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SOIL MOISTURE AND WINTER WHEAT WITH SUGGESTIONS ON ABANDONMENT

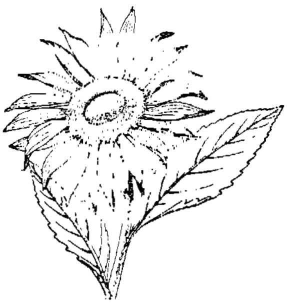

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FIG. 1.—General view of experimental plots of the Division of Dry Land Agriculture, United States Department of Agriculture, on the Fort Hays branch of the Kansas Agricultural Experiment Station, Hays, Kan. The picture was taken June 6, 1922.

FIG. 2.—Blank listing after harvest, an operation sometimes used as the first step in the preparation of a seedbed for winter wheat.

SOIL MOISTURE AND WINTER WHEAT WITH SUGGESTIONS ON ABANDONMENT[1]

A. L. HALLSTED AND O. R. MATHEWS

INTRODUCTION

The importance of the winter wheat crop to western Kansas is too well known to require comment. Nearly every farmer and every business man in that part of the state are dependent upon the wheat crop for their livelihood. For this reason, any method of increasing the chance of success or of avoiding failure with the crop is important to the section. It is a well-known fact that thousands of acres of wheat are planted in Kansas every year under conditions that are almost certain to result in failure. It is equally true that thousands of acres of wheat are allowed to mature and are then abandoned or harvested at a loss, the yield of which could have been fairly accurately predicted in the spring, thus making abandonment possible in time to prepare a better seedbed for the next crop.

The purpose of this publication is to acquaint farmers with methods of determining at seeding time their chances of obtaining a paying crop and of ascertaining relatively early in the spring whether or not the crop should be abandoned.

The fact that the yield of wheat in regions of low rainfall is more or less dependent upon the moisture content of the soil at seeding time has been generally recognized, and the effect of moisture content at seeding on the yield at Hays has been discussed in publications by Call and Hallsted[3] and by Hallsted and Coles.[4] The present publication is designed to bring the results of these studies up to date, to adapt them as far as practicable to all of western Kansas, and to present them in such a way that a farmer can easily apply them to his own conditions.

Acknowledgment.—The data presented from the Colby and Garden City branch stations have been accumulated through many years of work by agronomists located at these stations. The authors wish to acknowledge their indebtedness to the following for these data. At the Colby station: J. B. Kuska, B. F. Barnes, and J. J. Bayles. At the Garden City station: Ralph Edwards, J. G. Lill, C. B. Brown, F. A. Wagner, F. E. Keating, E. H. Coles, and R. L. von Trebra.

1. Contribution No. 20 from the Fort Hays Branch Experiment Station. The experiments reported in this bulletin were conducted by the Fort Hays, Colby, and Garden City branches of the Kansas Agricultural Experiment Station and the Division of Dry Land Agriculture, Bureau of Plant Industry, United States Department of Agriculture, coöperating.

2. Associate Agronomists, Division of Dry Land Agriculture, Bureau of Plant Industry, United States Department of Agriculture.

3. Call, L. E., and Hallsted, A. L. The relation of moisture to yield of winter wheat in western Kansas. Kan. Agr. Expt. Sta. Bul. **206.** 34 pp., illus. 1915.

4. Hallsted, A. L., and Coles, E. H. A preliminary report of the relation between yield of winter wheat and moisture in the soil at seeding time. *In* Jour. Agr. Res., Vol. 41, No. 6, pp. 467-477, illus. 1930.

SOURCE OF DATA

The results presented in this bulletin were obtained at the Kansas branch stations located at Hays, Colby, and Garden City, where work is carried on by the Division of Dry Land Agriculture of the United States Department of Agriculture in cooperation with the Kansas Agricultural Experiment Station. (Fig. 1.) Soil moisture determinations were carried on in connection with the crop rotation and cultural method experiments throughout the period of seedbed preparation and growth of the wheat crop, but only those made at seeding time are considered here.

SOIL TYPES

The three stations are located on fertile deep soils, typical of much of the wheat-growing area of western Kansas. There is considerable difference in the texture of the soils, but all of them are commonly classed as "hard-land" soils. The soil at Hays is classed as a silty clay loam and is the heaviest of the three. The soil at Colby is a silt loam, consisting almost entirely of silt and very fine sand. That at Garden City contains more sand and can be classed as a very fine sandy loam.

The soils differ somewhat in water-holding capacity, that at Hays being capable of retaining the most moisture and that at Garden City the least. All of them are capable of holding relatively large quantities of water, and, even on fallow, moisture seldom penetrates to a depth greater than that reached by the roots of the wheat plant.

At all three stations the soil is relatively uniform to a depth of many feet, and the depth to which moisture penetrates is limited by the quantity of water taken into the soil, rather than by any physical obstructions. These soils are capable of producing high yields of wheat under favorable moisture and climatic conditions.

METHOD OF DETERMINING THE QUANTITY OF WATER IN THE SOIL

The water content of the soil was determined by taking four cores of soil from each foot section of each plot to a depth of 6 feet. These cores were weighed, dried thoroughly in an oven kept at a temperature of 100 to 110° C., and then reweighed. The percentage of moisture in the soil was obtained by dividing the weight of the water driven off by the weight of the oven-dried soil.

Not all of the moisture in the soil is available to crops. The lowest point to which wheat normally reduces the moisture in the soil, designated as the minimum point of exhaustion, was determined for each foot section of soil by averaging the moisture contents at times during the growing season when it was certain that the supply of available moisture was exhausted and the crop was suffering for water. The minimum points of exhaustion so determined for the different foot sections at Hays were 12.1, 15.4, 13.4, 13.4, 13.4, and 15.1 percent for the first to the sixth foot, respectively. The difference between the water present in each foot of soil at seeding time and the minimum point of exhaustion represents the available water present at seeding time. Minimum points of exhaustion were established at the other stations in the same manner as at Hays. Because of the presence of more sand in the soils, the minimum points of exhaustion for the Colby and the Garden City soils were lower than for the Hays soil.

In the publications of Call and Hallsted and Hallsted and Coles moisture was dealt with in terms of percentage only. This is a logical way to present the data from a single station or soil, but the results obtained with one soil type are not applicable to other soil types when presented on this basis. Thirteen percent of moisture in a heavy clay soil may represent a dry condition, whereas the same percentage of moisture in a sandy soil may represent all the water it is capable of holding. Even when two soils vary but little in physical properties, equal moisture percentages may represent considerable difference in the quantities of water they are capable of supplying to growing crops.

In the present publication the calculations are carried a step farther, and the available moisture in the soil is expressed as inches of water. Precipitation is measured in inches, and to most readers the number of inches of water in a soil is a more understandable figure than the percentage of moisture. The number of inches of water does not refer to the depth to which the soil is wet, but to the actual number of inches of available water present. The inches of available water in the soil were determined from the percentage of available water and the weight of soil per cubic foot. Details of the procedure are not important. The results here reported deal with available water only, and any reference to the quantity of water in a soil refers to the quantity of water that the crop can use and not to the total quantity present.

THE ACCUMULATION OF WATER IN THE SOIL

Under climatic conditions like those in western Kansas, ground that has grown a wheat crop is usually dry at harvest time. Consequently the moisture that it is to have at seeding time depends upon two factors. The first of these is the quantity of rain between harvest and seeding, and the second is the proportion of this water that it is possible to store in the soil. With a very low rainfall, even the best method of handling land fails to store much water in the soil. Where no effort is made to conserve moisture, an abnormal amount of rain may be entirely wasted before seeding. The number of inches of rain between harvest and seeding is an indication, but not a true measure, of the quantity of water that may be in the soil at seeding. So much depends upon the tilth of the soil, the condition of the surface as to vegetation, and upon the manner in which the rain falls that an equal number of inches of rain on different fields the same year, or upon the same field in different years, may result in material differences in the quantity of water taken into and retained by the soil.

During a rain, the water that falls penetrates into the soil or runs off, the proportion taken into the soil depending upon the condition of the surface and the rapidity with which the rain falls. Water penetrates into a firm soil at a definite rate of speed, the rate depending upon the fineness of the soil and upon its physical structure. Rough or cloddy soil takes in water more rapidly than a smooth surface, because the spaces between clods permit water to get below the surface more rapidly than it could penetrate a firm soil. Trash and crop residues on the surface check runoff and allow more of the mater to be absorbed by the soil. Runoff is most serious on a smooth, fine surface. If rain falls slowly enough, it is all absorbed by the soil, regardless of the treatment; but in this section rains generally fall rapidly, and water loss by runoff frequently is heavy.

After water enters the soil, the depth to which it penetrates is definitely limited by the quantity that enters. Excluding the surface, where penetration above the natural rate is temporarily affected by open spaces between clods, movement downward takes place only as all soil through which the water passes reaches a certain degree of wetness. The quantity of moisture that a soil must contain before water can seep through it to a lower depth is called its "field-carrying capacity." A soil in this condition is noticeably wet. The depth to which moisture penetrates a dry soil is easily observed. The change from a wet to a dry condition takes place within a very short vertical space.

After rain stops falling the soil begins to lose moisture. That held near the surface is subject to loss by evaporation. If the surface is free from plant growth, evaporation is the sole source of loss. If crops or weeds are growing, loss takes place not only from the surface, but from all of the zone occupied by the roots of these plants. During the period from harvest to seeding, the loss from this cause is through weeds or volunteer wheat growth. Following a small rain, surface evaporation may remove most or all of the moisture taken into the soil. Loss of water by evaporation is unavoidable and accounts for a large part of the moisture lost from the soil. If rains are not too widely separated, much of the water held near the surface from one rain may still remain there when a second rain falls. When this occurs, not much water is needed to wet this surface layer, and more of the rain, if it falls slowly enough to be absorbed by the soil, is used in building up the subsoil supply. If rain falls too rapidly to be absorbed, the presence of water near the surface simply increases the amount of runoff. When water once penetrates to a depth great enough to escape surface evaporation, most of it remains in the soil until it is removed by the roots of plants.

For any water to reach the second foot of soil, all of the first foot must have been wet to its carrying capacity. For any water to reach the third foot, both the first and second feet must have been wet. Water reaches the fourth foot only after the first three feet of soil have been wet. The purpose of emphasizing this fact is to point out that a certain degree of wetness is necessary for the penetration of water, and that the change from a very wet to a very dry soil usually takes place within a linear space of only a few inches.

It was previously stated that loss by evaporation is unavoidable. This is true to a certain degree. Evaporation is capable of removing the moisture from the surface and from the soil near the surface. The depth to which evaporation will remove water rapidly, however, depends to some extent upon the condition of the surface soil. But it is a fact that the unavoidable alternate wetting and drying of the surface accounts for a large part of the loss of water from a clean-cultivated soil. Losses by weeds or volunteer wheat growth are especially bad in that they remove water from depths beyond the reach of evaporation. These losses are avoidable through clean cultivation.

Loss of water by direct evaporation is confined largely to the top 6 or 8 inches of soil, although loss from greater depths through vaporization has been observed during hot, dry periods. The quantity of water lost from below the first foot, however, is small, and the rate of loss is very slow compared with loss through root action.

RESULTS AT HAYS

The Fort Hays branch station represents a section where crop production is fairly stable. Average yields are high, total failures are comparatively rare, anti the response to cultural methods is pronounced. It is a favorable location for studying soil moisture problems, in that moisture is a limiting factor in crop production, and differences in the moisture supply are reflected in differences in yield. It is also favorably situated, in that moisture is not too much of a limiting factor. There usually is enough rain so that material differences in cultivation are reflected in material differences in water storage. The monthly and annual precipitation at Hays for the 26 years, 1909 to 1934, are given in Table I.

Soil samples have been taken at Hays for the determination of the moisture content following many different crop sequences and methods of cultivation. In this bulletin the results from only a small number of plots, where sampling has been conducted over a period of years, will be used. The inclusion of the results from all available determinations would not have changed the conclusions reached in this particular study.

The crop sequences include wheat after wheat or other small grain, wheat after fallow, wheat after corn, wheat after kafir, and wheat after green-manure crops. The behavior of wheat in various sequences is so different that the sequences will be discussed separately. As by far the largest percentage of the wheat in western Kansas is grown following wheat, this sequence is the most important and will be discussed first.

EFFECT OF THE QUANTITY OF AVAILABLE WATER IN THE SOIL AT SEEDING TIME ON THE YIELD OF WHEAT FOLLOWING WHEAT

The quantity of water stored in the soil at seeding time was determined for four methods of preparing wheat stubble for wheat. These methods were early plowing, early listing, early plowing and subsoiling, and late plowing. Subsoiling is not regarded as a practicable method of cultivation, but the results are included for comparison.

