 1.7 inches per season more available water than a nonleveled area over a five year period.

Grain sorghum was grown continuously in the level bench and also on fallow in a nonleveled area. Two years production totals were 21 bushels/acre greater production in the level bench than on the nonleveled area.

Leveling increased the storage of soil water by 1.2 to 3.0 inches annually which resulted in 3 to 4 bushels/acre higher winter wheat yields on the level vs nonleveled test area.

Near Garden City, KS, one operator has leveled some large fields where the slopes were 1 to 2%. The leveling appears to be quite successful for winter wheat production.

Lagoon Enlargement

Shallow lagoons or swales are common in the Great Plains. They are usually infested with weeds and periodically flood out any domestic crop planted in the bottoms. The soils are heavy textured and highly fertile.

Rehabilitation of lagoons for crop production is quite simple. Lagoons can be leveled and enlarged, about double, by moving lighter textured soil from the lagoon edges to and across the bottom. The ratio of contributing area to the newly leveled lagoon should be about 3:1 and not greater than 6:1. If watersheds are too large, diversion terraces may be built to obtain the desired ratio.

The additional water received in the lagoon with rich soil will usually permit continuous cropping of forage crops or high yielding domestic grasses and legumes. Costs may be amortized in 4 to 6 years from the increased yield.

Waterway - Level Pans

Waterway level pans is a system of combining land leveling, detention dikes, and spillways in a stair step fashion down a gentle and wide (over 200 feet) drainage. The detention dikes are constructed at the lower end of a leveled pan and includes a gate and spillway to control and measure the volume of water desired for storage. All pans include some drainage to avoid prolonged flooding.

Soil water storage is usually increased enough to permit annual cropping with domestic grasses, corn, alfalfa, grain sorghum and forage sorghum.

Costs for waterway pans can be amortized in 3 to 5 years by increased crop production.

Zingg Conservation Bench Terrace

The original field terraces in common use were of the narrow ridge type, hard to farm, and designed more to slow down drainage water. The broad flat-channel Zingg terrace, as installed at the Akron Station are designed specifically for water conservation and utilization on the bench with no runoff. The flat bench is about 80 to 100 feet wide, leveled to zero-zero slope, and fertilized to replace any fertility lost by the leveling process.

The Zingg terrace system is best adapted on deep soils and on long uniform slopes of 1 to 5%. Ratios of contributing to level bench area varies from 2:1 to 4:1 depending on precipitation probability, slope, and soil type.

At the Akron Station, level bench systems have more than doubled the yields of forage and grain sorghum produced on adjacent 1½% slope. Yields of fallowed winter wheat were increased about 5 bushels/acre on the bench as compared with no bench.

There is a real need to add nitrogen and phosphorus, about 40 lbs/acre each to newly constructed terrace bottoms where soil removal exposes lighter colored infertile subsoil.

Water Harvesting

Water harvesting from near impervious surfaces was thought to have been used 4,000 years ago on deserts to grow various cereal and vegetable crops.

Impervious membranes such as sheet metal, butyl rubber, asphaltic compounds, gravel, shingles, polyethylene, and sodium carbonate are relative efficient and durable in warm climates. However, with extremes of freezing and thawing at Akron, only sheet metal and butyl rubber have been successful for water harvesting.

SOIL EROSION

Wind Erosion

Dust storms in the Great Plains are synonymous with prolonged drought. Wind erosion on a massive scale occurred 1934 to 1939, again 1954 to 1956, and as late as February 1977. Soil erosion by wind is determined by wind velocity, surface soil water, degree of soil cloddiness, and surface roughness, vegetative cover on the field, and length of uninterruped wind flow.

In the Central Great Plains soil is most susceptible to wind erosion during the dormant season after winter wheat is planted, and not during the fallow season itself. The risk is intensified with poor wheat stands. Soil water shortages in the fall result in winterkill of the remaining plants, thereby depriving the soil of anchorage of healthy plants. The peak danger period is from February 15 to April 20 when small soil aggregates have been pulverized to dust by alternate freezing and thawing. It is also during this period that wind velocities are highest and sometimes to the extreme. Geographically, the wind erosion hazard is greatest in southeastern Colorado and the adjacent fringe of Kansas counties.

