Circular No. 700

Dry Land Rotation and Tillage Experiments at the Akron (Colorado) Field Station

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Division of Dry Land Agriculture
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Agricultural Research Administration

In cooperation with the Colorado Agricultural Experiment Station

UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON 25, D. C., May 1944

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CONTENTS

FARMING SYSTEMS AND CROPS ADAPTED TO THE HARD LANDS OF THE GREAT PLAINS

This circular summarizes 30 years of experimental work at the Akron Field Station, operated in the west-central Great Plains. Results of experiments in tillage methods and crop sequences are discussed, and, based on average results from these experiments, suggestions are made regarding farming systems that promise the greatest returns for the labor involved consistent with safety of operation. Results from Akron are generally applicable to a belt of high tableland extending north and south across the western reaches of the central Great Plains and are particularly applicable to the hard lands. The information should be of value to farmers in the area to which it applies both during and after the war.

Sound land utilization demands not only that the best adapted species and varieties of crops be grown by the safest and most productive methods but also that they be grown in farming systems that reduce the risk incident to farming in dry-land areas to as low a point as possible. Unbalanced farming systems or undue dependence on certain crops may be profitable for a time, but in the long run only those systems that maintain the farm as a going institution over periods of stress as well as in favorable cycles can be expected to endure.

The type of agriculture best suited to the area as a whole appears to be livestock raising supplemented by the production of food and feed crops. The emphasis on crop production, however, may vary widely, and there are many successful farmers who rely chiefly on grain.

The most important single crop is winter wheat. In the past this crop has been allowed to occupy too large a proportion of the farm acreage, and much of it has been grown by methods of land preparation that if used continuously could result only in ultimate failure. Winter wheat should seldom be grown on other than well-prepared fallowed land. Average yields with this method of preparation have been good, and complete failures infrequent. With less intensive methods annual yields have been lower and much more variable and complete failures much more frequent.

The sorghums are the next most important crop. Forage sorghums have long been the standard rough feed of the area. Recent development of early-maturing grain sorghums with palatable stover have reduced the dependence on forage sorghums and have made available a feed grain the yield of which is greater than that of corn on the hard lands. Although winter wheat and sorghums are the backbone of agriculture, other crops may be grown in combination with them. Pinto beans are an additional cash crop, of which the value per acre frequently exceeds that of winter wheat. Proso, barley, and oats may be grown for feed, and on the sandy land of the general area corn is an adapted crop. Alfalfa is of little value on the upland, but does well on subirrigated land and on land subjected to temporary floodings.

The crop varieties best adapted to the area are not discussed, because this information is already available in State publications.

The use of crops making their maximum demands for water at different seasons gives an opportunity to take advantage of temporarily favorable conditions and has the effect of cushioning the degree of failure in years with below-average rainfall. The use of a wide range of crops may not increase and may even decrease total production, but it makes yearly production more reliable. Even the best use of crops and cropping practices, however, is not sufficient to insure an adequate annual production. Safe agriculture requires the accumulation of feed reserves during favorable periods for use in years of low production.

THE AKRON FIELD STATION

The United States Dry Land Field Station (fig. 1), located in northeastern Colorado about 4 miles east of Akron (hereinafter referred to as the Akron Field Station), is one of a group at which the Division of Dry Land Agriculture has studied crop rotation and tillage methods on the Great Plains.[1] Located about 30 miles south of the South Platte River on a gently undulating plain at an altitude of about 4,560 feet, its accomplishments are applicable to a long belt of high

[1] J. E. Payne was superintendent of the station from 1907 to 1910; O. J. Grace from 1910 to 1920; and J. F. Brandon from 1920 to date.

tableland extending north and south across the western reaches of the central Great Plains. Geographically it is about midway north and south and on the western edge of the Great Plains.

The station was established in 1907, but it was not until 1909 that cultural and crop-sequence differentiation first became effective on the project used for that particular study.

Other divisions of the Bureau of Plant Industry, Soils, and Agricultural Engineering, either directly or through the Colorado Agri-

FIGURE 1.—A view from the building site at the Akron Field Station, showing the pine windbreak and the field used for cereal experiments.

cultural Experiment Station, cooperate in varietal, date-of-planting, and rate-of-seeding tests with winter and spring wheat, oats, barley, beans, proso, and grain and forage sorghums, in grass variety tests, and in weather readings. Breeding work with the adapted crops is also an active part of the station's work (*2, 8, 9, 12, 13, 14, 16, 17, 18*).[2]

EARLY DEVELOPMENT, TOPOGRAPHY, AND NATIVE VEGETATION

The first settlements in the western part of the central Great Plains naturally sprang up along the railroad lines completed throughout this area about 1882, but by 1885 there were many individual colonies in isolated spots all over eastern Colorado and western Kansas and Nebraska, generally along surveyed and prospective railroad lines.

The general retreat of the range cattlemen did not take place until about 1900 to 1910, when homesteading and the fencing out of farm tracts closed the open range. In about that decade there commenced a series of years when the production of winter wheat was comparatively certain. Wartime needs during World War I centered entirely too much attention on this one crop, and the introduction of tractors and other motorized equipment made its production possible on a large scale. Refinement in the efficiency of these machines main-

[2] Italic Numbers in parentheses refer to Literature Cited, p. 52.

tained this emphasis and even expanded the acreage of winter wheat after the close of the war, in the face of a diminishing value per bushel and a progressive uncertainty of production. Station records show that since about 1922 less favorable climatic factors have made it difficult to produce winter wheat on the hard lands of much of the region, even on good summer-fallowed land. Growers who continued to sow winter wheat almost exclusively on land given any of the other preparations, though they may have been reasonably successful up to that time, exhausted their financial reserves and severely stretched their credit. General large-scale winter wheat production collapsed during the period from 1928 to 1932, leaving much land idle.

An additional reason for the almost exclusive attention to wheat production is found in the fact that the hard red winter wheats grown were better adapted to the area than the varieties of other crops then available. The varieties of barley and oats introduced about 1928 changed this situation somewhat by being roughly 20 percent better adapted than their predecessors. Acclimated varieties of field corn became available about 1915, but the crop still remains very unreliable on the strictly hard lands. Early-maturing grain sorghum varieties with usable stover are now available and promise to replace much of the corn on these hard lands.

Larger units with livestock to supplement the farm income now seem to be necessary for a stable agriculture in the western part of the central Great Plains, particularly on the hard lands. Broken-out fields necessary for pasture can be reseeded to native grasses, since the seeds of many are now commercially available. Today many large mixed-farming units using recommended varieties are successful. Some farmers in the more favored sections continue to operate successfully by growing large acreages of winter wheat on well-prepared fallow.

The western part of the central Great Plains, away from the running streams, is gently undulating, with large level table areas and occasional "islands" of almost pure sand. Foothill territory above 5,500 feet and partially evergreen-covered forms a ridge extending eastward almost to Limon, in Colorado. The rainfall there is typical of the foothills and is higher than over the adjoining plains.

The topography of the land adjacent to the station is very gently undulating, with a general slope eastward to the Republican River. The land on which the cultural and crop-sequence experiments are conducted is nearly level.

The vegetation of the region is of two rather distinct types. That of the clay and sandy loam soils, locally termed hard lands, is typically short. The dominant species are buffalo grass (*Buchloë dactyloides* (Nutt.) Engelm.) and blue grama (*Bouteloua gracilis* (H. B. K.) Lag.). Areas apparently dominated by either may be found on the hard lands of this general region. Needle-and-thread grass (*Stipa comata* Trin. and Rupr.) and sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), as well as a few sedges, are present in small percentages. Niggerwool, or threadleaf sedge (*Carex filifolia* Nutt.), was conspicuous in certain small areas that are well adapted to wheat. Western wheatgrass (*Agropyron smithii* Rydb.) is also present in the hard-land grass cover, but dominates only the low areas that are subject to periodic temporary inundations.

The more sandy soils, ranging from what are locally termed soft lands up to almost pure sand, are covered in the native state by a semitall vegetation. Before about 1926 the transition from the short to the semitall type was marked. Blue grama, with a sprinkling of hairy grama (*Bouteloua hirsuta* Lag.), dominates the cover, but buffalo grass is almost entirely absent. Species contributing to the semitall nature of the vegetation are longleaf reedgrass (*Calamovilfa longifolia* (Hook.) Scribn.), sand dropseed, needle-and-thread grass, switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon furcatus* Muhl.), turkeyfoot (*A. halli* Hack.), and western wheatgrass. Native grasses lost ground coverage during the period 1930–38, and the interstices were filled with undesirable annual weeds (*19*), which seem able to become dominant when conditions are severe, just as annual cultivated crops have produced far more forage and grain for livestock feed per unit area than the native grases.

SOIL CHARACTERISTICS

The soils of that part of the Great Plains represented by the Akron Field Station are locally called hard lands and are classed as Brown (*20*). The clay and sandy clay to silt loam and very fine sandy loam support a native short-grass vegetation. Clay loams offer the most resistance to soil blowing, but are more subject to loss of rainfall by runoff and by surface evaporation and have not been so productive as the sandier soils. Soils of the Great Plains, which include also the Chestnut soils, are highly fertile, and any local or regional differences in productivity may be attributed to other factors, among which are (1) the normal rainfall and its distribution, (2) the ability of the soil to absorb rain and to hold it within the root-feeding zone of crops, (3) the comparative adaptability of the different crops to the varying soil types, and (4) the use of the best adapted varieties seeded at the right rate and time.

The hard lands are less efficient in the use of very limited rainfall than the soft or sandy soils, because they are more subject to loss by surface runoff and hold a higher percentage of soil moisture near the surface, where it can be lost by evaporation; on the other hand, they offer a larger potential reservoir for holding stored rainfall. The productivity of hard lands can be improved by using cultural methods that reduce or prevent runoff and by controlling weeds that use stored soil moisture. Fallow is an excellent device applicable to the hard lands for storing additional soil moisture for later crops. Undulating hard-land soils should be cultivated and seeded along contour lines, preferably in strips, unless strip cropping increases damage by insects.

At the Akron Field Station the soil on which the main tillage and crop-rotation experiments are conducted is a Brown soil classed as Rago silt loam.[3] The 4- to 8-inch silt loam surface soil merges into a 12- to 20-inch dark-brown clay, locally known as joint clay. The lower part is lighter in color and texture and merges into a pale grayish-yellow silt—the lime zone—several inches in thickness, and thereupon into unaltered loess.

Other experiments were conducted on land classed as Platner loam, which closely resembles the Rago soils but may be superior for corn production.

[3] Correlation report (March 10, 1942) for a soil survey of the Akron area by the Division of Soil Survey of this Bureau.

CLIMATIC CONDITIONS

Precipitation

Precipitation is the greatest single factor in crop production in the western part of the central Great Plains. In this area insufficient soil moisture regularly limits crop yields. Preventing runoff, which is controllable, is one of the greatest factors in crop production, but distribution of rainfall is also important. The poor distribution of a low average annual rainfall at the Akron Field Station over the last 15-year period undoubtedly contributed to the low yields of all crops, particularly that of winter wheat. The records show that as the annual rainfall approaches a critical point its distribution is of primary importance. The monthly, 6-month seasonal, and annual precipitation at the Akron station for the 31-year period and for the two shorter periods are shown in table 1.

Table 1.—*Monthly, seasonal, annual, and average precipitation by periods at the Akron Field Station for the 31 years 1908–38*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Seasonal, Apr. to Sept.	Annual
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1908	0	0.34	(1)	1.70	3.30	2.37	2.42	1.47	0.05	3.20	2.00	(1)	11.31	16.85
1909	(1)	1.38	3.06	.40	1.87	3.32	4.61	3.77	2.16	.86	.48	0.55	16.13	22.46
1910	.05	.16	.26	3.96	2.06	1.38	1.47	3.72	3.81	.05	.12	.32	16.40	17.36
1911	.60	.44	.06	2.63	1.15	1.48	1.34	1.30	2.40	1.47	.28	1.36	10.30	14.51
1912	.28	1.43	.78	2.49	2.86	3.39	3.58	1.58	1.88	1.99	.18	.29	15.78	20.73
1913	.22	.40	1.57	2.19	1.44	1.35	1.85	1.14	2.08	.34	.70	3.27	10.05	16.55
1914	.03	.32	.20	4.01	1.46	3.54	1.66	1.05	.23	2.08	.10	.90	11.95	15.58
1915	1.10	1.68	1.50	5.19	4.13	3.75	1.10	3.51	1.76	.48	.15	.65	19.44	25.00
1916	.50	(1)	.09	1.59	2.24	2.09	1.77	2.82	.26	1.02	.75	.61	10.77	13.74
1917	.28	.63	.72	.96	7.79	.56	1.52	1.78	2.19	.57	(1)	.50	14.80	17.50
1918	.70	.80	.60	1.20	1.76	.96	3.10	7.36	2.43	1.07	.75	1.55	16.81	22.28
1919	.07	.50	.65	1.96	1.59	2.27	1.79	.44	2.62	1.64	1.29	.70	10.67	15.52
1920	.35	.17	.90	3.28	2.90	3.97	4.72	1.45	1.80	.44	.47	.90	18.12	21.35
1921	1.22	(1)	1.25	2.77	.47	1.32	2.88	.92	.79	.97	.20	.65	9.15	13.44
1922	.65	.25	.15	3.96	3.63	1.43	3.24	1.24	.06	.05	1.90	.10	13.56	16.66
1923	(1)	.18	.95	1.65	4.94	2.17	3.62	.75	.82	1.91	.47	.70	13.95	18.16
16-year average	.38	.54	.80	2.50	2.73	2.21	2.54	2.14	1.58	1.13	.61	.82	13.70	17.98
1924	.50	.59	1.25	.31	3.26	.35	1.71	.77	4.04	.40	.13	.77	10.44	14.08
1925	.05	(1)	.39	2.24	1.19	2.90	1.08	1.01	.50	1.46	.47	.53	8.92	11.82
1926	.41	.05	.36	.18	3.77	1.42	6.46	5.07	.72	1.03	.41	.28	17.62	20.16
1927	.17	.29	2.41	2.27	1.46	5.16	3.00	3.74	.90	.14	.64	.22	16.53	20.40
1928	.13	.17	.32	.17	3.52	5.39	3.14	.25	.04	1.75	.49	(1)	12.51	15.37
1929	.07	.34	.32	3.43	1.19	1.15	4.44	2.66	2.67	2.76	.49	.09	15.54	19.61
1930	.07	(1)	.17	2.28	5.52	1.61	3.54	3.48	.39	.83	1.05	.09	16.82	19.03
1931	.01	.71	.95	.84	1.38	2.20	1.49	1.04	.50	.61	.11	.90	7.45	10.74
1932	.27	.25	.60	1.93	2.91	2.80	4.17	1.27	.05	.49	.19	.21	13.13	15.14
1933	(1)	.04	.74	4.58	4.15	.92	2.01	4.54	1.13	(1)	.04	.75	17.33	18.90
1934	.02	.91	.36	.64	1.42	4.14	.31	3.56	.75	.04	.37	.09	10.82	12.61
1935	.01	.23	1.22	3.25	7.35	3.08	.37	.83	2.24	.21	.26	.04	17.12	19.09
1936	.29	.15	.64	2.08	3.51	3.04	1.85	2.17	3.03	.94	.07	.44	15.68	18.21
1937	.16	.19	.82	.33	1.26	2.40	2.38	1.13	1.65	.08	.32	.63	9.15	11.35
1938	.18	.09	1.34	2.10	5.75	1.15	1.77	1.21	.73	.03	.68	.47	12.71	15.50
15-year average	.15	.27	.79	1.78	3.18	2.51	2.51	2.18	1.29	.72	.38	.37	13.45	16.13
31-year average	.27	.41	.80	2.15	2.94	2.36	2.53	2.16	1.44	.93	.50	.60	13.58	17.09

[1] Trace.

The average annual precipitation for the entire 31-year period was 17.09 inches; up to 1923 it was 17.98 inches. The average for the last 15-year period was 16.13 inches, a reduction of 10 percent from that of the former 16-year period. The highest annual precipitation in the 31-year period was 25.00 inches, in 1915; the lowest 10.74, in 1931.

Most of the precipitation comes in summer, the average seasonal precipitation, April to September, being 13.58 inches. For the first 16 years it was 13.70 and for the last 15 years 13.45 inches, a difference of 0.25 inch. The highest seasonal precipitation was 19.44 inches, in 1915; the lowest, 7.45, in 1931.

The 31-year average precipitation for the other 6 months was 3.51 inches. For the first 16-year period it was 4.28 and for the last 15 only 2.68 inches, a loss of 1.60 inches. The particularly low precipitation for the dormant season over the second period probably accounts in part for the relative uncertainty of winter wheat in this immediate region, even on well-prepared fallow. In localities where this did not occur, winter wheat maintained a comparatively better record. Good summer fallow usually carries winter wheat over winter and early spring, a period frequently deficient in moisture.

A study of figure 2, showing the station's average rainfall in 10-day intervals, shows why the very early varieties of small grains with reasonable yield capacities, seeded early, do best. The ideal varieties should be early enough to fill from the moisture received during the spring precipitation period, which usually ends between June 10 and

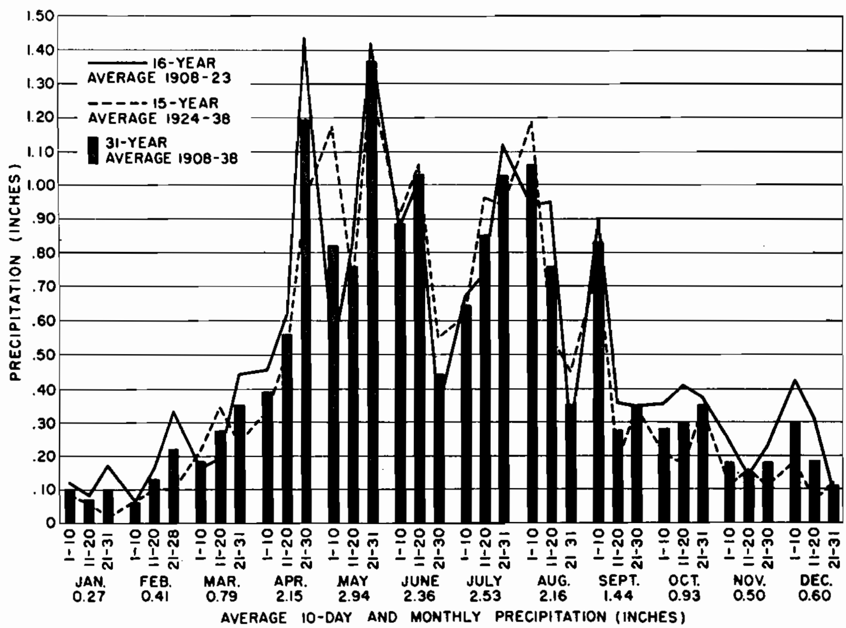

FIGURE 2.—Precipitation by 10-day periods at the Akron Field Station (average of 31 years).

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20. The average harvest dates for barley and winter wheat at the station are July 18 and 20, respectively. The present available varieties depart from the ideal in that they must try to fill during the low rainfall period of late June and early July.

Figure 2 shows also why production of ear corn is so uncertain. Corn usually tries to fill during the latter part of August, which is normally low in rainfall. It cannot be planted early enough to fill during the favorable rainfall period late in July and early in August. Date-of-planting experiments (*12*) indicate that corn yields best when planted as late as will permit maturing before frost, partly because there is more opportunity to store moisture before the corn begins to use it rapidly. Corn maturing shortly before frost is benefited by the favorable rainfall of early September and completes its development during relatively cool weather, which may permit a more efficient use of the limited water supply.

Analysis of the station rainfall from 1908 to 1938 in table 2 shows that 29.7 percent of the total precipitation falls in rains of 1 inch or more. This is the precipitation most likely to be partly lost by runoff, and while it may not be possible to hold all of it on the surface until it can infiltrate into the soil, the importance of preventing avoidable losses is apparent. Rains of less than half an inch, which constitute 43.9 percent of the annual total, are of little value during hot weather though beneficial at other times.

TABLE 2.—*Analysis of daily rainfall according to quantities as received during the period 1908–38*

Quantity group (inch)	Total number of rains	Annual precipitation
	Percent	*Percent*
0.01–0.24	69.6	22.4
0.25–0.49	15.7	21.5
0.50–0.99	9.7	26.3
1 or more	5.0	29.7

Most of the heavy rains occur between April 10 and June 20 and between July 10 and August 10, and few between June 21 and July 10. In spring to about May 20 and in fall after about September 1, rains are likely to fall slowly and are not subject to much runoff. Occurrence in spring, however, is likely to leave the surface soil so saturated that runoff loss from heavy rains following is increased. Level hard-land surfaces should be tilled after about May 15, so that they will absorb water readily and hold any temporary excess. A heavy rain falling in 20 to 40 minutes cannot be immediately absorbed, but infiltration into saturated hard-land surfaces generally can take place in 3 to 6 hours. The heavy rains from May 21 to August 10 are likely to be driving and intense, and runoff losses on the hard lands are often much greater than on soft or sandy soils, which absorb water more readily. The sandy lands are more reliable in their year-to-year crop production. With implements and methods now available the hard-land soils can be so handled that they will hold and absorb most of the hard rains; crop production may then more nearly approach that of the nearby sandy lands.

The comparatively deep working generally necessary to roughen the surface subjects a thick layer to evaporation loss during rainless periods. No data are available on the quantity of this additional evaporation loss, but in the absence of heavy rain it may occasionally result in a slight net loss of water. Unless wheat-seeding implements are available to deposit seed on a moist horizon through several inches of dry soil, land being fallowed for winter wheat should be leveled about July 15, and subsequent cultivation should be shallow, to avoid deep drying of the soil.

WIND MOVEMENT AND SOIL BLOWING

A composite of other climatic factors is presented in table 3. Wind movement, measured 2 feet above the surface of the ground, is of particular interest, as soil blowing was acute over the southern part of this region during the period 1930–38. March, April, and May all have average velocities above 7 miles an hour, and April has a 27-year average of 8 miles an hour. It is during these months that heavy soil blowing is most likely to occur. There has been no increase in average velocity in recent years over the earlier period for these months.

Soil blowing results from periodic high winds generally of short duration, but these are usually reflected in the average velocities. Reasons other than increased wind velocities must be sought as the cause of the widespread soil blowing over various sections of the west-central Great Plains during recent years. Texture of soil, lack of vegetative matter on the surface, and general lack of winter moisture seem to have been contributing factors. Where the winter precipitation was heavier, as in the Leroy section, soil blowing was not so troublesome.

