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STORAGE OF WATER IN SOIL AND ITS UTILIZATION BY SPRING WHEAT.

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INTRODUCTION.

The work of the Office of Dry-Land Agriculture Investigations covers many stations and consequently a wide range of soils and climatic conditions. It has been continuous at these stations for a relatively long term of years. It consequently offers exceptional opportunity for the generalization of data and the drawing of conclusions based on the average conditions of soil, location, and season. This possibility of generalization does not preclude or interfere with the recognition of the extremes of individual conditions, but makes it possible to assign to them their relative importance in the make-up of the whole.

The water-storage capacity of a soil and the depth to which crops are able to use the stored water are matters of prime importance. Other conditions being equal, the soil that will hold the greatest quantity of water within reach of plant roots should show the most material benefits from methods of cultivation calculated to conserve and accumulate soil moisture. It usually happens in the Great Plains, however, that the water-storage capacity of the soil is only partially used. During the greater portion of the time on most soils the quantity of water held in the soil is limited by the amount of water available for storage rather than by a lack of storage capacity.

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The present study is not intended primarily to establish the maximum depth to which a wheat crop is capable of feeding. The purpose is rather to determine and present the actual depth to which the wheat crop has utilized the soil in a series of seasons, on a wide range of soils, and under radically different cultivation methods. The data are classified to show whether this depth was limited by the depth of the soil itself, by the quantity of water available for storage, by the physiological limitations of the crop, or by the character of the season.

The material was obtained in connection with the preparation of United States Department of Agriculture Bulletin No. 1004, entitled "Use of Water by Spring Wheat on the Great Plains," by John S. Cole and O. R. Mathews. All the members of the technical staff of the Office of Dry-Land Agriculture Investigations from 1906 to date have contributed to the publication by the data they have obtained at the stations where they have been located.

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SOURCES OF INFORMATION.

At the time the work of the Office of Dry-Land Agriculture Investigations was inaugurated it was recognized by those in charge that a measure of the water content of the soil would be of great value in interpreting crop yields. For this reason frequent determinations of soil moisture were made at the stations then in operation, on plats receiving different cultural treatments. This work has been carried on continuously at these stations and at all stations where experiments have been subsequently started by the office mentioned except one, where the character of the soil prohibits soil sampling by the usual method. Moisture determinations have been made on all of the principal crops, but at the stations where wheat grows well it has been considered the basic crop and has been sampled more regularly than any other. It should not be inferred, however, that wheat is the most important crop at all the stations from which data are presented. At some of them it is, in fact, of little importance, but even at these certain data have been obtained on it for purposes of comparison. The moisture reactions of spring wheat and winter wheat have been found to be somewhat different. Spring wheat alone is considered in this publication, as more moisture determinations have been made with it than with winter wheat. Some of the stations having the best soil-moisture records have been necessarily omitted because the major part of their work has been with winter wheat.

The data presented consist of moisture determinations at 17 stations in different portions of the Great Plains on three plats of spring wheat, known as plats A, B, and C or D. The moisture history of these three plats constitutes a total of 135 crop years, after omitting years when some factor, such as hail, was responsible for crop damage and years when the number of samples taken was not great enough to determine the changes in moisture content of the plats.

The plats indicated by the same letter receive the same cultivation at all stations. They represent systems of tillage so different that they should show maximum differences in their moisture relations.

Wheat is grown continuously on plat A. No cultivation is given the plat in the fall after a wheat crop is removed or in the spring until nearly time for seeding, when it is given a shallow plowing and usually one harrowing. No effort is made to control weed growth or to enable the plat to take up or conserve moisture. The plowing is usually only about 3 inches deep and the harrowing after plowing represents a minimum of cultivation in preparing a seed bed. This plat was originally designed to serve as a contrast to other plats receiving thorough cultivation for the purpose of storing water.

Wheat is likewise grown continuously on plat B. This plat is given a deep plowing, usually 8 inches, as early in the fall as possible after the wheat crop is removed. It may be either worked down immediately or left rough for a period, depending upon whether it seems advisable to conserve the moisture already in the soil or to leave the ground rough in order to catch precipitation more readily. No expense is spared in either the number or character of operations necessary to keep the ground free from weeds and in good tilth. The plat usually receives two double diskings and one or more harrowings. It represents what should be the greatest efficiency in storing moisture between harvest and seeding, and indicates the maximum results from the use of moisture-conservation methods where a crop is grown every year.

Wheat is grown on land alternately cropped and fallowed on plats C or D. One of these plats is in crop each year and the other in fallow. By the use of two plats it is possible to obtain a record each year of wheat grown on fallowed land. The fallow plat is plowed in the spring to a depth of about 8 inches. It is kept free from weeds during the summer and fall, and an effort is made to maintain the surface of the soil in condition to take up moisture readily. These plats represent the approximate maximum that may be expected in moisture storage, when a year's crop is sacrificed in order to accumulate moisture for a crop the following year. Unpublished experiments in methods of fallow conducted by the Office of Dry-Land Agriculture Investigations have shown this to be one of the most efficient methods of fallowing. Plat C or D in this bulletin always refers to each plat in the year when wheat is grown.

RANGE OF MOISTURE CONTENT OF SOILS.