It has been found by observation and tests that wind erosion can be controlled by any and all four principles of control, namely:

- Produce or bring to the soil surface aggregates or hard clods large enough (½ to 3 inches diameter) to resist the wind force. In general, at least 65% of the surface soil particles must be in aggregates greater than 0.84 mm in order for a field to be wind resistant.

- Roughen the soil surface with implement furrows at not greater than 4 feet width between furrows.

- Reduce field width by strip cropping or by establishing vegetative barriers, thereby reducing wind speed and soil avalanching.

- Most important, establish and maintain vegetative cover in excess of 1,200 lbs/acre of straw mulch to protect the soil.

In this day and age, wind erosion should be minimal.

Water Erosion

As would be expected, the major hazard involves clean fallow on sloping land during torrential rain. Some of the strategies for reducing runoff and utilizing runoff were discussed under the Section "Earth Moving for Water Conservation".

In general, similar strategies to control wind erosion also apply to water erosion: (i) absorbing energy of raindrop impact with vegetative cover and hard soil clods, (ii) retarding erosion by reducing water velocity, (iii) restrain soil movement with surface roughness, and (iv) reduce length of downslope runs with intercepting terraces, land leveling, or strip cropping.

Water erosion from snowmelt rarely occurs in the semiarid Central Great Plains.

EFFECT OF TOP SOIL REMOVAL

Concept

Soil erosion by wind and water has removed varying amounts of top soil, probably ranging from 1 to 16 inches, on "hardland" loam and silt loam soils throughout the Central Great Plains. This soil removal has an unknown effect on soil constituents, fertility, and crop yields. An experiment was initiated at the Akron Station in 1955 to artificially remove top soil with a carryall to depths of 0-3, 3-6, 6-9, 9-12, and 12-15 inches to study the effects on certain soil constituents, soil water storage, soil temperature, and crop yields. The soil type used for the experiment was a Weld silt loam, a bench mark soil of the semiarid Central Great Plains.

The soil removal was accomplished in the fall of 1955 and involved cutting a 0.84% slope to a 0 x 0 slope in such a manner that 1-inch of soil was removed for every 10 feet up the slope.

Initial Soil Constituents (1956)

The results in this section are reported as soil removal progresses from 0-3 inches removal down to 12-15 inches removal. Soil samples were taken from 0-2 inches at the various removal depths.

The color of the new surface soil was dark brown → brown → red brown → grey brown → grey white in going from 0-3 to 12-15 inches removal.

pH increased progressively from 7.2 to 8.3 going from 0-3 to 12-15 inches removal.

Calcium carbonate (lime) increased progressively from 0.3 to 5.6%.

Bulk density decreased from 1.52 to 1.42 gms/cm^2 from the 0-3 inch removal to the 12-15 inch removal.

Percent clay increased from 18% at the 0-3 inch removal to 33% at 6-9 inch removal and down to 23% at 12-15 inches soil removal.

Organic matter decreased progressively from 2.1 down to 1.2%.

Sodium bicarbonate soluble phosphorus (P) decreased progressively from 24 lbs/acre to 5 lbs/acre. Levels below 20 lbs/acre are considered deficient in available P.

Surprisingly, total phosphorus averaged about 594 lbs/acre for all soil removal depths.

Percent total nitrogen (N) declined progressively from 0.11 to 0.08%.

The carbon/nitrogen (C/N) ratio gradually declined progressively from 11.2/1 to 8.3/1.

Nitrifiable nitrates showed a progressive decline from 56 lbs/acre in the 0-3 inch removal plots to 43 lbs/acre in the 12-15 inch removal plots. These results were obtained by six week incubation at 35°C (95°F).

Aggregate stability of soil clods was analyzed by the vacuum method and showed 57, 62, and 54% stable aggregates for the 0-3, 6-9, and 12-15 inches soil removal levels respectively.

Soil Water Storage in Fallow (1957-1961)

Soil water accumulation was recorded for each fallow year from 1957 to 1961.

Significant differences were obtained each year as the result of soil removal. The mean soil water storage for five fallow seasons was 4.8, 6.3, 6.3, 7.2, and 7.3 inches for soil removal depths of 0-3, 3-6, 6-9, 9-12, and 12-15 inches, respectively. Soil water gain in the 0-3 removal plots was significantly lower than any other removal level. There was a significant difference in water storage between the 3-6 and 6-9 removal plots versus the 9-12 and 12-15 inch removal plots.