The time of greatest danger of soil blowing is normally during late winter and early spring. Vegetative growth is still dormant during the early part of this period, and the winter has generally left the surface soil in condition to move unless there is sufficient dead or dormant plant material to protect it. Hard-land soils lacking such protection are generally safe from blowing after early spring cultivation and seeding. To prepare seedbeds for early spring-sown crops, use of the duckfoot cultivator or spring-tooth harrow, instead of the disk, will make them safer. Farmers on sandy land cannot safely grow barley, oats, or spring wheat because of the danger of blowing out. These small-grain crops do not produce high yields on this type of soil, even when stands survive and mature, but the yields are rather consistent from year to year. Cornfields on sandy land are sometimes blown level during May, and this necessitates replanting.

After soil blowing starts on a field it cannot be arrested until the surface is severely roughened or is covered by growing crops or weeds. It must be prevented, however, and can be by an adequate cover of dead or dormant vegetative matter and generally by suitable cultivation (*3*, *5*, *7*).

TABLE 3.—*Average monthly and seasonal evaporation, average monthly and annual mean, mean maximum, and mean minimum temperatures, and average monthly and annual wind velocity at the Akron Field Station, 1908–38* [1]

Items of comparison	Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or average
Evaporation ... inches	1908–23	-------	-------	-------	4.887	6.410	7.981	9.249	8.008	6.340	-------	-------	-------	42.875
	1924–38	-------	-------	-------	5.252	6.797	8.290	9.903	8.700	6.364	-------	-------	-------	45.306
	1908–38	-------	-------	-------	5.063	6.597	8.130	9.565	8.343	6.351	-------	-------	-------	44.049
Mean temperature ... °F	1912–38	24	29	36	46	56	67	73	71	62	49	37	26	48.0
Mean maximum temperature ... °F	1912–23	36	40	49	57	69	80	88	85	77	64	51	37	61.1
	1924–38	36	43	49	62	70	82	90	87	77	65	50	38	62.4
	1912–38	36	42	49	60	70	81	89	86	77	64	51	37	61.8
Mean minimum temperature ... °F	1912–23	12	15	22	32	42	52	57	55	46	34	23	13	33.6
	1924–38	11	17	23	33	43	52	59	57	47	34	22	14	34.3
	1912–38	11	17	22	32	42	52	58	56	47	34	23	13	33.9
Wind velocity per hour ... miles	1912–23	6.7	6.9	8.0	8.8	8.1	6.7	5.9	5.4	5.9	6.4	6.2	6.6	6.8
	1924–38	5.4	5.8	6.8	7.3	6.9	5.7	4.7	4.6	4.7	4.8	5.2	5.2	5.6
	1912–38	6.0	6.2	7.3	8.0	7.4	6.2	5.3	5.0	5.3	5.5	5.6	5.8	6.1

[1] Temperatures and wind velocities were not recorded regularly during the winter months until 1912.

Temperature

The average maximum and minimum temperatures by months are presented in table 3. The average maximum for the last 15 years was 1.3° F. higher than for the first 12 years. The most outstanding feature of the second period was the sharp increase in the number of high summer temperatures, as shown in table 4. Intense heat prevailed despite the fact that the seasonal precipitation was only 1 percent below that received during the prior 16 years. It was particularly intense during the 5-year period 1934–38.

TABLE 4.—*Analysis of temperatures of 100° F. or higher over 4 periods of years, 1908–38* [1]

Period	Years in period	Years with 100° temperatures	Days in period with 100° temperatures	Longest consecutive period with 100° temperatures	Year in which run occurred
	Number	*Number*	*Number*	*Days*	
1908–23	16	7	16	5	1919
1924–38	15	14	87	11	1934
1930–38	9	9	75	11	1934
1934–38	5	5	64	11	1934

[1] Temperatures for the summer months are available for all years from 1908 to 1938. In 1908, 1909, 1911, 1912 1915, 1916, 1917, 1920, 1923, and 1927 no temperature of 100° or higher was recorded.

The highest temperature during the 27-year period, 106°, was recorded in July 1934, twice in July 1936, and in August 1938. Prior to 1923 the highest on record was 103°. The longest consecutive period of temperatures of 100° or higher was 11 days in July 1934. The greatest number of temperatures of 100° or higher in any one year was 24 days, in 1936; prior to 1934 the greatest number was 6, in 1919.

Minimum winter temperatures were much the same for the two periods. The lowest on record during the 27-year period was −29° in January 1930. Winters are not severe, although periods of low temperature occur in most of them. The average annual number of days with temperature below zero is 13.

The average frost-free period is 144 days, extending from May 7 to September 28. This is based on a minimum temperature of 32° or below.

Evaporation

Evaporation is measured from a standard open tank 6 feet in diameter and 2 feet in depth, buried 20 inches in the ground. The data are presented in table 3. Evaporation was appreciably higher during the last 15-year period than during the first 16 years. It is usually high when the precipitation is low or the temperature high. Evaporation from an open tank is valuable as an indicator of the transpirational pull exerted by the atmosphere on growing crops. Although the seasonal rainfall over the last 15-year period was not especially low, the temperatures were abnormally high. The lack of control over temperature and evaporation by seasonal rainfall may suggest that a higher percentage of the precipitation fell as hard dashing rains during the last period. This does not appear to be true. During the first 16 years the 57 rains of 1 inch or more averaged 1.48 inches; during the last 15 years the 47 such rains averaged 1.55 inches.

The average April-September evaporation for the 15 years, 1924–38, was 2.431 inches more than for the preceding 16-year period; the 31-year average for these 6 months was 44.049 inches.

SCOPE OF EXPERIMENTS

The rotation block as laid out in 1908 contained 152 tenth-acre plots, each 2 rods wide and 8 rods long and separated on the sides by 3½-foot alleys and on the ends by 20-foot roadways, both of which are cultivated and kept free of weeds. Additional plots were added to the rotation block in 1924, 1928, and 1930. The location of the different rotations is given in figure 3. Yields from some plots

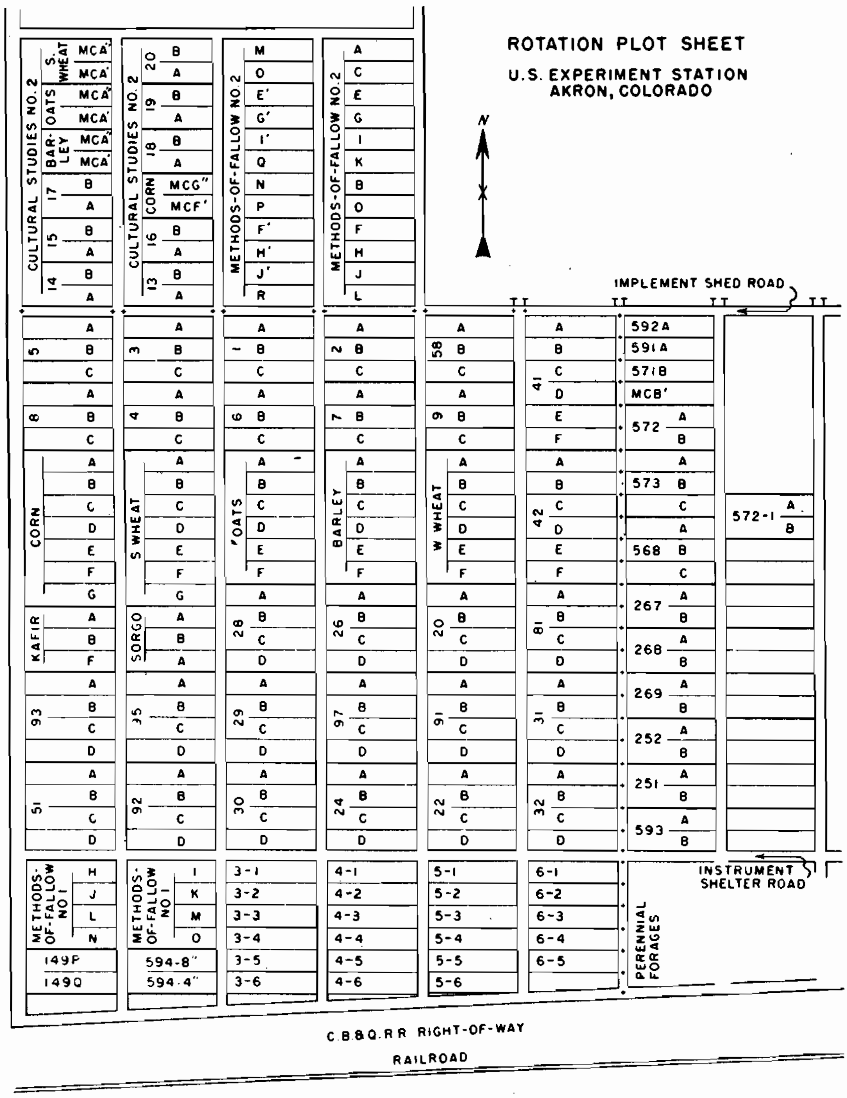

FIGURE 3.—Diagram of the main crop-rotation field at the Akron Field Station.

not in this rotation field are given also for comparison. Results of tillage experiments for the period 1909–23 were published in 1923 (*1*).

The cultivation methods and sequences under which the crops are grown are shown for the different crops in the detailed tables that follow. Research workers interested in the details of the rotations will find them described in Miscellaneous Circular 81, Supplement 1 (*4*).

Each rotation is represented by as many plots as there are years in the rotation. Every crop and every plot of fallow in a rotation is thus represented each year. In the 30-year period (1909–38) the following aggregate number of plot-year records of harvested annual crops have accumulated for study: Spring wheat, 616; winter wheat, 788; oats, 942; barley, 318; corn, 876; grain sorghum, 150; and forage sorghum, 135. The varieties grown in this study are presented in table 5.

TABLE 5.—*Varieties of the different crops used in the rotations for the years specified*

Crop and variety	Years	Crop and variety	Years
Spring wheat:		Forage sorghums:	
Beloturka (durum)	1909–24	Red Amber	1909–11 1922–38
Akrona (durum)	1925–35	Minnesota Amber	1912–14
Komar (hard red spring)	1936–38	Dakota Amber	1915–21
Winter wheat:		Grain sorghums:	
Turkey	1909–15	Red kafir	1909–11
Kharkof	1916–38	Dwarf Blackhull kafir	1912–19 1922–23
Oats:		Dawn kafir	1920–21 1924–25
Kherson	1909–19 1922–30	Otis kafir	1926–30
Sixty Day	1920–21	Kalo	1931–34
Brunker	1931–38	Coes	1935–38
Barley:		Winter rye:	
Hannchen	1909–12	Giant	1909–26
Coast	1913–28	Rosen	1927–38
Club Mariout	1929–38	Peas:	
Corn:		Different commercial field varieties	1909–38
Swadley	1909–22 1925–27		
Akron White	1923–24 1928–38		

The rates of seeding used for the various crops were as follows: Barley and oats, 5 pecks to the acre; spring wheat, 4 pecks; winter wheat and winter rye, 3 pecks; and field peas, 2 bushels. Grain and forage sorghums were planted in 44-inch rows, the plants of the former 6 to 9 inches apart and those of the latter very thick. Corn was planted in 44-inch rows, but the plant spacing was 18 to 30 inches.

The average dates of seeding the various crops were as follows: Winter rye, September 18; winter wheat, September 20; spring wheat, March 30; oats, April 1; barley, April 2; peas, April 5; corn, May 18; forage sorghum, June 2; and grain sorghums, June 4. These dates were based on experimental results from this station.

RESULTS OF TILLAGE AND ROTATION EXPERIMENTS

YIELDS OF PRINCIPAL CROPS

The average yields of all plots of the principal crops for all years are shown in table 6. These individual yearly averages were obtained from the yields from all plots growing a particular crop each year. Thus they are made up about equally of yields from good-, medium-, and poor-producing seedbed preparations. These average yields are a measure of the cropping possibilities of the region. The average farmer using ordinary methods of production might well hope to equal them, and the careful one using only the best methods might expect to exceed them.

Table 6 shows also the general average yields at the end of the first and second 15-year periods and the percentage loss of the last over the first. These losses were material and reflect the very adverse climatic factors of the second period. The loss in production was heaviest (60 percent) for spring wheat and corn; it was lightest (30 percent) for barley where Club Mariout, a variety better adapted than

TABLE 6.—*Annual and average yields per acre of crops grown by periods for the 30 years 1909–38*

Year	Grain					Forage and grain yields		Stover or straw	
	Winter wheat	Spring wheat	Oats	Barley	Corn	Corn	Sorgo	Corn	Barley
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1909	14.1	13.8	19.4	19.8	24.9	4,570	7,950	2,827	1,561
1910	14.1	9.2	13.3	12.0	10.9	2,241	3,620	1,478	978
1911	4.1	3.7	4.0	6.1	3.2	1,367	1,300	1,143	538
1912	33.8	19.7	42.3	30.8	30.9	4,535	6,100	2,372	2,098
1913	7.4	3.9	6.6	6.3	3.9	1,607	1,400	1,334	601
1914	25.5	16.6	42.2	37.8	11.3	2,730	3,560	1,939	1,830
1915	21.8	27.3	64.3	55.0	29.2	3,564	5,860	1,520	2,523
1916	13.7	7.1	11.3	11.0	1.1	915	550	838	701
1917	6.6	13.2	26.2	26.4	15.2	2,765	2,350	1,701	966
1918	5.3	1.1	1.4	4.3	12.4	3,076	3,200	2,208	562
1919	15.0	6.3	16.9	18.3	4.5	1,620	2,150	1,305	1,010
1920	14.2	18.7	44.2	32.1	35.6	4,356	6,270	1,864	1,376
1921	12.3	2.1	13.1	14.1	6.3	1,223	1,560	782	756
1922	.6	6.9	15.9	11.7	11.2	2,545	4,860	1,761	1,039
1923	3.2	4.6	14.4	18.6	17.8	3,464	4,910	2,218	1,662
15-year average	12.8	10.3	22.4	20.3	14.6	2,705	3,709	1,686	1,214
1924	3.9	.5	5.8	4.1	1.8	1,220	700	1,094	382
1925	6.5	3.4	6.7	5.1	.8	766	770	710	643
1926	1.3	.3	1.1	2.3	8.5	2,485	3,348	1,890	716
1927	16.3	11.2	33.7	32.0	8.2	1,474	3,370	900	2,416
1928	11.7	11.0	33.6	34.1	8.3	2,294	3,060	1,713	1,774
1929	4.0	1.7	1.6	1.4	13.7	2,281	3,920	1,322	700
1930	12.3	1.6	6.0	10.9	20.9	3,262	6,850	1,799	620
1931	7.3	1.0	7.2	9.1	.4	602	1,280	574	324
1932	2.2	3.6	13.0	7.5	4.2	1,694	1,870	1,400	340
1933	1.0	1.0	7.8	6.8	4.8	1,793	2,080	1,457	559
1934	1.9	.4	.2	1.5	.2	484	310	470	568
1935	6.2	11.2	38.2	46.8	10.7	2,444	2,810	1,695	2,721
1936	17.0	4.7	19.8	16.9	3.6	1,544	2,200	1,292	1,214
1937	11.0	3.8	13.0	11.2	1.2	885	1,170	801	774
1938	12.2	5.8	28.7	24.2	1.3	854	1,130	763	1,769
15-year average	7.7	4.1	14.4	14.3	5.9	1,605	2,325	1,192	1,040
Percentage of loss	40	60	36	30	60	41	37	29	14
30-year average	10.2	7.2	18.4	17.3	10.2	2,155	3,017	1,439	1,127

those grown previously, was introduced in 1929. It was next lightest for oats (36 percent) where Brunker replaced a less-adapted variety in 1931. Corn suffered a much greater loss in grain (60 percent) than in stover (29 percent). Forage sorghum lost 37 percent in yield over the prior 15-year period, but its average total yield for the 30 years was 3,017 pounds an acre, which was 862 pounds higher than that of corn. The sorghums are well adapted to the Plains environment. Barley and oats produced average yields of 17.3 and 18.4 bushels an acre, respectively, but the former, by reason of its heavier weight per bushel, is superior in pounds per acre produced. Winter wheat, with an average yield of 10.2 bushels an acre, is one of the crops best adapted to the region. It should be considered as a feed as well as a cash crop, as there are times when it is more economical to feed winter wheat than to purchase feed grains. Spring wheat produced an average yield per acre of 7.2 bushels. It was no better than winter wheat in favorable years and much poorer in most adverse years.

Proso is not represented in this rotation and cultural study block, but it is one of the reliable feed-grain crops for the region, particularly in the higher altitudes.

Yields of winter and spring wheat below 5 bushels an acre, of corn, barley, and oats below 8 bushels, and of forage sorghum below 1,200 pounds might arbitrarily be considered failures. The number of years when yields were low enough to fall within this arbitrary failure group are indicated in table 7. This again emphasizes the relative uncertainty of production during the 15-year period 1924–38.

TABLE 7.—*Frequency of average yields of 6 different crops that fell below the quantities arbitrarily set as practical failures*

Period	Years in period	Below 5 bushels of grain per acre		Below 8 bushels of grain per acre			Below 1,200 pounds of sorgo fodder per acre
		Winter wheat	Spring wheat	Oats	Barley	Corn	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1909–23	15	3	5	3	3	5	1
1924–38	15	6	12	8	7	9	5

FEED RESERVES

The 3 years of relatively low production prior to 1923 (1911, 1913, and 1918) were well distributed, but since that time such years occurred not only singly in 1929 but consecutively in groups of three beginning in 1924 and four beginning in 1931. It is these consecutive years of low production that exhaust monetary, feed, and credit reserves. The 30-year average yields have been creditable considering land valuations, but this average is made up of about equal numbers of years of high, medium, and low production. Yields for the 11 low years show how a wide selection of adapted crops in a diversified cropping system can cushion the degree of failure. The different grain crops varied in their degree of failure, and crops that grow later in fall, as sorghum and corn, sometimes produced fair crops in years when yields of small grains were very low. Forage yields were maintained much better than grain yields in the adverse years.

During the period of low production, 1924–26, failure to provide a reserve of grain and forage during the preceding favorable years would have meant at least a two-thirds reduction in livestock or the buying of extra supplies, which are generally high in price when the supply is thus limited. The 4-year period 1931–34 would have been equally difficult to surmount with only the 3 years 1927, 1928, and 1930 in which to create the necessary additional carrying reserve. That these feed supplies could have maintained most of the livestock over this later period, however, is revealed by the fact that average feed-grain yields for the period 1927–34 were less than 30 percent below the average yield for the whole 30-year period, and sorghum forage production was only a little below the long-time average. While not shown, the straw production of winter wheat, oats, and barley was very close to normal for this 8-year period.

Efforts to stabilize farming should be directed toward greater diversification of crops, with livestock supplementing the farm income; greater refinement in crop-production technique, which includes better soil preparation for retention of precipitation and for control of soil blowing; better dates and rates of seeding; and better adapted crop varieties. Greater granary storage, more silos, and more careful stacking of forage feeds also are indicated as necessary to carry reserves to supplement the crops produced in years of low production. With a diversified cropping system, sufficient ground cover should be produced annually to aid in the successful control of soil blowing.

WINTER WHEAT

Winter wheat stands first among the small-grain crops of the region, because of its excellent response to fallow, its high value as a possible grain feed, and its readily salable nature.