TABLE I.—MONTHLY AND ANNUAL PRECIPITATION AT THE FORT HAYS BRANCH STATION FOR THE 26 YEARS, 1909 TO 1934

YEAR.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1909	0.39	0.28	1.16	0.47	1.60	10.21	3.71	1.48	2.78	1.64	3.55	1.00	28.27
1910	.58	.26	.03	.91	3.53	2.71	2.45	3.92	1.28	.36	T	.14	16.17
1911	.12	2.12	.14	.82	2.27	.81	2.09	4.47	2.05	.30	.14	1.82	17.15
1912	.02	1.98	1.60	1.66	2.70	4.32	.88	3.52	1.98	.51	1.13	.03	20.20
1913	.36	.68	.41	2.78	5.72	3.53	.63	.11	4.80	.25	.72	3.11	23.10
1914	.04	.42	.15	2.31	2.36	3.39	2.77	2.63	.60	1.33	T	.63	16.63
1915	.68	1.80	1.74	3.13	6.82	3.97	8.18	4.11	2.44	.93	.30	.04	34.14
1916	.53	.15	.31	2.21	1.63	5.88	.30	1.97	1.26	1.14	.02	.61	16.01
1917	.11	T	.07	1.96	1.72	2.15	1.46	5.73	1.84	.09	1.64	.15	16.92
1918	.80	1.15	1.71	2.49	4.79	.53	3.04	1.76	1.42	2.41	1.10	2.38	23.58
1919	T	2.18	.33	4.51	6.85	3.51	1.16	.77	3.32	1.81	1.54	.15	26.13
1920	.05	.37	.30	2.04	3.32	1.87	1.89	5.11	1.56	3.58	.73	.46	21.28
1921	.40	.10	.49	3.58	2.59	3.67	3.36	3.04	.68	.05	.00	.50	18.46
1922	T	.93	1.71	4.51	2.61	2.18	4.20	.81	.43	.32	1.28	T	18.98
1923	T	.10	1.04	1.63	3.97	5.96	.70	4.15	4.52	4.37	.29	.37	27.10
1924	.31	.26	1.81	1.05	3.19	.77	2.32	1.95	1.03	.46	.25	1.11	14.51
1925	.05	.24	.38	4.27	1.01	4.13	6.73	3.33	.99	.75	1.12	.02	23.02
1926	.36	1.13	1.75	.81	2.16	2.55	1.94	.83	2.83	.60	1.12	.37	16.45
1927	.04	.98	1.85	3.09	1.84	8.03	1.82	6.63	2.80	T	.03	.10	27.21
1928	.03	1.57	1.42	1.27	3.13	9.13	6.86	1.78	.84	2.01	1.88	.02	29.94
1929	.20	.51	.01	2.30	3.95	1.54	7.14	2.84	3.58	2.96	1.51	.03	26.57
1930	.30	.63	.02	1.71	3.10	3.86	1.14	3.80	2.45	5.25	2.63	.14	25.03
1931	.02	.21	3.96	3.33	1.85	5.50	1.85	3.23	.24	1.57	3.76	.54	26.06
1932	1.82	.50	.82	2.32	3.28	8.57	2.03	5.19	5.14	1.69	.12	.18	31.66
1933	.07	.21	.33	2.14	2.82	1.07	2.12	2.73	2.03	.03	.54	2.17	16.26
1934	.29	1.16	.45	.37	1.55	5.15	.54	2.78	2.48	.52	.75	.02	16.06
Averages	.29	.77	.92	2.22	3.09	4.04	2.74	3.03	2.12	1.34	1.01	.62	22.19

T—Trace.

In the first three methods the soil was given the initial treatment as soon as practicable after harvest, and was subsequently cultivated as found necessary to control the growth of volunteer grain and weeds, and to keep the surface open enough for ready penetration of water until seeding time. The late-plowed plot was left untouched until a few days before seeding, when it was plowed and given the minimum amount of cultivation necessary to form a reasonably good seedbed.

Seeding on all plots was done on the same day and at approximately the same date each year, usually late in September or early in October, in order that the results would not be influenced by time of seeding. Seeding at a much earlier or later date might have modified the results. Seeding at this time has produced average yields fully as high as on any other date of seeding and represents a safe seeding date for the locality.

It is not presumed that the quantity of water in the soil is the only factor present at seeding time that influences yield. Other factors, particularly available nitrogen, are also important.

In land cropped every year, most of the water accumulating during the season between harvest and seeding is held within the first 3 feet of soil. There are occasional years when water reaches a depth of more than 3 feet, but these years are exceptional, and the quantity of available water below the third foot is usually small. Consequently discussions relative to available moisture are limited to data for the surface 3 feet.

In Table II are recorded the inches of available water in the soil at seeding time and the yields of wheat for each of the four plots. The crop year refers to the year in which the wheat was harvested.

The results of moisture determinations are not always uniform, as water penetration into soil is sometimes uneven. For this reason the results are subject to an experimental error. Too much stress should not be placed on small differences in the quantity of water held in the soil; confidence can be placed in wide variations.

It was impossible to make all soil moisture determinations exactly at seeding time. In many cases it was necessary to choose between determinations made shortly prior to or later than seeding. When this was necessary the following rule was adopted. When rain fell soon enough after seeding so that seeding could have been delayed until after the rain without loss of yield, the later date was selected. If rain fell so late that to delay seeding until after the rain would postpone it past the optimum date, the sampling made prior to seeding was used. In most years samples were taken so near seeding that no rains intervened, and data from the sampling give a correct picture of moisture conditions at the time seeding was done.

The data presented in Table II show that there is a close relation between the quantity of water in the soil at seeding and the yield. This relationship is mathematically expressed by a correlation coefficient of 0.778 with a probable error of 0.028, which indicates a high degree of relationship. A high content of available water in

TABLE II.—QUANTITY OF AVAILABLE WATER IN THE SOIL AT SEEDING TIME AND THE YIELD OF WINTER WHEAT ON FOUR PLOTS AT THE FORT HAYS BRANCH STATION FOR THE YEARS 1910 TO 1934

CROP YEAR (a).	Available water at seeding time.				Yield per acre			
	Late plowed.	Early plowed.	Early plowed and subsoiled.	Early listed.	Late plowed.	Early plowed.	Early plowed and subsoiled.	Early listed.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*
1910	3.5	4.8	....	....	21	28	....	....
1911	.2	2.1	1.9	1.9	0	0	0	1
1912	0	1.0	1.0	2.2	2	14	20	27
1913	1.1	1.2	1.7	1.2	1	2	4	8
1914	2.3	3.1	1.9	2.1	21	25	25	23
1915	0	.8	.7	.5	9	13	15	14
1916	1.9	5.2	4.9	4.0	9	23	28	23
1917	0	2.0	2.6	1.2	0	2	3	0
1918	.2	1.5	2.9	4.2	10	15	14	25
1920	2.4	3.0	3.5	3.6	20	24	26	24
1921	.9	3.1	5.3	4.1	4	27	31	27
1922	0	1.4	2.1	1.7	1	7	18	13
1924	6.0	5.3	5.9	5.7	31	38	47	40
1925	1.1	.8	.8	1.6	0	1	1	4
1926	1.0	2.7	2.7	3.3	4	15	17	19
1927	.7	1.9	2.0	2.7	4	6	7	7
1928	2.7	5.1	5.0	5.4	24	41	44	44
1929	1.7	5.0	4.6	4.2	19	21	20	22
1930	2.3	4.7	3.7	4.8	15	26	25	25
1931	4.5	4.0	4.2	4.8	23	25	27	26
1932	.2	2.6	2.8	2.9	13	35	33	33
1933	1.9	4.5	5.0	4.8	7	13	18	14
1934	.9	.9	.5	.5	0	0	0	0
Averages	1.54	2.90	2.99	3.06	10.3	17.4	19.2	19

(a) The crop year is the calendar year in which the crop was harvested. The years 1919 and 1923 are omitted, the former because the available water at seeding time was not determined, and the latter because the crop was destroyed by hail.

the soil at seeding time is followed by a high yield, and a low content by a low yield. Of course the relationship is not perfect, but when the differences in temperature, rainfall, wind velocity, and other climatic factors following seeding in different years are considered, it seems remarkable indeed that the water content at seeding time could play such an important part in determining the yield.

As an average, all the early preparations resulted in the storage of much more water than the late-plowed plot and produced much higher yields. Both the subsoiled and the listed plots (fig. 2) stored slightly more water than the early-plowed plot and produced higher yields, but the differences in available water do not fully explain the differences in yield. Among the early methods of preparation, the differences in the quantity of water stored and in the yields are not large.

In 1933, conditions in the spring were so unfavorable and drought and heat continued so long that an unusually large quantity of water in the soil at seeding failed to produce an average yield.

There were 27 cases among the various treatments where there was less than 1.5 inches of available water in the soil at seeding; 29

where there was from 1.5 to 2.9 inches; and 34 where there was 3 inches or more.

The yields of wheat within these groups show some interesting comparisons. Of the 27 cases where there was less than 1.5 inches of water in the soil at seeding, 20 produced yields of less than 10 bushels per acre, eight of these being complete failures. In six cases yields ranged from 10 to 19 bushels per acre, and in one case a yield of 20 bushels per acre was obtained. There was no yield of more than 20 bushels per acre.

Of the 29 cases where 1.5 to 2.9 inches of available water was present at seeding, 12 produced yields of less than 10 bushels per acre; eight produced yields ranging from 10 to 19 bushels per acre; six produced yields of from 20 to 29 bushels per acre; and three produced yields of 30 or more bushels per acre.

An entirely different picture is presented when 3 inches or more of available water was present at seeding time. The yield did not fall below 10 bushels per acre, and in only four of the 34 cases did the yield fall below 20 bushels per acre. Three of these occurred in 1933 when prolonged drought and heat reduced the yield to a low figure, despite an unusually large quantity of water in the soil at seeding. There were 22 cases with yields from 20 to 29 bushels; three with 30 to 39 bushels; and five with 40 bushels or more per acre. All the yields of 40 bushels or more per acre were obtained where more than 5 inches of available water was present in the soil at seeding time.

The results may be summarized as follows: With less than 1.5 inches of available water in the soil at seeding, the chances of practically complete failures were great, and only exceptionally favorable conditions during the crop year could produce even a reasonably good yield. High yields were exceedingly unlikely, if not impossible. The reason that this point is emphasized is the fact that nearly every year thousands of acres of wheat are planted under such conditions, with the hope that favorable weather may enable the crop to make a high yield. The almost positive assurance that poor conditions at seeding are not likely to be fully corrected, shows the futility of this hope.

With from 1.5 to 2.9 inches of available water in the soil at seeding time there was enough moisture to give wheat a good start, but not sufficient moisture to enable the crop to survive any long period of drought. Yields within this group range from nothing to over 30 bushels per acre, the ultimate yield depending upon whether conditions following seeding were favorable or unfavorable. The presence of from 1.5 to 2.9 inches of available water at seeding provided the possibility, but not the assurance of a good yield.

With 3 inches or more of available water present at seeding time, far less favorable conditions were required to produce crops above average than were required for the preceding groups. The probability of complete failure from drought almost disappeared. The presence of 3 or more inches of available water at seeding was an assurance of a reasonably good yield under all except the most adverse conditions. There was in addition the prospect that with favorable conditions high yields might be secured.

When wheat is grown following wheat, it is recognized that no method of cultivation will always insure an adequate quantity of water at seeding time. To store water there must be rain, and even the most effective methods cannot result in adequate storage of water when rainfall is deficient. The points deserving emphasis are the importance of stored water as a determining factor in the yield, and the desirability of storing as much water as possible. Losing moisture that might have been stored has resulted in a significant reduction in yield, and it is useless to expect conditions during the life of the crop to make up for unnecessary losses of moisture incurred before seeding.

EFFECT OF THE DEPTH TO WHICH THE SOIL WAS WET AT SEEDING TIME

The quantity of available water in the soil at seeding time gives a reliable index of what may be expected in production, but it is not a measure that can be applied easily. To determine the available water in the soil one must have certain basic facts, such as the portion of the total moisture that crops cannot use and the volume weight of the soil. In order to find a measure of wider adaptation a different method of study was used. It was previously stated that when water penetrates a dry soil the depth reached can be determined by observation. This is a measure that can be applied under the varying conditions that exist in the field.

The results from the same set of plots used in determining the inches of water present at seeding were studied to find the depth to which water had penetrated. No specific records were kept of the depth at which dry soil was encountered in taking soil samples, but the approximate depth of penetration could be determined from the moisture content of the foot sections.

The moisture content at seeding time, expressed as percentages, was studied for each year. Any foot section containing as much as 3 percent of available water was considered wet. Where a soil contained only a little more than 3 percent of available water in a foot section, it usually meant that the top few inches were wet and the remainder of the foot section dry. There was only one case where a foot section of soil contained as much as 3 percent of available water without all the soil above it containing much higher quantities, except on the late-plowed plot. On this plot there were two years when a small quantity of water was present below a dry layer, because of the rapid removal by weeds of water from nearer the surface.