In 1960, when precipitation was much below average, soil water storage increased progressively as the soil removal increment increased with differential significance obtained between each soil removal increment except between 9-12 and 12-15 inches. In years of above-average precipitation, soil water storage tended to be similar in the 3-6 and 6-9 inch removal plots, and also in the 9-12 and 12-15 inch removal plots.

Mean fallow efficiency of water storage ranged from 25.6% for the 0-3 inch removal plot to 33.3, 33.1, 38.1, and 38.5 for the 3-6, 6-9, 9-12, and 12-15 inch removal plots in that order.

It seems ironic that progressive soil removal would actually increase the efficiencv of soil water storage of precipitation during fallow. The explanation involves soil color reflectance of radiant energy and a shallow clay layer.

Soil Temperatures (1960-1962)

During fallow periods from May to September of 1960, 1961, and 1962, soil temperatures were recorded periodically at the 3-inch soil depth of each increment of soil removal.

The mean temperatures obtained decreased progressively from 77.5°F for the 0-3 inch removal plots to 76.3°, 75.7°, 74.8°, and 74.3°F for the 3-6, 6-9, 9-12, and 12-15 inch removal plots respectively. These plots ranged from dark brown color to grey white and imposed the temperature differential measured. The warmer dark colored soil matured wheat several days earlier than did the cooler lighter colored soil. Mean water storage in fallow was negatively correlated with mean soil temperature. Thus the cooler the soil the less water loss by evaporation.

An additional factor that may have influenced soil water storage during fallow was the high clay content and granular structure of the 4 to 8 inch depth soil zone. During short periods following a rain the 0-3 inch depth of the 0-3 to 6-9 inch removal plots would hold more water nearer the surface than the other removal increments, hence making soil water more available for evaporation.

Seedbed Soil Water

In dry years, the 0-3, 3-6, and 6-9 inch removal plots dried out deeper than the 9-12 and 12-15 removal plots for the reasons given above.

In September 1960, after extended drought conditions, the mean depth to seedbed moisture was 7, 8, 7, 4, and 3 inches for the 0-3, 3-6, 6-9, 9-12, and 12-15 inch removal plots respectively. Winter wheat failed to germinate in the 0-3 to 6-9 inch plots. A similar failure with winter wheat occurred in 1956 on the same plots.

In 1963 four blocks of plots containing all removal depths each were planted to Russian wildrye and with switch grass. A good stand of Russian wildrye was obtained. However, switch grass failed to germinate satisfactorily because of dry seedbed and was replanted to crested wheatgrass in 1967.

These seedbed water differences were significantly influenced by soil reflectance and associated temperatures, and the shallow clay layers.

Fertility Aspects of Soil Removal

The process of bringing a subsoil to the surface for subsequent aging, cultivation and dynamics of rapid temperature and soil water fluctuation induced a low level of soluble P to higher levels within two years - and by the end of six years approached the level of undisturbed surface soil. This increased P could come from improved inorganic solubility and/or from mineralized organic P. There are reasons to believe both causes are involved.

After three wheat crops it was found that wheat would respond to P in combination with N if subsoil levels of soluble P remained below 20 lbs/acre. When the subsoil level exceeded 20 lbs/acre by aging and cultivation, the need for fertilizer P on wheat diminished. In no case did N alone produce a response to summer fallow wheat even when 12-15 inches soil had been removed. Protein content of wheat, however, was reduced by soil removal. Addition of N did increase protein but not any greater on the deep soil removal plots than the shallower soil removal.

The supply of NO_3-N produced on subsoil during fallow was not proportioned to the organic matter content. Subsoils had a lower carbon/nitrogen ratio than surface soils and consequently accumulate higher quantities of NO_3-N than normally would be suspected. Nitrate N production was only reduced 25% on deeper soil removal plots as compared with a 50% reduction of organic matter on the same plot comparisons. In five years of testing, NO_3-N production in fallow exceeded 50 lbs/acre for all soil removal levels tested. For dryland fallow-wheat, any subsoil containing more than .060% total N should produce enough NO_3-N to minimize nitrogen deficiencies.