YIELDS UNDER DIFFERENT CULTURAL TREATMENTS

The 30-year results from different soil preparations for winter wheat and the average yields for the two 15-year periods are shown in table 8. Yields on all soil preparations were low during the second period. The 30-year average yield on fallow was 16.3 bushels an acre. This method suffered about the same number

TABLE 8.—*Yields (bushels per acre) of winter wheat under different cultural treatments for the 30 years, 1909–38*

Year	Late fall-plowed stubble	Early fall-plowed stubble	Subsoiled stubble	Early fall-listed stubble	Disked corn stubble			Rye used as green manure				Peas used as green manure				Fallow	
					Rotation 97	Rotation 81	Rotation 26	Rotation 24	Rotation 22	Rotation 20	Rotation 51	Rotation 91	Rotation 95	Rotation 93	Rotation 92	Rotation 28	CCC or CCD
1909	14.5	12.9	13.3	12.2	15.0	10.5	16.6	14.2	16.8	15.3	9.3	17.5	13.5	9.4	12.7	17.1	18.8
1910	11.4	10.2	6.9	8.8	19.3	18.4	15.3	14.0	17.9	17.8	13.0	15.3	13.7	10.8	11.1	18.2	17.7
1911	1.7	6.8	3.3	4.0	1.7	4.8	2.7	4.6	3.1	5.8	1.3	3.5	.8	1.8	3.5	9.3	11.8
1912	25.8	26.7	21.2	30.0	31.2	40.3	37.4	34.0	35.5	43.2	34.6	38.5	30.3	29.3	34.8	41.7	40.0
1913	3.3	2.0	3.2	7.2	12.8	9.2	12.2	6.8	8.2	6.2	12.3	3.8	4.2	5.7	3.0	15.0	10.3
1914	24.5	24.8	24.5	21.3	28.3	28.5	26.3	26.5	30.5	30.7	21.0	30.5	20.7	21.3	19.7	29.7	24.3
1915	22.0	20.8	21.0	18.2	23.2	29.0	26.5	24.5	23.5	28.8	24.0	16.5	12.3	10.0	16.2	26.5	28.3
1916	4.2	4.2	3.8	7.7	12.8	16.3	16.7	19.2	20.8	15.8	22.8	13.2	9.2	7.5	8.8	24.7	25.0
1917	2.7	5.0	5.7	3.8	2.2	11.2	4.2	5.7	4.2	6.3	9.2	5.2	4.8	6.3	10.0	15.0	11.3
1918	2.0	1.5	1.2	3.0	4.7	5.2	5.8	9.2	9.8	6.5	7.3	1.8	2.7	2.2	1.7	11.3	14.5
1919	7.6	20.3	12.5	14.2	6.2	15.7	17.5	14.2	14.5	18.7	10.7	18.7	15.7	5.8	11.0	24.5	28.0
1920	13.8	13.5	15.0	11.7	13.1	15.4	16.1	15.3	5.2	13.8	12.4	14.6	11.7	13.4	17.2	20.3	18.2
1921	3.0	7.0	5.8	9.0	7.3	5.3	7.0	18.2	18.2	15.3	14.8	17.7	8.7	8.3	8.8	28.5	26.5
1922	0	0	0	0	1.1	2.7	0	0	0	3.3	2.0	0	0	0	0	1.7	0
1923	.3	1.5	1.2	0	2.8	4.8	2.0	2.5	3.5	3.3	3.2	3.0	2.0	1.8	2.5	7.3	7.5
15-year average	9.1	10.5	9.2	10.1	12.1	14.5	13.8	13.9	14.1	15.4	13.2	13.3	10.0	8.9	10.7	19.4	18.8
1924	0	0	.8	.5	3.2	2.5	2.7	7.0	5.5	5.7	2.8	2.3	1.8	.8	1.7	9.5	6.3
1925	1.3	1.3	2.8	2.7	3.5	2.8	3.7	2.7	3.2	2.8	1.7	3.3	2.2	2.2	3.2	15.8	15.2
1926	0	0	0	.8	.5	1.0	.8	1.0	.8	.5	2.7	.5	1.3	.8	1.0	2.5	0
1927	4.0	9.3	6.3	10.8	12.3	27.7	22.0	18.7	17.5	16.2	11.7	17.7	16.5	8.3	13.7	20.8	26.2
1928	0	4.0	1.3	2.8	7.0	20.8	12.0	14.7	5.3	9.0	21.0	2.8	11.7	11.8	13.0	24.5	27.0
1929	.3	1.7	.3	.3	2.7	2.7	3.0	8.3	8.3	.2	4.3	4.0	4.3	4.3	1.8	10.7	10.0
1930	14.2	12.5	11.0	11.2	9.8	16.2	8.7	16.2	15.3	16.2	13.7	14.8	9.5	7.0	8.8	20.7	20.8
1931	2.7	1.7	4.2	2.2	6.2	8.7	8.8	8.0	8.2	4.2	5.7	5.8	5.5	3.5	5.3	14.5	12.7
1932	1.5	.3	.3	.3	4.3	9.0	4.7	2.5	2.2	1.2	.5	3.8	1.0	.7	.7	1.3	1.7
1933	0	0	0	0	0	0	0	0	0	0	4.3	0	2.0	4.7	3.0	2.8	2.8
1934	0	0	0	0	.8	2.8	.7	4.0	4.2	3.8	6.3	4.0	1.0	3.0	3.3	3.7	2.3
1935	4.7	5.3	5.5	5.3	6.5	6.2	7.3	6.7	6.0	7.8	6.7	8.2	7.0	6.3	6.5	8.3	7.8
1936	5.2	7.2	6.0	4.8	15.2	19.3	17.2	24.0	25.0	26.3	24.8	24.0	20.5	21.7	21.3	25.8	31.8
1937	3.2	7.2	7.3	7.5	6.8	6.8	8.5	16.2	19.2	16.3	12.3	13.8	13.7	11.7	11.8	14.7	17.5
1938	11.0	5.2	7.2	20.5	6.2	12.8	8.3	7.3	9.8	17.2	13.8	16.8	8.8	9.5	10.5	23.3	24.3
15-year average	3.2	3.7	3.5	4.6	5.7	9.3	7.2	9.2	8.7	8.5	8.8	8.1	7.1	6.4	7.0	13.8	13.8
30-year average	6.2	7.1	6.4	7.4	8.9	11.9	10.5	11.5	11.4	11.9	11.0	10.7	8.6	7.7	8.9	16.3	16.3
Number of yields below 5 bushels	20	14	15	15	12	9	11	8	9	9	9	13	13	12	12	5	5

of bushels decrease for the second 15-year period as did other methods, but its high yield makes the percentage decrease relatively low.

The practice in preparing and maintaining this fallow was moldboard plowing when the first spring weed crop was fully emerged and cultivating sufficiently often to keep all future growths subdued. Additional cultivations were occasionally performed when necessary to keep the surface open and receptive to rain infiltration. During the last 21-year period this plowing date has averaged June 2, and the number of cultivations other than plowing has been 2.7 a year.

There is agreement in the average yields from the two fallowed plots for the 30-year period. One plot was in 4-year rotation and the other in a 2-year rotation of alternate winter wheat and fallow. Annual yields do not evidence any loss of fertility where winter wheat and fallow alternate. There were 5 years when the yield per acre on fallowed land was below 5 bushels and 3 additional years when it was below 10 bushels. Fallow does not insure a paying crop each year, but the comparative certainty and high average yield of wheat on fallow mark it as the only method for the production of winter wheat on the hard-land soils of the western section of the central Great Plains. The risk of the loss of seed through winter-killing is particularly low on this preparation. Since the price of wheat may occasionally be in line with prices of feed grains, it is safest to produce it in a definite rotation and to have livestock where its feed as well as sale value may be realized. Livestock can aid in maintaining the farm income in years when the winter wheat yields, even on fallow, may be low or when the crop is a failure.

The average yields of winter wheat on fallow were divided into three groups to determine whether these yields had been determined by the precipitation pattern. The three groups were for yields per acre (1) of below 10 bushels, (2) of 10.0 to 19.9 bushels, and (3) of 20 bushels or higher.

The group of years with yields below 10 bushels an acre was characterized by low precipitation during the fallow period, particularly in the months immediately before seeding. This indicates that not only was moisture storage in fallowed land considerably below average in this group of years but also that seeding was done under unpromising surface-moisture conditions. Precipitation after seeding was slightly lower than in the group of years with yields of from 10 to 19.9 bushels and only about 2 inches lower than in the group of years with yields of 20 bushels or more. Evidently the conditions at seeding were such that near average rainfall thereafter did not produce yields much above the level of failure, which confirms other results (*10*) showing that moisture in the soil at seeding time has a strong influence on yields.

The groups of years of medium and of high yields compared closely in precipitation during the entire fallow period and in the months immediately preceding seeding. Evidently seeding in both groups of years was done under equally favorable conditions. During the period the crop was growing, however, the precipitation for the group of years with good yields was nearly 2 inches higher than for the group with yields from 10 to 19.9 bushels. Most of this additional rain came during the heading and fruiting period. It appears evident that the early growth of the crop was such that high yields were a possibility in both groups of years, but that in only the one group was rainfall during the latter part of the growing season high enough to enable the crop to benefit from this possibility.

These studies show that conditions at seeding frequently determine whether winter wheat on fallow is likely to fail or produce only a low yield, and that the final size of a crop seeded under favorable conditions is not determined until the latter part of the growing period.

The early fall plowing, listing, and subsoiling of winter wheatland were done as soon as possible after the bound grain could be shock-cured, hauled in, and threshed. Over the period 1909–38 this date averaged August 23. The average date of cultivation during the last 15 years has been August 14. The average harvest date over this same period was July 19. This represents a lapse of 26 days, despite efforts to shorten the span. The late fall-plowed plot CCA was worked just prior to seeding. The average additional delay was 32 days, but this was a period of low rainfall expectancy. (See fig. 2.) The average yield produced was 1 bushel an acre less than from the early fall-plowed plot. Early fall plowing and listing produced about the same average yields, showing that the date of the operation was more important than the implement used.

The 30-year average yield of each of the four continuously cropped plots was less than half the yield on fallowed land. The production hazard of growing wheat on wheatland was very high, and the practice is to be condemned except on the rare occasions when the soil is moist to a depth of 2 feet or more at seeding time. In 22 of the 30 years the average yield of wheat grown after wheat was below 10 bushels an acre, and in 16 of the 30 years it was below 5 bushels.

Cornland produced an average yield per acre of 10.4 bushels for the 30-year period. During the first 15 years the average yield was 13.5 bushels, but during the more adverse second period it was only 7.4 bushels. In only 4 of the second 15 years was the yield sbove 10 bushels. Winter hazards were particularly severe on winter wheat seeded on cornland during the last 15-year period. The relatively low yield is due to winter-killing, to spring instead of fall emergence, and to spring infestation of weeds. The method of production is to be condemned for its uncertainty rather than for its average yield. In rotations for hard lands, corn and other row-crop land should be used for spring-seeded crops. Yields on green-manured land are discussed later.

METHODS OF FALLOW

Winter wheat yields from different methods of preparing stubble land for fallow were obtained from two sets of plots designated as "Methods-of-Fallow Study No. 1" and "Methods-of-Fallow Study No. 2."

FALLOW STUDY NO. 1

This experiment covers the 16 years from 1923 to 1938. The data are presented in table 9. The methods studied consisted of fall plowing worked level, fall plowing left rough over winter, spring plowing, and summer plowing.

TABLE 9.—*Annual and average yields per acre (in bushels) of winter wheat from methods-of-fallow study No. 1 for the 16-year period 1923–38*

Year	Methods-of-fallow study No. 1 [1]				Year	Methods-of-fallow study No. 1 [1]			
	Plots H and I, fall-plowed, worked level	Plots J and K, fall-plowed, left rough	Plots L and M, spring-plowed	Plots N and O, summer-plowed		Plots H and I, fall-plowed, worked level	Plots J and K, fall-plowed, left rough	Plots L and M, spring-plowed	Plots N and O, summer-plowed
1923	5.5	4.7	5.5	2.3	1932	0.5	0.8	0.3	1.5
1924	5.5	8.7	11.7	3.0	1933	0	0	4.5	3.8
1925	5.7	5.7	5.8	2.8	1934	3.8	3.8	3.3	2.8
1926	1.8	2.3	1.7	1.0	1935	6.3	6.2	5.8	6.8
1927	18.5	21.3	15.2	15.0	1936	28.8	31.9	27.8	26.2
1928	29.3	35.7	36.0	10.2	1937	16.0	17.8	15.3	6.0
1929	6.5	5.8	6.5	2.8	1938	23.5	26.3	25.7	18.7
1930	11.7	16.5	19.0	8.2					
1931	9.5	12.0	12.3	5.8	16-year average	10.8	12.5	12.3	7.3

[1] Average plowing dates were as follows: H-I and J-K, August 15; L-M, June 2; and N-O, July 5. All plots were plowed with a moldboard plow.

The average yield on land plowed and worked level about August 15 of the fall preceding the fallow year (plots H and I) was 10.8 bushels to the acre; that of land plowed at the same time but left rough over winter (plots J and K), 12.5 bushels; and that of land left undisturbed until weeds started growing in the spring of the fallow year (plots L and M), 12.3 bushels. Working land in advance of the fallow year did not result in increased yields, and it introduced a soil-blowing hazard.

When plowing was delayed until early July of the fallow year (plots N and O) the average yield was only 7.3 bushels an acre, or 41 percent lower than on the L and M plots. The control of weeds during the growing season is a primary requirement of good fallow. The spring showing of green weeds is the dead line for the initial working of fallow land. At Akron the average date of the initial operation on good spring-plowed fallow is June 2.

Good spring-plowed fallow in this experiment received an average of 4.3 cultivations a year, exclusive of the moldboard plowing. These cultivations generally included a disking in advance of spring plowing to macerate the dead weed debris, particularly Russian-thistle, and a packing immediately after plowing. Cultivations to eliminate weeds averaged less than 3 a year, although the number varied from 1 to 5. Weeds must be destroyed as they emerge, and in addition the surface must be kept open and receptive to rainfall. Naturally the more frequent the consequential summer rains, the greater the number of cultivations necessary. The fall-plowed plots needed an average of one more cultivation to kill weeds than the spring-plowed plots. The extra cultivation was in spring before weed growth started on the spring-plowed plots. One fall-plowed plot required an additional fall cultivation for leveling. The summer-plowed plot required an average of only 1.6 cultivations, but the yield was 5 bushels an acre lower than that of plots plowed a month earlier.

A rough soil surface is less likely to become level during hard, beating rains than is a smoother surface; leveled surfaces become relatively impervious to water and are in condition to blow readily. The station has used the duckfoot or field cultivator in maintaining its fallow since 1922. It was the best implement then available to kill weeds and leave the surface uneven, rough, and open. Surfaces maintained with it, however, may sometimes be beaten down level by hard dashing rains. It was found that the duckfoot loosened the soil too deeply to make its continued use advisable until seeding time. A maximum of stored moisture is practically useless in winter wheat production if its upper horizon is so low that seeding machines cannot reach it. The practice adopted was to use the spring-tooth harrow for cultivations necessary after about July 15. The spring-tooth is a shallower working implement than the duckfoot and leaves the surface less receptive to hard beating rains, but it does tend to establish the top horizon of stored soil moisture nearer the surface. In comparatively recent years the rod weeder has been used in some of these late-season workings.

FALLOW STUDY NO. 2

This second study was initiated to obtain further information on the treatmen of stubble land being fallowed for winter wheat. The study previously discussed dealt largely with the time of beginning preparations with the moldboard plow. Methods-of-fallow study No. 2 deals not only with the time of beginning fallow operations but with the use of different implements.

Results from this experiment are presented in table 10. Annual yields for the nine pairs of plots are presented, and groupings are made according to the type of implement used for fallow cultivation and according to the time land preparation was begun.

The average yield for all nine methods was 13.3 bushels an acre. Yields for the individual methods ranged from 12.3 to 14.1 bushels. The yield of treatment I and J is a bushel below the average, owing principally to a low yield in 1938. With the exception of this one year this method compared favorably with the others. Differences between methods were small, and it appears that all nine were about equally effective in storing and conserving soil moisture for winter wheat. This is shown even more forcibly by grouping comparable treatments.

The implements used for the initial cultivations apparently had no influence on the moisture storage, as plots given timely cultivation, but not moldboard-plowed or listed, produced yields equal to those that were. The average yields of all listed plots, all surface-tilled plots, and all plowed plots were within 0.2 bushel of the general average.

Several spring treatments in this study entailed early spring surface working in advance of weed emergence to close possible soil cracks and thus create a better surface tilth, but these apparently only added to the cost, for they did not increase the yields obtained. Evidently early-spring working in advance of weed emergence did not result in greater or less soil-moisture storage.

The yields of the group of plots on which tillage was started in the fall were practically the same as for the group where tillage was delayed until spring. Initial working of the fall-cultivated plots was performed about August 15, 26 days after harvest. Such cultivation did not increase crop yields above those on spring-tilled land; if fall working of weedy stubble land for fallow is to be any better than timely spring working, it must be done immediately after combine or header harvesting. Working promptly may conserve any moisture not used by the crop by immediately stopping all weed growth and may also conserve some of the precipitation (approximately 2½ inches) that normally falls during the period July 20 to August 15. Fall working should be with some implement that will not only destroy weeds but will also leave them and the crop debris on the surface

TABLE 10.—*Annual and average yields per acre (in bushels) of winter wheat from methods-of-fallow study No. 2 for the 11-year period 1928–38*

Year	Moldboard-plowed plots					Shallow-cultivated plots				Listed plots			Fall-cultivated plots, A and B, C and D, E and F, G and H	Spring-cultivated plots, I and J, K and L, M and N, O and P, Q and R
	Plots E and F, early fall-disked, spring-disked, spring-plowed	Plots G and H, early fall duck-footed, spring duck-footed, spring-plowed	Plots I and J, spring-plowed	Plots O and P, early spring duck-footed, spring-plowed	Average	Plots C and D, early fall- and early spring-cultivated	Plots K and L, early spring-cultivated	Plots Q and R, late spring-cultivated	Average	Plots A and B, early fall-listed	Plots M and N, spring-listed	Average		
1928	30.3	31.8	31.0	35.8	32.2	29.7	35.2	32.2	32.4	31.2	34.2	32.7	30.8	33.7
1929	9.5	9.8	8.7	9.3	9.3	5.5	8.2	10.8	8.2	4.5	4.8	4.7	7.3	8.4
1930	13.5	14.2	11.3	13.7	13.2	12.2	10.8	12.7	11.9	11.5	13.3	12.4	12.9	12.4
1931	14.5	13.7	12.5	14.0	13.7	14.5	10.5	15.5	13.5	11.5	12.7	12.1	13.6	13.0
1932	1.0	2.2	3.2	1.3	1.9	1.2	4.0	1.2	2.1	1.7	1.2	1.5	1.5	2.2
1933	5.7	6.3	4.7	5.2	5.5	5.8	5.0	3.3	4.7	5.5	2.8	4.2	5.8	4.2
1934	2.7	4.2	2.5	2.7	3.0	3.2	1.7	1.0	2.0	4.2	4.0	4.1	3.6	2.4
1935	8.7	8.0	7.3	7.5	7.9	7.8	6.8	9.8	8.1	9.8	8.7	9.3	8.6	8.0
1936	24.3	24.2	23.8	24.5	24.2	22.2	23.2	23.3	22.9	20.2	21.8	21.0	22.7	23.3
1937	19.5	17.7	17.7	18.3	18.3	22.8	17.8	20.3	20.3	21.5	19.7	20.6	20.4	18.8
1938	18.7	20.8	12.3	23.3	18.8	21.0	18.8	22.0	20.6	23.8	20.2	22.0	21.1	19.3
Average	13.5	13.9	12.3	14.1	13.5	13.3	12.9	13.8	13.3	13.2	13.0	13.1	13.5	13.2

(fig. 4). Such a surface not only will resist soil blowing but will trap snow almost as well as undisturbed stubble. Clean year-round cultivation, if it can be accomplished without encouraging soil blowing, may pay increased-yield dividends in regions of limited rainfall. Fallow experiments with this type of cultivation have been begun, but it will be several years before dependable results will be available.

Fall working weedy stubble later than August 15 probably would have been less efficient than working on that date, judging from the results of the comparison between the early and late fall-plowed stubble plots of the continuous winter wheat series.

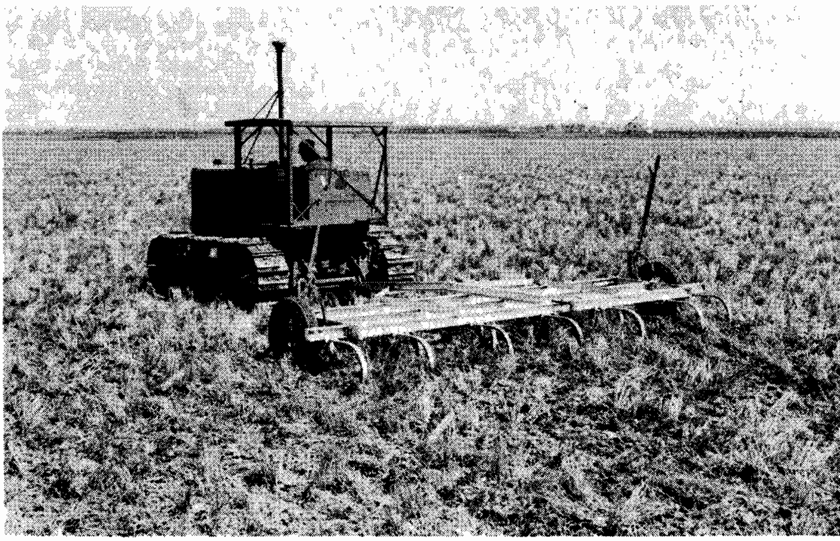

FIGURE 4.—Weeds may be killed without destroying the stubble cover by use of undercutting implements. The stubble on the surface protects the soil from erosion and will catch nearly as much snow as undisturbed stubble. Photographed at Hays, Kans.

The fall working in this experiment entailed about one extra cultivation, hence that much added cost. The cheapest fallow, in number of necessary cultivations, is decidedly in favor of initial spring working. There is not much evidence that moldboard plowing saved subsequent summer cultivations. Plots I and J, which were spring-plowed, required 2.4 cultivations a year, while plots Q and R, which were surface-worked at the same initial date, had an average of 2.7 cultivations. Soil-moisture determinations were not made on the method-of-fallow experiments. Soil-moisture studies, however, on fallow in earlier years showed that 1 year of bare fallow does not store soil moisture below the possible feeding range of winter wheat roots. Some soil moisture may occasionally remain temporarily bottled up at a lower depth, but stored moisture will ultimately reach it and some following crop of winter wheat will be able to use it. There is little or no loss of moisture by leaching from the soil at the Akron Field Station in an alternate fallow-winter wheat rotation.

MAINTENANCE OF SUMMER FALLOW

There are four major requirements to be met in maintaining good fallow for winter wheat in this general region: (1) To enable precipitation to enter the soil; (2) to conserve this soil moisture; (3) to have the top horizon of the stored moisture near enough to the surface by fall to permit seed to germinate; and (4) to have a surface maximumly resistant to soil blowing. Timeliness in performing all necessary cultivations and use of implements that leave the surface not only free of weeds but also open and cloddy are of primary importance in attaining the first two objectives. Cultivation during the fore part of the fallow season with implements that form small basins is recommended. The use of shallow-working implements during the latter part of the fallow season is necessary for the third objective. The use of implements that leave the surface cloddy and with trash and debris on top in cultivations to control weeds and the use of furrow-seeding machines meet the fourth requirement. Methods-of-fallow studies Nos. 1 and 2 showed that dates of initial treatments from about August 15 to about June 1 and all implements used were about equally efficient, provided the land was kept free of weeds during the summer season. In both methods-of-fallow studies the cultivation after June 1 was uniform except for plots N and O of the No. 1 study, which were not initially worked until a month later. The cultural implements used have already been mentioned. The seeding implement was a 12-inch disk drill, the so-called deep-furrow type.

Careful technique is needed in preparing and maintaining good fallow, and its effectiveness can be measured by the quantity of soil moisture stored near enough to the surface to permit seeding on its top horizon, by its resistance to soil blowing, and by the yield of the crop obtained from it. Nonpulverizing implements are most effective when weeds are in the seedling stage. Forced workings later than this generally necessitate an additional cross-cultivation with them, or the use of the one-way disk or rod weeder. No blanket recommendation can be made as to the proper cultivation implements to use. Many good operators on particularly level stretches of land have continued to use the one-way disk in preparing and maintaining their fallow with satisfactory moisture penetration and no particular blow problem, but this is not the safest type of cultivation for the general run of land capable of being fallowed.

Farmers who plan to grow row crops should work their fallow in April or early May. The next cultivation will not normally be needed until after June 1. Under no condition is it justifiable to delay the first working beyond the time of active weed emergence, for if weeds are not promptly killed they seriously reduce the efficiency of the fallow.

COMPARISON OF COMMON AND FURROW DRILLS

Results from three fallowed plots seeded with a common drill and three seeded with a furrow drill are given in table 11. Both drills were of the disk type, one spacing rows 8 inches apart and the other 12. The wide-row spacing, which gained attention in the central Great Plains about 1926, allows winter wheat to be planted in deep furrows. This particular experiment covers the 11 years 1928–38. The plots seeded with the furrow drill averaged only 0.8 bushel more to the acre, but annual yields were higher in 8 of the 11 years.