The quantity of water that may be held within any unit of soil is subject to a definite limitation. When the moisture content of any section of soil increases to a point where the molecular attraction of the moisture for the soil particles is exceeded by the pull of gravity, there is a movement of water downward through the soil. It is in this manner that water falling upon the surface of a soil is conducted to the lower depths. Each successive layer of soil must become wet to a certain degree before water can reach the layer below. The addition of water in any considerable quantity to any foot section of soil necessitates that all of the soil above must have been wet enough to permit the passage of water through it. The condition of a soil holding all of the moisture that it is capable of holding against the pull of gravity is called its "field carrying capacity." Burr describes this condition of the soil as follows:

> The maximum water-holding capacity of a soil is the amount of water that soil will retain against the pull of gravity. When water is added to a soil in sufficient amount the film of water around each soil particle becomes thickened and the small spaces between the soil particles filled with water. In the addition of water a point is reached where the attraction of gravity overcomes the force that holds the water to the soil particles, and the water is drawn downward into the lower soil. If no more water is added a point is reached where the pull of gravity is equalled by the force that holds the water to the soil and there is no further movement except by the slow action of capillarity. The amount of water in the soil at this time is termed "maximum water-holding capacity" or "saturation point."[1]

It will be noted that Burr used the term "maximum water-holding capacity." This term describes the condition of the soil accurately, but has been used by other investigators in a different sense; therefore the term "field carrying capacity" is preferred.

The fact that the moisture content of a soil must be at its field carrying capacity before water is conducted to the lower depths does not indicate that it remains in that condition for any long period of time. The water held within a soil is removed by direct evaporation, by the action of plants, and to a limited extent may be transported by vaporization and recondensation.

The field carrying capacity of each individual foot section of soil at the 17 stations included in this publication has been determined for every foot section that has been wet often enough to permit accurate determination of the point. It has been determined by averaging the moisture content of each individual foot section of soil every time it has been wet enough to permit moisture to move through it into the foot section below.

The averages show that the field carrying capacity of a soil depends upon the physical character of the soil and bears a linear relation to its moisture equivalent and other physical constants. It is a little lower than the moisture equivalent as described by Briggs and McLane.[2]

The moisture equivalent of each foot section of soil in the plats from which data are here presented has been determined.

Loss of water from the soil takes place in various ways, but the principal loss in a soil upon which a wheat crop is growing is the water taken up by the roots of the crop and transpired by the plant tissues. Not all of the water in the soil is removed, as there is always a residue not available to plants. A soil whose moisture content is at a point where plant roots can no longer remove water is in a condition termed its "minimum point of exhaustion." This condition is described by Burr as follows:

> The minimum point of exhaustion of water from the soil by the plant is the point at which the force exerted by the plant in obtaining water is equalled by the attraction of the soil for the water. At this point the plant can obtain no more water from the soil and will suffer until water is supplied.[1]

The minimum point of exhaustion of a soil bears a direct relation to the wilting coefficient as determined by Briggs and Shantz.[3] Al-

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[1] Burr, W. W. The storage and use of soil moisture. Nebraska Agr. Exp. Sta. Research Bul. 5, 88 pp., illus. 1914.

[2] Briggs, Lyman J., and McLane, John W. The moisture equivalent of soils. U. S. Dept. Agr., Bur. Soils Bul. 45, 23 pp., 1 fig., 1 pl. 1907.

[3] Briggs, Lyman J., and Shantz, H. L. The wilting coefficient for different plants and its indirect determination. U. S. Dept. Agr., Bur. Plant Indus. Bul. 230, 83 pp., 9 figs., 2 pls. 1912. Bibliographical footnotes.

way, McDole, and Trumbull[5] have recognized the wilting coefficient of a soil as the dividing line between wetness and dryness and have pointed out the possibility of distinguishing by observation whether the moisture content of a soil is appreciably above or below that point. In at least the first few foot sections of a soil the minimum point of exhaustion is considerably lower than the wilting coefficient, and the soil when at or near the minimum point can be recognized as dry.

The minimum point has been determined for each foot section of the soil studied by an average of determinations made while the crop was suffering for water, the water content of the soil not being reduced. The point varies with the character of the soil and to some extent with the distance from the surface.

A soil in which the moisture content is at the minimum point is spoken of in this bulletin as dry. One in which the moisture content is at the field carrying capacity is spoken of as filled with water, and one in which the moisture content is between the minimum point and the field carrying capacity is spoken of as partly filled. All water held above the minimum point is termed "available water."

The range between the field carrying capacity and the minimum point of exhaustion in a uniform soil becomes gradually less as the distance from the surface increases. In such a soil the sixth foot section, for example, even when filled with water, contains considerably less water available to plants than the first or second foot of soil. The range between the minimum point and the field carrying capacity is particularly small in the lower depths of some of the heavier soils. In a few of these it is often difficult to determine whether or not moisture available to the wheat crop is present in the fifth and sixth foot sections.

MANNER OF STUDY.

The moisture determinations made on the wheat plats consist of measurements of the water content of each individual foot of soil to a depth great enough to include the zone of feeding of the crop. The depth varies from 2 to 6 feet with the different soils. The moisture content is expressed as a percentage of the weight of water-free soil.

The records at most stations have been kept long enough to permit the establishment of the field carrying capacity and the minimum point of exhaustion for most foot sections of soil under conditions ordinarily obtaining in these plats in the field. At stations with a shorter record the fewer determinations combined with the known moisture equivalent and wilting coefficient of the soils have permitted a close estimation of these factors. With the carrying capacity and minimum point of exhaustion of a soil established, a determination of the water content of any foot section enables one to determine whether available water is present in the soil and whether the water-storage capacity of the soil is being fully utilized.

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[5] Alway, F. J., McDole, G. R., and Trumbull, R. S. Interpretation of field observations on the moistness of the subsoil. Jour. Amer. Soc. Agron., v. 10, No. 7/8, pp. 265–278. 1918.