The possibility of iron deficiency with highly calcareous subsoil is high, particularly with crops such as sorghum types and millet.

In 1961 sudangrass did not significantly respond to either nitrogen or phosphorus when grown after fallow on any of five soil removal depths tested. In 1962, however, sudangrass under continuous cropping did respond significantly to N and NP after 9-inches of soil removal.

Reseeding eroded soil with grass, Russian wildrye, and fertilizing over a three year period (1965, 1966, 1967) showed a consistent yield response to N alone at all levels of erosion, but did not respond to P applications.

Russian wildrye yields responded favorably in 1968 and 1970 to residual N that had been applied in 1965, 1966 and 1967. Yields of Russian wildrye as measured in 1967, 1968, 1970, 1980 and 1981, whether fertilizer or nonfertilized, consistently decreased with depth of soil removal.

Attempts to obtain a yield response in 1967 to Fe (iron) in combination with N on crested wheatgrass as opposed to N alone did not succeed.

Dry matter yields of nonfertilized crested wheat exceeded the yield of nonfertilized Russian wildrye by about 46% in 1980.

Dry matter yields of fertilized and nonfertilized crested wheatgrass exceeded fertilized and nonfertilized Russian wildrye by 84 and 61% respectively in 1981.

In all cases, the yield of grasses decreased steadily with increased depth of soil removal. The grass yields at the deepest soil removal level, 12-15 inches, averaged only 50% of the yields at 0-3 inch soil removal.

In all grass testing, water-use efficiency was more than doubled by the use of N applications. Water-use efficiency also tended to decrease with depth of soil removal as the grass stands became older.

DEEP PLOW (1967-1972)

Deep plowing is a one shot treatment that can be used to breakup and dilute thin layers of impervious clay and hardpans that are shallow in the soil profile. In this manner, water infiltrates the soil faster and deeper and thus less exposed to evaporation.

Deep plowing experimentation at the Akron Station was initiated in 1967 on a Weld silt loam soil that contains a thin genetic B_{21} clay layer 4 inches thick. This type soil covers several hundred thousand acres in the region. Deep plowing to 17 inches as a dilution technique was tested against shallow 4 inch disking.

The results of the deep plowing proved positive even for dryland conditions. Deep plowing saved an average 0.8 inches more soil water per fallow season than did shallow disking. Additionally, using straw mulches gained another 0.7 inches above that of plowing alone. Deep plowing increased grain yields of barley and winter wheat by 4.7 bushels/acre. The added mulch increase yields 3.0 bushels/acre. Thus, grains were increased 7.7 bushels/acre and total dry matter by 1,385 lbs/acre, which equals 885 lbs/acre net yield gain per inch of extra stored soil water.

The results given above suggest that dryland conservation practices can be additive in benefits.

MILLET CULTURE (1973-1977)

The millets, proso and foxtail, are among the best adapted crops for northeastern Colorado and western Nebraska. Unfortunately millet is too often planted as a last minute after thought and not as a planned crop.

Recent experiments at the Akron Station suggest that millet yields can be surprisingly high with limited water under certain conditions of management.

Experiment 1 - Yield and water use efficiency of proso millet under three dryland crop rotations: continuous millet, millet after winter wheat, and millet after fallow.

Results showed that the yield of proso millet was directly related to the amount of stored soil water at the preplant stage. The base point for grain production was 5.5 inches which is about 2½ to 3 inches less than winter wheat. Total water use to produce 18 to 20 bushels/acre was only 10 inches and it took very little extra water to increase yields to 30 and 40 bushels/acre. Water-use efficiency also increased rapidly.

The best overall production was achieved where millet followed winter wheat. The yield was 27.3 bushels/acre as compared with continuous millet at 19.2 bushels/acre. In this case, the extra 1½ months time lag succeeding wheat added another 1.08 inches more stored soil water.

Experiment 2 - Fall weed control in wheat stubble as preparation for cropping with proso millet.

This experiment showed that by reducing the weeds in wheat stubble by fall sweep and/or herbicides, more water and soil nitrates would be available for the succeeding millet crop. These growth inputs for the years tested, although modest, at 0.68 inches water and 15 lbs/acre of nitrate nitrogen, were sufficient to increase the yield of millet by an average 5 bushels/acre. Fall sweep + atrazine at 1 lb/acre proved the best treatment tested. Not attempted but certainly a good bet would be a combination of contact and preemergence herbicide (1/8 lb paraquat + 3/8 lb 2,4-D + 1/2 lb atrazine/acre).

