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AGRICULTURAL EXPERIMENT STATION.

KANSAS STATE AGRICULTURAL COLLEGE.

(In Cooperation with the Bureau of Plant Industry, United States Department of Agriculture.)

The Relation of Moisture to Yield of Winter Wheat in Western Kansas.

MANHATTAN, KANSAS.

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FOREWORD.

The data presented in this bulletin were obtained by the United States Department of Agriculture in cooperation with the Fort Hays Branch Experiment Station, at Hays, Kan. Credit is due the Office of Dry Land Agriculture and the Biophysical Laboratory, of the Bureau of Plant Industry, for assistance in outlining the work and in furnishing laboratory equipment. The investigational work was under the immediate direction of Mr. A. L. Hallsted, of the Office of Dry Land Agriculture, Bureau of' Plant Industry, who is located at the Fort Hays Station. W. M. JARDINE, *Director*.

SUMMARY.

As an average of four years, late-fall-plowed ground contained 2.7 per cent of available moisture at seeding time, early-fall-plowed ground 4.2 per cent, and summer-fallowed ground 8.8 per cent.

The late-fall-plowed ground with an average of 2.7 per cent of available moisture produced an average of 5.9 bushels of wheat, early-fall-plowed ground with 4.2 per cent of available moisture produced 11.1 bushels of grain, and sumrner-fallowed ground with 8.8 per cent of available moisture produced an average of 21.2 bushels of grain.

As an average of four years, the yield of grain secured was in direct proportion to the supply of available moisture in the soil at seeding time.

In seasons with severe climatic conditions, such as prolonged drouths and hot winds, it is impossible to store in the soil sufficient water to insure a crop of wheat, but with normal weather the crop will be in proportion to the water stored in the soil at seeding time.

As an average of six years, ground subsoiled once in three years and prepared each season for wheat by plowing early in

the fall has produced an average yield of 18.1 bushels an acre, which is 3.9 bushels more than ground plowed at the same date but not subsoiled.

Alternate cropping and summer-fallowing have produced an average yield of 21.3 bushels of wheat an acre, but as a crop is grown but once in two years on the fallowed ground, the average annual yield was 10.6 bushels an acre.

Summer fallowing is of value in enabling the farmer to distribute his work more evenly and to provide an opportunity for deep plowing. A system in which the ground is summer-fallowed once in three or four years will prove profitable.

Summer-fallowing is of greatest value in a rotation of crops in central and western Kansas. By means of the fallow it is possible to grow kafir or some of the other sorghum crops in rotation with wheat. In such a rotation the ground should be fallowed after the sorghum crop, and the fallowed ground planted, to wheat.

There is little danger that fallowed ground will blow if properly handled. The fallow should be cultivated with tools like the spring-tooth harrow and shovel corn cultivator, that work the lumps to the surface, that leave the ground ridged, and do not pulverize the soil.

THE RELATION OF MOISTURE TO YIELD OF WINTER WHEAT IN WESTERN KANSAS.

L. E. CALL and A. L. HALLSTED.

In western Kansas moisture is the limiting factor in the production of wheat. The soils of this section of the state are deep, well-stored with plant food, and abundantly fertile when supplied with the moisture necessary for plant growth. They absorb the rainfall readily when they are properly cultivated and when they are well supplied with humus. They retain moisture well when judiciously handled, and give up their moisture freely when it is needed by plants for growth. These characteristics make the soil admirably adapted to good farming methods.

The major part of the rainfall in western Kansas comes in the summer months. It is therefore necessary in growing wheat to use methods by which the summer rainfall may be stored for the growth of the wheat during the late fall and the early spring. It is the purpose of this bulletin to give the results of a study, made at the Fort Hays Experiment Station, of the effect of different methods of preparing land for wheat upon the moisture conserved in the soil and upon the ability of the wheat plant to utilize this moisture.

RAINFALL.

The average precipitation at Hays, Kan., for a period of forty-six years is 22.98 inches. By far the greater portion of the moisture falls between April 1 and September 30. Were it evenly distributed, it would be ample to produce good yields every year. But excessively wet periods are frequently followed by exceedingly dry periods which are of long duration and which are acompanied by unfavorable climatic conditions such as high temperatures and high and hot winds.

EVAPORATION.

While the total rainfall and the distribution of the rain are essential, the rapidity with which the water evaporates and thus escapes again into the air is also important. It is possible to grow crops with a comparatively small rainfall if at

TABLE I. Monthly and annual precipitation at Hays, Kan.

YEAR.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual.
1868	0.15	1.90	0.89	0.48	1.80	1.10	0.70	3.70	0.20	0.90	3.20	0.50	15.52
1869	0.10	3.30	1.40	0.80	1.10	4.80	2.50	3.54	1.34	0.60	0.20	0.64	20.32
1870	0.03	0.01	1.08	3.15	1.40	0.67	2.25	1.50	5.50	2.50	0.00	1.70	19.79
1871	0.10	T.	0.25	4.60	2.75	0.67	2.40	2.30	6.00	1.80	1.63	0.50	23.00
1872	0.25	0.46	0.75	0.96	3.92	0.80	4.42	1.92	2.50	0.00	0.04	0.34	16.36
1873	0.38	0.62	0.40	1.40	7.88	2.44	1.38	4.08	0.86	0.60	0.42	0.22	20.68
1874	1.32	1.80	4.02	2.34	3.68	2.18	0.34	0.90	7.08	0.88	1.07	1.27	26.88
1875	2.92	2.90	2.20	3.34	3.66	4.52	4.54	5.50	1.40	0.38	0.00	0.72	32.08
1876	0.10	2.18	6.14	3.46	2.04	0.70	4.06	2.60	2.82	1.24	1.24	2.06	28.64
1877	1.58	0.94	0.98	2.94	3.86	3.20	4.36	2.50	1.50	3.82	1.28	3.25	30.21
1878	1.24	0.78	0.68	0.82	2.92	6.96	6.86	4.94	4.94	0.70	0.62	3.94	35.40
1879	1.00	0.10	0.16	2.80	0.48	2.60	7.04	3.02	0.30	0.16	2.36	0.60	20.62
1880	0.40	0.50	0.10	0.26	4.00	2.12	4.22	5.14	2.06	0.76	0.72	0.60	20.88
1881	1.38	0.60	0.68	1.12	4.92	2.14	4.12	1.46	2.74	1.10	0.24	0.38	20.88
1882	0.20	0.12	T.	2.68	5.34	2.01	1.16	1.40	0.30	1.50	0.46	0.10	15.27
1883	0.64	0.16	0.88	2.34	2.96	4.08	2.70	0.98	0.62	4.98	T.	0.86	21.14
1884	0.14	0.30	0.62	3.76	2.96	1.56	4.93	2.40	0.46	2.16	0.10	0.65	20.04
1885	0.47	0.64	0.32	2.43	3.10	1.40	8.21	2.50	3.08	2.23	0.53	1.04	25.95
1886	2.52	0.44	2.39	3.06	1.80	3.60	6.66	2.41	3.06	1.44	0.68	0.68	28.74
1887	0.40	0.70	0.10	2.23	3.02	3.29	1.08	4.64	3.34	2.32	0.65	0.56	22.33
1888	0.20	0.15	2.25	1.51	3.18	1.56	4.85	4.00	0.48	0.70	0.10	1.20	20.18
1889	1.56	0.32	1.50	2.95	6.57	4.22	2.78	3.28	0.56	2.17	1.45	0.00	27.36
1890	1.37	0.40	0.20	4.00	0.55	1.40	2.22	2.48	1.25	0.45	0.80	0.05	15.17
1891	1.05	0.35	1.65	0.92	2.05	4.84	4.09	1.29	4.73	1.59	0.13	1.52	24.21
1892	0.32	1.81	2.06	0.92	4.87	1.13	3.92	5.08	0.40	0.52	0.40	1.10	22.53
1893	0.05	0.05	T.	0.20	3.11	3.55	2.79	5.20	2.65	0.16	0.20	0.20	18.16
1894	T.	0.95	0.00	1.85	1.65	3.90	0.65	T.	1.65	0.30	0.10	0.75	11.80
1895	0.30	1.95	0.10	1.20	0.22	0.80	2.59	4.40	0.26	0.70	0.05	0.07	12.64
1896	0.50	T.	0.45	4.56	3.01	6.19	1.64	1.95	4.90	3.85	0.35	0.30	27.70
1897	0.20	0.50	1.60	7.92	1.65	3.10	2.83	2.22	2.66	3.75	T.	0.30	26.73
1898	1.25	0.25	0.36	2.38	10.42	1.97	2.36	1.40	7.21	0.75	1.10	2.10	31.55
1899	T.	0.20	0.25	0.45	2.10	6.03	5.15	0.55	2.30	2.00	2.00	0.65	21.68
1900	0.10	1.35	T.	6.35	3.48	3.37	3.07	3.46	2.98	1.95	0.10	0.22	26.38
1901	0.20	1.45	1.25	5.55	1.41	1.53	0.50	5.67	2.58	1.26	0.75	0.70	22.85
1902	1.00	0.55	3.80	0.26	4.28	6.44	3.84	5.64	4.93	2.56	T.	1.35	34.65
1903	0.15	4.20	1.03	2.01	10.08	4.40	2.72	4.55	0.55	1.95	0.88	T.	32.52
1904	0.10	0.06	0.28	0.88	4.22	2.90	2.75	2.90	0.95	1.75	0.06	0.60	17.45
1905	0.65	0.54	0.73	2.54	3.71	4.94	3.98	0.86	1.61	1.43	2.74	T.	23.73
1906	0.15	0.37	0.73	1.67	1.51	2.29	5.79	2.87	3.39	2.94	0.86	0.51	23.08
1907	0.64	0.22	0.85	0.11	0.80	4.72	9.09	2.85	2.06	1.06	0.11	1.76	24.27
1908	T.	0.92	T.	2.18	2.98	6.05	2.82	5.29	0.74	1.76	1.79	0.03	24.56
1909	0.39	0.28	1.16	0.39	1.28	10.04	3.66	1.37	2.90	1.78	3.55	1.00	27.80
1910	0.58	0.26	0.03	0.97	3.88	2.58	2.02	4.01	0.80	0.32	T.	0.14	15.59
1911	0.12	2.12	0.14	0.78	2.10	0.85	2.66	3.44	2.56	0.30	0.14	1.82	17.03
1912	0.02	1.98	1.60	1.65	3.40	3.49	0.55	3.96	1.59	0.56	1.13	0.03	19.96
1913	0.36	0.68	0.41	2.97	5.72	3.34	0.60	0.11	4.64	0.25	0.72	3.14	22.94
Av. 46 yrs. 1868–1913	0.58	0.88	1.01	2.22	3.30	3.18	3.34	2.96	2.42	1.45	0.76	0.87	22.98
Av. 1909–1913 inc.	0.30	1.06	0.67	1.35	3.20	4.06	1.90	2.58	2.50	0.64	1.11	1.23	20.66