There is an experimental error in sampling, depending largely upon the lack of uniformity of the soil. Different soils vary greatly in this respect. Almost all soils in the Great Plains become less uniform in character and structure as distance from the surface in-

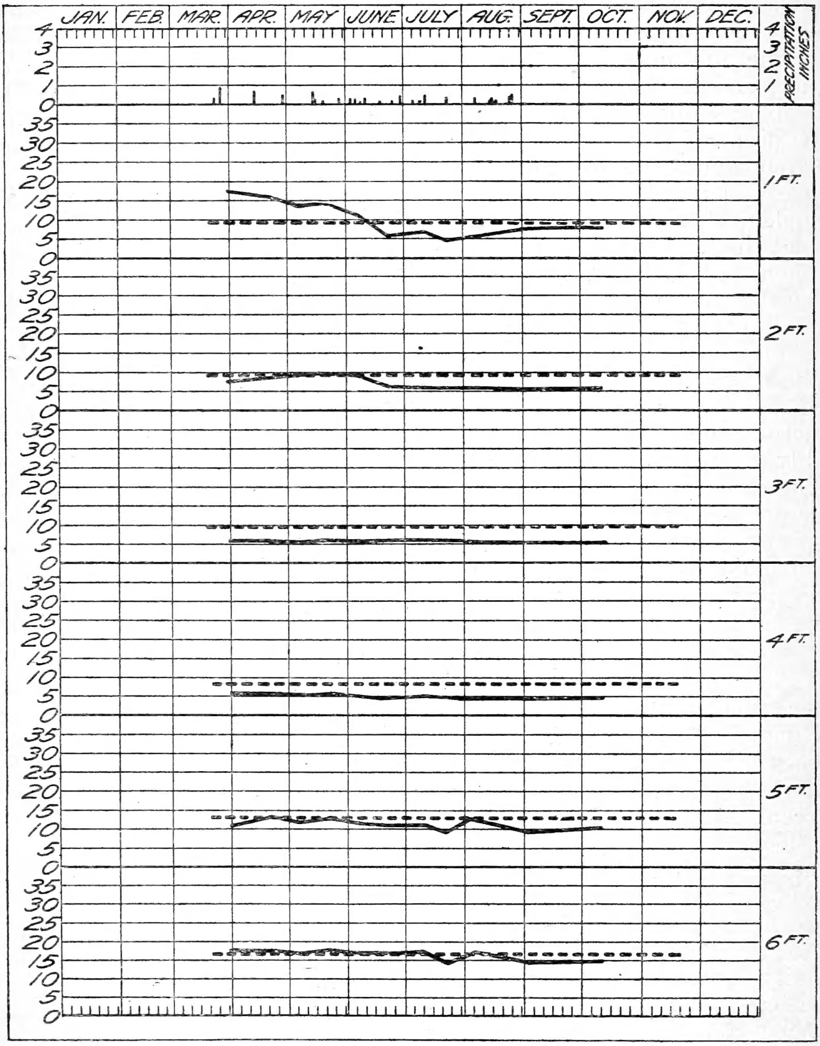

Fig. 1.—Diagram showing the percentage of water in the several foot sections of soil of plat B in wheat at Williston, N. Dak., at each date of sampling in 1910.

creases. Thus, any single sampling can not be taken as giving an exact measure of the water content of a plat, but must be considered as giving a close approximation, the closeness depending upon the uniformity of the soil. In all of the years and stations under study there have been only a few moisture determinations that have been considered as not providing a true indication of the moisture content of the plat.

The object of this study is not to determine the exact quantity of water used from each foot section of soil each year, but rather to determine the extent to which the moisture-storage capacity of the soil has been utilized and the extent to which the stored water has been removed at harvest.

The moisture content of each foot of soil of each plat at every determination during the season has been charted. By a study of the diagram it can be determined quickly and with a considerable degree of accuracy whether available moisture has been present in any foot of soil during the growing season and whether the available moisture in any foot of soil has been removed.

Figure 1 shows the moisture content of each individual foot of plat B at Williston, N. Dak., in 1910. The successive determinations of the moisture content of each foot have been connected by lines. The resulting curves give a good history of the moisture content of each foot of soil for the season; the dotted lines represent the wilting coefficients of the several foot sections.

The soil in the first foot at the time of the initial determination was at its field carrying capacity. This moisture content was not maintained by rainfall, and by harvest, July 26, the moisture of the first foot had been reduced to the minimum point of exhaustion. The second foot of soil possessed only a small quantity of available moisture, and this supply was exhausted long before harvest. There is no evidence to indicate that any available moisture was present below the second foot, and results from other plats and from this plat in other years show that it was dry as far as water available to crops is concerned. A point worthy of note is the fact that the minimum point of exhaustion of the soil in the lower depths more nearly approximates the wilting coefficient than in the upper depths. The greater experimental error in the fifth-foot and sixth-foot depths is indicated by the broken curves of those sections. The fact that the crop suffered severely for lack of water was noted several weeks before harvest. The extent of drought injury is indicated by the low yield of 1.3 bushels per acre.

The depth to which the crop used water that year was less than 2 feet. The storage capacity of the first foot of soil was all utilized and that of the second foot only partly utilized.

CLASSIFICATION OF DATA.

The presence of available moisture in the soil each year and the extent to which the moisture present has been used are divided into five classes, which are indicated by symbols. These symbols are designed to show at a glance the moisture history of any foot section of soil for a season. The condition represented by each symbol is as follows:

(1) A condition where the soil has been filled with water to its field carrying capacity at some time during the growing season and where all of the

available moisture has been removed by harvest time. This represents full use of water and soil and is indicated by the symbol F.

(2) A condition where available moisture was present in the soil during the growing season and where the moisture content was reduced but not exhausted at harvest. It is indicated by the symbol PW and represents partial utilization of the moisture in the soil and the presence of available water in the soil at harvest. In some cases, particularly in the first foot, it may indicate a condition where all of the available water has been removed at some time before harvest but where precipitation near harvest time has again raised the moisture content above the minimum point.

(3) A condition where the soil was only partly filled with moisture and all of the available water was removed by harvest. This is indicated by the symbol PD and represents partial use of water and a soil dry at harvest.

(4) A condition where available moisture was present in the soil but was not used. It is designated by the symbol OW representing zero use, although water was present. In a very few cases, particularly in the first foot of soil, it indicates a year with so much rain near harvest time that the soil at harvest is at its field carrying capacity.

(5) A condition where no moisture has been used and no available moisture has been present in the soil during the growing season. This is designated by the symbol OD, representing zero use of water and a dry soil.