Experiment 3 - Preemergence herbicides for spring preplant weed control treatment of proso millet.

Pigweeds have been by far the leading weed contaminant in growing millet at Akron. Attempts to control pigweed and other broadleafs with low rates of 2,4-D usually failed. Therefore, a series of preemergence herbicides were attempted. Milogard and atrazine were easily the most successful of the herbicides tested at rates as low as 1/4 and 1/2 lb/acre applied with 15 gallons/acre water carrier. The herbicides were applied three to four weeks before millet planting.

Millet yields were increased an average 8 and 6 bushels/acre for atrazine and milogard at 1/2 lb/acre rate, respectively during a three year test. Plots remained 100% weed free from date of planting to harvest with no evidence of damage to millet. The general results suggest that application of 1/3 lb/acre is sufficient of either herbicide as a preemergence weed control treatment for millet.

There was little evidence that dryland millet would respond to 20 to 35 lbs/acre of nitrogen fertilizer. The only response obtained with N on millet occurred in 1973 when there was a very large volume of snowmelt that flushed nitrate nitrogen several feet deep in the soil profile. Nitrogen at the rate of 25 to 40 lbs/acre is recommended, however, on irrigated proso and foxtail millet, respectively.

Millet should be planted anytime from late May up to June 20th. There is a tendency for late June and early July planted proso to grow short in height because it is sensitive to decreasing sunlight hours in August.

Total water use of 13 inches/acre will produce 40 to 50 bushels/acre of proso millet.

Proso millet has a protein content similar to wheat.

With weed free millet, seeding rates should be reduced from 10 to 12 lbs/acre down to 6 to 8 lbs/acre. The rows can be widened to 12 to 14 inches. This will permit the millet to grow taller and be easier to harvest.

TECHNOLOGY AND WINTER WHEAT YIELDS

For most of this century, research agronomists and farmers have conducted many studies and field trials for stabilizing and increasing winter wheat yields. A great deal of progress has been, especially since World War II, in the quality of fallow. These improvements have been reflected in higher and higher wheat yields as shown here:

Experiment Station

For the following decades 1926-35, 1936-45, 1946-55, 1956-65, and 1966-75, wheat yields at the Akron Station have gradually increased from 11.1 bushels/acre to 22.7, 24.8, 26.1, and 36.0 bushels/acre in the same order as the decades. Wheat yields have averaged 38.5 bushels/acre from 1976 to 1981.

Wheat yields at the North Platte Experiment Station increased from 27.9 bushels/acre to 29.1, 35.6, 39.1, and 46.0 bushels/acre for the five decades beginning 1926-35 and ending 1966-1975.

At the Colby, Kansas Experiment Station the wheat yield trend was intermediate between the other two stations. Yields averaged 15.8, 18.6, 23.0, 31.9, and 39.9 bushels/acre for the five decades beginning 1926-35 and ending 1966-1975.

For all three stations combined the water-use efficiency of grain yields increased from 32.1 lb/acre/inch precipitation received 1926-35, to 39.2, 46.9, 51.4, and 72.5 lbs/acre during the succeeding decades of 1936-45, 1946-55, 1956-65, and 1966-75.

The data strongly refute the concept that improved weather may have been more responsible for yield increases than technology. Water-use efficiency, as independent of variations in precipitation, increased steadily for each decade as wheat yields. For all locations, water-use efficiency increased the most during the 1966-75 period when annual precipitation actually dropped 11% as compared with the previous decade. Reasons for much of the yield increase of winter wheat are pointed out in a succeeding section.

Commercial Wheat Yields

Commercial winter wheat yields were collected and analyzed mostly from 1946 to 1977 of the 58 major wheat producing counties of the Central Great Plains west of the 100th meridian. This area includes 24 counties of western Kansas, 18 counties of western Nebraska and 16 counties of eastern Colorado. Some highlights of this study are given:

- Wheat yields varied from year to year in normal response to climatic conditions; however, the general trend was consistently upward from 1941 to 1977 at the rate of 0.5 bushel/acre/year.