the same time only a small quantity of water is lost by evaporation. Likewise, when evaporation is high and a large quantity of water is lost in this way, a greater supply in the form of rain will be necessary to insure a good crop.

Daily records were kept of the amount of evaporation that took place from a free water surface during the growing season of the past seven years. The following table shows the evaporation from 1907 to 1913:

TABLE II. Evaporation at Hays, Kan., during six summer months, 1907-1913.

YEAR.	April.	May.	June.	July.	August.	Sep.	April to Sept.
1907	6.520	7.199	7.261	8.612	7.846	7.210	44.648
1908	6.450	7.181	7.977	7.967	8.181	6.625	44.381
1909	6.370	9.203	7.211	7.735	10.215	6.737	47.471
1910	8.339	4.855	7.797	9.258	7.601	5.969	43.819
1911	6.564	8.887	13.981	11.885	10.274	8.233	59.824
1912	6.077	8.284	6.417	9.987	9.178	8.022	46.965
1913	6.610	7.640	8.530	13.820	14.450	7.250	58.300
Average for 7 years	6.704	7.607	8.453	9.895	9.678	7.007	49.344

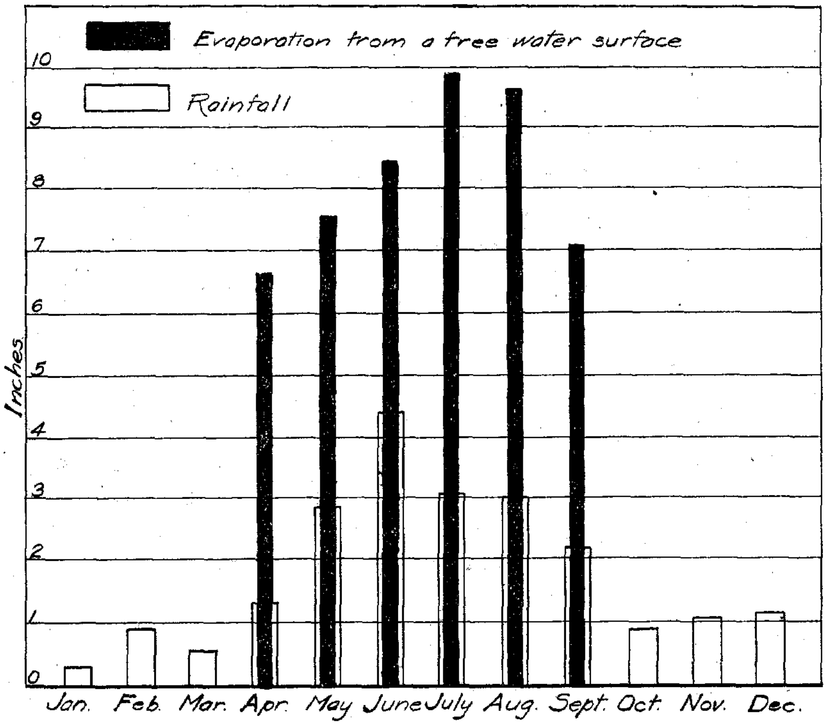

PLATE 1. A comparison of the average monthly rainfall and evaporation at Hays, Kan., 1907-1913.

These records, in addition to showing the water loss from a free water surface during the six months, indicate the general weather conditions during this period. When the weather was cool, cloudy, damp, or rainy, the evaporation records show that there was little or no loss from a free water surface. On the other hand, when the sun was bright, the temperature high, and the wind strong and hot, the evaporation was excessive from both soil and plants. It is, therefore, possible by studying the exaporation records to determine accurately the condition of the weather during any period.

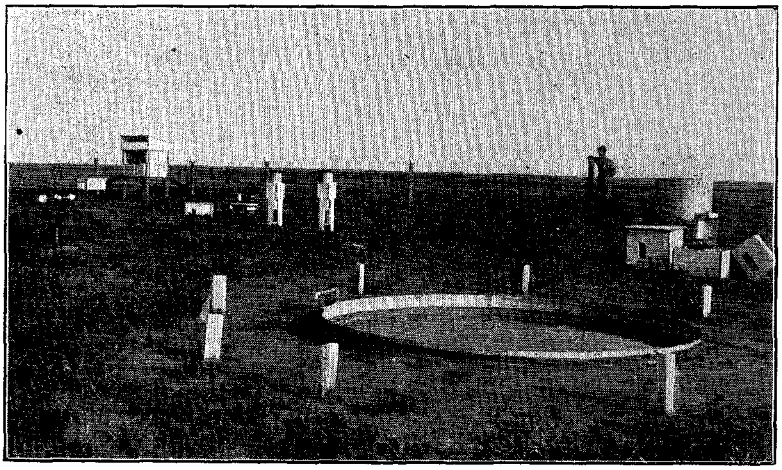

PLATE 2. The weather instrument used at the Hays Branch Experiment Station to determine rainfall and evaporation.

THE SOIL.

The soil on the station farm is a grayish-brown silty clay loam of the Summit series.

The surface soil is twelve to fifteen. inches deep. It is of a light nature and does not pack badly except after heavy rains. If plowed dry, it turns up cloddy and works hard, but slackens readily by means of rain or of freezing. The soil blows easily when the surface is made smooth by packing rains or by cultivation. Although the soil seems to be of a calcareous formation, it does not contain much lime in the top six feet. The amount of lime in the soil increases with depth from the seventh to the tenth foot. The native vegetation was buffalo and grama grasses.

SOIL MOISTURE.

In considering soil moisture, it should be remembered that there is a limit to the amount of water the soil can hold. This limit is called the "carrying capacity" of the soil. When the surface soil has been filled to its carrying capacity and more rain falls, the water will either be lost by surface drainage or will be drawn from the surface soil down into the subsoil. This may continue until the soil is filled to its carrying capacity to a depth of several feet. The soils of western Kansas are seldom filled to their carrying capacity to a greater depth than two to three feet, except when summer-fallowed.