In the following discussion, when mention is made that available water was present to a specified depth, it does not necessarily mean that the soil in the lowest foot section was filled. A statement that moisture was present in 3 feet of soil means that the first and second feet were filled or nearly so, and that the third foot might contain any amount from one half inch to as much as it was capable of holding. Three percent of moisture in a foot section in this soil is equivalent to about one half inch of water. When mention is made that the soil was wet to a certain depth, all the available water was not always contained within that depth. There might have been some water present in the top of the next foot section, but not enough to raise the water content of the entire foot section 3 percent above the minimum point.

Comparison of the depth to which water penetrated, with the quantity of water in the soil at seeding time, showed that the two were definitely related. When the soil was wet to a depth of 1 foot (the second foot containing less than 3 percent of available water) the total quantity of available water in the soil was less than 2 inches in nearly every case. Where the soil was wet 2 feet, the moisture content generally ranged from slightly under 2 inches to 3.5 inches. Where the soil was wet to a depth of 3 feet or more, the available water content was 3.5 inches or more in all but one instance. In that particular instance the amount of available moisture in the third foot barely exceeded 3 percent.

A study of the yield in comparison with the depth to which the soil was wet gave results similar to those where the total quantity of water was used as a basis.

There were 12 years when the late fall-plowed plot, and one year when the early-plowed plot, contained less than 3 percent of available water in any foot section. In eight of these 13 cases the yield was 4 bushels or less per acre. In only three years did the yield equal or exceed 10 bushels, and in no year did it reach 20 bushels.

There were 22 cases when the soil was met in the first foot only. In 13 of these the yield was less than 10 bushels per acre; in six, the yield was between 10 and 20 bushels per acre; and in three, the yield was 20 bushels per acre or more, the highest yield being 25 bushels per acre.

The first and the second foot sections of soil were wet in 24 cases. In only eight of these was the yield under 10 bushels per acre; it was between 10 and 20 bushels per acre six times; between 20 and 30 bushels per acre seven times; and over 30 bushels per acre three times, the maximum yield being 35 bushels per acre.

There were 31 cases when the soil was wet into the third foot or deeper. In only one of these was the yield under 10 bushels per acre. This was the year mentioned before, when there was some moisture in the third foot, although the total quantity of water in the soil was only 2.6 inches. There were only three cases when the yield was between 10 and 19 bushels to the acre, all of these yields occurring in 1933. In 19 cases, the yields were between 20 and 29 bushels per acre; in three, between 30 and 39 bushels per acre; and in five cases yields of more than 40 bushels per acre were obtained.

When the wheat was planted in a dry or nearly dry soil, the average yield was 5.3 bushels per acre. When only the first foot was wet, the average yield was 8.3 bushels per acre. When the first and second foot sections were wet, the average yield was 16.9 bushels per acre; and when the soil was wet into the third foot, or deeper, the average yield was 26.5 bushels per acre.

Summing up the results, it can be stated that when seeding was done in a dry soil, there was only one chance in four of a yield of as much as 10 bushels per acre being produced and no chance of a high yield.

When only the first foot was wet the chances were about three in five that the yield would be less than 10 bushels per acre, and only one in seven that the yield would be 20 bushels or more per acre.

When there was water in both the first and the second foot sections, there was only one chance in three that a yield of less than 10 bushels per acre would be produced, and there were two chances in five of producing a yield of 20 bushels or more per acre.

With water in the first 3 feet or deeper, the chance of the yield falling below 10 bushels was only one in thirty-one, and the chances were nearly seven in eight that a yield of 20 bushels or more would be produced.

The increasing certainty of producing a crop with the increase of available water in the soil at seeding time makes it certain that an adequate supply of water at that time is one of the greatest assurances of a crop, and that hopes of obtaining a good crop in spite of poor conditions at seeding time are not likely to be fulfilled.

The results show not only the value of water in the soil, but the value of knowing the quantity of available water that is present. With advance knowledge of conditions at seeding time, whether to seed or not to seed can be determined with a fair degree of accuracy, and an idea can be formed as to what the chances are that it may become necessary to abandon the crop later in case it is seeded.

When the soil is dry or is wet to a depth of only a few inches at seeding time, the chances of producing a crop are poor. When this condition exists, planting can well be delayed to see whether enough rain falls to improve conditions. The necessity for crop abandonment arises most frequently when wheat is seeded under such unfavorable conditions. When available water is present in the second foot, as well as the first, wheat generally gets a good start, but unfavorable conditions during the life of the crop may make abandonment desirable. With the soil wet into the third foot at seeding time conditions severe enough to cause failure are rare and not likely to arrive until late in the life of the crop, and the question of abandonment will seldom arise.

The depth to which water has reached may be easily determined in any field, regardless of local variations in rainfall or soil type. Crop predictions based on rainfall have value for regions as a whole, but are not applicable to local conditions because of variations in the amount of rain, and because differences in soil treatment may make crop prospects radically different in fields receiving the same amount of rain.

The depth to which water has penetrated can be determined by digging a hole with an auger, post-hole digger, or spade. The change from a wet to a dry soil is marked enough so that anyone can detect, it. A soil where water has penetrated is wet, not just visibly moist. Noticeable moisture may be present in soil dry to crops, but the difference between wet and barely moist soil can easily be noted by the difference in the ease with which the auger goes into the ground.

EFFECT OF PRECIPITATION BETWEEN SEEDING AND HARVEST

The relationship between the quantity of water in the soil at seeding time and the yield is close. After wheat is planted, the precipitation during the life of the crop is of most concern to growers. The four methods of soil treatment considered under the preceding heading were studied to determine the effectiveness of precipitation during the life of the crop in overcoming adverse conditions at seeding time. The average quantity of water in the soil of each plot at seeding time, the average yield of a plot, and the average rainfall between seeding in the fall and June 15 the next year were determined. June 15 was selected for the date on which to end the period, as it was felt that rains falling after June 15 would be of little value to the crop. The average harvest date for wheat at Hays is about July 1. (Fig. 3.)

Each crop year was then examined to determine whether the water in the soil at seeding time, the yield, and the precipitation from seeding to June 15 were above or below their respective averages. Results from the different plots compared closely, hence the individual plot records are not presented. The results for all plots all years were as follows:

1. There were 49 cases when the amount of water in the soil at seeding time was below the average for the method. In 41 of these cases the yield was below the average for the method, in spite of the fact that precipitation during the life of the crop was above average in 26 instances. Above average rainfall after the crop was planted raised the yield to above average in only one third of the cases in which it occurred. When the number of times that the rainfall after seeding was not above the average is considered, the

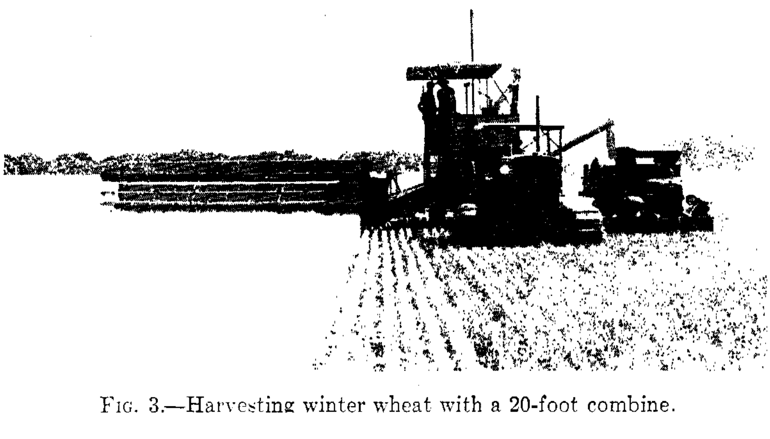

FIG. 3.—Harvesting winter wheat with a 20-foot combine.

chances of rain after seeding correcting an unfavorable initial condition appear to be poor indeed—about one in six.

2. In 41 cases the water content at seeding was above the average for the method. In 36 of these the yield was equal to or above the average for the method, in spite of the precipitation being below average in 25 of the 41 cases. Precipitation below the average during the growing period reduced the yield to below the average in only one fifth of the cases in which it occurred. Since rainfall following seeding is as likely to be unfavorable as favorable, the chance of obtaining an above average yield from a favorable initial water content is very good.

It is not believed that a crop would be produced at Hays without rain even though the water content of the soil at seeding time was much above the average. Such a condition has not yet occurred. The amount of rain during the growing season has nearly always been sufficient to produce good yields of wheat following wheat on plowed or otherwise cultivated plots when an adequate supply of moisture was present at time of seeding.

It may be stated as results of investigations covering 24 years, that with wheat following wheat at Hays the chances of unfavorable conditions at seeding time being corrected or, in other words, the chances of producing above average yields from below average quantities of available water in the soil at seeding time were about one in six; but with an above average quantity of water in the soil at seeding, the chances were seven in eight that an average yield would be produced.

These facts are given to emphasize once more the necessity of storing within the soil as much of the rainfall between harvest and seeding as it is possible to conserve. In years of deficient rainfall during the period between harvest and seeding, the moisture content at seeding time will be small regardless of how the soil is handled. In the past, any land that was cultivated during the summer usually was seeded. With the information now available, one may judge more accurately whether to take the chance offered of raising a wheat crop, to fallow the land, or to plant a row crop. If land with a low moisture content is planted to wheat, the fact that conditions after seeding must be much better than average for a good crop to be produced, may help a grower in deciding whether or not to abandon the crop in the spring.

RESULTS WITH WHEAT ON FALLOW

The fallowed plot was allowed to stand untouched from harvest of winter wheat one year until May the next year, when it was plowed. From plowing until seeding in the fall it was cultivated as necessary to control weeds. The cultivation necessary to control weeds was sufficient to prepare a good seedbed. This method of Fallowing has been used at all stations, and has, on the whole, produced yields comparing favorably with other methods.

In the maintenance of fallow, care was taken to use implements that did not pulverize the surface soil. (Fig. 4.) A cloddy surface absorbs water more readily than a smooth one and is less subject to damage by blowing. Fallow that has been properly cared for does not present any greater hazard of injury from soil blowing than other methods of soil preparation. On the contrary land that has been fallowed is often less subject to wind damage, because wheat seeded on it forms a better covering in the fall.

In well-cared-for fallow, available water was usually present to a depth of at least 5 feet at seeding time, although there were a few exceptions. The average quantity of available water stored in the first 6 feet of soil on fallowed land during the years 1910 to 1934 was 7.7 inches. There were only 3 years during this period when the quantity of stored water did not materially exceed 5 inches.

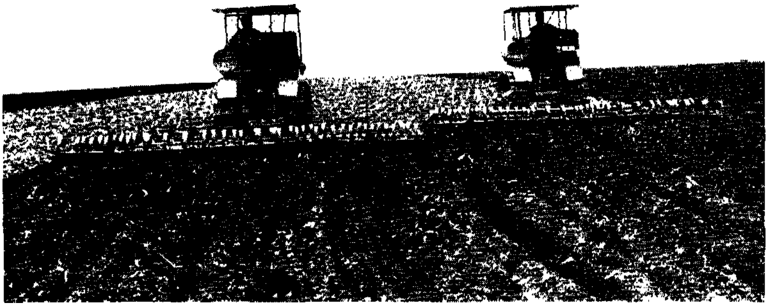

FIG. 4.-Spring-tooth cultivators in operation on a fallow field.

Where wheat followed wheat, the presence of 3 or more inches of available water in the soil at seeding time was generally an assurance that at least a reasonably good crop would be produced. With this fact in mind, it would appear reasonable to assume that a method of cultivation storing at least 3.5 inches of water each year, and generally very much more, would insure a crop. Fallow provided that quantity of water, but it did not positively assure a good crop. There were no total failures on fallow, and the yields materially exceeded those on other preparations, but the yield was not proportional to the quantity of water stored.

Yields on fallow suffered in some years, not because of unfavorable conditions in the early life of the crop, but because of too favorable conditions. The long period necessary for the storage of moisture on fallowed land also favored the formation of nitrates. The accumulation of nitrates frequently resulted in a heavy straw growth. In years of ample rainfall, wheat on fallowed land sometimes lodged and actually produced lower yields than wheat on cropped land. In other years it made a very rank growth during the spring months, and when hot, dry weather came suddenly, it was not able to extend its roots rapidly enough to provide sufficient moisture to keep from firing, even though water was present at depths well within the zone occupied by roots in normal seasons. Where less favorable conditions existed early in the season, wheat on fallow survived prolonged periods of drought and matured a fair crop under exceedingly adverse conditions.

The quantity of available water in the first 6 feet of soil of the fallowed plot in inches at time of seeding, and the yield of wheat are given in Table III. The relation between yield and water is not so close as on cropped land. The relationship is expressed by the correlation 0.271, with a probable error of 0.130, which indicates a very low degree of relationship.