It is apparent that there is no definite line of demarcation between these classes. In some cases the classification of a foot section of soil might have been changed by a moisture determination at some date when none was made. In general, however, the designations give a very close approximation of the status of any foot section of soil for the season, and the large number of cases makes up to a great extent for the lack of refinement of data.

Making application of these symbols to the data illustrated in Figure 1, the first foot section would be classified as F; the second as PD; and the third, fourth, fifth, and sixth sections as OD.

In Table 1 these symbols are used to indicate the moisture history of each foot of soil each year at each of the 17 stations. The yield in bushels per acre is given for each plat each year, to indicate to what extent drought injury has reduced the yield of the different plats, as practically all low yields were the result of drought injury. As stated before, years when some factor, such as hail, was responsible for a low yield are not included. Years when the moisture determinations were so infrequent as to leave a material doubt as to the classification of the different foot sections of soil are likewise omitted.

It must be understood that close comparisons can not be made between corresponding plats at different stations in any one year. The stations are in most cases rather widely separated and subject to local conditions of rainfall and other climatic factors. In many cases the differences between two stations, even in one State, during the same season may be greater than those between different seasons at one station. Each station must be considered as a unit both in soil and climate in this study.

No attempt will be made to describe the soil of the different stations further than is necessary to indicate the facility of its penetration by water and roots. Peculiarities that inhibit the soil from functioning in these respects are perforce noted.

A brief summary of the soil utilization at each station will be made, and points of special interest considered.

TABLE 1.—*Yield of wheat on each plat and designation of the extent to which each foot section of soil functioned at 17 field stations in the Great Plains area for the 14-year period from 1907 to 1920, inclusive.*

[KEY TO SYMBOLS OF WATER USE.—F=full use; PW=partial use, with water remaining in the soil at harvest; PD=soil dry at harvest, but only partial use because never filled to capacity; OW=no use, although water was present; OD=no use, and (or because) soil was dry.]

Station, plat, and foot section of soil.	Yield per acre (bushels) and symbol showing use of water.													
	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Assinniboine:														
Plat A, yield											3.5		1.5	7.2
Section 1											F		PD	F
Section 2											PD		PD	PD
Section 3											PD		OD	OD
Section 4											OD		OD	OD
Plat B, yield											3.8		1.0	7.5
Section 1											F		PD	F
Section 2											PD		OD	PD
Section 3											OD		OD	OD
Section 4											OD		OD	OD
Plat C or D, yield											11.7		2.2	10.5
Section 1											F		PD	F
Section 2											F		PD	F
Section 3											F		PD	PD
Section 4											PW		PD	OD
Section 5											OW		PD	OD
Section 6											OD		OD	OD
Huntley:														
Plat A, yield						11.0	16.0	18.3	24.5	5.8	7.8	1.5	0	8.2
Section 1						F	F	F	F	PD	F	F	PD	F
Section 2						OD	F	PD	F	OD	F	PD	OD	F
Section 3						OD	PD	OD	PD	OD	F	OD	OD	F
Section 4						OD	OD	OD	OD	OD	PD	OD	OD	OD
Section 5							OD	OD						
Section 6							OD	OD						
Plat B, yield						7.8	11.8	20.2	25.3	7.8	6.8	5.7	0	7.0
Section 1						F	F	F	F	F	F	F	PD	F
Section 2						OD	PD	PD	F	OD	F	F	OD	F
Section 3						OD	OD	OD	OD	OD	F	PD	OD	PD
Section 4						OD	OD	OD	OD	OD	PD	PD	OD	OD
Section 5							OD	OD						
Section 6							OD	OD						
Plat C or D, yield							22.6	19.5	36.5	13.5	11.3	18.8	.7	6.8
Section 1							F	F	F	F	F	F	PD	F
Section 2							F	F	F	F	F	F	PD	F
Section 3							F	F	F	PD	F	F	OD	F
Section 4							PD	OD	PD	OD	PD	PD	OD	OD
Section 5							OD	OD						
Section 6							OD	OD						
Sheridan:														
Plat A, yield											6.5		.5	16.2
Section 1											F		F	F
Section 2											F		PD	F
Section 3											PD		OD	F
Section 4											PD		OD	PD
Section 5											OD		OD	OD
Section 6											OD		OD	OD
Plat B, yield											5.3		0	20.5
Section 1											F		PD	F
Section 2											F		OD	F
Section 3											PD		OD	F
Section 4											OD		OD	PD
Section 5											OD		OD	PD
Section 6											OD		OD	OD
Plat C or D, yield											3.3		5.3	23.5
Section 1											F		F	F
Section 2											F		F	F
Section 3											PD		F	F
Section 4											OD		F	F
Section 5											OD		F	PW
Section 6											OD		PD	PW

TABLE 1.—*Yield of wheat on each plat and designation, etc.*—Continued.