AVAILABLE AND UNAVAILABLE MOISTURE.

Not all the moisture held in the soil is available to plants. It is known that when the moisture in the soil is reduced to or below a certain amount plants begin to wilt, normal growth and development stops, and the plant is unable to secure additional moisture. The point below which the moisture can not be reduced by plants is called the "minimum point of exhaustion," and marks the division point between available and unavailable moisture. The moisture a soil contains above the minimum point of exhaustion is available moisture, and can be used by plants. The moisture contained in the soil below this point can not under any circumstances be used by the plant, and is unavailable moisture.

The soil where this work was conducted has an average moisture-carrying capacity, to a depth of six feet, of about 22.6 per cent, or approximately 830,000 pounds of water to the acre foot (one acre one foot deep). The moisture-carrying capacity of the surface soil is slightly higher than that of the subsoil. The minimum point of exhaustion for wheat is about 12.4 per cent, which means there is about 12.4 per cent of moisture held by the soil that the wheat plant can not use in its growth. The soil of the station farm can carry, therefore, to a depth of six feet, an average of 10.2 per cent of available moisture, but crops usually begin to suffer after 6.5 per cent of the available moisture has been used.

THE TILLAGE METHODS USED.

The experimental work upon which this paper is based consisted of a number of different methods of preparing a seed bed for winter wheat. The work was started in 1906. Five different methods were used. These include four methods where wheat was grown continuously and one method where wheat was grown alternate years on summer-fallowed ground. Two plots of ground were used, so that a crop of wheat was produced each season, and each year a plot was summer fallowed, to be planted to wheat the next year. The methods of preparation were as follows:

1. Late Fall-Plowing.
2. Early Fall-Plowing.
3. Early Fall-Plowing and Subsoiling.
4. Listing (Early Fall).
5. Alternately Cropping and Summer-Fallowing.

Late Fall-Plowing. The ground which was plowed late in the fall and continuously cropped to wheat was left untouched after harvest until a few days previous to seeding, when it was plowed about four inches deep and double-harrowed to pulverize clods and level the surface for seeding.

Early Fall-Plowing. The ground that was early-fall-plowed and continuously cropped to wheat was plowed six or seven inches deep as soon as practical after harvest, was packed with subsurface packer or disk, and was cultivated at intervals until seeding time with harrow or cultivator as often as was necessary to prevent weed growth and to keep the surface in good, loose condition to receive water.

Early Fall-Plowing and Subsoiling. The ground that was early-fall-plowed, subsoiled and continuously cropped to wheat was plowed every year and treated the same as the early-fall-plowed ground discussed above, except that every third year it was subsoiled. This was accomplished by using a subsoiler independent of the plow and drawn by a team behind the plow,

PLATE 3. Some of the tillage experiment plots at the Hays Station.

so that the subsoiler followed in the furrows. It loosened the soil five to eight inches below the bottom of the furrow, without bringing the subsoil to the surface.

Listing. The ground that was prepared by listing and continuously cropped was listed about six inches deep early in the fall at the same time that the early-fall-plowed ground was plowed. After being listed, the ground was gradually leveled by cultivation at intervals, as was necessary to prevent the growth of weeds and to keep the surface loose. Usually for the first cultivation after listing a lister cultivator was used, and for subsequent cultivations a harrow or shovel cultivator. By this method a good seed bed was usually prepared by seeding time.

Alternate Cropping and Summer-Fallowing. The method of alternate cropping and summer-fallowing requires the use of two plots of ground which alternate one with the other, one plot growing a crop while the other is fallowed for a crop the following year. The method of handling the soil during the fallow period was as follows:

The ground was plowed as soon as practical after harvest, or at the same time that the early-fall-plowed plot was plowed, and during the first fall was treated the same as the early-fall-plowed plot, except that it was not seeded. Late in the fall, or the last time it was cultivated, a shovel cultivator was used for the purpose of leaving the surface of the soil ridged to prevent blowing and to keep it in good condition to receive moisture.

In the spring cultivation was again resumed. Ordinarily the harrow and cultivator were used alternately. The cultivations were only frequent enough to prevent weed growth and to keep the surface in good condition to receive moisture and to prevent blowing.

In July the ground was again plowed six or seven inches deep, and was packed with subsurface packer or weighted disk. The same method of surface cultivation that was used before plowing was continued until seeding time. This is considerably more work than could be recommended in handling fallowed ground. Ordinarily, if the ground to be fallowed is disked in the early spring, plowed in May or early June, and cultivated enough to keep down weed growth, good results will be obtained, and the cost of handling the land will not greatly exceed the cost of preparing ground for wheat in the ordinary way.

SEEDING.

The plots were all seeded at the same time and in the same manner, with the same variety and amount of seed.

The late-fall-plowed ground was left untouched from the time it was seeded until harvest. The other plots were cultivated once the following spring with weeder or harrow if the conditions were such as to make this treatment advisable.

SOIL MOISTURE DETERMINATION.

In the spring of 1909 soil-moisture investigations were started upon four plots of ground, one of which was late-fall-plowed, one early-fall-plowed, and the other two were alternately cropped and fallowed. At a later date similar work was started upon the other methods of cultivation, but the following discussion will be confined to the results secured from the methods of cultivation upon which work was started in 1909.

Soil samples for the determination of moisture were taken at intervals of two weeks from April 1 to September 30. In addition to the regular samples, one set was taken in the spring as early in March as weather conditions would permit, and another set of samples was taken in the fall as late as possible, usually at the last of October or the first of November. The samples were taken regularly to a depth of six feet, and occasionally to a depth of ten feet. They were taken in sections of one foot each, and moisture determinations were made upon each foot separately.

SEASON OF 1909-1910.

The first soil-moisture determinations were made in the spring of 1909, but the wheat crop for that season was destroyed by hail early in June; consequently the data secured for that year have been omitted.

The hail storm was followed by a wet period from June 9 to July 14, during which time moisture in all ground increased rapidly. For a time after July 14 there was a general decrease in the moisture, which may be attributed to weeds that were allowed to grow on all but the fallowed ground until July 23, when they were plowed under. After this date there

GRAPHIC CHART SHOWING MOISTURE IN THE SURFACE SIX FEET OF SOIL PREPARED IN DIFFERENT WAYS FOR WINTER WHEAT. SEASON 1909-1910.

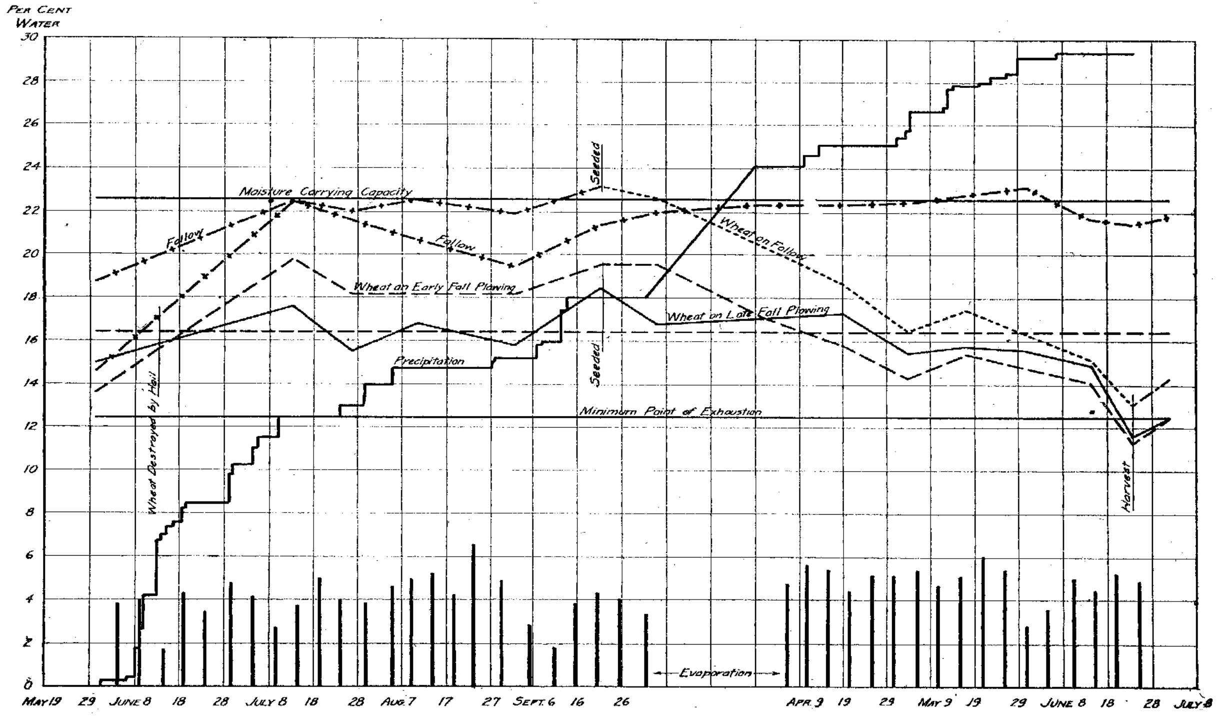

PLATE 4.

was a gradual increase in moisture in the late- and early-fall-plowed ground until November 5. The moisture in the fallowed ground for some reason continued to decrease until after September 1, after which it again rapidly increased until November 5. At this time the moisture content of all plots reached the maximum for the season. The following table shows the gain in moisture from June 1, 1909, to seeding time, September 21. Eighteen inches of rain fell during this period.