TABLE III.—QUANTITY OF AVAILABLE WATER IN THE SOIL AT SEEDING TIME, AND THE YIELD OF WINTER WHEAT ON FALLOW AT FORT HAYS BRANCH STATION FOR THE YEARS 1910 TO 1934

CROP YEAR (a).	Available water at seeding time.	Yield per acre.	CROP YEAR.	Available water at seeding time.	Yield per acre.
	Inches.	*Bushels.*		*Inches.*	*Bushels.*
1910	8.7	43	1924	7.4	46
1911	7.3	3	1925	7.9	23
1912	3.5	29	1926	8.7	26
1913	7.8	10	1927	5.1	11
1914	7.4	22	1928	7.6	49
1915	6.1	11	1929	8.7	23
1916	10.3	34	1930	8.3	27
1917	7.7	7	1931	10.3	35
1918	7.2	36	1932	8.0	51
1920	10.2	37	1933	10.8	22
1921	8.1	37	1934	7.9	22
1922	8.0	25			
			Averages	7.96	27.3

(a) The years 1919 and 1923 are omitted, the former because the available water at seeding time was not determined, and the latter because the crop was destroyed by hail.

This is to be expected because initial moisture conditions are favorable in nearly every year, consequently yields are frequently decided by factors other than moisture. In 1934 the wheat on fallow lived through one of the longest periods of heat and drought on record and matured a fair crop. In that year observations on other plots showed that wheat fed to a depth of at least 8 feet, where moisture was available to that depth. It was able to endure the period of drought because it started to suffer early in the season, and did not make the rank growth characteristic of wheat on fallow. In 1917, with an equal amount of water present in the soil at seeding time, the crop was severely injured by drought and produced a very low yield. In that year it made a heavy top growth, and when hot, dry weather came it could not extend its roots rapidly enough to keep the top growth supplied with water. It came to a forced maturity without using all the available water in the fourth foot of soil. Water present in the fifth and sixth foot sections was not used.

In 1915 lodging severely reduced the yield of wheat on fallowed land. Partial lodging reduced yields to some extent in other years.

The extra quantity of water conserved by fallowing increased the average yield of wheat on that method of cultivation, but part of the value of the water was lost because of the over stimulation of the crop. If there was some way of preventing excessive vegetative growth on fallow, the quantity of water stored would be enough to produce a good yield in all but exceedingly adverse years. Several methods of accomplishing this have been investigated, but none has proved successful so far.

Pasturing a heavy early growth in the fall or early spring was found by Swanson[5] to slightly decrease the moisture used during the fall and winter period. The yield of wheat obtained was about 10 percent higher than where excessive growth was allowed to continue unchecked. Considered from the mixed farming standpoint, the use of wheat for pasture paid high returns for the water used in producing the surplus growth. Pasturing is a valuable means of utilizing excessive growth after it has been produced, but from the standpoint of grain production alone it would have been better if the growth had not been excessive.

RESULTS WITH WHEAT ON CORN AND KAFIR STUBBLES

Wheat on corn ground does not show so close a connection between water in the soil at seeding time and yield as does wheat after wheat. There is, however, a marked relationship.

The average quantity of water stored in the first 3 feet of soil on corn land is smaller than on early-prepared wheat land. The average yields are nearly equal. Yields following corn, however, are much more erratic than yields following wheat.

There are two principal reasons for this. The water content of the soil near the surface on corn ground is generally lower at seeding time than on well-prepared wheat land, but sometimes there is moisture remaining in the lower depths that is available to wheat but not to corn. The roots of corn do not extend so deeply into the soil as do those of wheat, and corn will suffer severely from drought while moisture is present in the fourth and deeper foot, sections. Sometimes corn leaves enough moisture in the upper layers of soil, or enough rain falls to enable wheat roots to reach this deeper moisture. In wet years this may materially benefit the crop. In other years available water is present in the deeper foot sections, but a dry layer of soil nearer the surface prevents wheat roots from reaching it. Roots do not readily penetrate a soil where the moisture content is at, or even near, the minimum point. Thus the presence of moisture in the lower foot sections is no assurance that wheat can use it. The irregular use of water at lower depths partly explains the erratic behavior of wheat after corn. A second reason why the moisture content at seeding time is a less sure indication of yield where wheat follows corn than where wheat follows wheat, is the fact that less moisture is present near the surface in corn ground, thus often causing poor stands of wheat. Wheat coming

5. Swanson, A. F. Pasturing winter wheat in Kansas. Kan. Agr. Expt. Sta. Bull. 271. 29 pp., illus. 1935.

through the winter with a poor stand is sometimes able to withstand early droughts that damage wheat with a better stand. For this reason the relative yield of wheat following corn in poor years is sometimes better than in good years.

The depth to which corn ground is wet is not so easily determined as for wheat, as corn does not always dry the soil so thoroughly. Where the soil on corn ground becomes noticeably wet after the crop is harvested, one can feel assured that the resulting yield will be at least as high as on wheat land wet to the same depth.

The same may be said for kafir stubble, although the yield of wheat following kafir was much lower than that of wheat following corn. Owing to the later maturity of kafir, the soil on kafir stubble frequently was nearly dry at time of seeding, and poor stands of wheat were frequent. The soil was seldom wet enough to give wheat a good start, but the meagerness of the growth sometimes enabled it to live through times of drought on smaller quantities of rain, than the heavier growth on better-kept land. The depth to which the soil was wet was not a good measure of the yield of wheat to be expected on kafir land; except that the soil was generally wet to a shallow depth, and resulting yields were low.

RESULTS WITH WHEAT AFTER GREEN-MANURE CROPS

Wheat grown after green-manure crops at Hays produced lower yields than wheat on fallow. The reason for this is apparent from a study of the soil moisture. Owing to the time of plowing under green-manure crops, less water was stored than on fallow, but the moisture was sufficient for the excessive accumulation of nitrates characteristic of fallow. Wheat on green-manured land had the disadvantage of the extra growth made possible by the heavy accumulation of nitrates, but did not have the additional water supply that usually enabled fallow to mature the extra growth. As a result, wheat on green-manured land often was severely injured by drought. The depth to which the soil was wet on this preparation was not a good indication of yield, as a quantity of water sufficient to mature a crop on land previously planted to wheat often failed to mature the crop on green-manured land.

ABANDONMENT OF WHEAT AT HAYS

When the condition of winter wheat in the spring is poor, the question of whether or not the crop should be abandoned arises. Many farmers, if they felt certain that only a low yield of wheat could be expected, would be willing to abandon the crop relatively early in order to commence preparation for the next crop. The hope that conditions later in the season will change early unfavorable prospects so materially that a good crop will be produced, often induces them to allow crops to mature that will no more than pay for harvesting. The assurance that early abandonment would not result in loss of a valuable crop would enable many to decide to abandon.

It has been shown that on cropped land a close relationship existed between the water in the soil at seeding time and the yield.

It follows that the smaller the quantity of water in the soil at seeding, the more frequent will be the need for crop abandonment. For this reason abandonment is considered from the standpoint of condition at seeding.

There were 12 crop years 1911, 1912, 1915, 1917, 1918, 1921, 1922, 1925, 1927, 1929, 1932, and 1934, when the late fall-plowed plot contained less than 3 percent of available water in any foot section, except the second foot in 1929, or the moisture conditions were such that the soil would have appeared dry when worked with a digging or boring tool. There was only one year, 1922, when the early-plowed plot was dry at seeding time. An effort was made to ascertain whether a greater total production for two years would have been obtained by maturing a crop planted in dry soil and following it with another wheat crop, than would have been obtained by abandoning the first crop and fallowing the land for a crop the second year. This was done by adding the yield of a crop planted in dry soil to the yield of the early-plowed plot the following year and comparing this combined yield with the yield of a plot fallowed the first year and cropped the second.

For example, the Iate-plowed plot was dry when the 1915 crop was seeded. The crop produced 9 bushels per acre, but allowing it to mature prevented land preparation in time for fallowing. Had the plot been plowed at harvest time in 1915 and given good preparation until time for planting the 1916 crop, the yield (as represented by the early-plowed plot) would have been 23 bushels per acre, or a total of 32 bushels for the two years. If the 1915 crop had not been seeded, or had it been abandoned early in the spring, the yield (as represented by the crop on the fallowed plot in 1916) would have been 34 bushels per acre.

The yield of wheat planted in a dry soil for the 12 crops, where records are complete (1934 omitted), added to the yield on the early-plowed plot the next year gave a total of 242 bushels. The yield of the fallowed plot alone in the years following those when the wheat was planted in a dry soil was 268 bushels, in spite of the fact that in 1923 the crop was destroyed by hail. Thus the land where wheat was planted on a dry soil in one year and on early-prepared land the next year actually produced 26 bushels less than where a single crop was produced on fallow, and 12 extra seedings and nearly as many extra harvests were required. Evidently the best time to abandon a crop of wheat to be planted on dry soil was before it was planted.

There were only two years in which there was a marked difference in favor of harvesting two crops. One of those was in 1919, when growth on fallow was so heavy that the wheat lodged, and the yield was low.

With enough water present at seeding time to give the crop a good start, adverse moisture conditions during the winter may bring up the desirability of abandonment. The earlier that it can be known definitely that it will pay to abandon the crop, the earlier can plans for the next crop be made. It is not likely that actual cultivation of the land will begin before April, and ability to determine whether or not to abandon the crop by the first or even by the 15th of April is all that is required. During the years that work has been carried on at Hays, however, it was possible in many years to determine at a much earlier date that abandonment would be desirable.

There were 26 cases, in addition to those when the soil was dry at seeding time, when the available water content at seeding time was less than 2 inches, or when the soil was wet to a depth of not much more than 1 foot. In 16 of these cases the precipitation from seeding date to December 31 was less than 2 inches. In all of these the yield was so low that abandonment would have been preferable. If the plot had been harvested each year and cropped to wheat on early-prepared soil the next year, the total yield for the 13 cases for which records are complete (1934 omitted) would have been 237 bushels. If the crop had been abandoned and the land fallowed in each case, the resultant yield would have been 282 bushels. Allowing the wheat to mature each year reduced the total yield by 45 bushels. The expense of the additional harvestings was at least equal to that of keeping the land fallowed. Thus, even though the crops were not total failures, work would have been reduced by abandoning them.

Not all the crops receiving more than 2 inches of rain from seeding to December 31 produced good yields, but 2 inches was an amount that could not be reduced without material loss of yield. Even in 1915, when the precipitation was slightly above 2 inches and a reasonably good crop was obtained, only a small loss would have been experienced if the wheat on early-plowed land had been abandoned and the land fallowed.

It appears safe to state that when the soil is wet to a depth of not more than 1 foot at seeding time, the occurrence of less than 2 inches of rain during October, November, and December places the crop in such a condition that, on the average, it is more profitable to abandon it and fallow the land than to allow it to mature.

When the soil was wet to a depth of not more than 1 foot at seeding time, and the precipitation exceeded 2 inches during the next three months the advisability of crop abandonment could not be determined even by April 1. The quantity of water in the soil was enough to give the crop a good start and to maintain it during the winter. Whether or not the crop should be abandoned depended upon conditions after it started growth in the spring.

After wheat has been planted, there is a natural hesitancy about abandoning it while any hope of a crop remains. The fact that wheat planted under adverse conditions, which are not corrected in the months immediately following, can be abandoned early in the spring and any loss of yield more than compensated for by a higher yield from the following crop should assist farmers in making up their minds relative to abandonment.

Wheat planted under more favorable conditions, or wheat receiving more rain following planting, does not reach a condition warranting abandonment early in the season. It appears safe to state, however, that when wheat has exhausted its moisture supply and is firing badly by the middle of May, it is more profitable to plow it up and begin to fallow for the next crop than to allow it to mature.

In the absence of moisture determination at seeding time, there is another measure that may be applied in deciding whether or not to abandon a wheat crop. Rainfall during the period of preparation for a wheat crop is a moderately good measure of the water that will be in the soil at seeding time.

Past experience at Hays shows that when the rainfall from July 1 to December 31 was less than 8.5 inches, the chances were great that wheat on well-prepared land (early-plowed or listed) following wheat would best be abandoned. In no year was a good crop produced with a low rainfall during this period and in only one year was a fair crop produced. This is a measure that can be applied to early-prepared land. Wheat on later-prepared land may reach a condition warranting abandonment with a larger quantity of rain.

It is not presumed that abandonment will be decided upon as early as January 1. It is not necessary to make a decision so early. T'he occurrence of a low amount of rain from July to December is a strong indication that abandonment of the crop will be advisable. If conditions are not corrected by above normal rainfall during January, February, and March, it is almost certain that abandonment would he profitable. Wheat in such years can be abandoned and the land fallowed with the assurance that, on the average, a higher yield of wheat will be obtained the following year than would be obtained on the two annual crops.