Station, plat, and foot section of soil.	Yield per acre (bushels) and symbol showing use of water.													
	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Williston:														
Plat A, yield	.....	.....	.....	1.7	2.7	25.2	16.8	23.8	19.3	23.2	.....	.....	.....	.....
Section 1	.....	.....	.....	F	F	PW	F	F	F	PW	.....	.....	.....	.....
Section 2	.....	.....	.....	OD	PD	F	F	F	F	F	.....	.....	.....	.....
Section 3	.....	.....	.....	OD	OD	F	PD	F	PD	PD	.....	.....	.....	.....
Section 4	.....	.....	.....	OD	OD	PD	OD	OD	PD	PD	.....	.....	.....	.....
Section 5	.....	.....	.....	OD	OD	OD	OD	OD	OD	OD	.....	.....	.....	.....
Section 6	.....	.....	.....	OD	OD	OD	OD	OD	OD	OD	.....	.....	.....	.....
Plat B, yield	.....	.....	.....	1.3	2.8	23.8	11.7	22.5	14.5	24.3	.....	.....	.....	.....
Section 1	.....	.....	.....	F	F	F	PD	F	F	PW	.....	.....	.....	.....
Section 2	.....	.....	.....	PD	PD	F	PD	F	PD	F	.....	.....	.....	.....
Section 3	.....	.....	.....	OD	OD	F	PD	F	PD	PD	.....	.....	.....	.....
Section 4	.....	.....	.....	OD	OD	PD	OD	OD	OD	OD	.....	.....	.....	.....
Section 5	.....	.....	.....	OD	OD	OD	OD	OD	OD	OD	.....	.....	.....	.....
Section 6	.....	.....	.....	OD	OD	OD	OD	OD	OD	OD	.....	.....	.....	.....
Plat C or D, yield	.....	.....	30.6	4.2	7.6	39.7	16.5	19.4	27.7	28.0	.....	.....	.....	.....
Section 1	.....	.....	F	F	F	F	F	F	F	PW	.....	.....	.....	.....
Section 2	.....	.....	F	F	F	F	F	F	F	F	.....	.....	.....	.....
Section 3	.....	.....	F	F	PD	F	F	F	F	F	.....	.....	.....	.....
Section 4	.....	.....	F	F	PD	F	F	F	PW	PW	.....	.....	.....	.....
Section 5	.....	.....	PW	F	PD	PW	PW	F	PW	OW	.....	.....	.....	.....
Section 6	.....	.....	OW	PW	PD	OW	OW	PW	PW	OW	.....	.....	.....	.....
Dickinson:														
Plat A, yield	37.0	24.3	26.8	17.4	5.7	(1)	13.5	10.5	25.8	16.7	5.5	.....	0	15.6
Section 1	PW	F	F	F	F	.....	F	PD	PW	PW	F	.....	PD	PD
Section 2	PW	F	PW	F	PD	.....	F	OD	PW	PW	PD	.....	PD	PD
Section 3	PW	F	PW	PD	OD	.....	PD	OD	PW	PW	PD	.....	PD	OD
Section 4	.....	.....	PW	PD	OD	.....	PD	OD	OW	PW	PD	.....	OD	OD
Section 5	.....	.....	OW	PD	OD	.....	OD	OD	OW	PW	PD	.....	OD	OD
Section 6	.....	.....	OW	PW	OW	.....	OW	OW	OW	OW	PD	.....	OD	OD
Plat B, yield	31.6	17.7	25.2	18.2	1.4	(1)	20.5	8.9	28.7	21.0	2.7	.....	1.3	12.8
Section 1	PW	F	PW	F	F	.....	F	F	PW	PW	F	.....	PD	PD
Section 2	PW	F	PW	F	PD	.....	F	PD	PW	PW	PD	.....	PD	PD
Section 3	PW	PD	PW	PD	OD	.....	F	OD	PW	PW	PD	.....	PD	OD
Section 4	.....	.....	PW	PD	OD	.....	F	OD	OW	PW	PD	.....	OD	OD
Section 5	.....	.....	OW	OW	OW	.....	PD	OD	OW	OW	PD	.....	OD	OD
Section 6	.....	.....	OW	OW	OW	.....	PD	OD	OW	OW	PD	.....	OD	OD