TABLE III. Moisture content of soil to a depth of six feet June 1 and September 21, 1909, and gain in moisture during this period.

PLOT.	Moisture content June 1.	Moisture content September 21.	Gain.
Late-fall-plowed	14.9%	18.3%	3.4%
Early-fall-plowed	13.7	19.0	5.9
Fallowed	14.5	21.5	7.0

While the moisture content in all plots had been reduced by the previous crop to within one per cent of the same point, when the minimum point of exhaustion was reached, June 1, the plots did not gain equally in moisture during the late summer months. The late-fall-plowed plot gained 3.4 per cent of moisture, while the early-fall-plowed plot gained 5.9 per cent, and the fallowed plot gained 7 per cent. These data clearly show the value of early plowing and early cultivation in conserving and storing moisture.

It will be seen from the moisture curves in Plate 4, that there was a general decrease in moisture in all plots from No-

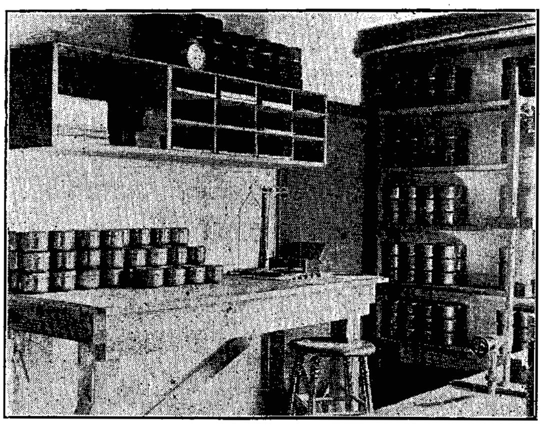

PLATE 5. A corner of the soil laboratory.

vernber 3, 1909, to June 21, 1910, when the minimum moisture content was reached. Because of a ranker growth of wheat, the moisture content of the early-fall-plowed ground was reduced the most rapidly, and between April 1 and harvest contained less moisture than the late-fall-plowed ground. The fallowed ground also lost moisture rapidly during the growing period of the wheat crop, but the fallowed ground at all times contained more moisture than any of the other plots, and when the crop matured, at which time the minimum moisture content for the season was reached, the ground which had been fallowed still contained 0.7 per cent of available moisture, while all the available moisture was exhausted in the other plots.

The following table shows the amount of moisture removed from the soil during the months of April and May, when the most rapid growth occurred:

TABLE IV. Loss in moisture from April 1 to May 31, 1910.

PLOT.	Moisture content April 1.	Moisture content May 31.	Loss.
Late-fall-plowed	16.9%	15.5%	1.4%
Early-fall-plowed	17.0	14.6	2.4
Fallowed	20.4	16.3	4.1

These figures show that during April and May the fallowed ground supplied considerably more moisture to the wheat than did the early-fall-plowed ground and more than double the amount supplied by the late-fall-plowed ground.

The table which follows shows the amount of moisture removed from the soil during the growing period of the wheat and the yields secured with each method of preparation:

TABLE V. Available moisture in the surface six feet of soil at seeding time, amount used by the wheat in its growth, and yield for the season of 1910.

PLOT.	Soil moisture.				Precipitation from Sept. 1, 1909, to June 24, 1910.	Acre yield.	
	September 21, 1909.		Total content June 24.	Loss from Sept. 21 to June 24.		Grain, bushels.	Straw, pounds.
	Total moisture.	Available moisture.					
Late-fall-plowed	18.3%	5.9%	11.3%	7.0%	12.41	20.3	2,985
Early-fall-plowed	19.6	7.2	11.2	8.4	12.41	27.8	3,135
Fallowed	23.2	10.8	13.1	10.1	12.41	42.5	4,845

GRAPHIC CHART SHOWING MOISTURE IN THE SURFACE SIX FEET OF SOIL PREPARED IN DIFFERENT WAYS FOR WINTER WHEAT. SEASON 1910-1911.

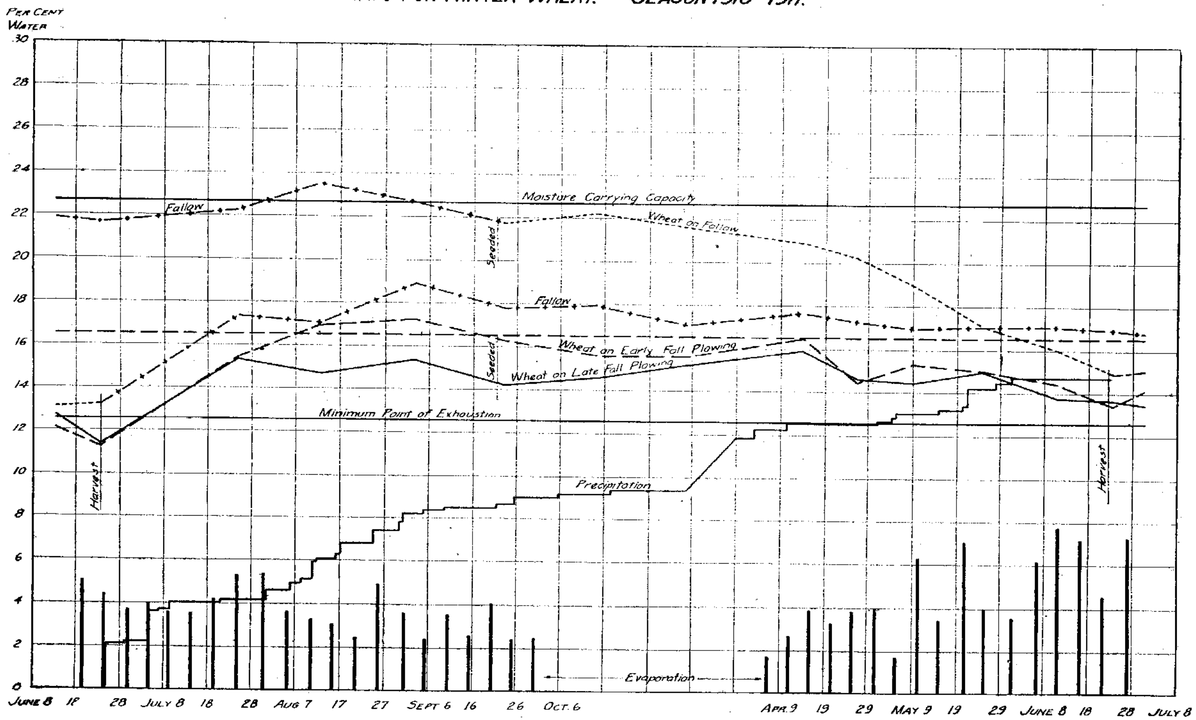

PLATE 6.