TABLE 11.—*Annual and average yields (in bushels) of winter wheat, seeded with furrow and common drills, for the period 1928–38*

Year	Furrow drill				Common drill[1]			
	Rotation E-F	Rotation G-H	Rotation I-J	Average	Rotation E′-F′	Rotation G′-H′	Rotation I′-J′	Average
1928	30.3	31.8	31.0	31.0	30.3	32.2	28.8	30.4
1929	9.5	9.8	8.7	9.3	9.5	10.7	10.2	10.1
1930	13.5	14.2	11.3	13.0	13.0	11.8	12.8	12.5
1931	14.5	13.7	12.5	13.6	15.0	14.3	15.0	14.8
1932	1.0	2.2	3.2	2.1	.2	.5	.8	.5
1933	5.7	6.3	4.7	5.6	3.5	3.8	3.3	3.5
1934	2.7	4.2	2.5	3.1	2.2	1.2	1.8	1.7
1935	8.7	8.0	7.3	8.0	8.2	8.0	8.0	8.1
1936	24.3	24.2	23.8	24.1	20.8	20.3	18.7	19.9
1937	19.5	17.7	17.7	18.3	18.0	18.5	17.2	17.9
1938	18.7	20.8	12.3	17.3	19.3	19.7	12.2	17.1
Average	13.5	13.9	12.3	13.2	12.7	12.8	11.7	12.4

[1] Pairs of plots, as E-F and E′-F′, are identical in cultural treatments other than the type of drill used.

Spring stands were nearly always observed to be better on the plots seeded with a furrow drill, but stands on the plots seeded with a common drill were never so bad that the plots became weedy. The better stands on the plots seeded with a furrow drill are indicated by the straw yields, which were higher. The seeding rate of 3 pecks an acre was probably about right for the common drill, as stands poorer than those that survived would undoubtedly have resulted in weed competition. In a rate- and date-of-seeding experiment conducted at the station, 2 pecks an acre has been found sufficient when seeding with a furrow drill in a good season on well-prepared fallow (*15*).

FREQUENCY OF PLOWING AND OTHER STUDIES

In order to study the role of the moldboard plow in seedbed preparation for winter wheat, a frequency-of-plowing experiment was begun in 1925 on the north end of the east series of the cultural study block. (See fig. 3.) The yield data from this study and from some other plots representing miscellaneous studies are given in table 12.

These studies include plots moldboard-plowed every year, every other year, and every third year; a plot plowed only when absolutely necessary; a plot prepared with a disk every year; a plowed plot where the wheat is seeded in cultivated strips; and a listed plot where wheat is seeded in strips in lister furrows. In rotations 572 and 573 the plots are disked in the years that they are not plowed. A rotation (568) of 2 years of wheat and 1 of fallow is used for comparison with the continuously cropped plots.

It has already been shown that the period of years covered in this study was unfavorable for the production of winter wheat in continuous cropping sequences, and the yields are consequently very low. It was, however, a period that should have brought out sharp contrasts between methods of preparing stubble land for winter wheat. The very close agreement between the average yields of treatments is the outstanding feature of these results.

Five early fall-disked stubble plots, representing 70 plot-years, produced an average yield of 3.7 bushels an acre. Three similar ones, moldboard-plowed on the same average date, representing 42 plot-years, produced an average yield of 3.6 bushels. Rotation 591, not plowed or otherwise worked until necessary, produced an average yield of 5.0 bushels. The comparatively high yield of this plot was due to lack of winter-killing in 1927, when stands on other plots were seriously reduced. Downy chess (*Bromus tectorum* L.) forced the plowing of this plot in 1931, about midway of the 14-year period. The moldboard plow was not measurably better than the disk for winter wheat production over this period. The plowed and disked plots of rotations 572 and 573 produced closely comparable yields and are further evidence that moldboard plowing performs no required function. Rotation 591 demonstrates, however, that plowing or other efficient working is occasionally necessary to control weeds.

Rotation 592, early fall-plowed and seeded in strips of three rows of winter wheat alternating with equal-width cultivated alleys, returned 5.7 bushels to the acre, the highest 14-year average yield from continuously cropped land. Its yield of 5.3 bushels during the 11-year period from 1928 to 1938 was exceeded by both plots in rotation 572–1. In this 2-year rotation the wheat on one plot was planted in three-row strips in the bottoms of lister furrows. On the other plot, the wheat was grown on disked land following wheat in strips.

Seeding wheat in cultivated strips entails one or two spring cultivations between the strips of wheat, or if seeding has been done in lister furrows, to level the ridges. The yearly production in narrow intertilled strips was as erratic as that in solid-seeded plots, and the average yield was not high enough to warrant that method of planting.

Row-spaced seeding of winter wheat, especially in the bottoms of early fall-listed furrows, should theoretically have favored fall emergence and growth, and hence winter survival. The spring stands, however, were generally poorer. Wheat did not survive any better in the deep furrows left by the lister than in the shallower furrows left by the furrow drill. There were actually about half as many plants on the strip-planted plots as on those seeded solidly with the furrow drill.

The relatively high yield on the disked plot in rotation 572–1 indicates the possibility of some carry-over in moisture from the strip-planted plot.

One of the most important points brought out by this study is that no method of preparing stubble land for wheat has increased the yields enough for a crop grown continuously to compete with one on fallowed land. The yield on the fallowed plot in rotation 568 was approximately three times as high as on most of the plowed and disked plots and twice that of wheat grown in the cultivated strips. The total yield on the two plots in rotation 572–1 was practically the same as that on the fallowed plot, but annual yields were much less dependable. Winter wheat in this general region is not regularly successful when grown continuously by any method of soil preparation or seeding.

There was apparently no carry-over of moisture after a wheat crop had been grown on fallow in rotation 568. Some growers have felt that they should obtain a good yield from a second crop after well-prepared fallow, as the stubble of wheat grown on fallowed land is generally free of weeds. This has not been true in the

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TABLE 12.—*Annual and average yields per acre (in bushels) from studies of frequency of plowing and disking and types of seeding with winter wheat for the 14-year period 1925–38*

Year	Disked plots						Early fall-plowed plots				Early fall-plowed, seeded in strips, rotation 592	No preparation, rotation 591	Fallowed, rotation 568	Rotation 572–1	
	First-year disking			Second-year disking, rotation 573	Continuous disking, rotation 571	Average	B′	Rotation 572	Rotation 573	Average				Early fall-listed, seeded in lister furrows	Early fall-disked
	Rotation 572	Rotation 573	Rotation 568												
1925	2.8	2.0	1.3	2.3	3.3	2.3	2.5	2.7	2.5	2.6	2.7	2.7	19.8	----------	----------
1926	.3	.3	.8	.3	1.3	.6	.7	.7	.7	.7	2.0	1.7	3.5	----------	----------
1927	9.2	8.0	1.8	4.3	17.8	8.2	7.0	6.2	3.7	5.6	16.0	23.2	22.3	----------	----------
1928	0	0	0	0	0	0	0	0	0	0	0	1.7	34.7	4.0	7.8
1929	.5	.7	2.7	2.5	1.2	1.5	.5	.8	2.3	1.2	2.2	1.8	9.3	7.3	3.0
1930	13.0	12.7	10.7	12.5	7.2	11.2	9.7	11.0	11.2	10.6	6.7	0	13.7	15.7	11.7
1931	3.0	3.5	4.0	6.0	3.5	4.0	3.7	3.7	3.8	3.7	8.7	9.2	12.8	8.0	5.8
1932	1.2	1.0	2.5	.7	.5	1.2	2.2	1.7	1.5	1.8	2.2	1.2	8.8	2.7	2.5
1933	0	0	0	0	0	0	0	0	0	0	0	1.7	0	3.2	1.5
1934	0	0	0	0	0	0	0	0	0	0	1.8	0	2.7	.3	1.7
1935	5.2	4.7	5.7	4.5	5.3	5.1	6.0	4.5	3.8	4.8	8.2	6.5	5.0	2.8	4.7
1936	7.5	7.3	7.7	8.5	8.2	7.8	4.5	6.0	6.0	5.5	10.3	6.3	16.8	4.0	14.8
1937	5.3	4.8	5.7	4.0	8.2	5.6	7.5	6.2	5.0	6.2	8.3	6.5	18.0	6.3	5.3
1938	2.0	1.2	7.8	5.0	7.2	4.6	8.7	9.2	6.5	8.1	10.3	6.8	14.0	9.5	13.8
14-year average	3.6	3.3	3.6	3.6	4.6	3.7	3.8	3.8	3.4	3.6	5.7	5.0	13.0	----------	----------
11-year average	3.4	3.3	4.3	4.0	3.8	3.7	3.9	3.9	3.6	3.8	5.3	3.8	12.3	5.8	6.6

series of years covered by this study; the yield the second year after fallowing in rotation 568 was no higher than on the other disked plots. It is highly probable that during the period from 1909 to 1921, when after-harvest rainfall was heavier, yields the second year after fallow might have proved better than on a more weedy stubble. The best wheat growers now fallow their land regularly every other year, instead of planting wheat in the stubble left by that grown on fallowed land. Planting on stubble is now confined principally to the years when the quantity of moisture present at seeding time is much above average.

WINTER WHEAT FOLLOWING MISCELLANEOUS CROPS

Winter wheat was grown alternately with other crops on land not in the rotation field and on a different type of soil that classed as Platner loam. About one-third of the land is on a gentle slope, and the rest is nearly level. The level part was subject to occasional sheet-water flooding. The different crops were in two replications, one of which was on the higher and the other on the lower land.

The crops chosen to alternate with winter wheat were potatoes, foxtail millet, forage sorghum, pinto beans, soybeans, proso, and Sudan grass. The locations of the different crops were comparable, and the data are useful in determining the value of these other crops in sequence with winter wheat. The winter wheat yields are presented in table 13.

TABLE 13.—*Yields (in bushels) of winter wheat following various other crops in 2-year rotations for the years 1927–37*

Year	Preceding crop								
	Potatoes	Foxtail millet	Sorgo	Pinto beans	Corn, 44 by 24-inch spacing	Proso	Sorgo (1 plot)	Sudan grass	Soybeans
1927	24.3	21.8	22.7	21.8	25.7	-------	-------	-------	-------
1928	29.0	14.8	26.5	24.3	24.0	-------	-------	-------	-------
1929	12.9	6.3	5.4	6.6	4.9	-------	-------	-------	-------
1930	17.4	11.5	15.4	19.0	27.8	-------	-------	-------	-------
1931	16.8	8.2	8.3	12.8	8.9	15.9	-------	-------	-------
1932	11.3	6.1	6.7	5.6	5.4	12.4	8.5	13.2	-------
1933	8.9	4.8	6.5	6.8	5.0	7.9	4.7	5.7	8.4
1934	3.5	1.0	.8	1.0	2.1	7.7	1.3	1.0	10.6
1935	0	0	0	0	0	0	0	0	0
1936	24.8	13.6	16.2	24.8	23.2	16.8	-------	(1)	24.4
1937	22.3	7.9	8.0	10.8	9.4	10.0	7.7	6.8	13.2
11-year average	15.6	8.7	10.6	12.1	12.4	-------	-------	-------	-------
7-year average	12.5	5.9	6.6	8.8	7.7	10.1	-------	-------	-------
5-year average	-------	-------	-------	-------	-------	-------	4.4	5.3	-------

[1] Winter wheat not grown on Sudan grassland in 1936.

Potato land.—This produced an 11-year average yield per acre of 15.6 bushels, which is 3.2 bushels higher than on cornland, but even this yield does not warrant production of winter wheat on potato land. Soils light enough to be suited to potato production generally prove hazardous for seeding winter wheat that same fall, because potatoes are not harvested early enough to make possible a satisfactory early seeding date. Potato land is best adapted to spring-seeded crops. Harvesting generally leaves the surface in suitable condition to resist soil blowing; if not, it may be listed and made safe.

Pinto bean land.—The land where pinto beans had been grown produced an 11-year average yield of 12.1 bushels—about equal to the yield of 12.4 on cornland for the same period. Bean land, however, requires special handling. The crop feeds heavily on moisture that falls up to about September and generally leaves the surface soil very dry. Harvesting leaves a smooth pulverized surface without a protecting crop residue. The station was able to prevent soil blowing on bean land seeded to winter wheat by planting with a furrow drill, by generally getting fall emergence and some growth, and by having the tenth-acre plots flanked by plots with stubble. A good general rule is not to follow beans with winter wheat, but to reserve the land for spring-sown crops.

Soybean land.—Winter wheat was grown on soybean land for a short period of years. Soybean land is at least as productive as land on which dry beans have been grown and is equally susceptible to soil blowing. The recommendations made for pinto bean land would apply equally to soybean land.

Forage sorghum land.—The average yield of winter wheat following forage sorghum was 15 percent less than on cornland.

Foxtail millet land.—Foxtail millet fully bears out its local reputation of being "hard on the land." Winter wheat following it produced 30 percent less than on cornland and 18 percent less than on forage sorghum land.

Proso land.—Proso stubble over a 7-year period produced 71 percent more winter wheat than the foxtail millet stubble and 31 percent more than the cornland, although in the good year covered by the experiment the yield on cornland was much higher. Proso provides a good preparation for winter wheat where it is desirable or necessary to plant that crop on any preparation other than fallow. The stubble is usually free of weeds, and any that are present have a very short time after the harvest of a normally seeded proso crop to sap moisture that may have been left in the soil. Proso is shallow-rooted and consequently may leave moisture at lower depths. The surface is always in good tilth for seeding winter wheat without any prior working. The lightly disturbed stubble is excellent winter protection against soil blowing and is sufficient to catch a fair share of the winter-drifting snow. While loose and friable in fall, recent experience has shown that the proso stubble land is hard and tight by spring.

Sudan grassland.—Over a 5-year period a single plot of winter wheat on Sudan grass stubble produced about 1 bushel an acre more than comparable forage sorgo stubble. Sudan grass produces only half as much tonnage to the acre as the forage sorghums in this section, so it should leave the soil in better condition for crops that follow.

EFFECT OF BARNYARD MANURE ON WINTER WHEAT PRODUCTION

The study of the effect of barnyard manure on winter wheat production was made on the south end of the east series of the cultural study block. (See fig. 3.) Applications of manure are made every other year to plots in fallow-winter wheat and corn-winter wheat rotations.

Fresh barnyard manure was applied to fallow-winter wheat rotations at the rate of 7 tons an acre and to the corn-winter wheat rotations at the rate of 8 tons. These quantities, intended to replace the nitrogen used by the crops in the rotations, provide an overabundance of potassium and phosphorus. All the plots comprising this study are situated side by side and were handled uniformly except for the manure treatments or the lack of them.

Manure was applied to the wheat stubble in rotations 268 and 251 and was turned under when the plots were plowed. In rotation 268 it preceded a season of fallow, and in rotation 251 it preceded a crop of corn. The average dates of plowing were May 31 for fallow and April 27 for corn. Manure was applied as fall top dressing to winter wheat on rotation 269 on the average date of October 13, and as spring top dressing on rotation 269–1 on the average date of April 16. The average date of seeding winter wheat was September 18. Yields are given in table 14.

Average grain yields of all winter wheat plots in the manured rotations were below those in comparable unmanured rotations at the end of the 14-year period, although they were fully as high during the early years. The average yield of the spring top-dressed plot in rotation 269–1 was higher than that of the unmanured rotation for the 8 years it has been in operation. This average difference is due principally to a much higher yield in 1938, probably caused by a difference in stand. For the other 7 years the average yield of the unmanured rotation was slightly higher.

An abundance of usable nitrates on plots receiving manure should be reflected in increased straw yields. All manured plots produced higher average straw yields than comparable unmanured plots. The two top-dressed plots produced higher straw yields than the rotation where manure was plowed under.

Examined on the basis of annual yields, the effects of manuring or not manuring appear to be so strongly seasonal that trends are still obscure. While the average effect of manure appears to be depressing to grain yields, the results are not consistent from year to year. In the last year reported, 1938, yields on all manured plots, except rotation 251, materially exceeded those on comparable unmanured ones.

TABLE 14.—*Yields of winter wheat in rotations with and without manure during the period 1925–38*

Year	Grain yield—						Straw yield—					
	On fallowed land				On cornland		On fallowed land				On cornland	
	No manure (267)	Manure plowed under (268)	Fall top-dressed (269)	Spring top-dressed (269-1)	No manure (252)	Manure plowed under (251)	No manure (267)	Manure plowed under (268)	Fall top-dressed (269)	Spring top-dressed (269-1)	No manure (252)	Manure plowed under (251)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1925	20.8	23.0	27.5	----------	13.3	11.0	1,900	1,820	2,250	----------	650	1,040
1926	1.7	3.0	4.3	----------	1.0	2.2	1,050	1,270	1,390	----------	1,190	1,320
1927	31.5	24.7	29.7	----------	23.7	26.8	2,510	3,420	4,120	----------	3,180	2,940
1928	22.7	20.8	22.0	----------	10.0	4.8	3,540	3,900	3,680	----------	2,450	2,010
1929	10.0	9.7	8.3	----------	3.3	1.8	1,300	1,220	1,700	----------	750	190
1930	15.7	11.2	12.7	----------	13.5	10.8	2,160	1,430	1,740	----------	1,630	2,150
1931	15.5	12.8	10.3	12.8	9.5	10.3	2,070	1,780	1,530	1,730	880	1,730
1932	2.3	4.5	4.0	1.7	4.0	3.2	1,610	2,530	3,510	4,050	2,060	2,560
1933	0	5.0	0	4.5	0	0	(1)	(1)	(1)	(1)	(1)	(1)
1934	3.8	2.5	2.3	2.8	1.7	0	770	700	1,010	680	200	300
1935	7.0	6.2	6.8	8.2	5.8	6.2	1,430	1,630	1,940	1,710	1,400	1,380
1936	28.2	25.5	18.5	25.7	13.3	10.0	3,510	3,770	3,090	4,360	1,650	1,600
1937	21.3	17.3	15.5	21.5	8.0	5.3	2,120	1,660	1,320	2,110	720	730
1938	12.0	14.2	15.2	20.2	8.5	8.2	2,080	2,130	2,870	3,090	1,640	1,510
14-year average	13.8	12.9	12.7	----------	8.3	7.2	1,861	1,947	2,154	----------	1,314	1,390

[1] Harvested growth consisted largely of weeds; straw yields were computed as zero.

The effect of season is also apparent on straw yields. While applications of manure increase yields of straw on the average, there are many cases in which the straw yields on unmanured plots were higher.

In 31 of 48 annual comparisons, grain yields were higher on unmanured rotations than on comparable manured ones, but straw yields were higher on only 19 of 46 such comparisons. It appears that in any one year the effect of manure on grain yields may be helpful, harmful, or neutral, with the tendency for the number of years when it is harmful to exceed those when it is helpful. With straw yields the reverse holds true, with the tendency for manure to be helpful in the majority of years.

There is at present little evidence to indicate that fertility supplied by manure is beneficial to winter wheat grain yields in this area. While it increases the straw yield and probably the potential productivity of wheat, this greater potential capacity has been of no value in grain production under the limited rainfall of the area.

Results with rotations 269 and 269–1 indicate that spring top dressing is the preferable way of applying manure. In years when winter wheat makes little fall top growth, it has been hard to apply fall top dressing of manure without damaging stands by trampling or smothering. It is evident that spring top dressing is less damaging in these respects. While manure naturally contains many seeds of weeds and crops, the emerged stands have never proved troublesome to winter wheat in this experiment.

There is considerable evidence that a year of clean fallow provides all the available nitrates needed for winter wheat production. Whether it will eventually become necessary to apply manure to supply necessary fertility elements and what is the proper frequency of such applications remain to be solved. The quantities that have been applied to these rotations have not caused any visible overstimulation of the wheat.

Present indications are that any manure to be disposed of on the farm may be applied as infrequent spring top dressings to winter wheat with little or no reduction in grain yield and the possibility of benefit.

Spring Wheat

Spring wheat yields from the various cultural and crop-sequence methods under study are presented in table 15.

The 30-year average yield with all methods of producing spring wheat is 7.2 bushels to the acre. This may be compared with a similarly obtained average of 10.2 bushels of winter wheat. Annual average yields of spring wheat exceeded those of winter wheat in only 7 of the 30 years. In spite of improvement in spring wheat varieties, the region remains a winter wheat region.

Spring wheat does not respond so well as winter wheat to good cultural treatments. The 30-year average yield of spring wheat from two fallowed plots was 10.2 bushels an acre. The yield for the same period from two fallowed plots seeded to winter wheat was 16.3 bushels. Fallow does not increase yields of spring wheat enough to justify that preparation for the crop, but killed spots in fields of winter wheat seeded on fallowed land may be filled in with one of the good milling hard red spring varieties.

Spring wheat yields more nearly approach those of winter wheat on cornland. This is particularly true on the hard lands, where fall emergence of winter wheat on corn ground is difficult to obtain and where later hazards are consequently severe. Cornland in rotations without green-manure or sod crops produces higher yields when disked than when plowed either in fall or in spring. Cornland is probably better adapted to other spring-seeded crops, as barley, proso, or the grain sorghums, than to spring wheat.

A stubble plot, CCG, fall-plowed very late, produced 2.0 bushels an acre less spring wheat than was produced in the same years by CCB, which was plowed about August 15. This agrees with the yields of winter wheat from comparably treated plots, where the difference was 1 bushel. The yield of spring wheat from late fall plowing may have been proportionately lower because weeds were killed on the winter wheat plot when it was plowed about September 18. The spring wheat plot was not plowed until about November 20.