When the soil was wet to a depth of much more than 1 foot at seeding time. or when the rainfall between harvest and January was above 8.5 inches, the question of abandonment could not be decided until too late a date to obtain full advantage of early preparation for fallow. It appears very probable, however, that if by May 15 the crop is damaged to such an extent that it cannot produce more than a low yield, plowing it up rather than allowing it to mature will, on the average, be a profitable practice.

RESULTS AT COLBY

The station at Colby represents a section where wheat production is as important to the section as at Hays, but is distinctly less stable. Yields are more erratic and the average much lower. Production is on a more extensive scale, and larger units, cheaper methods of production, and lower land values compensate to some extent for the lower average yields.

Conditions at Colby are materially different from those at Hays, and an explanation of this difference should precede discussion of results, since results are materially influenced by conditions. Colby is located approximately 100 miles west and 35 miles north of Hays. The elevation is 3,140 feet as compared to 2,000 feet for Hays. The greater elevation gives it a distinctly shorter growing season. The

TABLE IV.—MONTHLY AND ANNUAL PRECIPITATION AT THE COLBY BRANCH STATION FOR 21 YEARS, 1914 TO 1934

YEAR.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1914	0.05	0.45	0.21	1.21	3.07	2.32	5.01	1.85	0.52	0.87	T	0.51	16.07
1915	.38	1.49	1.43	3.61	4.55	4.03	6.60	4.17	.67	1.10	.48	.48	28.99
1916	.55	.05	.33	2.03	1.33	3.15	2.07	1.48	.40	.62	.21	.37	12.59
1917	.12	.20	.56	1.66	2.01	1.42	3.07	5.78	4.25	.28	.42	.20	19.97
1918	.77	1.79	1.34	1.05	2.16	.19	1.86	1.88	2.16	2.87	.21	2.63	18.91
1919	T	1.57	.59	2.80	2.23	2.47	3.95	.65	2.07	.82	1.63	.19	18.97
1920	.23	.31	.46	3.74	2.42	5.68	4.19	3.75	2.56	2.71	.27	1.31	27.63
1921	1.15	.03	.58	1.88	1.85	3.52	4.24	2.23	2.80	.45	.18	.46	19.37
1922	.18	.35	1.26	4.08	2.55	1.34	2.74	1.38	.43	.08	3.13	.02	17.54
1923	.05	.18	.88	2.80	6.28	3.27	3.46	3.55	1.87	3.33	.12	.75	26.54
1924	.22	1.82	1.78	.48	1.30	.80	1.77	3.09	1.78	.95	.14	1.97	16.10
1925	.23	.25	.47	1.44	3.52	1.07	1.50	3.50	2.00	.82	.16	.39	15.35
1926	.52	.12	.50	.87	2.08	1.57	.57	2.04	.92	.22	.83	.34	10.58
1927	.11	1.26	1.59	3.51	.43	3.75	2.00	1.87	2.68	.25	.10	.45	18.00
1928	T	.48	1.53	.89	4.53	5.40	2.66	1.19	.29	2.06	.65	.06	19.74
1929	.06	.76	.13	3.15	3.25	1.96	1.07	1.13	3.02	1.70	1.81	.02	18.06
1930	.20	.32	.08	2.41	5.11	3.29	1.57	4.15	.73	5.54	1.23	.15	24.78
1931	0	1.51	2.14	.92	1.32	2.00	2.77	1.49	.35	.93	1.06	.04	14.53
1932	.38	.57	.34	2.05	1.46	3.98	3.26	1.03	.83	.34	.27	.35	14.86
1933	T	.08	.70	2.22	2.56	.14	3.65	4.92	.76	.30	.94	.42	16.69
1934	.06	.87	.51	.36	.92	1.59	.41	1.40	.75	.09	.18	.23	7.37
Averages	0.25	0.69	0.83	2.05	2.62	2.52	2.78	2.50	1.52	1.25	0.67	0.54	18.22

T—Trace.

annual rainfall is aproximately 4 inches less Winter wheat is harvested later in the summer and seeded slightly earlier in the fall. The precipitation during the period between harvest and seeding is much lower than at Hays The shorter period between harvest and seeding and the lower rainfall during that period explain why early cultivation after harvest has been much less effective in storing moisture at Colby than at Hays

Wheat stubble at Colby is, as a rule, clean and relatively free from weeds and frequently remains that way during the period from harvest to seeding. This is in distinct contrast with Hays where a prolific growth of weeds or volunteer wheat in grain stubble after harvest is the rule rather than the exception. For this reason late preparation at Colby is less wasteful of moisture than at Hays. Wheat at Colby has another advantage over that at Hays in that it remains dormant, or nearly dormant, for a longer period during the winter, but it suffers in that the rainfall during the period between seeding and harvest is more likely to be deficient. More of the precipitation at Colby comes in the form of snow, and the catching of snow by crop residues frequently is important in determining the yield.

The points outlined indicate some of the reasons why results at Colby are different from those at Hays. However, in spite of the fact that there are material differences in the quantities of water conserved at the two places by similar methods of cultivation, the results generally confirm those at Hays.

The monthly and annual precipitation at Colby from 1914 to 1934, inclusive, are given in Table IV.

Three methods of cultivation with continuous wheat were tested at Colby; namely, early plowing, late plowing, and summer fallowing. Crops on summer fallow at Colby have not suffered so much from over simulation as at Hays, and results on the summer fallow can be compared better with results where wheat follows wheat. There is also a four-year rotation at Colby in which wheat is grown on corn ground, on early plowing after wheat, and on unplowed wheat stubble. Results from this rotation will be discussed separately.

EFFECT OF THE QUANTITY OF AVAILABLE WATER IN THE SOIL AT SEEDING TIME ON THE YIELD OF WHEAT GROWN CONTINUOUSLY AND ON ALTERNATE FALLOW

The quantity of water in the soil at seeding time and. the yield of wheat after wheat on late-plowed, on early-plowed, and on fallowed land at Colby are shown in Table V. The late-plowed, early-plowed, and fallowed plots were handled in the came manner as at Hays. On the early-plowed plot, when rainfall was deficient there was sometimes difficulty in settling the soil enough to make a firm seedbed. It often remained loose throughout the crop season, probably facilitating drying out of the soil. There were occasional years at Colby when the quantity of water stored by fallowing was small.

The data in Table V show that there is less relation between the quantity of water in the soil at seeding time and the yield at Colby

TABLE V.—QUANTITY OF AVAILABLE WATER IN THE SOIL AT SEEDING TIME AND THE YIELD OF WINTER WHEAT ON SOILS PREPARED BY THREE METHODS OF CULTIVATION AT THE COLBY BRANCH STATION FOR THE YEARS 1915 TO 1934

CROP YEAR (a).	Available water at seeding time (b).			Yield per acre.		
	Late plowed.	Early plowed.	Fallowed.	Late plowed.	Early plowed.	Fallowed.
	Inches.	*Inches.*	*Inches.*	*Bushels.*	*Bushels.*	*Bushels.*
1915	1.1	3.2	4.0	9	19	20
1916	2.5	3.3	6.0	9	19	26
1917	.1	.1	1.4	0	0	0
1918	3.7	3.2	5.1	11	5	8
1919	1.1	1.2	1.1	26	8	14
1920	.8	1.6	5.9	20	15	32
1922	.8	.6	3.1	12	15	18
1923	0	.6	3.9	10	5	(c) 2
1924	2.6	2.3	7.8	11	9	32
1925	.6	1.7	7.1	5	6	28
1926	.8	1.3	3.0	2	1	13
1927	0	0	1.4	2	1	3
1928	.9	1.3	6.0	20	18	38
1929	.6	1.4	7.5	5	6	14
1930	1.5	1.1	4.8	27	29	43
1931	1.1	.7	8.8	9	6	23
1932	.5	1.6	8.1	0	6	37
1933	.2	.4	6.1	0	0	0
1934	1.0	2.4	6.9	0	0	6
Averages	1.05	1.47	5.16	9.4	8.8	18.8

(a) The crop year is the calendar year in which the crop was harvested. No data are available for 1921.
(b) Determinations were to a depth of 3 feet on late plowed and early plowed and 6 feet on fallowed.
(c) The low yield on fallow in 1923 was due largely to a poor stand.

than at Hays. The relationship is expressed by the correlation 0.556, with a probable error of 0.062. This means that while there is some relationship, it is much less pronounced than at Hays. One reason for this is that on the late-plowed and the early-plowed plots the quantity of moisture stored was almost never high enough to be a preponderant factor in determining yield. The relationship between water in the soil at seeding and yield is greater on fallow than on cropped land, indicating that on fallow at Colby moisture still remains the limiting factor. This is in contrast with Hays, where moisture conditions were normally so good on fallow that other factors were more important in determining the yield.

Applying to the Colby data the same measure that was used at Hays, it is found that there were 29 times when the quantity of available water stored in the soil at seeding was less than 1.5 inches, eight times when it was from 1.5 to 2.9 inches, and 20 times when it was 3 inches or more.

Of the 29 cases when the available water content of the soil at seeding time was less than 1.5 inches, 20 produced yields of less than 10 bushels per acre, five produced yields from 10 to 19 bushels per acre, and four produced yields of 20 bushels or more per acre, the maximum being 29 bushels. The average yield of this group was 7.8 bushels per acre. There were 12 cases where the yield was

3 bushels or less per acre, the yield being too low to pay for harvesting. The fact that in several years the yield exceeded 20 bushels per acre would indicate that a good start in the fall was less important than at Hays.

There were only eight cases when the quanity of available water in the soil at seeding time was from 1.5 to 2.9 inches. The reasons for this lay in the facts that land that had been in wheat seldom accumulated as much as 1.5 inches of water during the summer, and fallow usually contained more than 3 inches.

Of the eight cases, one was a total failure, four others produced yields of less than 10 bushels per acre, two produced yields of from 10 to 19 bushels, and one produced a yield of over 20 bushels. The number of cases is too small to draw any definite conclusions, but the indications are that the chances of total failure are reduced by the presence of as much as 1.5 inches of available water in the soil at seeding time. The average yield for this group of crops was 10.4 bushels.

There were 20 cases when the quantity of available water in the soil at seeding time was 3 inches or more, 16 of these being on the fallowed plot. This shows how seldom any method of cultivation other than fallow is capable of storing that much water. Of the 20 cases there were five with yields less than 10 bushels per acre, one of these being a total failure, six with yields of from 10 to 19 bushels, four with yields of 20 to 29 bushels, and five with yields of more than 30 bushels per acre, the maximum being 43 bushels. The average yield for this group was 19.7 bushels. The total failure in this group indicates that conditions following seeding may be severe enough to cause failure, even with as much as 6 inches of available water in the soil at seeding time. That this occurred only once in 20 cases shows that such a condition is exceptional.

With less than 1.5 inches of available water in the soil at seeding time there was a strong probability of failure, and exceptionally favorable conditions after seeding were required to produce a good yield. High yields were a possibility but were seldom realized.

With from 1.5 to 2.9 inches of water at seeding, the chances of a complete failure were materially reduced. There were too few cases in this group to draw conclusions, other than that yields were likely to be above or below average, depending upon the precipitation after seeding. The possibility of a good crop was present, but conditions after seeding were not favorable enough to permit the crop to make a high yield in many of the years.

With more than 3 inches of available water at seeding, the chances of a total failure became small. Yields of less than 10 bushels per acre were few, and good yields could be expected in a majority of the years. The assurance of a crop was much greater than when less water was present at seeding time.

The conclusions do not vary materially from those drawn from the data obtained at Hays. There is, however, this major differencc. At Hays early methods of preparing wheat stubble enabled the soil to store more than 3 inches of water in nearly half the years, and more than 1.5 inches of water in better than three fourths of the years. At Colby early preparation stored more than 3 inches of water in only one sixth of the years, and as much as 1.5 inches in considerably less than one half of the years. Early preparation was less effective in storing water at Colby than at Hays because there was less water to store. Late preparation was less wasteful of moisture, because there was less moisture to waste, and, as mentioned before, fewer weeds to waste it. The value of water in the soil at seeding time was as great at Colby as at Hays, but there was less opportunity to provide an adequate water supply by early cultivation. Early preparation was definitely a paying proposition at Hays, but was of doubtful value at Colby. It would appear from the available data that earlier preparation gradually loses its effectiveness as one moves from Hays toward the higher elevation and lower precipitation at Colby. Somewhere between the two stations early preparation, on the average, ceases to show advantage over late preparation.

A definite line cannot be drawn east of which early preparation is superior to later preparation, and west of which it is not. It is believed, however, that weed growth provides a criterion of the value of early preparation in doubtful sections. When the stubble is clean at harvest and no rains occur to start weeds or volunteer growth, early preparation will be of little or no value. When there is a heavy early growth of weeds early cultivation will probably pay, but much of its value may be lost if the weeds are allowed to make much growth bcfore they are destroyed.