At seeding time the late-fall-plowed plot contained 18.3 per cent of total moisture and 5.7 per cent of available moisture in the upper six feet of soil, the early-fall-plowed plot contained 19.6 per cent of total moisture and 7.2 per cent of available moisture, while the fallowed plot contained 23.2 per cent of total moisture and 10.8 per cent of available moisture. Thus, the fallowed ground at seeding time contained 50 per cent more available moisture than the early-fall-plowed ground and 83 per cent more moisture than the late-fall-plowed ground. The late fall-plowing produced 20.3 bushels of wheat to the acre, the early fall-plowing 27.8 bushels, and the summer-fallowed 42.5 bushels. Therefore, the summer-fallowed ground with 50 per cent more available moisture at seeding time than the early-fall-plowed ground produced 53 per cent more wheat, and with 83 per cent more available moisture than the late-fall-plowed ground produced 109 per cent more wheat. Thus, yields secured from all treatments were in direct proportion to the amount of available moisture in the ground at seeding time. Although the fallowed plot produced over 100 per cent more grain than the late-fall-plowed plot, it still contained at harvest time over 3 per cent more moisture than this plot and nearly 2 per cent more moisture than either of the continuously cropped plots.

SEASON OF 1910-1911.

After harvest in 1910 the moisture content gradually increased in all ground. The late-fall-plowed plot was left untouched after harvest until it was plowed September 17. The early-fall-plowed and fallowed plots were plowed July 27, and were treated alike thereafter.

The following table shows the amount of moisture each plot gained from June 24, 1910, when the wheat was harvested, to seeding time, September 22. The rainfall during this priod was 8.73 inches:

TABLE VI. Moisture content of the upper six feet of soil June 24 and September 22, 1910, and gain in moisture during this period.

Plot.	Moisture content June 24, 1910.	Moisture content September 22, 1910.	Gain.
Late-fall-plowed	11.3%	14.1%	2.8%
Early-fall-plowed	11.2	16.2	5.0
Fallowed	13.1	17.7	4.6

This table shows that the late-fall-plowed plot gained only 2.8 per cent in moisture, while the other plots made gains of 5 per cent and 4.6 per cent, respectively, during the period between harvest and seeding.

Thefollowing table shows the amount of available moisture in the ground at seeding, the amount used by the crop during the growing season, and the yield of wheat obtained with each treatment:

TABLE VII. Available moisture at seeding time, amount removed from the soil during the growing season, and yield of all plots for the season of 1911.

Plot.	Soil moisture.				Precipitation from September 22, 1910, to June 23, 1911.	Yield.	
	September 22, 1910.		Total content June 23, 1911.	Loss from September 22, 1910, to June 23, 1911.		Grain, bushels.	Straw, pounds.
	Total content.	Amount avilable.					
Late-fall-plowed...........	14.1%	1.7%	13.5%	.6%	6.04%	0.0	0.0
Early-fall-plowed..........	16.2	3.8	13.3	2.9	6.04	0.3	80.0
Fallowed.................	21.6	9.2	14.8	6.8	6.04	2.6	795.0

At seeding time the late-fall-plowed ground contained but 1.7 per cent available moisture, the early-fall-plowed ground contained 3.8 per cent, while the fallowed ground contained 9.2 per cent. Thus, this season the fallowed ground contained 142 per cent more available moisture at seeding time than the early-fall-plowed ground, and 441 per cent more available moisture than the late-fall-plowed ground. The crop on the late-fall-plowed ground was a complete failure, while the crop on the early fall-plowed ground made a yield of 0.3 bushels an acre, and on the fallowed ground 2.6 bushels an acre.

As in 1910, the yield is in proportion to the amount of available moisture in the soil at seeding time. The loss of moisture from the plots during the season of 1910-1911 was less than in 1909-1910. As shown in Plate 6, the moisture content was not reduced so low in 1910-1911 as it was in the previous year. The cause of the crop failure this season was unfavorable weather conditions. As shown by the precipitation curves from seeding date, 1910, to June 23, 1911, there was but one rain that exceeded one-third inch, and the total rainfall for the period, including the winter months, was but 6.04 inches. There were also long intervals with little or no rainfall, when the rate of evaporation was exceedingly high. Such unfavor-

GRAPHIC CHART SHOWING MOISTURE IN THE SURFACE SIX FEET OF SOIL PREPARED IN DIFFERENT WAYS FOR WINTER WHEAT. SEASON 1911-1912.

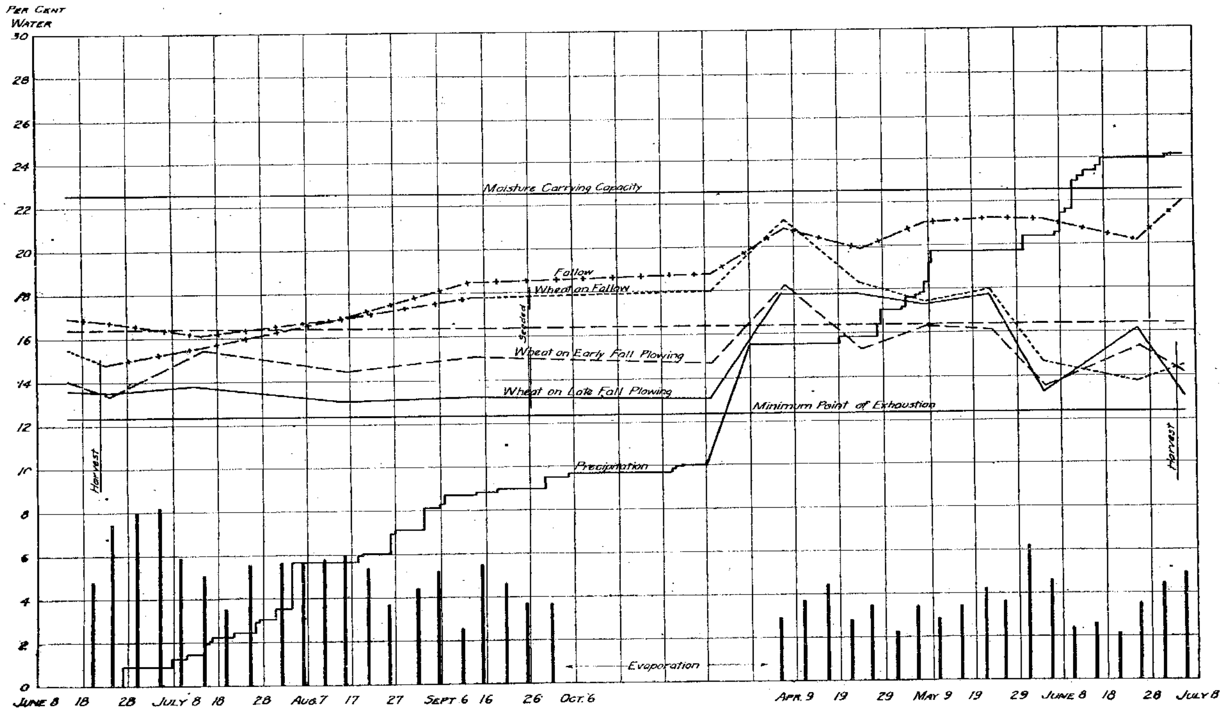

PLATE 7.

able climatic conditions made it impossible for the crops to use all the available moisture in the soil. During the corresponding period in 1909-1910 there was a rainfall of 12.41 inches. The evaporation was also comparatively low. Thus the season was favorable for plant growth, which made it possible for the crop to use all the available moisture in the soil.

SEASON OF 1911-1912.

Between the time of harvesting the crop of 1911 and the time of seeding the following fall there was a slight increase in moisture content in all plots except the one that was left unplowed until shortly before seeding.

The following table shows the change of moisture content in the ground during this period:

TABLE VIII. Moisture content of soil June 23 and September 13, 1911, and gain in moisture during this period.

Plot.	Moisture content, June 23.	Moisture content, September 13.	Gain or loss.
Late-fall-plowed	13.5%	13.3%	—0.2%
Early-fall-plowed	13.3	15.1	1.8
Fallowed	14.8	18.6	3.8

This data shows that the late-fall-plowed plot actually lost 0.2 per cent of moisture during the period from June 23 to September 13, 1911, while the moisture content of the early-fall-plowed plot increased 1.8 per cent and that of the fallowed plot 3.8 per cent. Again, the value of early fall-plowing and subsequent cultivation is demonstrated as a means of conserving moisture.

The moisture in the soil at seeding time and at harvest and the yield of the crop for the season of 1912 are shown in the following table:

TABLE IX. Available moisture at seeding time, amount removed from the soil during the growing season, and yield of wheat on each plot for the season of 1912.