Plat C or D, yield	28.3	33.8	35.7	26.8	23.3	(1)	27.0	20.1	38.7	22.8	12.3	.....	5.2	21.1
Section 1	PW	F	PW	F	F	.....	F	F	PW	PW	F	.....	PD	PD
Section 2	PW	F	PW	F	F	.....	F	PW	PW	PW	F	.....	PD	PD
Section 3	PW	F	PW	F	F	.....	F	PW	PW	PW	F	.....	PD	PD
Section 4	.....	.....	PW	F	F	.....	F	PW	PW	PW	PW	.....	PD	PD
Section 5	.....	.....	OW	PW	PW	.....	PW	PW	OW	PW	PW	.....	PD	OD
Section 6	.....	.....	OW	OW	PW	.....	PW	OW	OW	OW	PW	.....	PD	OD
Mandan (main field):														
Plat A, yield	.....	.....	.....	.....	.....	.....	.....	.....	30.5	19.2	15.3	12.7	7.5	1.5
Section 1	.....	.....	.....	.....	.....	.....	.....	.....	PW	PW	F	F	F	PD
Section 2	.....	.....	.....	.....	.....	.....	.....	.....	PW	F	PD	F	F	PD
Section 3	.....	.....	.....	.....	.....	.....	.....	.....	PW	F	PD	PD	F	OD
Section 4	.....	.....	.....	.....	.....	.....	.....	.....	OW	PW	PW	PW	PD	OD
Section 5	.....	.....	.....	.....	.....	.....	.....	.....	OW	PW	OW	PW	PD	OD
Section 6	.....	.....	.....	.....	.....	.....	.....	.....	OW	OW	OW	PW	PD	OD
Plat B, yield	.....	.....	.....	.....	.....	.....	.....	.....	32.1	18.5	14.8	15.3	5.3	1.0
Section 1	.....	.....	.....	.....	.....	.....	.....	.....	PW	PW	F	F	F	PD
Section 2	.....	.....	.....	.....	.....	.....	.....	.....	PW	F	PD	PD	F	OD
Section 3	.....	.....	.....	.....	.....	.....	.....	.....	PW	F	PD	PD	PD	OD
Section 4	.....	.....	.....	.....	.....	.....	.....	.....	PW	PW	PD	PD	PD	OD
Section 5	.....	.....	.....	.....	.....	.....	.....	.....	OW	OW	OW	OW	PD	OD
Section 6	.....	.....	.....	.....	.....	.....	.....	.....	OW	OW	OW	OW	PD	OD
Plat C or D, yield	.....	.....	.....	.....	.....	.....	.....	.....	39.3	21.8	17.2	32.0	15.7	9.5
Section 1	.....	.....	.....	.....	.....	.....	.....	.....	PW	PW	F	F	F	F
Section 2	.....	.....	.....	.....	.....	.....	.....	.....	PW	F	F	F	F	F
Section 3	.....	.....	.....	.....	.....	.....	.....	.....	PW	F	F	F	F	F
Section 4	.....	.....	.....	.....	.....	.....	.....	.....	PW	PW	PW	F	F	F
Section 5	.....	.....	.....	.....	.....	.....	.....	.....	PW	PW	PW	OW	OW	PW
Section 6	.....	.....	.....	.....	.....	.....	.....	.....	OW	PW	OW	OW	OW	PW
Edgeley:														
Plat A, yield	4.1	13.3	28.3	4.0	.7	35.0	16.3	11.3	34.8	[2] 5.5	8.3	.....	.5	8.8
Section 1	F	F	F	F	F	PW	F	F	PW	PW	F	.....	F	F
Section 2	PD	F	F	PD	F	PW	PW	PW	PW	PW	F	.....	F	PW
Plat B, yield	7.0	15.3	23.3	5.2	.5	27.0	12.1	9.2	26.2	[2] 3.8	7.5	.....	1.8	9.2
Section 1	F	F	F	F	F	PW	F	F	PW	PW	F	.....	F	F
Section 2	PD	F	F	F	F	PW	PW	PW	PW	PW	PW	.....	F	PW
Plat C or D, yield	9.9	16.0	27.0	5.7	.7	30.3	16.8	13.0	40.3	[2] 6.8	4.5	.....	.3	3.8
Section 1	F	F	F	F	F	PW	F	F	F	PW	F	.....	F	F
Section 2	F	F	F	F	F	PW	PW	PW	PW	PW	F	.....	F	PW