- Three distinct down yield cycles and three up or higher yield cycles of varying duration occurred. Each successive down cycle showed yield improvement over the previous down cycle. Each successive high yield cycle showed significant improvement over the previous high cycle. Wheat yields only averaged 6.8 bushels/acre planted during the 1930's, and have averaged 26.8 bushels/acre planted from 1969 to 1977. Yields in these same 58 counties have averaged 30.7 bushels/acre planted for 1978, 1979, and 1980 combined.

- Despite periodic drought conditions in recent years there has been no down yield trend since 1969 except a small drop in 1976 when wheat yields were still a respectable 21.5 bushels/acre.

- For all counties combined, yields averaged 13.8, 18.1, and 23.5 bushels/acre for the decades of 1946-55, 1956-65, and 1966-75, respectively. The yield increase of the latter two decades compared with 1946-55 was 0.43 and 0.54 bushels/acre/year in that order.

- All 58 counties showed a progressive increase in wheat yields per planted acre.

- Long term yield difference persisted between climatic districts within the region even though yields improved in all districts.

- Yield increases were greater in the northern cooler half of the climatic districts than the southern half by a margin of 10.8 versus 8.54 bushels/acre.

- Yield increases were greater in the wetter eastern half of the region than the western half by a margin of 11.7 versus 7.2 bushels/acre.

- The greatest yield increase differential occurred between the northeast quarter (southwest Nebraska and northwest Kansas) and the southwest quarter (east-central Colorado and southeast Colorado) by a margin of 12.5 versus 5.7 bushels/acre.

- Wheat plantings are often abandoned because of such disasters as hail, late frost, winterkill, disease, and insects. By far the most important reason has been failure to cope with drought, both short term and long term. Abandoned wheat acreages averaged 28% during 1936-45, and gradually decreased to 22, 20, 16, and 12% for the years 1946-55, 1956-65, 1966-75, 1976-1980 in that order. In western Nebraska wheat acreage abandoned has exceeded 8% only twice since 1970.

Wheat Yield Improvement Factors

	Percent of wheat yield gain
. Improved stored soil water in fallow Better mechanical and herbicide weed control Better use of stubble mulch More runoff water engineering	45%
. Improved wheat varieties Shorter straw Higher tillering capacity Earlier ripening to escape heat damage Disease resistance	30%
. Improved planting equipment Deep furrow drill to reach seedbed water More acres planted per day at a more opportune time	10%
. Improved harvesting equipment Faster, cleaner	10%
. More fertilizer on sandy and weak soils	5%

It is expected that there will be greater use of herbicides in fallow and commercial fertilizer in the near future.

MISCELLANEOUS ITEMS

Plastic Mulch

Black plastic mulch, 6-mil, was tested on grain sorghum with plastic applied at 0, 67%, and 100% soil cover where sorghum was planted in 42 inch rows with and without deep lister furrows. There were initial soil water levels of 7 to 9 inches and 10 to 13 inches for each plastic treatment.

Black plastic increased soil temperatures by an average 7°F between sorghum rows and 3°F in the row at 2-inches soil depth. This extra heat speeded up the maturity of sorghum by several days.

Soil nitrate nitrogen under black plastic increased from 18 to 122 lbs/acre between June 15 and August 31 as compared with an increase of only 18 to 75 lbs/acre without black plastic.

Sorghum dry matter yields were highly correlated with initial soil water levels and percent plastic cover used.

Evaporation losses were reduced about 20 and 46% with the use of 67 and 100% plastic cover.

Dry matter production averaged 300, 400, and 600 lbs/acre/inch for the 0, 67, and 100% plastic cover.

It would not be economical to use plastic mulch under dryland conditions but plastic would certainly be an excellent media for vegetable and flower gardens.

On Fallow Machinery

Tandem disk - It remains the authors opinion, after 30 years dryland research experience, that the tandem disk for dryland farming is indeed the poorest choice. Only the moldboard plow destroys stubble as quickly. But the tandem disk pulverizes soil clods even worse than the plow.

Moldboard plow - Little used on dryland except by some operators in the Nebraska panhandle to bury cheatgrass (downy brome) seed. If the field plowed once is replowed, then the cheatgrass seed is thrown back on the soil surface.