From the values in Table V it may be noted that the late-plowed plot contained a little less moisture at seeding on the average, than the early-plowed plot, but produced a slightly higher average yield. The early-plowed plot generally contained more moisture, but not enough more to greatly improve crop prospects. Wheat on the early-plowed plot frequently had a better stand, made a better early growth, and consequently exhausted its moisture supply earlier than that on the late-plowed plot. Wheat on late-plowed land made poor fall growth and used little moisture in the fall or early spring. It often was able to maintain life and produce a crop on rains that fell too late to revive the wheat on early-plowed land. If conditions following seeding were unfavorable, the better seeding conditions provided by early plowing were not beneficial. When early preparation does not store enough moisture to take care of the better growth that is produced its value is lost.

EFFECT OF THE DEPTH TO WHICH THE SOIL WAS WET

The depth to which the soil was wet at seeding was determined at Colby in the same manner as at Hays. The results resemble those at Hays, although there are some differences.

There were eight cases when the soil was dry at seeding. In seven of these, the yield did not exceed 2 bushels per acre. In the other case a yield of 10 bushels was obtained. Evidently seeding in a dry soil offers little possibility of producing a crop. When the odds have been 7 to 1 that a crop planted in dry soil would not pay for harvesting, good farm practice would suggest the inadvisability of planting a large acreage under such conditions.

There were 25 cases when the soil was wet in the first foot only. In 14 of these the yield was less than 10 bushels per acre, in six cases it was between 10 and 19 bushels, and in five cases it was 20 or more bushels. When the soil was wet in the first foot only, the chances of obtaining a yield of 10 or more bushels par acre were about 2 in 5.

There were only seven cases in which the soil was wet into the second foot but not deeper, and the number of instances is so small that little weight should be given to the results, except as indicating a trend. In four of these cases the yield was less than 10 bushels per acre. Thus, the chance of obtaining a yield of more than 10 bushels per acre was a little less than even. There were no high yields in this group, but this was probably accidental.

There were 17 cases when the soil was wet to a depth of 3 feet or more. Nearly all of these were on fallow. In fact, there has been no year since 1916 when the soil on the plots where wheat was grown each year was wet to a greater depth than 2 feet at seeding time. Of the 17 cases when water was present in the third foot, or deeper, five produced yields of less than 10 bushels per acre, three produced yields between 10 and 19 bushels, and nine produced yields of 20 bushels or more per acre. There was an equal chance that the yield would be 20 bushels or more per acre.

Comparing the results with those at Hays, it is seen that the crop prospects increased similarly with the depth to which the soil was wet, although yield levels were higher at Hays.

The chance of obtaining a crop from seeding in a dry soil was poorer at Colby than at Hays. When the first foot only was wet, chances at the two places were about equal. Both places showed increased crop prospects as the depth to which the soil was wet increased. The possibility of failure through conditions developing after seeding were greater at Colby than at Hays.

EFFECT OF PRECIPITATION BETWEEN SEEDING AND HARVEST

The influence of rainfall after seeding on the yield was much stronger at Colby than at Hays, probably because there was usually a smaller quantity of water in the soil and the rainfall contributed a larger proportion of the water used by the crop.

The relative importance of the two factors was studied at Colby as at Hays. The average rainfall between seeding and harvest, the average yield, and the average quantity of water for each plot were used as bases for determining the effect rainfall after seeding had on the yield. The results for the continuously cropped plots were as follows:

There were 32 cases when below average quantities of available water were present at seeding. Twenty-three of these produced yields below the average. In 15 of the 32 cases the rainfall was above average, but, only seven of these 15 cases produced yields above average. Above normal rainfall made up for a deficiency at seeding in nearly half of the years in which it occurred. However, rainfall after seeding was below normal in many years, and for the whole group the chances were more than 2 in 3 that below average conditions at seeding time would not be corrected.

There were 25 cases when the quantity of available water in the soil was average or above. In 18 of these the yield was above average, although the precipitation was below average in 17 of the 25 cases. Thus the chances were approximately 2 in 3 that above average condition at seeding would not be nullified, although below average rainfall brought the yield below average in nearly half of the cases when it occurred.

The chance of a below average quantity of available water in the soil at seeding being corrected through above average rainfall after seeding was greater at Colby than at Hays. The chance of an above average quantity of water being nullified by low rainfall was likewise greater. However, even at Colby there was less than one chance in three for below average conditions at seeding to be corrected, or above average conditions to be nullified through rainfall after reeding.

RESULTS WITH WHEAT ON OTHER METHODS OF SOIL PREPARATION

In addition to the continuously cropped plots of wheat, the soil moisture was determined for a shorter period of years on a rotation consisting of corn, wheat on corn ground, wheat on early-plowed land following wheat, and wheat stubbled in following wheat. Moisture determinations were made on this rotation from 1917 to 1920, and from 1924 to 1934. Unfortunately one of the years when no determinations were made was the most favorable for planting in stubble.

For the 15 years for which data are available, the corn ground contained an average of 1.59 inches of available water at seeding time, as compared to 1.56 inches for the early-plowed plot. The average yield was 9.9 bushels per acre on the corn ground, and 8.9 bushels per acre on the early-plowed land. Not the quantity of water, but where it was held, made the difference in favor of the corn ground. The first foot of soil on the corn ground was drier at seeding than the first foot of the early-plowed plot. This resulted in a smaller fall growth and consequently less use of moisture during the fall period. The corn ground usually held in the second and third feet a small supply of water that the corn crop did not use, But which was available for wheat. This water was of material help in some years.

The plot on which wheat was seeded in stubble contained an average of only 0.99 inch of available water at seeding, a quantity materially lower than on the other methods of cultivation. In spite of this, it produced an average yield of 8.5 bushels per acre, which is very little lower than the yield on early-plowed land. Observations showed that the stubble on this plot caught much more snow during winter than did the other plots. Evidently the snow held by the stubble was of material value in enabling the wheat to overcome the handicap of less water in the soil at seeding time. Stubbling in is a common practice in this section of the state, as it is the cheapest method of growing wheat. The results to date show that wheat seeded in clean stubble may be expected to produce yields nearly equal to those on other methods of preparing wheat land for wheat. The number of years that stubbling in may be practiced without reducing yields has not yet been determined. Soil moisture determinations made on a continuously stubbled-in plot show that continuous stubbling in reduces yields to a greater extent than could possibly be accounted for by differences in moisture Occasional plowing is undoubtedly essential.

The effect of seeding on a dry soil was apparent in this rotation. There were 10 cases when the soil was dry at seeding time, six of them on the stubbled-in plot. In eight cases the yield was 2 bushels per acre or less. In the other two the yields were less than 10 bushels per acre. Unless there was moisture enough in the soil at seeding time to germinate wheat, the chances of securing a crop appear to be very poor.

ABANDONMENT OF WHEAT AT COLBY

The occasion for abandonment of wheat is likely to arise more frequently at Colby than at Hays. More wheat is seeded under adverse conditions, and in such cases the need for abandonment is more frequent. As a rule, however, decision on whether or not to abandon the crop cannot be reached at so early a date at Colby as at Hays.

The economy of not planting, or of abandoning early in the spring, wheat that was planted in a dry soil, is greater at Colby than at Hays. There were 18 cases when wheat was planted on dry soil on the continuously cropped land or the rotation described. Had the wheat not been planted and the land been fallowed in the spring, the total yield would have been 256 bushels (the yield of the plot of fallow). By allowing the crop to mature and planting wheat again the next year, the total yield was 146 bushels, a difference of 100 bushels in favor of not planting.

Much wheat is planted in dry soil with the knowledge that crop prospects are poor, but with the hope that rain shortly after seeding may make the production of a profitable crop possible. Many operators believe it desirable to do this rather than wait for rain, because their acreages are so large that waiting for rain may unduly delay seeding. When an operator has a very large acreage to seed, the chances are that he will do at least part of his seeding regardless of conditions. This is especially true when wheat is stubbled in, as the crop is planted at no expense other than the cost of the seed and the seeding operation.

The knowledge that wheat seeded in a dry soil stands so great a chance of failure should have the effect of limiting the number of acres planted. When a large acreage is to be planted it appears to be a good practice to plant a portion of the land, and then wait to see if rain falls. If rain comes, the remainder of the land can be planted If not, the land can be left over winter and then planted to some other crop or prepared for wheat by beginning fallowing operations in May. The assurance that the total wheat production for two years is almost certain to be greater by fallowing one year and growing a crop the next than by planting in dry soil and harvesting crops in two years should more than compensate for the fact that in rare years wheat planted on a dry soil produces a paying crop.

Where wheat is planted on soil containing enough moisture to enable it to start, whether or not to abandon the crop cannot as a rule be decided early in the spring. There are occasional winters so dry that the wheat dies and the need for abandonment is apparent early. In most years there is enough moisture during the winter to maintain the top growth, and the question of abandonment cannot be decided early.

There are, however, many years when it is possible to tell by the first of May that the crop is capable of producing, at best, only a low yield. In such years the crop could be abandoned, and fallow operations started in early May with the assurance that the possible sacrifice of a low yield would be more than compensated for by increased returns from the next crop.

Unless the necessity for abandonment can be foreseen early enough to permit preparation for fallow by the middle of May, the probability that fallow will store an adequate quantity of water for the next crop becomes small.

RESULTS AT GARDEN CITY

The station at Garden City represents an extensive wheat-growing area in southwestern Kansas. Conditions are different from those at Hays or Colby. Garden City is located a little more than 100 miles almost directly south of Colby. Its distance west gives it a high elevation (2,840 feet) and a rainfall similar to that of Colby. Its distance south gives it the earlier harvest date, later optimum seeding date, and shorter dormant period characteristic of Hays. There is a comparatively long period between harvest and seeding for the conservation of moisture, but the average quantity of rain that falls during the period is smaller than at Hays. Evaporation is higher than at either Hays or Colby.

Wheat has been grown at the Garden City station since 1909, and soil moisture records were kept during most of the period. However, during the early years of the station the wheat crop was injured by so many factors other than moisture, that not many years' records are available. During those years wheat growing had not become general in southwestern Kansas, and the wheat plots at the station were about the only green vegetation in that section during the winter months. As a result rabbits concentrated on these plots and destroyed several wheat crops. Grasshoppers, birds, and hailstorms contributed to the damage.

The years for which soil moisture data are available probably represent average condition. The past few years of drought have been exceptionally severe, but this is compensated for by the ex-

TABLE VI.—MONTHLY AND ANNUAL PRECIPITATION AT THE GARDEN CITY BRANCH STATION FOR 22 YEARS, 1913 TO 1934

YEAR.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1913	0.15	1.15	0.50	1.21	2.30	3.12	4.97	0.87	5.47	0.23	1.19	2.42	23.58
1914	.27	.20	.03	1.74	3.63	1.44	.56	.64	.15	1.48	T	.41	10.55
1915	.45	2.54	.93	2.67	4.39	2.95	1.66	6.60	2.27	1.79	.12	.13	26.51
1916	1.09	T	.60	2.80	.40	4.21	.20	3.89	1.16	.67	T	.51	15.53
1917	.30	0	.60	2.74	3.27	1.19	2.96	2.99	1.13	.13	.30	.16	15.77
1918	.34	.64	2.21	.79	2.48	1.91	3.58	.64	2.00	3.23	.13	3.10	21.05
1919	.18	1.52	1.53	2.24	.86	.60	3.00	1.12	3.20	1.65	.72	0	16.62
1920	.20	.23	.21	1.24	2.47	3.27	3.49	3.12	2.55	2.83	.86	.43	20.90
1921	1.02	.32	T	2.63	.96	5.81	2.21	2.25	2.46	.20	0	.65	18.51
1922	.24	.19	1.35	3.55	3.31	.64	2.05	2.49	.07	0	.49	T	14.38
1923	T	T	.41	3.92	6.69	6.88	4.52	3.86	6.19	3.10	.33	.29	36.19
1924	T	.76	1.73	2.08	1.06	1.39	1.09	1.74	1.73	.59	T	.55	12.72
1925	T	.46	.80	2.54	2.06	1.16	1.30	1.81	2.00	.28	1.01	T	13.42
1926	.33	.38	1.09	.91	2.35	2.98	2.05	2.56	1.15	0	.73	.32	14.85
1927	T	.30	1.26	1.59	.16	3.66	1.87	2.42	2.77	.15	T	.04	14.22
1928	0	1.22	.82	1.43	6.84	9.03	5.44	2.21	.25	3.09	.76	.10	31.19
1929	.11	.19	.63	1.69	3.71	1.85	1.55	1.46	2.24	1.57	1.19	0	16.19
1930	.14	.25	0	1.93	3.72	1.24	2.67	.52	3.40	7.09	1.90	.17	23.03
1931	0	.71	1.86	1.94	3.69	1.29	3.13	4.28	.28	1.22	.59	.40	19.39
1932	1.03	.33	.79	2.07	.95	5.75	1.25	3.35	.50	.93	.14	T	17.09
1933	.02	.28	.27	2.00	2.76	1.73	1.23	4.77	3.01	1.39	1.13	.78	19.37
1934	0	1.44	.41	.36	.81	1.05	.14	1.16	.37	1.13	.19	.02	7.08
Averages	.27	.59	.82	2.00	2.68	2.87	2.31	2.49	2.02	1.49	.53	.48	18.55

T—Trace.

ceptionally good period from 1929 to 1931, inclusive. The records used for this moisture study are for the years when moisture determinations were made at seeding time and when the crop was not destroyed by some agency other than drought. Records for 1923 to 1934, inclusive, are complete, but the 1928 crop was destroyed by hail, and that year is omitted.