Three stubble plots fall-plowed about August 15 in rotations not containing crops that apparently depress yields produced a 30-year average yield of 6.5 bushels an acre. Two spring-plowed stubble plots from rotations similarly free from such crops produced average yields of 7.5 bushels. Early fall-plowed and

Table 15.—*Annual and average yields per acre (in bushels) of spring wheat from different crop sequences and soil preparations during the 30 years 1909–38*

Year	Early fall-plowed			Late fall-plowed	Spring-plowed			Fallowed	Disked	Subsoiled	Listed	Green-manured			Moldboard-plowed		Spring-disked	Spring-plowed
	Corn, 3[1]	Oats, 4, 8, 58	Wheat, CCB	Wheat, CCG	Corn, 2	Oats, 9	Wheat, CCA	Fallow, 5, CCC or CCD	Corn, 1, 31, 41, 42	Wheat, CCE	Wheat, CCF	Rye, 29	Peas, 30	Sweetclover, 32	Wheat, 4 inches	Wheat, 8 inches	Wheat, CCA″	Wheat, CCA′
1909	19.2	10.3	10.3	------	20.8	14.3	14.3	18.4	15.5	11.2	9.6	14.7	12.0	10.1	------	------	------	------
1910	11.2	5.8	6.2	------	15.3	6.3	11.3	12.2	11.4	5.5	7.1	11.7	12.4	3.8	------	------	------	------
1911	3.4	3.7	4.1	0	1.3	.3	2.9	4.8	1.7	1.5	1.2	3.3	1.8	1.7	------	------	------	------
1912	30.3	18.8	20.7	14.5	26.5	20.3	21.3	20.5	19.0	16.0	17.2	19.2	20.3	20.5	------	------	------	------
1913	1.4	.6	.8	.6	6.8	1.0	4.8	9.0	2.8	.5	2.1	1.5	1.5	3.9	------	------	------	------
1914	14.3	13.6	12.2	9.7	18.5	21.2	22.2	22.5	16.7	9.8	14.2	15.3	13.3	11.2	------	------	------	------
1915	31.2	24.1	25.8	22.2	30.0	26.5	26.3	32.7	27.7	23.7	23.7	28.7	23.5	26.2	------	------	------	------
1916	5.2	3.2	3.8	1.0	6.3	1.8	9.3	12.7	6.3	1.7	5.5	10.8	3.2	6.3	------	------	------	------
1917	16.5	10.9	16.2	11.3	15.7	16.0	19.3	16.1	10.0	10.3	12.7	13.8	8.8	20.8	------	------	------	------
1918	1.5	0	0	0	1.3	0	0	3.5	0	0	0	1.3	0	0	------	------	------	------
1919	8.0	8.8	11.0	2.3	9.0	3.5	7.5	10.6	4.4	6.0	5.5	7.0	4.3	5.0	3.7	4.5	------	------
1920	16.0	16.2	15.3	19.0	22.1	20.4	17.4	21.9	19.5	15.3	15.8	16.4	17.7	20.3	15.6	23.8	------	------
1921	1.7	4.3	4.0	.3	1.7	1.0	4.3	1.9	1.6	1.3	1.2	1.8	1.0	1.2	1.3	1.3	------	------
1922	8.2	5.9	4.2	2.3	6.7	9.8	6.7	10.6	4.5	3.3	4.7	6.2	9.3	6.0	9.3	7.3	------	------
1923	3.7	4.8	3.2	3.7	6.7	9.2	6.8	8.0	3.5	3.2	3.8	3.9	2.8	1.5	7.6	8.2	------	------
15-year average	11.5	8.7	9.2	------	12.6	10.1	11.6	13.7	9.6	7.3	8.3	10.4	8.8	9.2	------	------	------	------
1924	0	0	0	0	0	3.8	1.8	1.3	0	0	1.7	.7	0	0	1.7	2.8	------	------
1925	2.8	1.9	3.3	2.0	5.3	5.2	5.3	9.6	1.9	2.5	4.0	2.5	2.7	.2	3.3	4.0	------	------
1926	.3	.2	.5	.3	.7	0	.7	.7	.3	.3	.3	0	0	0	.3	.5	------	------
1927	15.8	11.2	9.8	5.2	9.8	14.5	11.7	13.4	12.9	6.5	8.3	9.5	9.8	6.0	14.7	12.7	------	------
1928	12.2	7.6	8.3	2.2	15.2	7.0	13.7	21.5	14.4	4.8	10.0	13.3	14.2	3.8	7.7	6.3	------	------
1929	.5	1.9	.8	.3	1.7	2.7	1.8	3.5	1.7	.8	1.0	4.3	2.2	.2	.5	1.8	------	------
1930	2.2	1.5	1.7	1.0	2.5	1.2	1.0	2.2	1.4	1.0	1.2	2.3	3.0	1.8	.8	1.0	1.3	2.0
1931	.5	.6	.5	.3	1.2	2.3	1.3	2.3	.8	1.0	.3	.5	.3	.3	1.5	1.3	1.7	1.3
1932	1.7	2.6	1.2	.3	6.7	4.2	3.2	8.7	5.9	.5	1.2	2.7	3.8	1.7	------	------	3.0	1.0
1933	0	.2	0	0	.8	1.0	0	2.6	.4	0	0	4.8	2.7	1.5	------	------	1.5	3.0
1934	0	0	0	0	0	0	0	1.6	0	0	0	1.0	1.7	1.8	------	------	0	0
1935	13.3	10.7	11.7	8.2	9.8	10.8	9.7	12.1	11.5	8.3	12.5	11.0	12.2	9.2	------	------	14.3	12.5
1936	4.2	3.6	3.2	1.7	3.2	4.3	2.7	8.1	5.4	2.5	4.5	7.2	6.0	6.8	------	------	5.0	3.7
1937	2.7	4.3	2.8	3.5	3.5	3.0	2.3	5.9	4.3	2.3	4.0	6.8	5.8	2.0	------	------	1.3	2.7
1938	5.7	6.1	5.2	3.0	6.2	5.7	3.7	6.5	6.2	3.8	6.8	7.8	7.7	4.3	------	------	7.2	4.5
15-year average	4.1	3.5	3.3	1.9	4.4	4.4	3.9	6.7	4.5	2.3	3.7	5.0	4.8	2.6	------	------	------	------
Average, all years	7.8	6.1	6.2	4.1	8.5	7.2	7.8	10.2	7.1	4.8	6.0	7.7	6.8	5.9	5.2	5.8	3.9	3.4

[1] Numerals or symbols in headings indicate rotation numbers or plots.

early fall-listed stubble land produced yields of the same order but lower than those on spring-plowed stubble land.

In 1930 a so-called poor method of preparing stubble land for early spring drill-seeded crops was begun by merely disking for wheat, oats, and barley. The CCA'' plots are disked each year and are directly comparable with the CCA' plots, which are spring-plowed continuously. This study is carried on at the extreme north side of the plot field. (See fig. 3.) The 9-year average yields from the two spring wheat plots, one moldboard-plowed and the other disked, are 3.3 and 3.9 bushels an acre, respectively. The plow apparently performed no essential function, but both treatments failed because a small-grain crop was followed by another small-grain crop on land without an adequate store of soil moisture.

The greatest objection to disking stubble land for early spring drill-seeded crops appears to be the matter of weed infestation. Moldboard plowing under such circumstances aids in controlling the immediate emergence of weeds. There are annually more weeds emerging with the grain on the stubbled-in plots in this study, but this weed problem has naturally solved itself. If the season is favorable, the crop shades out the weeds; if not, the plowed plots are only a little less weedy at harvesttime. Under these latter conditions the disked plots are actually easier to harvest because the size of a Russian-thistle has much to do with the ease with which it passes through a grain binder, header, or combine harvester. The greater competition on the disked plots holds down the size of the weeds.

Results with spring wheat show that its production by any method could be justified only by a sharply increased demand.

Oats

Oat yields from the various cultural and crop-sequence methods under study are presented in table 16. The average yields suffer in comparison with those of barley because the variety that now appears best adapted was not used in the rotations until 1931.

Oats are well suited to farm rotations because they appear to be able to produce some crop nearly every year, even on the poorest soil preparations, and because they respond sharply to better soil preparations and higher precipitation. A further value is that the straw is more palatable and more useful for feed than that of other cereals.

Following small-grain crops on nine plots oats produced a 30-year average yield of 16.4 bushels an acre. Five plots fall-plowed about August 15 produced an average yield of 16.3 bushels. Two comparable plots spring-plowed just prior to seeding about April 1 produced an average yield of 17.1 bushels. Listing stubble land about August 15 was at least equal to plowing and was safer from soil blowing. Two spring-plowed corn stubble plots produced an average yield of 20.3 bushels an acre. Two spring-disked corn stubble plots in rotations not containing organic amendments produced an average yield of 20.7 bushels. Here again the moldboard plow performed no essential function in seedbed preparation.

Oats were more productive on cornland than following small grains. The average yield of 20.5 bushels per acre from the four cornland plots mentioned may be compared with the average yield of 16.4 bushels on the nine plots following small grains.

Yields of oats on disked sorgo land, however, are about 16 percent lower than on comparable disked cornland. It was shown earlier in this circular that yields of winter wheat following sorgo were about 15 percent below those following corn. The lower yields following sorgo might be ascribed to the fact that total yields of sorgo exceed total yields of corn. Sorgo land appears to be little or no better for oats, and probably not for other crops seeded in fall or early spring, than small-grain stubble land.

The shorter growing grain types of sorghums should not be so hard on the soil as the forage sorghums, which records show (*2*) produce a much greater tonnage. There is no evidence, however, from the study covering oats alone that they are not equally hard on the land. During the 15-year period 1924–38, when early dwarf grain sorghums were used, two rotations producing oats on grain sorghum land returned an average yield of 14.5 bushels an acre. Two directly comparable rotations with oats on disked sorgo land produced an average yield of 14.0 bushels an acre. Both types of sorghum seem to use all the available soil moisture.

The three plots of oats on fallow produced an average yield of 27.7 bushels an acre. They, however, do not agree closely in yield. Rotation 8 produced the lowest yield, but it is probable that much of the difference was due to location.

TABLE 16.—*Annual and average yields per acre (in bushels) of oats from different crop sequences and soil preparations during the 30 years 1909–38*

Year	Early fall-plowed			Spring-plowed			Subsoiled	Early fall-listed	Summer-plowed	Disked		Green-manured			Fallowed	Spring-plowed	Spring-disked
	Wheat, 1, 3, 5[1]	Barley, 6	Oats, CCB	Wheat, 2	Oats, CCA	Corn, 7, 9	Oats, CCE	Oats, CCF	Sod crops, 41, 42	Corn, 4, 20, 28, 29, 30, 32, 91	Sorghum, 22, 24, 58, 93, 95	Rye, 26	Peas, 97	Sweetclover, 31	Fallow, 8, 81, CCC or CCD	Oats, CCA′	Oats, CCA″
1909	19.3	20.8	14.1	18.3	21.1	21.6	16.1	15.0	14.5	20.9	15.3	21.0	22.0	13.0	28.9	--------	--------
1910	14.1	10.2	8.0	14.8	10.9	20.8	11.3	11.1	2.5	18.2	8.5	20.0	11.9	5.2	17.1	--------	--------
1911	10.5	15.9	15.9	1.7	4.4	5.3	8.4	5.3	0	.4	0	2.7	0	3.9	7.1	--------	--------
1912	47.7	37.2	46.9	46.9	41.9	49.6	30.3	54.7	28.5	38.5	37.9	38.4	38.4	45.8	56.4	--------	--------
1913	7.6	.6	.6	16.6	6.6	5.0	0	3.6	1.8	7.3	5.5	5.0	1.3	5.0	16.5	--------	--------
1914	35.6	39.1	36.9	47.5	39.4	49.4	30.3	40.9	32.8	48.5	40.0	44.4	38.1	41.6	45.9	--------	--------
1915	55.9	57.2	57.2	56.9	56.9	71.4	57.5	50.0	41.9	68.5	64.8	76.6	69.1	76.0	79.2	--------	--------
1916	2.6	7.8	7.2	2.2	9.1	12.7	4.1	13.1	.8	18.0	10.1	15.6	8.1	5.0	22.5	--------	--------
1917	25.8	28.8	29.7	39.1	38.1	32.1	28.4	31.3	6.7	25.7	19.2	37.2	20.0	21.3	35.4	--------	--------
1918	0	0	0	0	0	0	0	1.3	0	.5	0	5.5	0	0	7.7	--------	--------
1919	24.4	27.8	32.8	11.6	24.7	17.4	30.0	25.3	6.4	11.9	3.8	17.5	11.9	23.8	31.8	--------	--------
1920	21.2	36.3	34.9	45.8	39.0	47.0	50.9	35.9	36.8	55.7	44.5	43.9	56.3	35.8	49.1	--------	--------
1921	14.2	21.6	14.7	6.6	10.0	11.3	19.1	10.3	7.2	13.2	7.7	17.8	17.8	4.1	24.3	--------	--------
1922	10.1	12.5	12.2	18.8	19.7	16.6	6.6	5.9	2.4	18.7	13.7	20.9	18.1	14.7	31.5	--------	--------
1923	8.5	14.2	9.7	14.1	16.7	20.7	12.8	13.7	7.6	15.1	14.1	15.1	11.9	7.6	23.9	--------	--------
15-year average	19.8	22.0	21.4	22.7	22.6	25.4	20.7	21.2	12.7	24.1	19.0	25.4	21.7	20.2	31.8	--------	--------
1924	1.4	1.3	1.9	15.0	8.4	4.4	1.6	11.3	3.2	5.7	5.2	6.6	3.4	2.8	14.7	--------	--------
1925	3.9	5.6	5.0	8.1	3.1	11.1	3.8	10.3	2.8	7.5	4.8	1.9	3.8	1.9	16.4	--------	--------
1926	.8	.9	1.6	1.6	3.1	1.9	1.6	1.3	.8	.7	.7	.3	.3	0	2.2	--------	--------
1927	31.9	46.9	35.0	40.6	29.4	35.4	26.6	30.9	29.9	31.5	28.8	31.9	32.8	26.6	50.8	--------	--------
1928	9.7	10.9	18.8	13.4	20.6	37.7	13.1	26.3	27.4	44.4	46.1	31.6	28.1	9.1	56.2	--------	--------
1929	.5	1.3	1.6	3.1	1.3	1.9	.6	1.6	1.1	.9	.6	2.2	1.3	1.6	5.8	--------	--------
1930	6.0	7.8	5.0	3.4	2.8	5.9	4.4	3.4	3.4	6.6	5.4	8.1	6.9	5.9	9.1	7.2	5.3
1931	4.0	5.9	4.4	8.4	1.6	10.2	3.8	3.1	3.8	9.7	6.5	12.2	11.6	3.1	10.3	8.1	4.1
1932	6.9	4.7	7.8	11.3	5.9	17.2	5.3	5.6	5.0	19.0	11.7	5.6	8.4	8.4	30.7	10.3	6.9
1933	5.1	6.6	6.6	6.9	4.7	4.1	5.9	6.6	4.7	6.6	7.2	12.5	7.2	12.8	18.0	9.7	9.7
1934	0	0	0	0	0	0	0	.6	0	.3	0	0	0	0	1.6	0	0
1935	38.7	54.1	49.4	38.4	32.5	35.0	36.9	46.6	30.7	38.7	34.5	37.2	29.7	40.0	43.3	39.1	37.5
1936	9.9	15.3	12.2	10.9	8.1	13.3	10.3	18.8	27.7	21.3	23.3	23.8	27.2	21.3	34.7	13.8	12.2
1937	10.6	11.3	9.7	8.8	5.9	12.5	8.4	9.4	10.8	14.2	14.1	19.4	19.7	8.1	22.4	8.4	3.4
1938	30.7	54.7	28.1	24.1	24.1	36.0	21.3	29.1	20.5	26.3	22.8	34.4	32.8	23.1	37.7	21.6	21.9
15-year average	10.7	15.2	12.5	12.9	10.1	15.1	9.6	13.7	11.5	15.6	14.1	15.2	14.2	11.0	23.6	--------	--------
Average, all years	15.3	18.6	16.9	17.8	16.3	20.3	15.1	17.4	12.1	19.8	10.6	20.3	17.9	15.6	27.7	13.1	11.2

[1] Numerals or symbols in heading indicate rotation numbers or plots.

Oats are a favored grasshopper food, and this rotation was on the western edge of the station plot field where it was bordered by a fence line frequently infested with grasshoppers. It is altogether likely that the oat yield of rotation 8 was reduced below the level of that of the other two plots through greater grasshopper damage. The average yield of the other two plots was 29.6 bushels, which probably better represents the yield that should be obtained on fallow.

The oat yields on sod were substantially equal for the two 15-year periods and were lower than in other sequences. Oat yields on other preparations were much lower during the second period than during the first. The two types of sod, alfalfa and bromegrass, were plowed at about the same time. During the first 15-year period the average date was August 12, and during the second period it was July 9. The land was then clean-cultivated until oats were seeded the following spring. The comparative yields during the two periods are probably affected not only by the difference in the dates of midsummer plowing but also by the presence or absence of sod to be turned under. During the second 15-year period very few stands of alfalfa or bromegrass were obtained.

In these rotations sod crops (or weeds when it was not possible to obtain and maintain stands of sod crops) occupied the land for 3 successive years before being plowed, and annual crops then occupied the land 3 years. It is reasonable to expect then that the sod was normally at least as dry at plowing time as land that had grown an annual drilled crop the previous year and had not been disturbed until the plowing date. Since there was very little sod to plow under during the second 15-year period, any reduction in oat yield below that on fallowed land should be almost wholly chargeable to the midsummer plowing. The average yield of these two plots for the second 15-year period was 51 percent below the yield on fallowed land plowed at the regular time. This checks closely with winter wheat results over a similar period of years, when delayed plowing for fallow until July 5 reduced the yield 41 percent. During the period 1909–23, when sod was on the land in more years and when plowing was done at a later date, the yields on sod land were only about one-third of those on fallow.

Oats, like winter wheat, extract all the soil moisture provided in fallowed land and leave a typically dry stubble. Proof of this is provided by 3-year rotations 4, 8, and 9. Rotation 8 is fallow, oats, and spring wheat; in rotations 4 and 9 corn replaces fallow. The average yield of spring wheat following oats on cornland in rotations 4 and 9 was 7.2 bushels per acre; the yield of spring wheat following oats on fallow in rotation 8 was only 6.2 bushels.

Spring-plowed oat stubble land in the comparison of plowing and disking studies produced an average yield of 13.1 bushels an acre over the 9-year period 1930–38. A comparable spring-disked stubble plot produced an average yield of 11.2 bushels. This is the only case where moldboard plowing of stubble land was noticeably better than disking.

Oats on land where bean varieties had been grown produced an average yield of 21.3 bushels for the 12-year period 1927–38. Oats on rotation 4, the best yielding plot on disked cornland, produced an average yield of 20.4 bushels for the same period. The results with oats agree with those of winter wheat, where it was shown that yields on bean land were equal to those on cornland.

Average acre yields of oat straw were approximately as follows: From stubble land, 800 to 900 pounds an acre; from row-crop land, 1,000 to 1,100 pounds; and from fallow, about 1,700 pounds.

Barley

Barley, another crop that appears to be well adapted to the region, has produced more pounds of grain an acre than other spring-grown cereals. The number of plots in the cultural study block is limited, but the responses to different crop sequences and tillage methods appear to be much the same as in oats. The yields from the various cultural and crop-sequence methods under study are presented in table 17.

The average yield of 15.5 bushels to the acre on stubble land fall-plowed at an average date of August 15 was only 0.2 bushel lower than on land plowed just prior to early spring seeding. Listing stubble land about August 15 resulted in yields nearly equal to those on fall-plowed land and did not induce soil blowing. The response to fallow was excellent, the 30-year average yield being 28.1 bushels an acre. There was no total failure on fallowed land during the 30 years.

One disked cornland plot in rotation 6, the only plot of cornland in a rotation not containing a green manure, produced an average of 20.2 bushels an acre. Three plowed small-grain stubble-land plots yielded an average of 15.6 bushels,

TABLE 17.—*Annual and average yields per acre (in bushels) of barley from different crop sequences and soil preparations during the 30 years 1909–38*

Year	Early fall-plowed	Spring-plowed		Sub-soiled	Early fall-listed	Fal-lowed	Disked	Spring-plowed	Spring-disked
	Barley, CCB[1]	Barley, CCA	Oats, 7	Barley, CCE	Barley, CCF	Fallow, CCC or CCD	Corn, 6, 51, 92	Barley, CCA'	Barley, CCA''
1909	16.8	19.7	22.2	19.8	19.2	24.6	18.7	-------	-------
1910	10.5	13.1	10.2	6.9	12.6	16.0	12.9	-------	-------
1911	16.3	8.7	2.3	5.2	4.6	12.6	1.7	-------	-------
1912	27.9	28.8	35.2	22.5	36.0	40.2	28.9	-------	-------
1913	3.1	4.6	7.9	1.5	4.4	16.3	6.4	-------	-------
1914	36.7	32.1	40.2	27.9	30.8	46.3	42.0	-------	-------
1915	47.9	43.1	50.0	52.3	46.0	73.7	60.5	-------	-------
1916	5.0	4.4	6.5	4.2	9.4	20.4	16.4	-------	-------
1917	26.9	27.3	32.9	13.5	29.2	38.3	23.1	-------	-------
1918	1.0	2.1	3.1	0	4.4	11.3	5.5	-------	-------
1919	23.7	18.8	18.3	15.8	20.4	33.5	11.4	-------	-------
1920	23.4	19.6	29.3	31.9	30.1	41.9	37.5	-------	-------
1921	10.8	7.5	7.5	10.6	11.7	34.2	14.8	-------	-------
1922	7.7	9.5	15.8	6.9	5.0	24.6	11.8	-------	-------
1923	13.0	16.9	20.0	13.8	15.1	29.8	19.7	-------	-------
15-year average	18.0	17.1	20.1	15.5	18.6	30.9	20.8	-------	-------
1924	.8	6.5	5.0	.6	5.2	11.5	2.4	-------	-------
1925	1.3	7.7	5.8	.6	2.7	18.1	3.3	-------	-------
1926	1.0	1.7	2.3	1.0	2.7	5.6	2.2	-------	-------
1927	34.8	37.9	34.8	20.2	23.3	51.0	28.6	-------	-------
1928	19.8	23.3	23.3	15.2	21.7	67.5	45.3	-------	-------
1929	.8	1.3	1.0	.4	1.0	6.0	.6	-------	-------
1930	15.2	10.4	11.0	7.5	8.5	15.0	10.2	9.6	9.8
1931	5.0	5.2	9.8	4.4	5.2	25.4	9.0	4.6	4.4
1932	4.8	4.0	7.3	3.1	6.0	16.0	8.7	7.3	5.0
1933	5.2	3.3	6.9	2.9	3.1	16.3	7.7	7.9	9.2
1934	1.5	.4	0	.6	.6	8.1	.8	0	0
1935	57.3	51.6	44.6	39.2	45.2	57.3	42.0	39.0	34.2
1936	10.0	10.6	15.0	10.0	13.8	30.4	20.9	9.8	15.6
1937	11.0	6.0	4.6	11.3	7.7	23.3	12.2	6.0	2.5
1938	26.3	17.9	21.7	19.0	16.7	28.3	29.2	11.0	11.9
15-year average	13.0	12.5	12.9	9.1	10.9	25.3	14.9	-------	-------
Average, all years	15.5	14.8	16.5	12.3	14.7	28.1	17.8	10.6	10.3

[1] Numerals or symbols in headings indicate rotation numbers or plots.

ranging from 14.8 to 16.5 bushels. Cornland is a much better preparation for barley than stubble land.