One Way disk - If used only once during fallow such as early spring, the one way disk is not a bad implement. The disks can be set shallow and at an angle to kill cheatgrass, volunteer wheat, and germinating broadleaf weeds. The shallow angle does not bury much stubble but mostly undercuts and lays stubble to the side. However, if the one way disk is used more than once and at deeper depths, end results approach that of the tandem disk. Disking should be followed with sweeps or rodweeder (tongs attached) later in June.

Skew treader - This is an emergency tool in those cases during July or early August under wet soil conditions with germinating weeds. The treader,can be used to flip out those weeds even if the soil is too wet for rodweeding. The skew treader is an especially good tool in preparing a seedbed for spring planted crops such as millet and barley. The treader, working only about 1½ inches deep, levels and packs the seedbed and eliminates small germinating weeds very effectively.

Harrow, spring tooth - Can only be used in a stubble free fallow succeeding tandem disking or moldboard plowing. Can flip out small germinating weeds. The harrow also packs a seedbed. Harrows pulverizes clods too much.

Chisel - 2-inch shanks - Often used as the second operation in fallow, usually in June, running at 6 to 8 inches depth (depth estimated by operators is usually exaggerated by 3-inches). The chisel shanks leaves a furrow that can be useful in case of torrential rain. The quality of weeding with chisels depends upon having shanks close enough together to disturb all the soil. At the Akron Station, chisels have never been used on bulk fallow as not considered desirable or necessary.

Duckfoot - A hybrid tool halfway between a chisel and a sweep. Shanks are set at 24 to 28 inches apart with wing shaped small sweeps, 16 to 18 inches width, attached to the bottom of the shank. This implement tends to bury too much stubble because of the numerous shanks. The duckfoot is designed to operate at good speed so there is enough soil turbulence to shake weed roots from the soil. The small sweep blades operate best at about 3 to 3½ inches soil depth.

Sweep, V blade - Blades should be 5 to 6 foot width and operated at 4 inch maximum depth at 4 mph if the sweep is to kill weeds but still lift clods and stubble over the sweep blade without destruction. An ideal tool for undercutting crop stubble (wheat in particular) after harvest. The only time a sweep is not successful is during wet humid conditions where undercut weeds will fall back and reroot. This usually occurs mostly in early to mid-spring. The sweep is an excellent tool for the second and possibly the third operation during summer fallow about June 20th and July 15 to 20th.

Rodweeder, with semichisels - An excellent subsurface operating implement for seedbed preparation. The rotating bar at 3 inches working depth is a very effective weed killer. The semichisels, which makes soil contact ahead of the bar, throws soil clods and stubble over the bar without burial or destruction. The rodweeder also packs the seedbed and levels the soil to some extent.

Fallow sequence - A good fallow program, assuming no herbicide usage, would begin by undercutting wheat stubble with a sweep within a week after July harvest, and then leave undisturbed overwinter. About April 25 to May 7 the stubble should be onewayed shallow and at an angle. This would be succeeded by sweeping June 15 to 20, and rodweed late July and late in August.

With minimum tillage, new wheat stubble would be sprayed with a hot contact and a long-term preemergence herbicide. The field would remain undisturbed until about June 15 to 20 next spring. Then use a sweep, late in June, a sweep or rodweeder late July, and a rodweeder late in August.

Border Weeds

Soil tests showed that sunflowers, 6 feet tall, in a fence row extended roots laterally to 12 feet inside a wheat field. Moisture probing revealed that the sunflowers exhausted all available water 3-foot deep to 8-foot distance and about half of the available water to the 12 foot mark. In many cases when wheat fails about one drill swath wide the blame is assumed to be caused by grasshoppers. In most cases, the culprit is weed root extension.

Similarly, one of the complaints of farmers concerning strip cropping in the Central and Southern Great Plains is that along the edges of stubble strips, they assume grasshoppers are responsible for killing wheat several drill rows into adjacent planted strips. However, most operators permit weeds to grow in the stubble after wheat harvest. The strip border weeds sap soil water and nitrogen at least 4 to 10 feet. This problem could be eliminated by undercutting the border weed growth with V-blade sweeps or treating with herbicides.