Plot.	Soil moisture.				Precipitation from September 13, 1911, to July 5, 1912.	Yield.	
	September 13, 1911.		Total content July 5, 1912.	Loss.		Grain, bushels.	Straw, pounds.
	Total content.	Amount available.					
Late-fall-plowed	13.3%	0.9%	13.1%	0.2%	15.57	2.3	265
Early-fall-plowed	15.1	2.7	14.3	.8	15.57	13.8	3425
Fallowed	17.9	5.5	14.5	3.4	15.57	29.2	5240

The above table shows that at seeding time the late-fall-plowed plot contained only 0.9 per cent available moisture, the early-fall-plowed plot contained 2.7 per cent of available moisture, and the fallowed plot contained 5.5 per cent of available moisture. The fallowed plot at this time contained twice as much available moisture as the early-fall-plowed plot and six times as much as the late-fall-plowed plot.

There was a decided increase in moisture content of all the plots during the winter months, due to on unusually large amount of precipitation.

The maximum moisture content, therefore, was reached in the spring, about April 6, instead of at seeding time as usual. The moisture content of the plots April 6,1912, was as follows: late-fall-plowed, 17.9 per cent; early-fall-plowed, 18.4 per cent; fallowed, 21.3 per cent. Most of this moisture, however, fell after a date so late in the fall that the wheat did not derive any particular benefit from it before spring; in fact, the wheat suffered in the fall from a lack of moisture.

There was a rapid decrease in the moisture content of the early-fall-plowed and the fallowed ground from April 6 to April 23, while the moisture content of the late-fall-plowed ground remained practically unchanged. This was due to the thick stand of wheat on early-fall-plowed and fallowed ground. This wheat during the period made considerable growth, while on the late-fall-plowed ground the wheat, most of which did not germinate until spring, was too thin and small to use much moisture.

By referring again to Table IX it will be seen that at seeding time in 1911 the late-fall-plowed plot contained less than 1 per cent of available moisture, the early-fall-plowed plot contained but 2.7 per cent of available moisture, while the fallowed plot contained 5.5 per cent of available moisture. The yields of grain secured were 2:3 bushels on the late-fall-plowed ground, 13.8 bushels on the early-fall-plowed ground, and 29.2 bushels on the fallowed ground. Again, as in the two preceding years, the yields vary directly with the amount of available soil moisture in the ground at seeding time.

GRAPHIC CHART SHOWING MOISTURE IN THE SURFACE SIX FEET OF SOIL PREPARED IN DIFFERENT WAYS FOR WINTER WHEAT. SEASON 1912–1913.

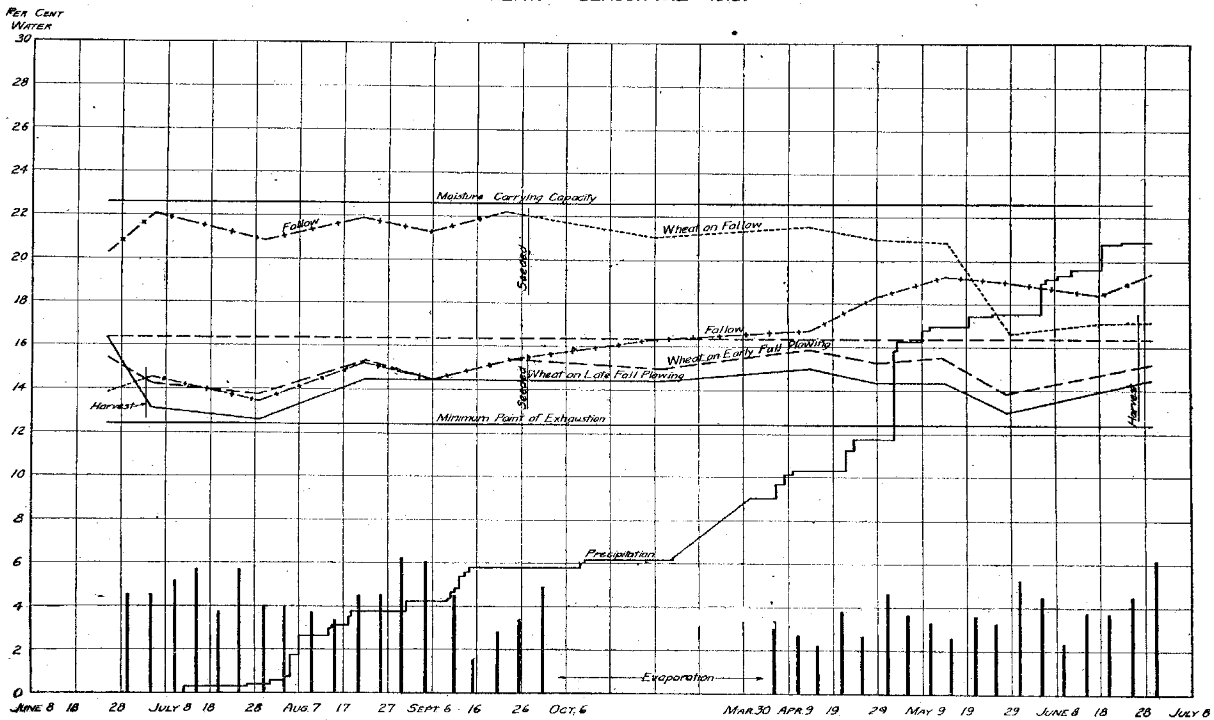

PLATE 8.

SEASON OF 1912-1913.

For about one month after the harvest of 1912 there was a slight decrease in the moisture content of the ground, due to the continuation of the drouth, which extended from about the middle of June to the last of July. After this date the moisture content of the plots Slowly increased until September 23, or seeding time. The table which follows shows the increase in moisture in the soil during this period:

TABLE X. Increase in moisture content of soil from July 5 to September 23, 1912.

PLOT.	Moisture content July 5.	Moisture content September 23.	Gain.
Late-fall-plowed	13.1%	14.6%	1.5%
Early-fall-plowed	14.0	15.5	1.2
Fallowed	14.5	15.5	1.0

These results are slightly contradictory to results obtained in previous years, in that the fallowed ground made the smallest gain in moisture and the late-fall-plowed plot the largest. It will be observed that the increase in moisture content, however, was small in all plots, being 1.5 per cent in the late-fall-plowed ground, 1.2 per cent in the early-fall-plowed ground, and 1.0 per cent in the fallowed ground. The reason for so small an increase in moisture was the very low rainfall, which amounted to only 5.80 inches.

In the fall, after seeding, there was a slight decrease in the moisture content of the early-fall-plowed and the fallowed ground, while there was practically no change in that of the late-fall-plowed ground. There was then little change in the moisture content until April 9, after which there was a general decrease until May 28, when the lowest moisture content previous to harvest was reached. On May 2 there was a heavy storm, with five inches of rain. This rain fell in a few hours and came so rapidly that it did not increase the moisture content of any of the plots, practically all being lost by surface run-off. Crops on the late- and the early-fall-plowed plots were suffering from drouth by the middle of May. The wheat on the fallowed plot did not begin to suffer until about two weeks later.

The following table shows the relation of moisture to yield of wheat for the season of 1913:

TABLE XI. Available moisture at seeding time, amount removed from seeding time until harvest, and yield of wheat on each plot for the season of 1913.

Plot.	Soil moisture.				Precipitation from September 23, to June 27, 1913.	Yield.	
	September 23, 1912, seeding date.		Total content May 28, 1913.	Loss, seeding to harvest.		Grain, bushels.	Straw, pounds.
	Total.	Amount.					
Late-fall-plowed	14.6%	2.2%	13.0%	1.6%	15.24	0.8	815
Early-fall-plowed	15.5	3.1	13.9	1.6	15.24	2.3	1273
Fallowed	22.2	9.8	16.7	5.5	15.24	10.3	3245

It will be observed that the loss of moisture is figured from September 23, 1912, seeding date, until May 28, when the minimum content was reached, one month previous to harvest. After May 28 the moisture content was increased by rains which began to fall after June 6. This, however, was not until after the wheat was so badly damaged that recovery was impossible.

PLATE 9. Wheat grown on summer-fallowed ground.

It may be noted that while the late- and the early-fall-plowed plots each lost 1.6 per cent, or the same amount of moisture from seeding to harvest, the late-fall-plowed plot produced but 0.8 bushel of wheat, while the early-fall-plowed plot produced 2.3 bushels, or nearly three times as much grain. The difference in the yield may be partly due to the fact that while the moisture content of both plots closely approached the unavailable point, the early-fall-plowed plot contained about 1 per cent more available moisture, which gave it an advantage over the late-fall-plowed ground. The fallowed plot, which produced more than four times as much grain as the early-fall-plowed plot and nearly twelve times as much as the late-fall-plowed plot, contained at seeding 9.8 per cent of available moisture, while the late-fall-plowed plot contained but 2.2 per cent and the early-fall-plowed plot contained 3.1 per cent.