The monthly and annual precipitation at Garden City from 1913 to 1931, inclusive, are given in Table VI.

EFFECT OF THE QUANTITY OF AVAILABLE WATER IN THE SOIL AT SEEDING TIME ON THE YIELD OF WINTER WHEAT GROWN CONTINUOUSLY AND ON ALTERNATE FALLOW

Soil moisture determinations were made on early-plowed wheat land, late-plowed wheat land, and summer-falloweed land. The cultivations were the same as for the same methods at Colby and Hays. The number of inches of available water in the soil at seeding time on each of these plots and the yield of wheat are given in Table VII. The relation between available water content at seeding time and yield is expressed by the correlation coefficient 0.594, with a probable error of 0.070, which is slightly higher than for Colby, but much lower than for Hays. As at Colby, water was still the limiting factor on fallowed soil.

TABLE VII.—QUANTITY OF AVAILABLE WATER IN THE SOIL AT SEEDING TIME AND THE YIELD OF WINTER WHEAT ON THREE METHODS OF CULTIVATION AT THE GARDEN CITY BRANCH STATION FOR CERTAIN YEARS, 1914 TO 1934

CROP YEAR (a).	Available water at seeding time (b).			Yield per acre.		
	Late plowed.	Early plowed.	Fallowed.	Late plowed.	Early plowed.	Fallowed.
	Inches.	*Inches.*	*Inches.*	*Bushels.*	*Bushels.*	*Bushels.*
1914	0	.7	1.2	7	6	15
1915	0	0	4.3	10	10	22
1923	0	.2	4.7	0	0	(c) 2
1924	3.0	4.9	6.6	14	21	23
1925	0	.4	5.7	0	0	13
1926	.1	.4	1.3	1	2	3
1927	.1	.6	4.7	0	0	0
1929	.7	2.9	7.3	13	19	26
1930	.2	.9	5.5	8	15	28
1931	1.0	1.1	3.2	22	26	32
1932	.1	1.6	7.0	2	8	28
1933	0	.2	5.6	0	0	7
1934	.5	.2	3.6	0	0	2
Averages	.44	1.08	4.67	5.9	8.2	15.5

(a) The crop year is the calendar year in which the crop was harvested.
(b) Determinations were to a depth of 3 feet on early-plowed and late-plowed and 6 feet on fallowed.
(c) Low yield on fallow in 1923 due largely to poor stand.

There were 21 cases when the available water content at seeding time was less than 1.5 inches. Of these, 17 produced yields of less than 10 bushels per acre, five produced yields of from 10 to 19 bushels per acre, and two produced yields of more than 20 bushels per acre. The average for the group was 5.8 bushels

There were only two cases when the available water content at seeding time was from 1.5 to 2.9 inches. Both of these were on early-plowed land. In one of the years the yield was less than 10 bushels per acre, and in one it was over 10 bushels. The average was 13.5 bushels.

There were 13 cases when 3 or more inches of available water were present at seeding time. Eleven of these were on the fallowed plot. In this group there were four yields of less than 10 bushels per acre, two yields of from 10 to 19 bushels per acre, six yields of from 20 to 29 bushels per acre, and one yield of more than 30 bushels per acre. Thc average yield for the group was 16.8 bushels per acre.

With less than 1.5 inches of water in the soil at seeding the chances of failure were great. In 14 of the 24 cases the crop was a total failure or the yield too low to more than pay for harvesting. Good conditions after seeding were necessary if even a fair yield was to be secured, and exceptionally favorable conditions were necessary to produce a good yield. This occurred in only one year, 1931.

There were too few cases with from 1.5 to 2.9 inches of water to draw any conclusions.

The presence of 3 inches or more of available water at seeding time provided a better than even chance that a yield of more than 20 bushels would be produced. One total failure occurred when this quantity of water was present at seeding time, and there were two other years of very low yields, indicating that conditions following seeding may be so severe that a favorable condition at seeding is nullified.

EFFECT OF THE DEPTH TO WHICH THE SOIL WAS WET

There were 17 cases when the soil was dry at seeding, that is, it contained less than 3 percent of water in any foot section and would not have appeared otherwise than dry, except possibly for a thin surface layer. Ten of these were on late-plowed, six on early-plowed, and one on summer-fallowed land. Thus early preparation failed to provide adequate rnoisture to give wheat a good start in six of the 13 years, and summer fallow failed in one year. In the year 1926, when fallow was dry at seeding, there was some available moisture in the fifth and sixth foot sections of soil, but the second, third, and fourth foot sections were dry. Of the 17 cases when the soil was dry at seeding time, 12 produced yields of 3 bushels per acre or less, and the maximum yield obtained was only 13 bushels per acre. As at the other stations, seeding in a dry soil resulted in loss unless unusually favorable conditions followed seeding. The average yield of this group was 3.3 bushels.

There were six cases when the first foot only was wet, four of these were on the early-plowed plot and two on the late-plowed plot. Of these six cases there were three yields of less than 10 bushels per acre, two of these being total failures, one yield of between 10 and 19 bushels per acre, and two yields of over 20 bushels per acre. The average yield for this group was 11.5 bushels per acre.

There were only three cases when the first 2 feet of a plot were wet one year on each cultivation method. There were no failures and no high yields in this group. The average yield was 12.3 bushels per acre. The small number of cases probably accounts for the absence of a failure or high yield.

There were 13 cases when the soil was wet into the third foot or deeper. In this group were the only instances when the first foot section was nearly dry while the soil below contained considerable quantities of available water. The first foot of soil on the fallowed plot was dry at seeding in 1915 and 1923. In 1915 rain that wet the first foot of soil thoroughly occurred shortly after seeding, the crop was able to secure the moisture from the lower depths and a good yield resulted. In 1923 the weather remained dry after seeding, and no stand was obtained on the fallowed plot. The resulting yield was very low. Of the 13 cases when the soil was wet into the third foot or deeper, four produced yields of less than 10 bushels per acre, two produced yields of between 10 and 19 bushels per acre, and seven produced yields of over 20 bushels per acre, the maximum being 32 bushels.

Summing up the results, it may be said that when seeding was done in a dry soil, or a soil wet to a depth of not more than a few inches, the chances were more than 2 to 1 that the crop would be a failure. The fact that the soil on early-prepared land was dry at seeding in a third of the years shows that this method often failed to provide adequate moisture to give the crop a good start. The high temperature and high evaporation, coupled with the relatively low rainfall between harvest and seeding, are responsible for this condition.

When the soil was wet well into the first foot or into the second, there was better than an even chance that the yield would be above 10 bushels.

With the soil wet into the third foot the chances of failure were lower and there was better than an even chance that the yield would exceed 20 bushels per acre.

The fact that early plowing often failed to store much water has been noted previously. This preparation at Garden City offers an instance of a cultivation method increasing average yields without materially reducing the chance of failure. There were six failures on early-plowed, and only seven on late-plowed plots. Thus the reduction in the chance of failure by early preparation was small. The average yield following early plowing, however, was 8.2 bushels, which is materially higher than the 5.9 bushels per acre after late plowing. That this difference in yield was due to the water stored is shown by an examination of the results. In the four years that early preparation greatly exceeded late preparation in yield, it had stored an average of 1.6 inches more available water. The failure of early preparations to store water was due to the facts that the rainfall was too scanty and the temperature and evaporation too high to permit storage of much water except in years with unusually favorable conditions between harvest and seeding. In years when early preparation was able to store water the effect was evidenced by a greatly increased yield

EFFECT OF PRECIPITATION BETWEEN SEEDING AND HARVEST

The effect of rainfall between seeding and harvest upon the yield of wheat was studied at Garden City in the same manner as at the other stations.

Results were closely comparable with those at Colby. Below average quantities of available water at seeding time were compensated for by above average rainfall in approximately half of the years in which it occurred. Taking into consideration the number of times that a below average quantity of water in the soil at seeding time was followed by a below average rainfall, however, the chances appeared to be less than 1 in 3 that below average conditions at seeding would be corrected by above average rainfall after seeding. The actual number of times that an above average yield was obtained in years when the initial available water content was below the average for the method was only 7 in 23.

When the initial available water content was above the average for the method the number of times that the yield fell below average was 6 in 16 cases, although the rainfall was below average in 11 of the 13 years. Thus dry conditions after seeding reduced yields to below average in a little more than one third of the cases.

ABANDONMENT OF WHEAT AT GARDEN CITY

The necessity for abandonment of wheat arises frequently at Garden City, because in that section, as at Colby, acreages are large and much wheat is planted under poor moisture conditions with the hope that rains after seeding may improve prospects It is believed that the amount of wheat planted under dry conditions would greatly decrease if growers fully realized the long odds against obtaining a paying yield.

As at Hays and Colby it may be said that the best time to abandon wheat to be planted on a dry soil is before seeding Planting in a dry soil is so hazardous that there is little hope of success. On the average, planting in a dry soil produced less total wheat for that crop and the one following than would have been obtained by not planting at all and leaving the land fallow until the next year. This was true in spite of the fact that wheat on fallow failed more frequently than at the other stations.

When ground has been prepared early for wheat, it is probable that wheat will be planted, even though there is no moisture present at time of seeding. The knowledge that wheat planted under such conditions must be favored with above average rainfall after seeding to produce even a fair yield should enable a grower to decide whether or not to abandon the crop. If conditions after seeding are not good, a crop planted in a dry soil can be abandoned early in the spring and the land fallowed during the summer. In such a case. the seed is wagered on the prospect that above average conditions after planting may correct poor conditions at seeding.

It would appear highly desirable to limit severely plantings in years when wheat must be planted in a dry or nearly dry soil. Where acreages are too large to permit delaying all seeding until adequate rains are received in the fall, the necessary portion of the acreage can be planted in advance of rain. If adequate rains fall, the remainder of the acreage can then be planted. If not, the seed can be saved and the land fallowed or planted to some other crop in the spring. The planted portion of the acreage should be handled with the full knowledge that better than average conditions are required to produce a paying crop. In the absence of such conditions, more bushels of wheat can be produced by abandoning early in the spring and fallowing for the next crop than could be obtained by allowing it to mature.

Where wheat is planted in a moist soil, conditions following seeding may bring about the desirability of abandonment. The impossibility of producing more than a small crop can often be foreseen early in the spring. The knowledge that more bushels of wheat can be obtained by plowing up a crop in poor condition and fallowing the ground during the summer than can be obtained by allowing the crop to mature, should assist growers in making up their minds to abandon. May and June are the months of heaviest rainfall, and fallow, to be effective, must have an opportunity to store this moisture. Any delay beyond the first part of May in preparing for fallow will probably result in a decrease in the water stored.

DISCUSSION OF RESULTS AT THE THREE STATIONS

The effects of the quantity of water stored in the soil and of the depth to which the soil was wet at seeding time, on the yield have been discussed for the three stations. The fact that the depth to which the soil was wet was as accurate a measure of predicting yields as the quantity of available water in the soil at seeding time has been shown. It is a measure that can be applied easily to most of the wheat-growing area in western Kansas. It cannot be applied to the very sandy areas without some modification, as a given quantity of water penetrates deeper into a sandy soil than into the finer soils upon which the three stations are located. Soil moisture studies on a sandy soil at Woodward Okla., indicate that a given quantity of water will penetrate approximately one half farther into that soil than into the soil at Hays. Consequently a quantity of water that would wet the soil to a depth of only 1 foot at Hays would wet a sandy soil to a depth of 18 inches or more. This must be taken into consideration when attempting to apply the results to sandy loam soils, and the depth to which the soil is wet must be discounted accordingly.

It has been shown that the depth to which the soil is wet at seeding time is definitely related to the yield, and that the prospect of a good crop increases with the depth to which the soil is wet. This holds true at all stations, although the assurance that favorable conditions at seeding will not be nullified by adverse conditions after seeding is much greater at Hays than at the stations with a lower precipitation. The results from all the stations are so similar, however, that average results may be applied to all the area. The crops that may be expected from the different depths to which the soil is wet at seeding expressed as chances and as percentages are given in Table VIII. The data in Table VII are from four plots at Hays, three at Colby, and three at Garden City, the yields of which were given in Tables II, V, and VII.