In 1930 a study of seedbed preparations for corn was begun, with corn in 2-year rotations with barley. The principal difference among them was in the method of preparing the land. Yields (not shown in the table) of these five plots on disked cornland vary considerably. How much of the variation can be accounted for by the method of preparing the land for corn is questionable.

Two plots of continuous barley, one on spring-plowed land and one on spring-disked land, produced 9-year average yields of 10.6 and 10.3 bushels, respectively, a difference too small to be considered significant.

Barley straw yields were about 900 to 1,000 pounds an acre from stubble and cornland seedings and about 1,700 pounds from fallowed land.

CORN

Corn was the leading row crop when these experiments were begun, but well-adapted grain sorghums that mature at this altitude now produce higher yields on the hard lands. Being row crops, both probably respond similarly to different cultural treatments. Experiments with sorghums, unfortunately, are not nearly so complete as those with corn. In the following discussion of corn yields, rotations with green-manure or sod crops are not included, as they appear to depress the yields of the other crops. The results are summarized in table 18.

Six fall-plowed grain stubble plots produced an average acre yield of 10.2 bushels, and three spring-plowed plots averaged 10.6 bushels. Plowing about August 15 was no more effective in preparing stubble land for corn than timely spring working. If fall working is to be a better preparation than timely spring

TABLE 18.—*Annual and average yields (in bushels) of corn (grain) from different cultural treatments and in different crop sequences by periods during the 30 years 1909–38*

Year	Main field													Cultural studies								
	Early fall-plowed			Late fall-plowed	Spring-plowed					Subsoiled	Listed		Fallowed	Spring-plowed		Spring-listed				Spring-listed, split ridges	Fall-listed	
	Oats, 1, 3, 6, 26, 81, 97[1]	Spring wheat, 4, 29, 30	Winter wheat, 20, 28, 91	Corn, CCB	Oats, 2, 31, 41, 42	Barley, 7	Spring wheat, 9, 32	Winter wheat, 51, 92, 251, 252	Corn, CCA	Corn, CCE	Winter wheat, 149	Corn, CCF or CCG	Fallow, CCC or CCD	Barley, 17	Barley (straw returned), 20	Winter wheat, 13, 14	Barley, 15	Barley (straw returned), 19	Corn, CCG'	Barley, 18	Barley, 16	Corn, CCF'
1909	26.8	22.2	22.7	27.3	25.9	21.7	21.1	22.2	30.0	32.9	------	26.1	25.0	------	------	------	------	------	------	------	------	------
1910	8.0	6.1	8.7	18.3	7.4	16.6	14.6	10.7	21.6	12.7	------	15.1	21.4	------	------	------	------	------	------	------	------	------
1911	7.0	5.8	1.8	0	.5	0	.4	.4	1.3	0	------	1.3	12.9	------	------	------	------	------	------	------	------	------
1912	30.1	32.5	27.4	46.9	28.0	34.9	36.7	29.3	33.9	37.1	------	22.0	33.6	------	------	------	------	------	------	------	------	------
1913	1.0	0	0	9.9	2.6	9.9	0	9.3	13.6	4.3	------	9.0	13.8	------	------	------	------	------	------	------	------	------
1914	11.0	7.0	8.2	17.3	11.9	13.9	11.3	12.2	15.9	13.9	------	9.5	18.6	------	------	------	------	------	------	------	------	------
1915	31.9	31.1	29.6	29.2	33.5	30.3	30.9	28.6	21.9	22.3	21.3	19.6	19.6	------	------	------	------	------	------	------	------	------
1916	0	0	0	4.8	0	0	0	0	7.1	3.2	0	2.4	9.7	------	------	------	------	------	------	------	------	------
1917	12.7	13.1	13.7	21.9	13.2	16.7	15.0	22.1	25.1	20.6	2.4	8.2	27.4	------	------	------	------	------	------	------	------	------
1918	7.9	8.9	8.8	12.6	10.3	13.4	11.5	10.8	13.1	18.5	8.4	29.7	32.6	------	------	------	------	------	------	------	------	------
1919	6.5	4.5	3.8	5.0	.9	5.9	1.3	3.2	4.1	5.8	5.4	8.0	8.4	------	------	------	------	------	------	------	------	------
1920	35.1	35.1	31.7	36.9	38.2	36.9	35.4	41.3	35.5	35.9	29.4	29.6	40.1	------	------	------	------	------	------	------	------	------
1921	4.8	5.5	6.6	3.1	3.7	9.5	6.4	8.5	7.0	3.5	9.8	9.4	19.0	------	------	------	------	------	------	------	------	------
1922	8.8	9.8	8.2	15.3	8.0	11.7	7.7	8.9	14.7	15.0	14.7	22.5	29.6	------	------	------	------	------	------	------	------	------
1923	13.0	17.3	16.1	19.9	19.5	15.1	24.5	25.3	19.1	17.9	0	9.4	35.3	------	------	------	------	------	------	------	------	------
15-year average	13.6	13.3	12.5	17.9	13.6	15.8	14.5	15.5	17.6	16.2	------	14.8	23.1	------	------	------	------	------	------	------	------	------
1924	.8	.8	1.0	1.1	2.2	3.9	4.9	1.8	1.6	1.1	0	1.2	7.5	------	------	------	------	------	------	------	------	------
1925	0	0	0	.8	0	0	0	.8	2.0	.9	0	2.6	13.3	------	------	------	------	------	------	------	------	------
1926	10.7	10.7	8.2	7.7	6.1	13.1	5.5	8.1	7.9	6.0	8.3	5.1	13.6	------	------	------	------	------	------	------	------	------
1927	8.9	9.4	7.7	7.6	7.4	8.5	7.8	9.6	6.0	10.5	2.8	6.5	9.0	------	------	------	------	------	------	------	------	------
1928	6.0	6.9	6.0	17.4	5.0	9.2	6.0	6.4	17.8	14.3	8.6	14.8	18.7	------	------	------	------	------	------	------	------	------
1929	15.2	13.8	15.2	13.6	14.0	16.4	13.7	12.5	16.3	10.9	4.6	10.6	17.3	------	------	------	------	------	------	------	------	------
1930	25.0	19.1	15.5	21.4	22.7	28.8	23.8	13.8	25.5	18.3	21.9	22.3	19.1	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1931	0	0	0	0	.4	.3	.5	1.3	0	0	1.6	.9	.3	0	3.6	1.1	0	3.1	2.0	4.6	0	0.3
1932	3.9	1.8	2.0	12.8	1.8	2.4	1.4	2.3	16.1	3.2	------	15.1	2.4	3.2	2.8	9.3	12.2	7.8	6.8	9.3	10.8	3.9
1933	3.2	2.3	2.7	7.9	2.7	2.3	4.3	4.8	9.2	9.9	------	8.7	19.6	5.1	7.3	8.9	11.9	3.2	5.5	4.5	7.6	5.3
1934	0	0	0	.4	0	0	0	0	.7	.7	------	1.6	2.3	0	0	1.3	.4	0	2.0	.4	1.2	.5
1935	13.3	11.8	11.7	11.2	6.2	7.2	8.0	11.1	15.1	13.7	------	13.7	14.5	13.5	8.7	18.3	22.0	10.0	15.9	14.7	19.7	19.9
1936	2.3	1.8	2.3	3.9	1.2	2.0	1.4	2.4	5.9	4.5	------	12.7	19.9	5.6	1.9	8.8	7.7	4.0	14.7	4.3	6.5	14.8
1937	0	.8	.7	1.7	0	0	0	1.7	1.5	2.3	------	3.4	11.2	.8	1.3	.8	0	0	.9	0	.7	1.6
1938	1.1	.5	.7	2.7	.7	.5	.5	.6	2.0	2.7	------	2.7	9.3	1.1	.7	1.5	.1	.8	2.7	1.2	2.8	2.9
15-year average	6.0	5.3	4.9	7.3	4.7	6.3	5.2	5.1	8.5	6.6	------	8.1	11.9	------	------	------	------	------	------	------	------	------
Average, all years	9.8	9.3	8.7	12.6	9.1	11.0	9.8	10.3	13.1	11.4	8.2	11.5	17.5	3.7	3.3	6.3	6.8	3.6	6.3	4.9	6.2	6.2

[1] Numerals or symbols in headings indicate rotation numbers or plots.

[2] Yields were obtained from these plots in 1930, but irregular stands made the yields unreliable and their use inadvisable in averages where the production for this 1 year constituted so great a proportion of the whole.

culture, it must be done immediately after header or combine harvest, especially when the stubble promises to grow considerable vegetation that fall. If it cannot be done before August 15, its only possible value is in better distribution of field work.

Among these fall-plowed plots, four following oats produced an average yield of 10.5 bushels an acre, one following spring wheat 9.6 bushels, and one following winter wheat 9.5 bushels.

Spring-plowed plots on barley, oats, and spring wheat stubble produced corn yields between 10 and 11 bushels to the acre. The yield on barley stubble was highest and that on wheat stubble lowest. The common opinion among observant farmers that the stubble of oats and barley is more favorable than spring or winter wheat stubble for crops that follow was confirmed by the small but consistent difference in yield shown on both the fall- and the spring-worked stubble plots planted to corn. Oats and barley are regularly harvested earlier than winter or spring wheat, leaving a little longer period after harvest for possible replenishment of soil moisture by rainfall.

Cornland was a better preparation for corn than small-grain stubble, as it produced average yields ranging from 11.4 to 13.1 bushels an acre. Cornland ranked between stubble land and fallow as a preparation for all succeeding crops, even winter wheat, for which it was pointed out that the additional winter-killing hazard makes this method of planting inadvisable. It may be said that at the end of 30 years corn follows itself better than it follows any other crop or treatment except fallow. There have been no troublesome diseases or insect enemies that make it undesirable to grow corn continuously on the same land. Corn was binder-harvested on all plots in this study in all years and the fodder removed. There was little surface obstruction of these plots to catch blown snow over the winter period, yet over the entire period the spring-plowed cornland averaged 13.1 bushels, or 0.5 bushel more than the fall-plowed. This slight difference in yield may be due to excessive aeration of the furrow slice on late fall-plowed land over the dry winter period. The greatest difference in favor of spring plowing, 1.2 bushels an acre, was during the second 15-year period, when the winter precipitation was deficient, and the drying out of very late fall-plowed land was most likely a factor. Fall-plowed cornland plots and plots with the short corn stubble still standing should be about equal in their natural ability to catch snow, especially since this late fall-plowed land nearly always turned up dry and cloddy. Any difference in moisture retention was not due to the extent of surface obstruction. Loosening the furrow slice immediately in advance of a period of such low precipitation as the winter period appears inadvisable, except when necessary to prevent soil blowing.

During 12 of the years from 1909 to 1923, one of two corn-stubble plots was fall-listed and "nosed out" at seeding time and the other spring-listed at seeding. Over this period the corn yield on fall-listed land was 2.9 bushels an acre higher than on spring-listed land.

During this particular period, however, the yield on fall-plowed cornland exceeded that on spring-plowed cornland by 1.8 bushels. The yield on the fall-plowed plot was higher than on the fall-listed plot. Corn stubble land listed in fall over the period just specified and in spring the rest of the 30-year period produced an average acre yield of 12.1 bushels. Over this same period the fall-plowed and spring-plowed corn stubble plots produced average yields of 12.6 and 13.1 bushels an acre, respectively. The advantage of listing over plowing is due to its ease and economy and to the greater soil-blowing protection it affords.

Comparison between two corn stubble plots planted to corn with a lister, one of which was early spring-cultivated and the other left untouched until planting, was possible in 16 years. The difference in yield in favor of early spring working was only 0.6 bushel an acre. The benefit of early working in seedbed preparation for corn and other lister-planted row crops, however, is greater than is shown by the difference in yield. Land early spring-worked lists easily, whereas that not worked until planting time is often so dry and hard that listing is difficult and costly, and planting in the same operation places the seed in a cloddy seedbed. This is particularly true when the spring has been unusually dry prior to the seeding date. It is good practice to perform this early spring work to insure economy in later field operations, particularly on nearly bare soil, such as is left after harvesting row crops. Fall listing is more advantageous than spring listing in years when the roughened surface catches more snow than the stubble of harvested row crops. Such fall working may also be indicated to create a surface that resists soil blowing. Upending the root clumps of harvested row crops, other than beans, often prepares a rougher, more secure surface than the stubble left in harvesting.

Corn produces a higher acre yield of grain on fallow than on any other preparation under study, but its average increase over five plots of corn after corn was only about 46 percent, which is not a satisfactory response. In rotations corn may be planted for several successive years on the same land. The yields of corn after corn will be 10 to 20 percent higher than those after small grains as the stubble is ordinarily handled.

In the 2-year rotations 251 and 252 the yield of winter wheat grain was lower and the yield of straw higher in the manured rotation. This manure was plowed under directly in advance of the corn. The results for corn resembled those for winter wheat in that the grain yield was lower and the stover yield higher on the manured rotation. The depressing effect of the manure on the corn was not noticeable from one application, but whether this was due to the type of season is not certain, since annual results vary so widely. It is probable that manure can be occasionally applied as a top dressing to winter wheat in a 2-year rotation of winter wheat and corn without reducing yields. Sandy lands should profit from more applications of humus and fertility elements, and spreading barnyard manure in advance of lister-planted corn may be a good practice.

Listing winter wheat stubble land for corn was practiced in a 2-year rotation (149) from 1915 to 1931. This rotation was at the extreme southwestern corner of the plot near the railroad right-of-way, and ground squirrels damaged the stands, particularly in 1923 and 1924. Severe grasshopper damage followed the harvest of adjoining wheat plots in 1917, 1925, 1927, and 1929. The average yield from the listing for the other 11 years was 11.8 bushels an acre. The average from fall-plowed winter wheat stubble land in rotation 28 for the same years was 12.0 bushels. Listing was done in spring about half the time and in fall the rest. During the years that it was done in fall, yields were higher than on the fall-plowed land. Moldboard plowing in spring or fall and surface planting is more expensive than listing and planting, even when planting is done in the bottoms of the old furrows as a separate operation. The lister method thus is a more practical way to prepare stubble land for corn than moldboard plowing, even though the yields may be no higher.

Six rotations of corn and barley were established mainly to determine the best method of preparing the stubble land for corn. Yields for these rotations for the 8 years 1931–38 are also shown in table 18.

The methods of field preparation for corn used on the different rotations (15–20) were as follows:

15. Spring-listed; lister-planted in same furrows.
16. Early fall-listed; lister-planted in same furrows.
17. Spring-plowed; surface-planted with furrow openers.
18. Spring-listed; lister-planted by splitting ridges.
19. Straw returned; fall- and spring-disked; lister-planted.
20. Straw returned; fall-disked, spring-plowed; surface-planted with furrow openers.

Early fall-listed barley stubble produced a yield of corn 0.6 bushel lower than spring-listed barley stubble. Fall-listed corn stubble produced a yield 0.1 bushel lower than spring-listed corn stubble. In spite of this, fall listing is recommended in years when row-crop stubble is thin or short and there is danger of soil blowing. Such row-crop stubble may be fall-worked so that the root clumps are upended, which will almost always prevent soil blowing and make it possible for the land to retain more of the winter precipitation. A tall thick row-crop stubble probably holds snow and conserves moisture as effectively as any method of fall working that can be done.

The yield of corn on all plots of spring-plowed barley stubble was 1.6 bushels an acre lower than on all plots of spring-listed barley stubble. During the same series of years the acre yield on spring-plowed corn stubble in the main field was 1.9 bushels lower than on cornland not listed until planting. This indicates that much of the difference shown between the two methods in this study is due to the fact that the period 1931–38 was generally favorable for listing.

Listing barley stubble land in spring and splitting the ridges at planting produced lower yields than listing in fall or spring and planting in the same furrows. On the hard lands of this section nosing out old furrows provides a better seedbed than making new furrows when listing at planting time. This is further evidenced by rotation 19, which was kept free from weeds during fall and early spring with a disk and planted with a lister, and by results elsewhere in the Plains. If land listed in fall or early spring becomes weedy, it is more profitable to kill the weeds by a cultivation than by splitting the ridges at planting. Splitting the ridges in planting does not appear to reduce yields on sandy lands and may be beneficial.

Rotations 19 and 20 in this group were begun to determine the effect of leaving all the barley straw on the land. The plots were harvested with a binder, and the straw was returned after threshing. The average quantity of straw returned during this series of drought years was about 100 pounds to a tenth-acre plot. Since these plots were kept free from weeds by disking in fall and spring they are not exactly comparable with rotations 17 and 18, where the stubble was left undisturbed until plowing or listing in spring, but they permit some comparisons.

Rotation 20 produced an average yield 0.4 bushel lower than rotation 17, which was likewise spring-plowed but did not receive an application of straw. The slightly lower yield may have been due to the effect either of fall disking on rotation 20 or of turning under the straw. Rotation 19 resembles rotation 18 in that the corn was planted in new lister furrows, but its average yield was 1.3 bushels an acre lower. As with the preceding pair, the lower yield may have been due to either of two causes.

It appears reasonably evident that straw in addition to that left by the binder does not increase the yields of following crops and may reduce them. There is little doubt that plowing under large quantities of undecomposed matter is undesirable under dry-land conditions.

In the group of years covered by this experiment, listing was generally superior to plowing and confirms the following statement made in Farmers' Bulletin 773 (*11, p. 14*): "In some semiarid sections early summer conditions are favorable for rapid growth. The plants make a tender, rapid growth and become larger than the later moisture supply will support. Listing retards this rapid early growth and is often a decided advantage on this account."

Listing and planting in one operation promotes the slowest growth, but this method often results in faulty stands on the hard lands, Nosing out previously made furrows produces a growth intermediate between listing and planting in one operation and surface planting Stands on this method are better than where the first listing is done at planting time. Surface planting promotes early growth too vigorous to be maintained if later conditions are not favorable. In good years the highest corn yields are generally produced on surface-planted land. For dependable production, however, listing in advance of planting and nosing out the samo furrows at planting time is recommended.

The yield of stover on surface-planted land was higher than on listed land. This further indicates that the advantage of listing is the smaller vegetative growth that reserves more of the moisture supply for the formation of grain. An additional factor in favor of listed corn is that it is better braced to withstand severe winds. When lister furrows are closed by cultivation, the roots are covered to a depth of several inches. Surface-planted corn in this section seldom sends out brace roots from the lower node.

Listed corn at the Akron station may be expected to produce average stover yields ranging from 1,100 to 1,400 pounds an acre. This is typical of what may be expected on the hard lands. Stover yields of surface-planted corn will average almost 300 pounds higher.

Grain Sorghums

Red, Dwarf Blackhull, and Dawn varieties of kafir were grown from 1909 to 1926, and a mature crop of grain was harvested in only 2 years, 1914 and 1923. Dwarf Yellow milo grown on the rotations from 1909 to 1921 also failed to mature. In this period of cool summer temperatures the grain sorghum varieties then available were not suitable for the locality. The kafir varieties at least returned yields of palatable forage that compared favorably with those of the forage sorghums over the first 15 years. Milo was grown strictly for grain, and since it failed in that it seemed better that the land be used for an extension of the limited cultural methods covering the forage sorghums. This change was made in 1922. The grain and fodder (total) yields of kafir are presented in table 19, but yields of milo stover for the period it was grown are not shown.

Otis kafir was used in the rotations from 1926 to 1930, because it was the first grain sorghum variety of a free-shelling nature acquired that promised to be early enough to mature. It did not, however, produce as much grain as Coes in the station's grain sorghum variety experiment. No initial stands were obtained in 1930, and a delayed replanting with a forage variety was made to prevent a fallow condition; that year is omitted from the table. A yellow kafir, later named Kalo, made a good showing in the variety experiment in 1930 and was used on the cultural study plots from 1931 to 1934, but proved to be dangerously late. Coes was then introduced and used through 1938. The yields from

TABLE 19.—*Annual and average yields (in bushels or pounds) of kafir from different cultural treatments and crop sequences during the 30 years 1909–38*

Year [1]	Grain yields (bushels)				Total weight (pounds)			
	Fall-plowed		Spring-plowed	Listed	Fall-plowed		Spring-plowed	Listed
	Wheat, 22, 93 [2]	Kafir, CCB	Kafir, CCA	Kafir, CCF	Wheat, 22, 93	Kafir, CCB	Kafir, CCA	Kafir, CCF
1909	-----	-----	-----	-----	10, 125	12, 950	11, 300	6, 500
1910	-----	-----	-----	-----	3, 830	2, 420	3, 080	1, 540
1911	-----	-----	-----	-----	4, 245	2, 930	2, 340	3, 020
1912	-----	-----	-----	-----	5, 080	4, 100	3, 740	2, 200
1913	-----	-----	-----	-----	1, 560	2, 740	3, 460	2, 050
1914	16. 4	15. 7	18. 5	22. 3	3, 400	3, 500	3, 900	3, 520
1915	-----	-----	-----	-----	3, 570	1, 300	2, 800	700
1916	-----	-----	-----	-----	1, 580	2, 450	1, 340	620
1917	-----	-----	-----	-----	2, 900	3, 700	5, 060	2, 000
1918	-----	-----	-----	-----	3, 175	3, 800	5, 250	2, 800
1919	-----	-----	-----	-----	4, 550	2, 620	3, 900	5, 000
1920	-----	-----	-----	-----	5, 010	5, 040	4, 380	1, 200
1921	-----	-----	-----	-----	2, 495	2, 920	2, 420	1, 100
1922	-----	-----	-----	-----	5, 000	5, 200	5, 450	6, 950
1923	14. 0	6. 7	12. 0	1. 2	3, 575	1, 950	2, 450	500
15-year average	-----	-----	-----	-----	4, 006	3, 841	4, 058	2, 647
1924	0	3. 0	2. 8	18. 3	600	540	850	2, 450
1925	0	0	0	0	575	300	500	200
1926	11. 3	14. 3	18. 2	16. 7	1, 925	2, 700	2, 800	4, 750
1927	0	. 3	2. 8	0	225	500	1, 200	0
1928	. 4	1. 2	. 8	0	700	1, 150	1, 150	150
1929	2. 1	4. 0	2. 8	0	1, 050	1, 300	800	0
1931	4. 0	3. 7	1. 5	5. 3	1, 050	1, 100	400	1, 100
1932	2. 4	3. 0	4. 0	5. 5	1, 375	2, 750	1, 850	1, 700
1933	6. 7	10. 3	9. 2	15. 8	2, 275	2, 550	2, 800	2, 500
1934	0	. 3	. 2	. 3	575	300	250	650
1935	9. 9	3. 0	5. 3	5. 3	2, 375	1, 200	1, 350	1, 550
1936	9. 6	17. 2	14. 5	11. 5	1, 850	2, 900	2, 700	2, 200
1937	5. 2	11. 2	6. 7	13. 5	1, 300	1, 550	950	1, 600
1938	5. 0	7. 5	5. 0	1. 7	825	1, 100	800	400
14-year average	4. 0	5. 6	5. 3	6. 7	1, 193	1, 424	1, 314	1, 375
29-year average	-----	-----	-----	-----	2, 648	2, 674	2, 733	2, 033

[1] No plots were planted to kafir in 1930.
[2] Numerals or symbols in headings indicate rotation numbers or plots.