Plant Rooting

In 1974, under conditions of deep soil water and little summer rainfall, proso millet extracted soil water to a depth of 6 feet. Heretofore, it was thought that maximum depth of rooting for proso millet was 36 to 42 inches at the most.

Domestic cool season grasses such as Russian wildrye, crested wheatgrass, and intermediate wheatgrass have extracted another 4 to 6 inches available soil water with no additional top growth, during July and August, after attaining maximum growth in late June and appeared to be in a state of dormancy.

It was found that a mixture of native plant species such as blue grama and buffalo grass, silver sage, western wheatgrass, and needle and thread grass, could extract soil water to about 1 to 2% below the wilting point of domestic crops and domestic grasses.

Sampling disclosed that native sod shallow disked to 4-inches depth, had a root weight of over 4,000 lbs/acre in the top 3 inches of soil. The top growth weight of native species seldom exceeds 500 lbs/acre.

SUPPLEMENTAL IRRIGATION FOR WHEAT, CORN, AND SORGHUM

While most of this report has dealt with dryland farming practices, the impact of irrigation in the West Central Great Plains has been phenomenal. This discussion will not cover the full range of irrigation water management, but will focus on some aspects of transition in the irrigated region that involve both dryland and irrigated technology.

With the advent of the center pivot sprinkler large acreages of dryland were developed for irrigation. This change began about 1965 and reached its peak in the mid-seventies. The major goal of the irrigators for a good portion of this time was to aim for maximum yield. Since water was readily available, it was essentially eliminated as a limiting factor in crop production. Since 1975 energy costs have increased several fold and water is no longer the relatively cheap, unlimited resource. Interest has changed from maximum yield with unlimited water to a philosophy of obtaining optimum yield for the amount of water applied. This implies a greater concern for the sensitivity of the crop to water stress and more particularly the sensitivity of a crop at different growth stages.

Several years work has been conducted at the Station regarding irrigation with limited water and with critical timing according to growth stage. The major effort has been with corn, sorghum, and winter wheat. Studies were conducted by dividing these crops into three broad growth stages defined as vegetative, flowering or pollination, and grain filling. Water was applied or withheld during all of these growth stages in order to provide treatments that either eliminated or imposed water stress during these stages. In addition some stress conditioning effects were included, that is, what happens if a crop is stressed during the vegetative stage and then the stress eliminated during the succeeding stage or the converse, a nonstress condition followed by stress?

In general, the results have shown that most crops are most sensitive to stress during the flowering stage (tasseling-silking for corn, heading-flowering for wheat, etc.). In terms of optimum yields, however, the first rule is to start out the season with a full soil water profile. If this can be accomplished by nature over winter or pre-plant irrigation, water can be withheld during the vegetative stage without major reductions in yield. As would be expected corn was more sensitive than sorghum. In fact sorghum, being more drought tolerant, produced good yields even when no more water was added after the boot stage as long as the soil profile was full to begin with.

Wheat has been shown to be very sensitive to supplemental irrigation. The most critical period is the heading-flowering stage through the early grain filling stage. Yield decreases have been common when early spring irrigations have been applied. These irrigations stimulate additional vegetative growth leading to rank straw production, but to a sacrifice in grain yield. Fall irrigations to build a reserve in subsoil water for wheat is very important and high water use efficiency results from this practice.

Continuous cropping of wheat under irrigation is feasible only when water is managed to restore the deep subsoil water. Steadily declining yields have been experienced with continuous cropping when the irrigation management was incorrect.

The best prospect for water conservation with supplemental irrigation appears to be with crop rotation schemes alternating intensively irrigated crops with dryland or limited irrigation. This would help to overcome some of the problems with depletion of subsoil water and also provide natural recharge by over-winter precipitation.

A COMMENT

Gravimetric Soil Moisture Sampling

The revolution in dryland research at Akron and other stations was largely enhanced in the mid-1950's by the advent of the hydraulic power auger for rapid soil water sampling. This made it possible to exam the crop response to the income and outgo of rain, snow, or irrigated water under nearly every conceivable system of experimental cropping, fallow, domestic grasses or native sod. Any responses between treatment A versus B could be examined closely, accurately, and with explainable differences. Since 1956 the Akron Station has averaged 15 to 20 thousand soil moisture samples per season.