TABLE VIII.—PROBABILITIES OF OBTAINING SPECIFIED YIELDS OF WHEAT WHEN THE SOIL WAS DRY OR WET TO DESIGNATED DEPTHS AT SEEDING TIME, AS DETERMINED BY RESULTS FROM HAYS, COLBY, AND GARDEN CITY

Depth to Which Soil Was Wet.	Failure (4 bus. or less).	10 bus. or more.	20 bus. or more.	30 bus. or more.
Dry	27 in 38 *or* 71%	7 in 38 *or* 18%	0 in 38 *or* 0%	0 in 38 *or* 0%
1 foot	18 in 53 *or* 34%	23 in 53 *or* 43%	10 in 53 *or* 19%	0 in 53 *or* 0%
2 feet	5 in 34 *or* 15%	21 in 34 *or* 62%	10 in 34 *or* 29%	3 in 34 *or* 9%
3 feet or more	6 in 61 *or* 10%	51 in 61 *or* 84%	43 in 61 *or* 70%	14 in 61 *or* 23%

The extremely low probability of success from planting wheat in a dry or nearly dry soil is evidenced by the percentage figures. Wheat planted under such conditions was a failure (4 bushels or less) in 71 percent of the cases, produced a yield of as much as 10 bushels per acre in only 18 percent of the cases, and in no case produced a yield as high as 20 bushels per acre.

Planting under such conditions was gambling against great odds without the chance of proportionate returns if the long chance won. In most forms of gambling the long chance pays the highest returns when it wins. In this case there was not only the least chance of winning, but a low return if the long chance did win.

With this condition, it would appear logical to limit severely the wheat acreage in years when conditions at seeding are very poor. Most growers realize that prospects of reaping a good crop are smaller when planting is done in a dry soil or a soil wet to a depth of only a few inches than when the soil is wet to a greater depth, but probably few realize the tremendous odds against obtaining a crop under these conditions. A fuller knowledge of what may be expected should have the effect of greatly reducing the acreage planted under such unfavorable conditions.

In most of the infrequent years when fair crops were obtained by planting on a dry soil, seeding could have been delayed until after rain fell without loss of yield. The number of years when rains sufficient to be of material help in producing a crop fell later than the date to which seeding could have been safely delayed, was very small.

The fact that wheat planted in a dry soil did not produce a yield as high as 20 bushels per acre in any year at any station, should be evidence enough of the remoteness of the possibility that bad conditions at seeding will ever be fully corrected.

When the soil was wet well into the first foot, the probability of obtaining a yield of 10 bushels or more per acre increased to 43 in 100. There was also one chance in five that the yield would be 20 bushels or more per acre. Thus the presence of enough moisture to give the wheat a start reduced the chance of failure by more than half, and more than doubled the chance of obtaining a yield of 10 bushels or more per acre. That wheat was a failure in 34 percent of the cases indicates that wheat planted in soil wet only in the first foot should be closely watched and should be abandoned in the spring if conditions after seeding continue unfavorable to such an extent that the crop is badly injured and cannot produce more than a low yield. On the average, if the wheat is badly injured by late April or early May, it is more profitable to plow or list the land early in May to prepare for the next crop, than to allow the crop to mature.

The abandoned wheat need not be a total loss. In many years such wheat can furnish grazing at a time when feed on pastures is scarce. Pasturing, if completed before time to start fallowing operations, will not reduce the opportunity to store moisture.

With the soil wet to a depth of 2 feet, the chance of failure dropped to 15 percent, the chance of a 10-bushel yield increased to 62 percent, and the chance of a 20-bushel yield increased to 29 percent. There was in addition nearly one chance in 10 that a 30-bushel yield would be realized. The increased depth to which the soil was wet increased not only the chances of a crop but also the size of the crop.

With the soil wet 3 feet or deeper, the chances of failure dropped to 10 percent, and the chance of a yield of 10 bushels increased to 84 percent. Chances of 20- and 30-bushel yields were also much higher than when there was less water in the soil at seeding time.

The deduction can be made that the rainfall between seeding and harvest usually is not sufficient to produce good crops of wheat. It nearly always must be supplemented by water in the soil at seeding time if good yields are to be obtained. The greater the quantity of water in the soil at seeding, the better the opportunity for a good crop becomes. Ample water at seeding time may enable a crop to overcome poor conditions that arise later, but only in rare instances is rainfall between seeding and harvest high enough or well enough distributed to fully correct poor conditions at seeding. That water is the limiting factor is shown by the fact that at all stations in practically all years, all the available water was used before harvest. Other factors limit the size of the crop in many years, but water is almost always a limiting factor.

Granting that the assurance of obtaining a crop of wheat increases with the depth to which the soil is wet at seeding time, the question arises how water sufficient to wet the soil to a depth great enough to provide a reasonable chance of a good yield can be stored. This differs at the three stations.

At Hays, early cultivation, either by plowing or listing, allowed the soil to accumulate moisture into the second foot or deeper in more than two thirds of the years, and provided enough moisture to give the wheat a good start in practically all years. Planting under very adverse conditions was confined almost entirely to land not given early cultural treatment. In most years early preparation was good insurance against failure, and wheat on early-prepared land produced yields of over 10 bushels per acre more than two thirds of the time. Preparation that was started early and kept the land free from weeds and volunteer growth between harvest and seeding was an effective means of combating drought.

Summer fallow at Hays accumulated moisture to a depth of 3 fect or deeper in all years, and reduced danger of failure to a very low figure. Fallowing increased yields more bushels per acre at Hays than at either of the other stations, but it is of less importance than at the other stations, because yields from early preparation are relatively so much better. Summer fallow at Hays may he looked upon as a means of controlling noxious weeds and of insuring yields in some years when other methods of tillage will not store adequate water.

At Garden City, the soil was wet to a depth of 2 feet or more in only one year on late preparation, and less than one third of the time on early preparation. Early preparation was effective in increasing yields in years when it stored considerable water, but in many of the years the quantity of water that could be stored was small. Where wheat followed wheat, even on early preparation, failure or near failure could be expected in approximately half of the years. Early preparation paid, but it paid because it increased yields materially in a few years rather than because it prevented failure.

Fallow at Garden City stored moisture to a depth of 3 feet or more in all but two of the 13 years, but in one of the years the value of the stored moisture was lost, because the first foot of the soil dried out so deeply that wheat failed to germinate. Fallow did not prevent failure, but it stored enough water to be an insurance against failure in most of the years. It did not increase the yield so many bushels as it did at Hays, but it was of greater importance, because other methods were relatively poorer. It was necessary to fallow at Garden City to provide the same degree of crop assurance that early cultivation provided at Hays.

Fallowing at Hays increased the yield of wheat 10 bushels per acre over early plowing, but this increase was only 57 percent. Fallow at Garden City increased the yield only 7.2 bushels over early plowing, but the percentage of increase was 89. Thus fallow nearly doubled the yield, and part of this additional yield was produced in years when wheat following wheat failed. Wheat grown after wheat at Garden City, even on early preparation, produced yields of 10 bushels or less per acre in about two thirds of the cases.

Low production costs at Garden City made small yields relatively more profitable than at Hays, but the fact that two or three successive failures occurred at different times on early-prepared soil points out the necessity of stabilizing production by employing some method of cultivation, such as fallow, that distributes production more evenly between years. A system of continuous wheat production, even by the most approved methods, can result only in alternate periods of prosperity and poverty, hence the desirability of diversification. There are very few farms capitalized and organized to meet three or more years of complete or nearly complete failure. Farmers growing wheat after wheat, even by early preparation, face this situation. Partial stabilization may be reached through keeping a portion of the land fallow, but successive years of low yields occur, even on fallow. Fallow is an aid to stabilization, hut it does not entirely prevent failure.

At Colby as at Garden City, land cropped to wheat each year was seldom wet deep enough at seeding time to provide any assurance of a crop. Early-prepared ground was wet into the second foot at seeding only about one fourth of the time. Yields from late preparation were as high as from early preparation. In most years there was enough water to give wheat a start, but not enough to provide an assurance that a crop would be produced. Years of successive failure, however, were less frequent at Colby than at Garden City. Where wheat was grown after wheat there was the prospect that yields would fall below 10 bushels per acre approximately two years out of three, and that two or more years of successive failure might occur.

Fallowing resulted in the soil becoming wet to a depth of 3 feet or more at Colby in all but five of the 19 years and was an effective means of preventing failure. Fallow provided a reasonable assurance that there would not be successive years of failure. Yields on fallow were about double those on other methods of land preparation, indicating that fallow should be more important at Colby than at the other stations. Fallowing was not a complete insurance against failure, indicating that other crops and livestock must enter into the farming program if complete failure in occasional years is to be avoided.

The fact that wheat on fallow at Garden City and Colby produced yields nearly double those on methods of preparation where wheat followed wheat, does not mean that all the wheat should be grown on an alternate fallow and crop basis. The desirability of including some fallow in the farming system as an insurance against failure appears to be self-evident. But in many years a crop may be obtained on wheat land with very little expense.

It would seem desirable to limit wheat acreage in years when wheat must be planted in a dry soil. Seeding can usually be delayed until well into October without materially decreasing yields, and, except where acreages are very large, it is better to wait for rain than to plant in hopes of rain. Land not planted to wheat in the fall may be planted to other crops the next spring, or it may be fallowed. If the land is fallowed, the grower can feel certain that on the average more wheat will be produced by the one crop planted on fallow than would have been produced by the crop planted in dry soil and a crop the following year.

If the soil is wet to a depth great enough to give wheat a start, but not great enough to provide a reserve supply of water, wheat can be planted with the purpose of harvesting the crop if conditions are favorable after planting, and of abandoning it if they are not. Wheat planted in a soil wet to a depth of only a few inches is dependent upon conditions after seeding. Average rainfall after seeding has almost never produced a good crop, but above normal rainfall has. Wheat planted under such conditions should be watched with the full knowledge that a low rainfall in the months following seeding is almost certain to result in failure. The absence of above normal conditions is an indication that abandonment may be desirable. Conditions much below normal are an almost positive assurance that abandonment will usually be best

The important matter is to recognize the need for abandonment, when it arrives and to take advantage of it. Land, where the wheat warrants abandonment, can be plowed or listed early in May with the assurance that any small yield that may be lost will be more than compensated for in the following crop, if the land is kept clean during the summer. Wheat land harvested in good years and abandoned in poor years gives the opportunity of reaping a crop when conditions are right and of fallowing when they are not.

Early abandonment when conditions warrant need not be looked upon as the loss of a crop. Rather it may be looked upon as a method of cultivation that helps to insure a crop the next year.

In some years wheat badly damaged by drought makes an astonishing recovery if abundant rains fall. However, this recovery is frequently more apparent than real. The growth that takes place on drought-injured grain is generally much later than normal, and ripening is delayed until the hottest part of the summer. The result frequently is a low yield of shriveled grain. The moisture that might have been saved for producing a crop the next year is used up in producing a crop of doubtful value. There is a possibility that prolonged cool weather may enable such a crop to fill properly, but this seldom occurs. On the average, it is better to save the moisture for the next crop than to allow it to he used by the drought-injured crop. Wise abandonment permits a wheat grower to take advantage of fallow in many years without too large a percentage of his land being in fallow every year.

SUMMARY AND CONCLUSIONS

The depth to which a given soil is wet at seeding time is a reliable measure of the amount of available water in that soil. Sandy soils must be wet to a greater depth than heavier soils to carry the same amount of water. Any farmer can easily determine with a spade or post-hole digger the depth to which the soil is wet.

The depth to which the soil was wet at seeding time has, on the average, borne a very close relationship to the yields obtained. with the comparatively heavy soils at any of the three stations wet to a depth of 3 feet, a good yield has been fairly well assured, and only very adverse conditions during the growth of the crop have been able to cause low yields or failure.

With the soil dry, or wet to only a few inches at seeding time, poor yields or failures have resulted more often than not.

When little or no rainfall occurs soon after wheat has been planted on soil moist to only a few inches, the probability of failure is greatly increased. If dry weather continues through the winter the probability of failure is increased to such an extent that abandonment of the crop is usually advisable.

When the initial soil moisture is deficient and the precipitation is low to April 1, it is probable that abandonment of the crop and the conservation of water in a summer fallow for a future crop will pay far better than allowing the water to be wasted by the poor crop and weeds on the land.

Early preparation at Hays resulted in the soil's becoming wet to a depth great enough to give the wheat crop a good start in most years. Late-prepared land frequently was dry or nearly dry at seeding time. Rainfall after seeding seldom compensated for lack of storage of water between harvest and seeding.

Early preparation was not effective in storing water at Garden City in all years, but increased the yield materially in years when considerable quantities of water were stored. It increased the average yield without materially reducing the danger of failure.

Early cultivation at Colby slightly increased the average quantity of available water in the soil without increasing the yield.

It was neccssary to fallow at Garden City and Colby to provide an assurance of a crop equal to that provided by early cultivation at Hays.