1924 to 1938 are useful in determining the crop's reaction to different cultural and crop-sequence practices. Kafir yields on two continuously cropped plots, fall and spring moldboard-plowed, yielded well together and about 1.5 bushels to the acre higher than the average of two winter wheat stubble plots. Fall plowing row-crop stubble is not advisable, as the yield is not increased and it may create a soil-blowing hazard. The plot listed continuously returned the highest 14-year average yield—more than 1 bushel an acre above those of the plowed plots.

In another experiment on soil of the same hard-land type Coes and Highland kafirs produced average yields from 1929 to 1937 that were 63 and 100 percent, respectively, higher than those of field corn grown in the same experiment (fig. 5) (*2*).

While listing and lister planting returned a heavier average grain yield than moldboard plowing and surface planting, it generally resulted in more replanting

FIGURE 5.—Comparative yields of Coes and Highland kafirs and corn at the Akron Field Station, 1929–37.

and more faulty stands. When the crop is continuous, however, as in this experiment, lack of stand one year may leave soil moisture to benefit the next year's crop. Such a carry-over of moisture is responsible for the higher yields from listing in 1924 and 1937. It would seem that for satisfactory stands each year surface planting would prove safer and better. In this respect sorghums differ from corn, for which lister planting is a recommended practice. These yields, however, show, that moisture stored deep in the soil remains rather safely sealed against loss by surface evaporation.

Fall plowing, spring plowing, and listing grain stubble land for sorghums have not been compared in these experiments, but there would appear to be no reason why results should not be the same as for corn. Listing and seeding in one operation is not recommended for corn, and it is a poorer practice for the sorghums, which require a better seedbed for successful germination.

Grain sorghums follow themselves satisfactorily. Yield increases over grain stubble land are about the same as for corn. There are as yet no diseases or insect enemies in the region that prevent growing grain sorghums on the same land until it is desirable to change over to some other crop or treatment. It can be safely said that any row crop will produce higher grain yields following itself than it will following any small-grain crop with the possible exception of proso. The loss (about 15 percent) in yield of the small-grain crops that immediately follow sorghums, compared with those that follow corn, is not serious, considering the greatly superior grain and stover yield of sorghums. It is believed that in rotations sorghums should follow themselves 2 to 3 years or more.

The total weights of kafir show that yields on the plot planted with a lister were much lower than on the surface-planted plots during the favorable period 1909–23, but about equal to them for the less favorable period 1924–38. The great reduction in total yields on all methods for the second period is caused in part by the use of smaller growing, earlier maturing varieties. Total yields of these smaller varieties, however, were higher than those of corn for the same period.

The stover of such dual-purpose sorghums as Coes and Highland kafirs is useful as livestock feed, and the quantity produced is higher than that of corn (*2*).

Forage Sorghums

Forage sorghums or sorgos are the hay and forage feed of much of the Great Plains region, but adaptation to the higher altitudes of the central Great Plains of free-shelling grain sorghums with a creditable yield of palatable stover may mean less attention in the future to the strictly forage varieties. Yields of forage sorghums are presented in table 20.

Cultural methods covering the production of the forage sorghums are few despite the additions made in 1922, but the same methods apply as to corn and to grain sorghums. As a strictly forage producer, sorgos are probably the most reliable of the Plains cultivated crops, and the yield will generally be fair even on the poorer seedbeds. On the other hand they, as well as the grain sorghums, are among the most responsive to fallow and to good seedbed preparations. The same precautions as for the grain sorghums, however, should be observed in fitting them into rotation practices.

One plot of sorgo seeded on fall-plowed spring wheat stubble land in a 3-year rotation produced an average yield per acre of 2,997 pounds of field-cured fodder for the 30-year period. Two plots on fall-plowed winter wheat stubble in 4-year rotations including green-manure crops averaged almost the same as the one just considered for the 15 years 1924–38.

Continuous sorgo in rows produced nearly equal average yields on fall and spring plowing, and these yields were little or no greater than on fall-plowed grain stubble land.

Sorgo continuously drill-seeded on spring-plowed land during the 15 years from 1924 to 1938 produced only about 73 percent as much field-cured forage as that grown in rows continuously or that grown in rows on small-grain stubble land. Drill seedings on the hard lands are often so badly infested with Russian-thistle as to make harvesting very difficult. This weed is not so troublesome on the sandy lands, where drill seeding is sometimes practiced to leave a closer spaced stubble to prevent soil blowing. The row method of planting, however, is more certain of producing fair yearly yields even on sandy land.

Seed yields were taken from rotation 58, 1926–38, to establish an average grain yield for forage sorghums when planted thickly for feed. Seed was produced during 8 of the 13 years, and the average yield was 535 pounds an acre. In view

TABLE 20.—*Annual and average yields (in pounds) of sorgo from different cultural treatments and crop sequences during the 30 years 1909–38*

Year	Fall-plowed			Spring-plowed	
	Spring wheat, 58 [1]	Winter wheat, 24, 95	Sorgo, CCB	Sorgo, CCA	Sorgo, drilled, CCA′
1909	7,950				
1910	3,620				
1911	1,300				
1912	6,100				
1913	1,400				
1914	3,560				
1915	5,860				
1916	550				
1917	2,350				
1918	3,200				
1919	2,150				
1920	6,270				
1921	1,560				
1922	3,250	5,475	5,100	5,000	
1923	4,900	5,575	4,550	3,950	4,100
15-year average	3,601				
1924	500	600	750	1,050	550
1925	650	675	950	900	0
1926	2,640	3,495	3,950	3,160	1,800
1927	4,700	2,400	3,750	3,600	3,450
1928	2,900	3,100	2,750	3,450	2,400
1929	3,950	3,975	4,000	3,700	2,900
1930	8,600	6,500	6,600	6,050	5,650
1931	750	1,450	1,200	1,550	900
1932	1,700	2,000	1,750	1,900	1,550
1933	2,100	2,050	2,150	2,050	2,750
1934	50	225	400	650	200
1935	2,950	3,000	2,550	2,550	1,450
1936	2,250	2,200	2,000	2,350	1,150
1937	900	1,350	1,100	1,150	450
1938	1,250	1,150	1,000	1,100	250
15-year average	2,393	2,278	2,327	2,347	1,697
Average, all years	2,997	2,660	2,621	2,598	1,847

[1] Numerals or symbols in heading indicate rotation numbers or plots.

of the fact that such seed remains viable for 5 years or more, farmers can maintain a seed supply by using slightly later varieties, as Leoti Red and Fremont, which are heavier in forage production than the Dakota and Minnesota Ambers commonly grown in the region (*2*). When conditions are favorable forage sorghums produce fair grain yields. Sufficient seed production to maintain a farm seed supply, however, is all that is required. The grain of the forage sorghums, while usable, is bitter and has much less feeding value than that of grain sorghums. Sorgos make the best forage when cut in the soft-dough stage of seed development. A few rows may be left standing to ripen more fully for seed when it is desirable to replenish the farm seed supply. For silage it is important to have the sorgo fully ripe. Forage sorghums for silage should not be planted so thick that they will not head and ripen in a season of average rainfall.

MISCELLANEOUS CROPS IN ROTATIONS WITH WINTER WHEAT

Yields of crops grown in 2-year rotations with winter wheat in another field on Platner loam soil are shown in table 21. The winter wheat stubble in these rotations was duckfoot-cultivated when necessary to control weeds after harvest and was kept clean in the fall. It was moldboard-plowed the next spring during the early part of April. After plowing, the land was kept free of weeds until the respective planting dates for the different crops. As was stated before, the second of these two replications was on lower land subject to occasional sheet-water inundations. These sometimes increased the yield of plots in the second replication, so the results are valuable chiefly for comparing the relative yielding ability of the crops represented.

TABLE 21.—*Acre yields of 8 crops grown in 2-year rotations on winter wheat stubble land at the Akron Field Station, 1926–38*

Year	Potatoes (bushels)	Grain yields (bushels) [1]						Total weight, grain and straw or stover (pounds)					Straw or stover (pounds)			
		Foxtail millet	Pinto beans	Corn, 24-inch spacing	Proso	Soybeans	Sudan grass	Foxtail millet	Proso	Sorgo	Corn	Sudan grass	Proso	Corn	Pinto beans	Soybeans
1926	76.3	7.1	11.7	12.7	-------	-------	-------	4,475	-------	7,025	3,802	-------	-------	2,913	1,050	-------
1927	84.9	11.9	11.0	30.9	-------	-------	-------	4,575	-------	4,575	3,916	-------	-------	1,753	700	-------
1928	23.3	3.7	3.8	9.5	-------	-------	-------	3,375	-------	4,150	2,941	-------	-------	2,276	1,473	-------
1929	58.8	10.8	5.3	27.0	-------	-------	-------	2,000	-------	6,575	4,850	-------	-------	2,960	480	-------
1930	159.1	28.9	22.3	42.1	-------	-------	-------	6,975	-------	11,475	6,064	-------	-------	3,117	1,610	-------
1931	0	5.6	2.7	1.6	10.9	-------	-------	1,175	1,575	3,050	1,037	-------	965	925	615	-------
1932	74.5	15.5	6.6	13.8	17.7	-------	7.5	3,275	2,450	5,075	2,143	2,300	1,460	1,177	780	-------
1933	100.0	6.6	7.5	7.8	9.0	4.2	5.9	2,375	2,625	5,375	2,519	4,350	2,125	1,973	1,375	850
1934	5.8	0	0	0	0	0	.6	1,100	1,075	850	267	290	1,250	267	295	0
1935	25.8	6.1	5.9	9.4	11.3	7.5	20.6	1,750	1,700	4,575	2,185	4,250	1,070	1,527	645	875
1936	0	1.5	2.4	4.9	9.8	2.7	2.5	2,300	2,267	2,900	1,743	1,900	1,717	1,400	790	433
1937	28.1	3.1	0	0	4.9	1.3	1.4	1,553	1,033	2,650	1,200	1,075	760	1,200	313	304
1938	8.9	3.9	.9	(2)	5.0	0	.9	2,287	1,607	2,233	(2)	1,000	1,327	(2)	487	0
Average	49.7	8.1	6.2	13.3	8.6	2.6	5.6	2,863	1,792	4,808	2,722	2,166	1,334	1,791	816	410

[1] Bushel weight used: Potatoes, beans, and soybeans, 60 pounds; proso, 56; foxtail millet, 50; Sudan grass, 32.
[2] Discontinued after 1937.

POTATOES

Potatoes were planted approximately 4 feet apart in 42-inch listed-out rows. Yields of 100 bushels an acre or more were produced in 1930 and 1933, and the 13-year average was 49.7 bushels. Potatoes appear to require much more soil moisture than is normally available in small-grain stubble land of the hard-land soils of this section. Since 1934, potatoes have also been planted elsewhere on the station on fallowed land. The heaviest yield from 1934 to 1938 was 78 bushels in 1937. The 5-year average was 34 bushels, as compared with 16 bushels on stubble land for the same period. During 12 of the years, 1908–22, Irish Cobblers planted on fallowed land averaged 115.0 bushels an acre. Potatoes respond sharply to the greater quantity of soil moisture in fallowed land.

Yields on the hard lands of the region, however, are so low that production other than for home consumption is not warranted. Planting on carefully prepared fallow tends to maintain a regular production, with tubers of better quality than those grown on stubble land.

FOXTAIL MILLET

Foxtail millet is a short-season crop requiring no more time to produce hay than proso requires to produce grain. It is usually drill-seeded and produces a fine-stemmed hay crop, the yield of which is slightly higher than that of proso, sometimes used for that purpose. In this experiment, however, it lacked 40 percent of producing as much total forage to the acre as sorgo. In other comparative experiments covering approximately the same period, foxtail millet lacked 31 percent of producing as much forage as sorgo. Despite its ability to produce a regular creditable yield of forage, it apparently has little place in rotation practices in the Great Plains region.

PROSO

Proso, also known as hog millet, broomcorn millet, and "Hershey," is a very short season grain crop. In this experiment it produced a 7-year (1931–37) average yield of 9.1 bushels an acre, while corn in the 24-inch plant spacing in the same years produced only 5.4 bushels. Proso is one of the most reliable grain feeds for the higher elevations of the region. Its effect on following crops does not appear damaging. Actually more winter wheat was produced on proso land than on adjoining cornland.

On land where winter wheat has been hailed out, proso has long been used as a catch crop. In mixed livestock farming it can well be used to furnish a part of the feed grain. In this experiment its straw production was slightly greater than the production of corn stover, and its straw is probably as usable for livestock maintenance as corn stover.

PINTO BEANS

Mexican pinto, one of the most reliable bean varieties in this area, was planted in nearly all years in this experiment and produced an average yield of 6.2 bushels an acre for the 13-year period 1926–38. During the same years in the variety experiment on oat stubble land that was kept clean after harvest but not spring-plowed, the same variety averaged 5.0 bushels. During this same period, winter wheat produced an average yield of about 4 bushels on small-grain stubble land. At prevailing prices the value per acre of beans was much higher than that of winter wheat. Beans were planted on fallowed land from 1934 to 1938 at another location on the station not far distant from the variety experiment. The 5-year average per acre yield on this preparation was 8.7 bushels. On the clean-cultivated oat stubble land in the bean variety experiment the yield of the same variety over the same period was 2.2 bushels an acre. This shows that beans respond sharply to fallow. The average yield of bean straw on stubble land during the period from 1926–38 was 816 pounds. Bean straw is a valuable roughage for livestock maintenance. The potential acre value of beans would warrant them a place as a secondary cash crop in diversified farm rotations on the Great Plains.

Beans are not suitable for planting alone in large acreages, because of the difficulty of preventing soil blowing during the following winter and spring. They can be grown and the land controlled, however, if they are planted in strips between crops leaving a good stubble cover and the bean land is deeply fall-listed, chiseled, or otherwise roughened to leave a cloddy surface after the crop is harvested. Yields of crops following beans are at least as high as on cornland.

SOYBEANS

Varieties of soybeans early enough to mature have been available for the past several years. Three or four varieties proved to be suitably early and about equal in yield. Soybeans are much more severely damaged by light hail than field beans. They are favorite food of jack rabbits, another very serious hazard to successful production. In this experiment the average yearly production from 1933 to 1938 was 2.6 bushels of beans an acre. Mexican pinto beans produced an average yield of 2.8 bushels for the same period. The price paid for soybeans is usually much less than for dry beans. The value per acre of soybeans in this test has been only about half that of pinto beans, and they leave a soil surface equally susceptible to soil-blowing in winter.

SUDAN GRASS

Sudan grass was planted mainly to compare its influence with that of forage sorghums on the following crop of winter wheat. Variety tests had already shown that over a series of years Sudan grass produced only about half as much forage to the acre as well-adapted forage sorghums (*2*). In this experiment it produced 59 percent as much forage as sorghum and slightly more than foxtail millet during the 7 years it was grown. Winter wheat on Sudan grassland produced less than 1 bushel an acre more grain than winter wheat on sorghum land in a comparable location.

Sudan grass should be harvested before the head has emerged from the boot unless seed production is desired. Immature harvesting is even more important for Sudan grass than for the forage sorghums, which remain fairly palatable even after fully ripe. Sudan grass cut while the head is in the boot makes a fine-stemmed haylike forage closely approaching alfalfa in palatability and feeding value, although it is lacking in calcium and phosphorus. Fully mature Sudan grass forage or stover is little more palatable than wheat straw.

For the 7 years it was grown in this experiment, Sudan grass produced an average yield of 5.6 bushels of seed an acre, with a high production of 20.6 in 1935.

Other Crops in Miscellaneous Experiments

SUNFLOWERS

Sunflowers were grown in forage-variety experiments in some of the early years, until it was found that their yield for silage was lower than that of field corn and much lower than that of forage sorghums. Seed production was so light in those years that no grain yields were taken. Despite this early experience, about 1931 a campaign for sunflower-seed production for oil spread over the section. It was claimed that new strains produced higher yields of seed than the variety used in the early experiment. Results with the new strains for the period 1931–38 confirmed earlier observations. The average yields of seed for the 6 years from 1931 to 1936 were 186 pounds an acre on fallowed land and 141 pounds on stubble land. Sunflowers are poorly adapted to this area because they require far more moisture than is normally available; in addition, they exert a depressing influence on yields of crops that follow.

STOCK BEETS AND ARTICHOKES

Stock beets were grown during some of the early years at the station, and both they and Jerusalem-artichokes were grown for a few years beginning in 1929. Stock beets produced some fair yields in the early years, but yields of both crops in the test begun in 1929 were low. Their water requirements appear to be entirely too high for successful production on dry land.

ALFALFA AND SWEETCLOVER

Alfalfa in rotation 42 has not returned a hay yield since 1929, when 400 and 550 pounds an acre were harvested from the second and third year stands. Rotation 42 is a 6-year rotation of 3 years of annual crops followed by 3 years of alfalfa. During the 8 years 1931–38, full stands were not established in the 3-year period. Alfalfa was a crop of questionable economic value on the upland soils from 1909 to 1923, and during the period 1924–38 it was a failure.

The natural sheet-water drainage basin that extends through the station contained a depression from 1920 to 1930 that generally held stagnant water up to the middle of the summer. This was surface-drained, and the land plowed and seeded to alfalfa varieties on May 8, 1932. It seemed desirable to determine the life tenure of alfalfa on land subject to periodic sheet flooding and to know what variety would produce the best average hay yields on such land. Good stands were obtained on all plots, which were one-tenth acre in size and not replicated. This land received one flooding each in 1934 and 1935 and none in 1936, 1937, or 1938. Stands decreased from those initially obtained, but enough plants still remained in 1938 to control infestation of annual weeds. Hay yields from these plots are given in table 22. It is significant that stands of alfalfa were established and maintained on this land when they could not be regularly obtained on the upland soil of rotation 42. The tenure of these stands was about 6 years, as no yields were obtained after 1938.

TABLE 22.—*Annual and average alfalfa yields per acre (in pounds) by variety from lowlands subject to periodic sheet-water flooding during the 6 years 1933–38*

Year	Grimm (Moffat County)	Grimm (Grand Junction)	Baltic (Meeker)	Ladak (Rocky Ford)	Common (Rocky Ford)
1933	1,950	1,900	2,100	1,800	1,450
1934	1,800	2,000	2,800	1,950	1,600
1935	3,700	3,650	4,150	4,700	3,700
1936	1,700	1,600	1,950	2,000	1,650
1937	0	0	0	0	0
1938	2,450	4,750	3,900	4,800	2,850
Average	1,933	2,317	2,483	2,542	1,875

Evidently, if alfalfa is produced at all in this section of the Great Plains, the plantings must be made on low-lying areas subject to periodic flooding, but where water does not stand long, or on subirrigated land. Ladak, with an average yield per acre of 2,542 pounds, upheld its reputation of being productive under conditions of seriously limited soil moisture, and Baltic was only a little less productive.

Sweetclover appears to be better adapted to general dry-land planting than alfalfa. In plantings on the hard lands of the station, it has had the appearance of being slightly the more rugged of the two, and up to about 1926 farmers had fair success with it on sandy lands. On rotations 31 and 32 where it was planted with spring wheat and oats as nurse crops, stands of sweetclover emerged regularly, but these rarely survived the ripening period of the grain crops. In the 15 years 1909–23, sweetclover planted with grain sometimes survived this period, but from 1924 to 1938 it very rarely persisted. Figure 2 shows why it is so difficult to carry sweetclover or alfalfa seedlings over the period represented roughly by the ripening date of small-grain crops. Practically all soil preparations furnish weeds as competitors of these crops over this very low rainfall period, regardless of whether a cover crop has been used. Methods-of-seeding studies with alfalfa and sweetclover from 1924 to 1929 showed that when seasonal moisture conditions were favorable, the stands that survived were obtained from all dates of seeding on all soil preparations; when conditions were not favorable, stands were either not obtained or failed to survive on all the different dates of seeding and on all soil preparations.

Seeds of native grasses that are much better adapted to the rigors of the climate than either alfalfa or sweetclover are now commercially available. It would appear logical that many efforts to establish stands of these grasses may prove futile; they are a permanent type of forage, however, and repeated plantings are justified, when necessary.

FLAX AND SAFFLOWER

Tests of flax over a long period and of safflower for a much shorter period indicate that both are unadapted for commercial production. They occasionally return creditable yields, but in such years spring wheat is nearly always relatively better. Over a period of years returns per acre from these crops at current prices are lower than from spring wheat, and spring wheat has not proved a reliable crop. Weeds are perhaps the worst enemy of both flax and safflower. No success has been attained in growing flax-wheat mixtures.

SUBSOILING

Recurrent statements regarding the value of deep tillage in dry-land areas make it desirable that pertinent data bearing on the subject be presented. At Akron the subsoil plow has been used to loosen the soil to a depth greater than that reached with ordinary tillage implements.

The yields from subsoiled plots and from comparable plots fall-plowed but not subsoiled are shown in table 23. Five crops—oats, barley, corn, spring wheat, and winter wheat—are available for this study. The fall-plowed and the subsoiled small-grain plots were worked at an average date of August 23, and the cornland plots at an average date of November 10. Plans called for subsoiling for 2 years and then plowing without subsoiling for 2 years. At the end of the 30-year period the plots so designated had been subsoiled 16 times (including 1908) and merely fall-plowed 15 times, though not at the exact intervals specified. Subsoiling was done by plowing with a moldboard plow and running a subsoiler in the bottom of every other furrow. This implement loosened the soil to a distance of about 10 to 12 inches on each side. The plowing depth was 6 to 7 inches, and the subsoiler penetrated to a like additional depth below the furrow bottoms. This implement has a pulling draft equal to the 14-inch moldboard plow, which it followed in this experiment. The subsoiled land was thus periodically loosened to a depth of 12 to 14 inches, always in the fall.