[1] Damaged by hail.
[3] Yield on all plats at Edgeley reduced by rust in 1916.

TABLE 1.—*Yield of wheat on each plat and designation, etc.*—Continued.

Station, plat, and foot section of soil.	Yield per acre (bushels) and symbol showing use of water.													
	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Belle Fourche:														
Plat A, yield	.....	.....	23.8	0	.....	0	6.2	4.0	56.5	10.6	4.4	8.5	.....	29.2
Section 1	.....	.....	F	F	.....	F	F	F	F	F	F	F	.....	F
Section 2	.....	.....	F	PD	.....	PD	PD	OD	F	F	F	PD	.....	F
Section 3	.....	.....	F	OD	.....	OD	OD	OD	OD	OD	PD	OD	.....	F
Plat B, yield	.....	.....	23.3	0	.....	0	7.9	4.8	57.7	10.8	2.8	9.8	0	28.7
Section 1	.....	.....	F	F	.....	F	F	F	F	F	F	F	PD	F
Section 2	.....	.....	F	PD	.....	PD	PD	PD	F	PD	PD	PD	OD	F
Section 3	.....	.....	F	OD	.....	OD	OD	OD	OD	OD	OD	OD	OD	F
Plat C or D, yield	.....	.....	32.2	5.0	0	0	16.8	15.8	57.2	18.7	11.1	35.0	6.2	29.2
Section 1	.....	.....	F	F	PD	F	F	F	F	F	F	F	F	F
Section 2	.....	.....	F	F	PD	PD	F	F	F	F	F	F	F	F
Section 3	.....	.....	F	F	OW	OD	F	F	OD	F	F	F	F	F
Ardmore:														
Plat A, yield	.....	.....	.....	.....	.....	3.3	8.8	.....	49.2	18.0	7.5	27.7	3.3	23.8
Section 1	.....	.....	.....	.....	.....	F	PD	.....	PW	F	F	F	F	F
Section 2	.....	.....	.....	.....	.....	PD	PD	.....	PW	F	F	PW	PD	F
Section 3	.....	.....	.....	.....	.....	OD	OD	.....	PW	F	F	PW	PD	F
Section 4	.....	.....	.....	.....	.....	.....	.....	.....	OW	PD	PD	PW	PD	PW
Section 5	.....	.....	.....	.....	.....	.....	.....	.....	.....	OD	.....	.....	.....	.....
Section 6	.....	.....	.....	.....	.....	.....	.....	.....	.....	OD	.....	.....	.....	.....
Plat B, yield	.....	.....	.....	.....	.....	3.2	7.3	.....	49.5	17.5	5.5	24.2	3.0	20.0
Section 1	.....	.....	.....	.....	.....	F	PD	.....	PW	F	F	F	F	F
Section 2	.....	.....	.....	.....	.....	PD	OD	.....	PW	F	F	PW	PD	F
Section 3	.....	.....	.....	.....	.....	OD	OD	.....	PW	F	PD	PW	PD	F
Section 4	.....	.....	.....	.....	.....	.....	.....	.....	OW	F	PD	PW	PD	PW
Section 5	.....	.....	.....	.....	.....	.....	.....	.....	.....	PW	.....	.....	.....	.....
Section 6	.....	.....	.....	.....	.....	.....	.....	.....	.....	PW	.....	.....	.....	.....
Plat C or D, yield	.....	.....	.....	.....	.....	6.5	3.4	.....	45.0	15.8	8.7	37.0	10.3	23.7
Section 1	.....	.....	.....	.....	.....	F	F	.....	PW	F	F	F	F	F
Section 2	.....	.....	.....	.....	.....	F	F	.....	PW	F	F	F	F	F
Section 3	.....	.....	.....	.....	.....	F	F	.....	PW	F	F	PW	F	F
Section 4	.....	.....	.....	.....	.....	PD	PD	.....	OW	PD	PW	PW	PW	F
Section 5	.....	.....	.....	.....	.....	.....	.....	.....	.....	PW	.....	.....	.....	.....
Section 6	.....	.....	.....	.....	.....	.....	.....	.....	.....	PW	.....	.....	.....	.....
Archer:														
Plat A, yield	.....	.....	.....	.....	.....	.....	10.3	6.8	26.8	2.3	15.6	.....	3.5	.....
Section 1	.....	.....	.....	.....	.....	.....	F	F	F	PD	F	.....	F	.....
Section 2	.....	.....	.....	.....	.....	.....	PD	F	F	PD	F	.....	F	.....
Section 3	.....	.....	.....	.....	.....	.....	OD	OD	F	PD	F	.....	PD	.....
Section 4	.....	.....	.....	.....	.....	.....	OD	OD	PD	OD	PD	.....	OD	.....
Plat B, yield	.....	.....	.....	.....	.....	.....	.....	7.5	23.7	2.4	13.6	.....	2.5	.....
Section 1	.....	.....	.....	.....	.....	.....	.....	F	F	PD	F	.....	F	.....
Section 2	.....	.....	.....	.....	.....	.....	.....	F	F	PD	F	.....	F	.....
Section 3	.....	.....	.....	.....	.....	.....	.....	PD	PD	PD	F	.....	OD	.....
Section 4	.....	.....	.....	.....	.....	.....	.....	OD	PD	OD	PD	.....	OD	.....
Plat C or D, yield	.....	.....	.....	.....	.....	.....	.....	10.1	25.7	2.8	14.9	.....	7.1	.....
Section 1	.....	.....	.....	.....	.....	.....	.....	F	F	F	F	.....	F	.....
Section 2	.....	.....	.....	.....	.....	.....	.....	F	F	F	F	.....	F	.....
Section 3	.....	.....	.....	.....	.....	.....	.....	PD	F	F	F	.....	F	.....
Section 4	.....	.....	.....	.....	.....	.....	.....	OD	PD	OD	F	.....	PD	.....
Scottsbluff:														
Plat A, yield	.....	.....	.....	.....	.5	8.7	12.0	5.7	[1]5.0	5.5	9.2	3.7	.....	12.3
Section 1	.....	.....	.....	.....	F	F	F	F	F	PD	F	F	.....	F
Section 2	.....	.....	.....	.....	PD	PD	PD	PD	F	PD	F	PD	.....	F
Section 3	.....	.....	.....	.....	PD	PD	PD	PD	F	PD	F	PD	.....	F
Section 4	.....	.....	.....	.....	OD	OD	PD	OD	PD	PD	F	OD	.....	F
Section 5	.....	.....	.....	.....	OD	OD	OD	OD	OD	OD	PD	.....	.....	PD
Section 6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	OD	.....	.....	.....
Plat B, yield	.....	.....	.....	.....	.5	6.3	7.8	6.7	16.2	5.7	7.0	6.7	.....	14 0
Section 1	.....	.....	.....	.....	F	F	F	F	F	PD	F	PD	.....	F
Section 2	.....	.....	.....	.....	PD	PD	PD	F	F	PD	F	PD	.....	F
Section 3	.....	.....	.....	.....	PD	PD	F	F	F	PD	F	PD	.....	F
Section 4	.....	.....	.....	.....	OD	OD	OD	OD	PD	PD	F	OD	.....	F
Section 5	.....	.....	.....	.....	OD	OD	OD	OD	OD	OD	OD	.....	.....	OD
Plat C or D, yield	.....	.....	.....	.....	.....	22.5	17.3	11.7	[1]12.5	11.2	18.7	21.3	.....	19.3
Section 1	.....	.....	.....	.....	.....	F	F	F	F	PD	F	F	.....	F
Section 2	.....	.....	.....	.....	.....	F	F	F	F	F	F	F	.....	F
Section 3	.....	.....	.....	.....	.....	F	F	F	F	F	F	F	.....	F
Section 4	.....	.....	.....	.....	.....	PD	F	F	F	F	F	F	.....	F
Section 5	.....	.....	.....	.....	.....	OD	PD	OD	PD	PD	PD	.....	.....	F
Section 6	.....	.....	.....	.....	.....	.....	PD	OD	OD	OD	OD	.....	.....	.....