The fallowed plot had three times as much available moisture at seeding time as either of the other two plots. It therefore seems probable that the increase in yield of the fallowed ground over the continuously cropped ground was largely if not wholly due to the advantage it had in .available moisture at the time when the crop was seeded.

The following table shows the relations that have existed between the available moisture in the soil at seeding time, the precipitation during the growing period, and the yield of the crop .:

TABLE XII. Amount of avilable moisture in the soil at seeding time, precipitation during the growing period of the wheat, and yield.

PLOT.	Year.	Available moisture contained at seeding time.	Total precipitation during growing period of the crop, inches.	Yield.	
				Grain, bushels.	Straw, pounds.
Late-fall-plowed	1910	5.9%	12.41	20.3	2,985
	1911	1.7	6.04	....	....
	1912	.9	15.57	2.3	265
	1913	2.2	15.24	0.8	815
Average	....	2.7%	12.32	5.9	1,015
Early-fall-plowed	1910	7.2%	12.41	27.8	3,135
	1911	3.8	6.04	0.3	80
	1912	2.7	15.57	13.8	3,425
	1913	3.1	15.24	2.3	1,273
Average	....	4.2%	12.32	11.1	1,978
Fallowed	1910	10.8%	12.41	42.5	4,845
	1911	9.2	6.04	2.6	795
	1912	5.5	15.57	29.2	5,240
	1913	9.8	15.24	10.3	3,245
Average	....	8.8%	12.32	21.2	3,531

It appears, as an average of four years' results, that for every time the amount of available moisture stored in the soil at seeding time has been doubled, the yield has been approximately doubled. It must not be understood or expected, however, that a certain amount of available moisture in the soil at seeding time will insure a certain yield of wheat. The yield secured will depend quite as much upon the amount and distribution of the rainfall during the growing season and other climatic conditions during the growth and development of the crop. But with favorable climatic conditions and normal precipitation, the yield of the crop will be determined largely by the amount of available moisture in the soil at seeding time.

It will be seen from this table that while there is a very close relation between the amount of moisture in the soil at seeding time and the yield, there are seasons, like the season of 1911, when the crop was a failure because of unfavorable weather conditions, although there was at seeding time a fairly large quantity of moisture stored in the soil on the fallow and early-plowed plots.

It is therefore evident that with the severe climatic conditions, such as prolonged drouths and hot winds, it is impossible to store in the soil sufficient water to insure a profitable crop of wheat every season, but with normal weather conditions the crop will be in proportion to the water stored and that in a series of years the largest yields will be secured from those methods of handling the soil which store and hold the largest supplies of moisture for the crop. These methods are early fall-plowing, early fall-listing, and summer-fallowing.

RESULTS OF SEVEN YEARS' WORK.

The preceding discussion has been limited to that portion of the work and to those seasons on which moisture data were available. As stated in the introduction, the moisture studies were not started until two years after the soil-tillage work was begun, and when they were started only three of the five different methods of soil treatment were studied. The complete record of all yields will be found in the following table, which gives the yield of wheat obtained each season upon each method of soil treatment since the beginning of the work:

TABLE XIII. Yield of winter wheat 1907 to 1913.

Method of Cropping.	Yield of grain and straw.														
	1907.		1908.		1909.		1910.		1911.		1912.		1913.		Average Grain,† bushels.
	Grain, bushels.	Straw, pounds.	Grain, bushels.	Straw, pounds.	Grain, bushels.	Straw, pounds.	Grain, bushels.	Straw, pounds.	Grain, bushels.	Straw, pounds.	Grain, bushels.	Straw, pounds.	Grain, bushels.	Straw, pounds.	
Late fall-plowing	11.7	....	25.6	2,555	*	*	20.3	2,985	....	....	2.3	265	0.8	8.15	10.1
Early fall-plowing	18.2	....	23.2	2,700	*	*	27.8	3,135	0.3	80	13.8	3,425	2.3	1,273	14.2
Early fall-plowing and subsoiling	13.6	....	30.5	2,890	*	*	39.8	3,475	0.3	55	20.1	3,450	4.1	1,673	18.1
Early fall-listing	12.4	....	28.1	2,765	*	*	36.7	3,680	0.6	195	26.6	4,440	8.4	2,215	18.8
Fallowing	11.2	....	32.3	3,110	*	*	42.5	4,845	2.6	795	29.2	5,240	10.3	3,245	21.3

*Destroyed by hail. †Season of 1909 not included in average.

The late-fall-plowed ground has produced an average of but 10.1 bushels an acre, which is less than any other method of preparation during the six years. The early-fall-plowed ground has produced 14.2 bushels an acre, or 4.1 bushels more than the late fall-plowing.

The ground that was early-fall-plowed and subsoiled has produced an average yield of 18.1 bushels an acre, which is 3.9 bushels more than the ground plowed at the same time but not subsoiled, and 8 bushels more than the ground plowed late in the fall and not subsoiled. The subsoiling was done but once in three years. The cost of subsoiling to a depth of five to eight inches below the bottom of the furrow slice has been about $3 an acre in addition to the cost of plowing; that is, ground that was subsoiled has cost about $1 a year more to prepare for wheat than ground plowed at the same time but not subsoiled. Thus the increase in yield, amounting to 3.9 bushels yearly, not only has been sufficient to pay for the additional cost of subsoiling, but has left a good profit besides. It appears from this work that subsoiling might prove profitable on some soils in western Kansas. Since the value of subsoiling will undoubtedly vary on the different soil types, and perhaps with different crops, a farmer should at first carefully test out the method on a small part of the farm. Subsoiling will undoubtedly prove most profitable upon the heavier types of soil, which absorb water slowly.

LISTING.

Listing early in the fall each season has produced the most wheat of any of the methods of continuous cropping. This ground has produced an average annual yield of 18.8 bushels an acre, or 4.6 bushels more than ground that has been plowed at the same time, and 8.7 bushels more than ground plowed late in the fall. Just why listing has proved so superior to plowing on these plots is not known and is difficult to explain, for large fields on the Station farm that have been continuously cropped and listed for wheat have not nearly equaled in yield the wheat grown on summer-fallowed ground. While moisture determinations have not been made for any considerable length of time on the ground receiving this treatment, the work that has been done thus far does not indicate that the listed ground has, at the time of seeding or at any time during the growing period of the crop, more available moisture than is found in the early-fall-plowed ground.

Listing is a cheaper method of preparing ground than plowing. Moreover, a larger area of ground can be worked in a given period of time with the lister than is possible with the plow, thus enabling the farmer to work his land more opportunely. It is often possible to cover an entire field with a lister while the soil is moist and in good condition to work, whereas the same force working with a plow could not cover the field until after the soil had become too dry for good plowing. It should be remembered, however, that ground listed late in the summer makes a poor seed bed for wheat, and that when land is prepared by listing the work should be done early, so that the ground may be worked down and thoroughly settled before seeding. It is advisable, where listing is the common practice, to plow the ground occasionally. There is a tendency for the lister to follow the same furrows year after year when the listing is done in the same direction. An occasional plowing will therefore leave the soil in such fields in better physical condition.

SUMMER-FALLOWING.

Alternate cropping and summer-fallowing have produced an average yield of 21.3 bushels of wheat an acre. This is an increase of 2.5 bushels over continuous cropping when the ground has been prepared by listing, an increase of 7.3 bushels over early fall-plowing, and an increase of 11.2 bushels over late fall-plowing. In alternate cropping and summer-fallowing but one crop is secured in two years. Thus twice as much ground is required for the same acreage of wheat as is necessary when the ground is continuously cropped. Therefore, if the yield of wheat on the fallowed ground is divided by two, the average annual yield from summer-fallow is 10.6 bushels an acre, 8.3 bushels less than from listing and 3.6 bushels less than from early fall-plowing, but 5 bushels more than from late fall-plowing. It is evident that, although but one crop is produced in two years, the practice is more profitable than late fall-plowing, and where so large an acreage of wheat is grown that the ground can not all be properly prepared for the crop it will undoubtedly prove profitable to summer-fallow a portion of the wheat land each season.