In 1909, the first crop year, all plots subsoiled in the fall of 1908 produced better yields than the fall-plowed ones. After that initial year, yields from the subsoiled plots generally ranged lower. At the end of the 30-year period they were lower by 11

TABLE 23.—*Annual and average yields per acre (in bushels) of 5 crops on fall-plowed and on fall-plowed and subsoiled land during the 30 years 1909–38*

Year	Fall-plowed					Fall-plowed and subsoiled [1]				
	Oats, CCB [2]	Barley, CCB	Corn, CCB	Winter wheat, CCB	Spring wheat, CCB	Oats, CCE	Barley, CCE	Corn, CCE	Winter wheat, CCE	Spring wheat, CCE
1909	14.1	16.8	27.3	12.9	10.3	16.1	19.8	32.9	13.3	11.2
1910	8.0	10.5	18.3	10.3	6.2	11.3	6.9	12.7	6.9	5.5
1911	15.9	16.3	0	6.8	4.1	8.4	5.2	0	3.3	1.5
1912	46.9	27.9	46.9	26.7	20.7	35.3	22.5	37.1	21.2	16.0
1913	.6	3.1	9.9	2.0	.8	0	1.5	4.3	3.2	.5
1914	36.9	36.7	17.3	24.8	12.2	30.3	27.9	13.9	24.5	9.8
1915	57.2	47.9	29.2	20.8	25.8	57.5	52.3	22.3	21.0	23.7
1916	7.2	5.0	4.8	4.2	3.8	4.1	4.2	3.2	3.8	1.7
1917	29.7	26.9	21.9	5.0	16.2	28.4	13.5	20.6	5.7	10.3
1918	0	1.0	12.6	1.5	0	0	0	18.5	1.2	0
1919	32.8	23.8	5.0	20.3	11.0	30.0	15.8	5.8	12.5	6.0
1920	34.9	23.4	36.9	13.5	15.3	50.9	31.9	35.9	15.0	15.3
1921	14.7	10.8	3.1	7.0	4.0	19.1	10.6	3.5	5.8	1.3
1922	12.2	7.7	15.3	0	4.2	6.6	6.9	15.0	0	3.3
1923	9.7	13.0	19.9	1.5	3.2	12.8	13.8	17.9	1.2	3.2
15-year average	21.4	18.1	17.9	10.5	9.2	20.7	15.5	16.2	9.2	7.3
1924	1.9	.8	1.1	0	0	1.6	.6	1.1	.8	0
1925	5.0	1.3	.8	1.3	3.3	3.8	.6	.9	2.8	2.5
1926	1.6	1.0	7.7	0	.5	1.6	1.0	6.0	0	.3
1927	35.0	34.8	7.6	9.3	9.8	26.6	20.2	10.5	6.3	6.5
1928	18.8	19.8	17.4	4.0	8.3	13.1	15.2	14.3	1.3	4.8
1929	1.6	.8	13.6	1.7	.8	.6	.4	10.9	.3	.8
1930	5.0	15.2	21.4	12.5	1.7	4.4	7.5	18.3	11.0	1.0
1931	4.4	5.0	0	1.7	.5	3.8	4.4	0	4.2	1.0
1932	7.8	4.8	12.8	.3	1.2	5.3	3.1	3.2	.3	.5
1933	6.6	5.2	7.9	0	0	5.9	2.9	9.9	0	0
1934	0	1.5	4.0	0	0	0	.6	.7	0	0
1935	49.4	57.3	11.2	5.3	11.7	36.9	39.2	13.7	5.5	8.3
1936	12.2	10.0	3.9	7.2	3.2	10.3	10.0	4.5	6.0	2.5
1937	9.7	11.0	1.7	7.2	2.8	8.4	11.3	2.3	7.3	2.3
1938	28.1	26.3	2.7	5.2	5.2	21.3	19.0	2.7	7.2	3.8
15-year average	12.5	13.0	7.3	3.7	3.3	9.6	9.1	6.6	3.5	2.3
30-year average	16.9	15.5	12.6	7.1	6.2	15.1	12.3	11.4	6.4	4.8

[1] Plots were subsoiled in advance of the 1909, 1910, 1913, 1914, 1915, 1918, 1919, 1922, 1924, 1927, 1928, 1931, 1932, 1933, 1935, and 1936 crops.

[2] Symbols indicate plots.

percent for oats, 21 percent for barley, 23 percent for spring wheat, and 10 percent for corn and winter wheat. The deep cultivation was obviously not an economical practice, since it added to the cost while decreasing the yield.

Comparisons were made to find whether yields the year following subsoiling were depressed more than in the second and third years following. For all five crops the average yield for the 16 years when crops were grown immediately after subsoiling was 1.8 bushels lower than on ordinary plowing. For the 14 years when they were grown the second or third year after subsoiling, the average yield was 1.5 bushels lower than on ordinary plowing. This indicated that the depression in yield caused by subsoiling was not confined to the crop immediately following.

The purpose of subsoiling was to loosen the soil beneath the furrow slice and to permit deeper penetration of water. If such greater penetration took place, it should be evidenced by higher yields on the subsoiled land in years with above-average rainfall. Results do not indicate that average yields on subsoiled land exceed those on plowed land, even in favorable years.

Green-Manure Rotations

Three different crops—winter rye, peas, and sweetclover—were plowed under for green manure to study their effect both on the crops immediately following and on subsequent crops. Yields of winter wheat, spring wheat, and oats immediately following green-manure crops are shown in tables 8, 15, and 16.

A green-manure rotation is in effect a modified summer fallow, moisture conservation during the early part of the fallow period being sacrificed in order to produce a growth of green matter to be turned under. Growing a green-manure crop necessarily uses a part of the water that can be saved by ordinary fallow.

Yields of crops immediately following green manures were materially lower than on fallowed land, and comparative yields between the different green manures appeared to be dependent upon the moisture consumed by them. Yields were highest following winter rye, which was plowed under early, next highest following peas, and lowest following sweetclover. Peas and sweetclover were both plowed under about a month later than winter rye, but sweetclover grew more vigorously than peas and left less moisture in the soil. Evidently moisture limitations prevented the crops from making productive use of any greater fertility that might have resulted from green manuring, as burning due to overstimulation was frequently evident.

Results were examined to determine the effect of green-manure crops on the second and third crops following. No increased yields above those in rotations containing ordinary fallow were observed, the tendency being for both the second and third crops after green manures to be lower than in comparable rotations with fallow. Since green-manure fallows produced lower yields of crops immediately following than ordinary fallow and did not increase the yields of subsequent crops, it is evident that their use has been unprofitable up to the present time.

Sod Rotations

In two 6-year sod rotations grass or alfalfa was grown for 3 consecutive years followed by oats, corn, and spring wheat. Yields from these rotations and from an average of three rotations used for comparison are presented in table 24.

Table 24.—*Average yields (in bushels) of oats, corn, and wheat for 2 periods in rotations with alfalfa and bromegrass and average yields of these crops in the same sequence in 3 rotations without sod crops*

Treatment and preceding crop	Rotation No.	First crop, oats		Second crop, corn		Third crop, wheat	
		1909–23	1924–38	1909–23	1924–38	1909–23	1924–38
Rotations with sod:							
Bromegrass	41	11.5	12.4	11.9	4.2	6.5	5.1
Alfalfa	42	13.7	10.5	13.2	3.8	7.6	5.6
Rotations without sod:							
Wheat	1, 2, 3	21.0	11.8	14.7	6.6	12.7	4.9

During the years 1909 to 1923, stands of grass were obtained in most years and yields of hay and of crops on sod land were obtained with a considerable degree of regularity. In the hotter, drier years following, particularly during the second 15-year period, 1924–38, much difficulty was encountered in obtaining stands of grasses. Frequently a stand would be only 1 or 2 years old when plowed under, and in the majority of cases the 3 years that a plot was supposed to be in grass elapsed without obtaining an adequate stand. In such cases the oat yields on these rotations represent those on weedy land plowed somewhat earlier than the normal date for small-grain stubble.

During the first 15-year period the yield of oats immediately following sod was much below that of oats grown on wheatland. Yields of corn and wheat in the sod rotations also were lower during these years, but not by so great a margin. In the second 15-year period, when there was little or no sod, average yields in the sod rotations were much the same as in rotations without sod.

These rotations have definitely shown that the effect on the crop immediately following sod plowed after a hay crop has been removed is bad, probably because of the extremely dry condition in which it leaves the soil, as plowing early in spring overcomes this difficulty. They have also definitely proved that the 3-year period between grass crops is not long enough to enable other annual crops in a rotation to make up for the loss in yield suffered by the crop immediately following sod—in fact, there has been no tendency for the second and third crops to be more productive than in rotations without sod.

The fact that grasses and alfalfa are not adapted to comparatively short rotations has led to a change to deferred rotations in recent years. Grasses are still grown on three of the six plots in a rotation, but they occupy the land for 12 years, one plot being plowed up and one seeded every fourth year. The annual crops, grown as a 3-year rotation, occupy the land for a 12-year period between grass crops. It is hoped that this method will make it possible to have a good sod to plow under each time a plot is broken up and that the 12-year period will be sufficient to enable any beneficial effect of sod to show itself in the growth and production of the annual crops. In these deferred rotations the bromegrass and alfalfa have been replaced to a large extent by native grasses. The low average yields of hay from alfalfa and bromegrass make it evident that grass crops in rotations must be utilized for pasture if during the 12 years they occupy the land they are to be an asset other than for their effect on the soil.

Sorghums in Rotations

Grain or forage sorghums are grown in five rotations. Four of these are 4-year rotations containing green-manure crops, and one (58) is a 3-year rotation of sorgo, oats, and wheat. Rotation 58 is comparable to rotations 4 and 9, which are rotations of corn, oats, and wheat. Average yields are given in table 25. The average yield of oats following sorgo was about 20 percent below that of oats following corn. The adverse influence of sorgo appears to extend to the third crop, as wheat yields in the sorgo rotation were below those in the corn rotations. A similar effect on the third crop in this rotation has been observed at other stations. The low yield of oats immediately following sorgo might well be ascribed to lack of moisture, as sorghums normally reduce the water content of the soil to a lower point than corn. The reduced yield the second year after sorghums can hardly

TABLE 25.—*Averages of 3-year rotations, showing the comparative yields per acre of corn and sorgo and their influence on the crops that follow, for the 30-year period 1909–38*

Rotation No.	First crop			Second crop, oats		Third crop, spring wheat	
	Corn		Sorgo, total	Grain	Straw	Grain	Straw
	Grain	Stover					
	Bushels	*Pounds*	*Pounds*	*Bushels*	*Pounds*	*Bushels*	*Pounds*
58			2,997	15.1	833	5.0	881
4 and 9	9.9	1,425		18.9	1,038	7.2	1,110

be explained on that basis, as the oat crops in the two rotations would have reduced the moisture content of the soil to about the same level. In the 4-year rotations, the yields of crops immediately following sorghums were below those following corn. No yield comparisons were possible the second year after corn and sorgo, as green-manure crops followed the oats in these rotations.

For the rotations as a whole, sorghums reduced yields of the following crops 15 to 25 percent, but the sorghums themselves produced yields 30 to 50 percent higher than those of corn in comparable rotations. In an experiment in another field, yields of winter wheat following sorgo were about 15 percent below those following corn (table 13), but the total yield of sorgo was more than 75 percent higher than that of corn (table 21).

The total yield of the sorghums was sufficiently above that of corn to more than compensate for the reduced yield of a grain crop immediately following, but it is not necessary to take this reduction each year. It was shown earlier that yields of sorghum after sorghum were relatively good; therefore, sorghums should be planted several years in succession on the same land. There is also an indication that late-planted crops, as proso and beans, suffer less in yield reductions following sorghums than do the small grains.

For soils suited to fallowing, it is recommended that sorghum land be fallowed before a fall-seeded or an early spring-seeded crop is grown.

Comparative Yields on Summer-Fallowed and Cropped Lands

A comparison of crop yields on fallowed land and on early fall-plowed land is shown in table 26. The yields for kafir are for only those years when a variety early enough to mature grain regularly was available. The small grains were grown on grain stubble land and the kafir on Sudan grass stubble, which probably approached grain stubble in moisture reduction. Corn was planted on land that had grown a crop of corn in 42-inch rows, and the soil undoubtedly contained more moisture than in the other cropped plots.

TABLE 26.—*Average yields per acre (in bushels) of 6 crops on early-plowed stubble land and on fallowed land for the 30 years 1909–38*

Crop	On stubble land, CCB	On fallowed land, CCC or CCD	Crop	On stubble land, CCB	On fallowed land, CCC or CCD
Winter wheat	7.1	16.3	Oats	16.9	31.1
Spring wheat	6.2	10.0	Corn	12.6	17.5
Barley	15.5	28.1	Kafir	[1] 10.6	[1] 19.7

[1] 12-year averages of Coes taken from Colo. Expt. Sta. Bul. 449 (2).

Winter wheat showed by far the strongest response to fallow, and corn the least. All of the small-grain crops except spring wheat showed sufficient response to fallow to justify their production on that preparation. The much greater increase of winter wheat, however, would indicate that fallowed land should generally be seeded to that crop. Spring-sown small grains are probably more economically grown on row-crop stubble if that is available.

The increased yield of the grain sorghums on fallowed land was great enough to indicate their production by that method if grain were the only consideration. Sorghums, however, are grown for forage as well as grain, and stover yields on fallowed land were only about 12 percent higher than on cropped land. The increased yield of corn on fallowed land is not sufficient to recommend its production by that method.

PRACTICES ADAPTED TO THE WEST-CENTRAL GREAT PLAINS

In the preceding parts of this circular, the results of experiments with different crops and their reaction to each other and to the different types of tillage have been discussed in detail. The question then arises as to how the information can be utilized in planning farming systems.

Rotations should include the crops best adapted to a region, and these should be grown in an orderly plan that permits most economical production. Rotations, besides systematizing the farm activities, permit crops to follow each other in sequences that take advantage of existing moisture conditions. For example, crops that extract all available soil moisture should be followed by fallow, by crops with comparatively low water requirements, or by late-planted crops that leave a period for water replenishment before planting. Crops that do not extract all the available water are best followed by crops that can and will use it. Considerations other than crop yields that may help determine the type of rotation are the quantity and distribution of labor, the maintenance of soil fertility, and the control of soil blowing. No one rotation can be outlined that will meet the requirements of all farmers, but underlying principles can be used by individuals in planning rotations suited to their own particular needs.

Any well-diversified rotation for the section presupposes livestock and an acreage, usually native grass, for pasture. The Colorado Agricultural Experiment Station recommends (*3*) that on the hard lands at least 25 percent of the farm unit be in sod and that the percentage be increasingly higher with greater sandiness of soil. The percentage of sod should also be higher on lands with lower productivity ratings. Naturally, the quantities of bulky feeds that must be grown depend upon the extent to which they are supplemented by pasture.

From the standpoint of their use, crops may be roughly divided into two groups, cash and feed. The livestock numbers on the farm determine the relative importance that must be assigned to the two groups. Over much of eastern Colorado the main dependence of the farmer should be on livestock.

The most important and best-adapted cash crops are winter wheat and pinto beans. Winter wheat can sometimes be used to advantage as a feed grain when the sale price is low. The best-adapted feed crops are the grain and forage sorghums, barley, proso, and oats. Feed grains are salable, but they generally have their greatest value when fed on the ranch. On sandier land corn also may be classed as adapted. It is around these crops that the farm rotations must be built. Until its place in rotation practice has been more definitely determined, grass when once established should be allowed to stand for an indeterminate period rather than to be made a definite part of a rotation.

The length of a rotation appears to make little difference, so long as the crops grown are congenial to each other. At Akron the simple 3-year rotations have tended to produce relatively high yields of all crops. These short rotations, with the exception of rotation 58, which contains forage sorghums, have no crops or treatments that have a bad effect on the crops that follow. Longer rotations free from such crops and treatments are equally productive and permit the inclusion of more adapted crops and a better acreage equalization of them—this appears to be important in the Great Plains region.

Nearly all adapted crops show a strong response to summer fallow, but where that treatment occupies only 20 to 25 percent of the cropped area in a rotation, the relatively stronger response of winter wheat makes it desirable that nearly all of it be sown to that crop. The very poor yields of winter wheat on other preparations also make it advisable that little or none be grown by such methods. Winter wheat, however, is not a family-supporting cash crop over much of the central Great Plains, even on fallowed land. Whether winter wheat is alternated with fallow on a separate unit of land, or whether the two are made a part of a longer rotation matters not, so long as the acreage is in accordance with the needs of the farming system. Fallow that is part of the general farm rotations, however, shifts over all the fields in a given period of time and aids in ridding the land of undesirable annual weeds. Fallowed land that is not wet to a depth of at least 36 inches should not be sown to winter wheat. It should be prepared to go through the winter, when it should normally have ample stored soil moisture by the time of seeding grain sorghums, pinto beans, or proso. This would not break up the rotation routine.

Sorghums are the most important feed crops, and the acreage needed will probably be greater than that for the crops that normally follow. Sorghums follow themselves satisfactorily, however, and this problem can be met by growing them for 2 years or more in succession. The yields of small grains following sorghums are lower than after corn or beans, but they are generally about equal to those on small-grain stubble land.

Pinto beans, which are planted late, are relatively more productive on small-grain stubble land than most crops and probably should be grown in that sequence. They do well, however, in other sequence positions. The tendency of bean land to blow makes it highly desirable that the crop be grown in strips alternating with crops that leave residues resistant to soil movement. Bean land provides a productive seedbed for spring-sown small grains.

The spring-sown small grains, barley and oats, can be planted to best advantage on fallow, bean land, or cornland, but they may be used after sorghums. The yields of crops following small grains are likely to be low; therefore, such stubble land should generally be used for beans, sorghums, proso, or other crops that are planted late in the following spring or it should be fallowed. If the stubble promises to grow a crop of weeds or volunteer grain, cultivation immediately after harvest with some implement that kills the growing vegetation without destroying the stubble cover is advocated for the conservation of water. This early fall cultivation should in some years make the small-grain stubble land greatly superior to sorghum land for the spring-sown small grains. Spring-sown grains should not be planted in the usual acreage unless there is at least 24 inches of moist soil. Proso is planted late and may be used on any land where moisture-consuming plant growth has been controlled prior to seeding. It finds one of its uses as a catch crop up to about July 1 on land where winter wheat has been ruined by a heavy rain and hail. It may be used on land where wheat has failed to come through the winter with an adequate stand. It has been pointed out that crops sown early in spring are not recommended for such a condition, because failure usually indicates a lack of reserve water in the soil.

Corn on soils to which it is adapted may be used to replace a part of the sorghum acreage. Corn ground is particularly suitable for the production of spring-sown small grains.

The average yields of the different crops given earlier in this circular furnish a basis for calculating the acreages needed for feed and the mean return that can be expected from cash crops. Since all crops are subject to complete or nearly complete failure, the matter of feed and cash reserves cannot be overemphasized. The acreage of feed crops should always be sufficient to build up and to maintain suitable reserves. Once feed reserves are built up, some adjustment in acreages may be desirable.

Rotations for Great Plains use must have a considerable degree of flexibility. It is sometimes better to fallow land than to plant it to crops under seeding conditions that doom them to almost certain failure. Sometimes land in such condition if clean-cultivated will build up sufficient soil moisture by the seeding time of some of the late-planted crops, and only a shift in the basic crop acreage that year will be necessary. Planting plans must take into consideration the yield prospects as evidenced by soil moisture conditions at the seeding time of the different crops (*6*, *10*). Any fallowed land not needed for winter wheat can be used for barley, oats, or sorghums. It has been pointed out that spring wheat and corn do not respond well to fallow treatments. The relative quantities of sorghums and grains that are produced may be adjusted by regulating the number of successive years that sorghum is grown. In any given year the acreage of grain may be varied by seeding a greater or a smaller part of the sorghum land to small grains.

Soil fertility of the land in the area represented by the Akron Field Station is high, and present requirements for maintaining productivity may be met by applying the manure produced on the farm. Care must be exercised in this matter, however, since stover yields are increased somewhat by the applications, but grain yields are generally depressed. It seems best to apply manure to land where the harvested crop is to be principally feed. Results with winter wheat indicate that manure can best be applied to that crop as a spring top dressing. Applications should not be heavy and should not be repeated at too frequent intervals, especially on the hard lands.

Management to prevent or control soil blowing is a necessary part of successful Great Plains rotations. If fallowed land seeded to winter wheat should not grow a protective cover that fall, soil blowing is almost sure to be encountered. Thus in known troublesome areas, winter wheat on fallow should not occupy too large a percentage of the farm area. In comparatively small areas reasonably effective control measures are available (*3*, *5*, *7*). Fallow left over winter should be furrowed or deeply ridged to prevent soil movement. Small-grain stubble land is usually safe during the late winter and early spring soil-blowing period. Land where a good crop of sorghum has been harvested is usually adequately protected by the stubble, but where a poor crop was produced the land usually needs some protective cultivation that will upend the root clumps and bring clods to the surface. Bean land is extremely susceptible to soil blowing, and cultivation after harvest to bring clods to the surface is essential. As an additional precaution, beans should be grown in strips with crops whose residues are known to resist soil blowing.

It has been brought out repeatedly in this circular that the purpose of all Great Plains cultivation is to control weeds, to keep the surface in condition to resist soil blowing, to permit ready penetration of rainfall, and to have a suitable seedbed. Deeper or more frequent cultivation than necessary to attain these objectives serves no useful purpose.

A sample 4-year rotation for the hard lands of the higher part of the central Great Plains might consist of (1) fallow; (2) winter wheat on fallow; (3) grain sorghums and beans in alternate strips on winter wheat stubble land, the beans to occupy much less than half the acreage; and (4) forage sorghums, grain sorghums, or possibly proso on the sorghum land and oats and barley on the bean land. A part of the sorghums in such a rotation might be replaced by corn, especially on the sandier lands, in which case spring-sown small grains could follow on that preparation. This rotation involves four equal-sized basic fields. If more sorghums are needed than this rotation provides, it can be lengthened to 5 years by dividing the land into five fields and adding another year of sorghums on the sorghum and small-grain land.

Fields can generally be so arranged that contour cultivation and strip cropping can be followed. A rotation involving strip cropping may sound very complicated when described, but it is relatively simple in field operation. Effort should be made to incorporate such a practice if it can be done without increasing insect damage and if the direction of the strips does not parallel that of the more severe winds. The region needs to become extremely conscious of the necessity for retaining as much as possible of the meager rainfall in the soil. Rainfall stored in the soil is the lifeblood of successful Great Plains agriculture.

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U. S. GOVERNMENT PRINTING OFFICE : O—1950

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