In summer-fallowing it is necessary to sow, harvest and thresh but one crop in the two years, so that the cost of producing a crop of wheat on summer-fallowed ground will not be twice the cost of producing wheat by the best method of continuous cropping. In fact, when the fallow is properly handled the cost of producing a crop by summer-fallowing will not greatly exceed the cost of producing a crop by the best methods of continuous cropping, provided the interest on the investment in land is not considered.

From the results of these tests, conducted where the annual rainfall is 22 inches, it is doubtful if it would prove profitable to crop and summer-fallow land alternately if it were possible to prepare the ground each season by either plowing or listing

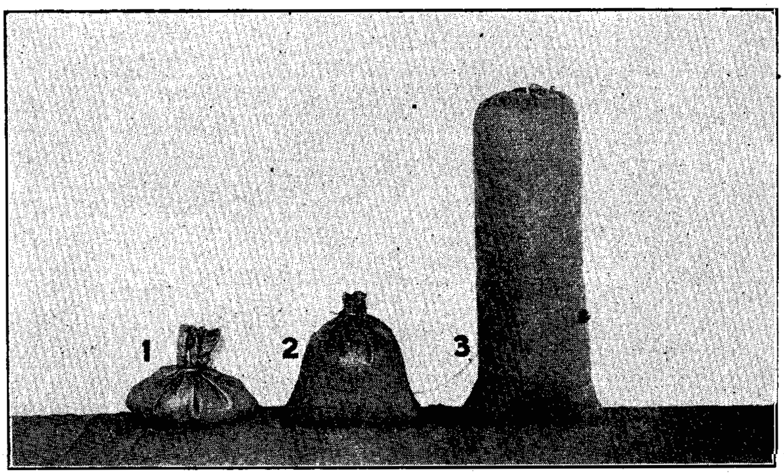

PLATE 10. The grain produced on one-fourth acre of ground prepared in different ways for winter wheat, season of 1913: (1) Late fall-plowing. (2) Early fall-plowing. (3) Summer-fallowing.

early in the summer. Where a large acreage of ground is to be prepared for wheat, with limited equipment, it is impossible to prepare all the ground at an early date. Under such conditions a system of summer-fallowing that will distribute the work through the different seasons of the year, and thus allow all work to be done more opportunely, will undoubtedly prove profitable.

A SYSTEM OF SUMMER-FALLOWING IN CONTINUOUS WHEAT GROWING.

In many sections of central and western Kansas land is cropped,continuously to wheat. In fact, on many farms wheat is practically the only crop grown. Under such conditions, where all the land is cropped to wheat each season, the ground is very poorly prepared, and thus small crops are grown. It has been suggested that for such conditions a system could be profitably practiced whereby one-fourth of the land would be fallowed each season and three-fourths planted to wheat. The ground to be fallowed could be double-disked early in the spring, and plowed as soon as spring rains fell and when the ground was in good condition for plowing. It is usually cool at this season of the year, equipment is available, and deep plowing can be done. There would also be sufficient time between plowing and seeding for the deep plowing to become thoroughly packed. The object should be to have all the summer-fallowed ground plowed before the opening of harvest. After plowing, the ground should be worked just enough to keep down weed growth; in fact, overworking should be avoided lest the ground become so smooth and fine that blowing might follow.

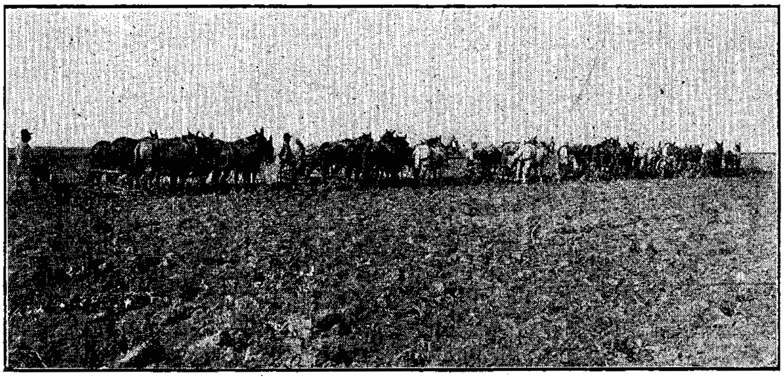

PLATE 11. Plowing ground in early June to be summer-fallowed for wheat.

The ground that had been summer-fallowed the preceding summer could be prepared by listing or disking as soon as possible after harvest. On a loose type of soil, where the plowing had been deep in preparation for the fallow and the ground was loose at harvest time, the best method of preparing the seed bed would be by disking, or, if there was little or no weed growth, by stubbling in the crop.

The ground that had been fallowed two years before should be plowed or listed to only a medium depth soon after harvest, and prepared for the crop in the best possible manner. The ground to be summer-fallowed the next season could be disked the fall or summer before, if labor was available for the purpose; if not, it could be left unworked until the following spring.

By such a system, a farmer handling 400 acres of wheat each year would divide his farm into four 100-acre fields, 100 acres to be summer-fallowed and 300 acres to be seeded to wheat, one-third of which would be sown on fallow, one-third on early-listed or -plowed ground and the other one-third sown on plowed or disked ground or stubbled in, depending upon the character of the soil and the season. Such a system of summer-fallowing would divide the work and distribute it throughout the year, and at the same time would not reduce, but would undoubtedly increase, the productiveness over that obtained in a system of continuous cropping.

USING SUMMER FALLOW IN A ROTATION OF CROPS.

The most profitable way of using the summer fallow is in a rotation of crops. It is a demonstrated fact that the most successful farmers in central and western Kansas are those who are following a diversified system of farming and growing feed crops for stock together with wheat. The sweet sorghums and kafir, feterita, and milo are the most profitable feed crops. To obtain the maximum yield of wheat and kafir or sorghum under such conditions the crops must be grown in rotation and not grown on the same land continuously. Wheat will not, however, make a profitable crop when sown on sorghum or kafir stubble. Kafir and sorghum grow late in the fall and exhaust the soil so thoroughly of moisture and available plant food that wheat sown upon such ground is usually a failure. Therefore, in planning a rotation of crops for such conditions, summer-fallowing is indispensable. Where wheat is the most important crop, a four-year rotation of wheat two years, sorghum or kafir one year, and summer fallow one year, can be followed. When kafir or sorghum is the most important crop, a four-year rotation of two years of kafir or sorghum, one year of summer fallow, and one year of wheat can be used. In either case the ground is summer-fallowed after kafir or sorghum, and in that way is stored with moisture and available plant food, and will produce the maximum crop the following year.

HANDLING SUMMER FALLOW TO PREVENT BLOWING.

An objection often raised to summer-fallowing is the danger of blowing. This danger has been greatly overemphasized. There is little danger of fallowed land blowing if the ground is properly handled. Fallowed ground may blow if cultivated with implements that pulverize the ground, like the disk har,-row and smoothing harrow, so often that the soil becomes fine and dusty. The danger is greater if the soil is dry when the work is done.

PLATE 12. Binding a field of summer-fallowed wheat at the Fort Hays Branch Experiment Station.

The secret of handling summer fallow is to work the ground only when it is moist, to work it only enough to keep down weed growth, and to work it in such a way that the surface of the soil is left rough and partly cloddy. The smoothing harrow should never be used on fallowed ground, and the disk should be used but little. These implements pulverize the ground and leave the surface smooth and dusty, thus making conditions favorable to blowing. When cultivation is necessary to kill weeds or break a crusted soil, implements like the spring-tooth harrow, the shovel corn-cultivator, the beet cultivator, or the alfalfa renovator should be used. These implements leave the ground ridged, pulverize the soil but little, and work the fine particles of soil down and bring the lumps and clods to the surface.

Wheat sown upon properly prepared. summer-fallowed land usually makes sufficient fall growth to hold the soil the following spring. In case it should not blowing may be prevented by top-dressing the field with straw and forcing the straw into the ground with a subsoil packer or a disk set straight and slightly weighted. Blowing can also be prevented by cultivating the field at right angles to the direction of the prevailing wind with a twelve-shovel two-row corn-cuitivator with all but four shovels removed. Such cultivation will usually keep a field from blowing and will injure but little wheat. In extreme cases, when a cultivator will not hold the soil, a lister can be run at right angles to the direction of the prevailing wind at intervals frequent enough to hold the soil. The lister will destroy some wheat, but may be the means of preventing the loss of the crop on an entire field.