[1] Damaged by hail.

TABLE 1.—*Yield of wheat on each plat and designation, etc.*—Continued.

Station, plat, and foot section of soil.	Yield per acre (bushels) and symbol showing use of water.													
	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
North Platte:														
Plat A, yield	24.5	22.7	23.0	6.8	0	12.8	2.0	6.0	22.7	17.2	4.2	.....	15.5	16.5
Section 1	F	F	F	F	F	F	F	F	OW	PD	F	.....	F	F
Section 2	F	PD	F	PD	PD	F	PD	PD	OW	PD	PD	.....	F	F
Section 3	F	PD	F	PD	OD	F	OD	OD	PW	PD	PD	.....	PD	F
Section 4	.....	OD	PD	PD	OD	PD	OD	OD	PW	PD	PD	.....	PD	F
Section 5	.....	OW	PD	PD	OD	PD	OD	OD	PW	PD	PD	.....	OD	PD
Section 6	.....	OW	OW	PD	OD	OD	OD	OD	PW	PW	PD	.....	OD	OW
Plat B, yield	26.0	27.3	15.3	6.7	0	11.2	1.8	5.2	22.8	17.5	5.2	.....	13.0	18.8
Section 1	F	F	F	F	F	F	F	F	OW	PD	F	.....	F	F
Section 2	F	F	F	PD	PD	F	PD	F	PW	PD	PD	.....	PD	F
Section 3	F	PD	PD	PD	OD	F	OD	OD	PW	PD	PD	.....	PD	F
Section 4	.....	OD	OD	PD	OD	PD	OD	OD	PW	PD	OD	.....	OD	F
Section 5	.....	OW	OW	OW	OW	PD	OD	OD	PW	PD	OD	.....	OD	F
Section 6	.....	OW	OW	OW	OW	PD	OD	OD	OW	OW	OW	.....	OW	F
Plat C or D, yield	31.8	40.5	18.0	18.3	0	10.5	10.0	15.2	27.8	19.7	18.7	.....	16.7	21.2
Section 1	F	F	F	F	F	F	F	F	OW	F	F	.....	PW	F
Section 2	F	F	F	F	PD	F	PD	F	PW	F	F	.....	PW	F
Section 3	F	F	F	F	PD	F	PD	PD	PW	F	F	.....	F	F
Section 4	.....	F	F	F	OW	F	PD	PD	PW	F	F	.....	F	F
Section 5	.....	PW	PW	F	OW	F	OW	OD	PW	PW	PW	.....	PW	F
Section 6	.....	PW	PW	PW	OW	F	OW	OD	PW	PW	PW	.....	PW	PW
Akron:														
Plat A, yield	.....	17.3	14.3	11.3	2.9	21.3	4.8	22.2	26.3	9.3	.....	.....	.....	.....
Section 1	.....	F	PW	F	PD	PW	F	F	PW	F	.....	.....	.....	.....
Section 2	.....	F	F	PD	OD	F	PD	F	F	F	.....	.....	.....	.....
Section 3	.....	F	PD	PD	OD	F	OD	PD	F	PD	.....	.....	.....	.....
Section 4	.....	.....	OD	OD	OD	F	OD	OD	PW	PD	.....	.....	.....	.....
Section 5	.....	.....	OD	OD	OD	PD	OD	OD	PW	OW	.....	.....	.....	.....
Section 6	.....	.....	OD	OD	OD	OD	OD	OD	OW	OW	.....	.....	.....	.....
Plat B, yield	.....	14.0	10.3	6.2	4.1	20.7	.8	12.2	25.8	3.8	.....	.....	.....	.....
Section 1	.....	F	PW	F	PD	F	PD	F	PW	PD	.....	.....	.....	.....
Section 2	.....	F	F	PD	F	F	OD	F	F	OD	.....	.....	.....	.....
Section 3	.....	F	PD	PD	F	PD	OD	PD	PD	OD	.....	.....	.....	.....
Section 4	.....	.....	OD	OD	OD	OD	OD	OD	OD	OD	.....	.....	.....	.....
Section 5	.....	.....	OD	OD	OD	OD	OD	OD	OD	OD	.....	.....	.....	.....
Section 6	.....	.....	OD	OD	OD	OD	OD	OD	OD	OD	.....	.....	.....	.....
Plat C or D, yield	.....	.....	18.5	8.5	4.7	16.0	5.7	14.2	33.8	12.3	.....	.....	.....	.....
Section 1	.....	.....	PW	F	PD	F	F	F	PW	PD	.....	.....	.....	.....
Section 2	.....	.....	F	F	F	F	F	F	F	F	.....	.....	.....	.....
Section 3	.....	.....	F	F	F	PD	F	F	F	F	.....	.....	.....	.....
Section 4	.....	.....	F	PW	PD	OD	PD	OD	F	PD	.....	.....	.....	.....
Section 5	.....	.....	OW	PW	PD	OD	PD	OD	PW	PW	.....	.....	.....	.....
Section 6	.....	.....	OW	PD	PD	OD	OD	OD	OW	OW	.....	.....	.....	.....
Garden City:														
Plat A, yield	.....	.....	2.1	2.5	0	3.5	[1]	1.5	17.5	0	0	.....	0	0
Section 1	.....	.....	F	F	PD	F	.....	F	F	F	F	.....	F	F
Section 2	.....	.....	PD	F	PD	F	.....	F	F	PD	PD	.....	F	PD
Section 3	.....	.....	OD	PD	PD	PD	.....	PD	PD	OD	OD	.....	F	OD
Section 4	.....	.....	OD	OD	OD	OD	.....	OD	.....	.....	.....	.....	PD	OD
Section 5	.....	.....	OD	OD	OD	OD	.....	OD	.....	.....	.....	.....	OD	OD
Section 6	.....	.....	OD	OD	OD	OD	.....	OD	.....	.....	.....	.....	OD	OD
Plat B, yield	.....	.....	3.2	5.2	0	6.3	[1]	4.3	12.6	0	0	.....	0	0
Section 1	.....	.....	F	F	PD	F	.....	F	F	F	F	.....	F	F
Section 2	.....	.....	PD	F	PD	F	.....	F	F	F	PD	.....	F	F
Section 3	.....	.....	OD	PD	PD	OD	.....	PD	PD	OD	OD	.....	F	PD
Section 4	.....	.....	OD	PD	OD	OD	.....	PD	.....	.....	.....	.....	F	PD
Section 5	.....	.....	OD	OD	OD	OD	.....	OD	.....	.....	.....	.....	OD	OD
Section 6	.....	.....	OD	OD	OD	OD	.....	OD	.....	.....	.....	.....	OD	OD
Plat C or D, yield	.....	.....	6.7	7.7	0	9.3	[1]	5.3	21.6	5.0	0	.....	1.1	7.0
Section 1	.....	.....	F	F	PD	F	.....	F	F	F	F	.....	F	F
Section 2	.....	.....	F	F	F	F	.....	F	F	F	F	.....	F	PW
Section 3	.....	.....	PD	F	F	F	.....	F	F	F	F	.....	F	PW
Section 4	.....	.....	PD	F	PD	PD	.....	PD	F	F	F	.....	F	PW
Section 5	.....	.....	OD	PD	PD	OD	.....	PD	F	PD	PD	.....	OD	PW
Section 6	.....	.....	OD	OD	OD	OD	.....	OD	PD	OD	PD	.....	OD	PW

[1] Damaged by hail.

TABLE 1.—*Yield of wheat on each plat and designation, etc.*—Continued.

Station, plat, and foot section of soil.	Yield per acre (bushels) and symbol showing use of water.													
	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Dalhart:														
Plat A, yield	...	(1)	0	(1)	0	(1)	0	7.8	...	(1)	0	...	...	...
Section 1	...	...	PD	...	PD	...	PD	F	...	...	F	...	...	...
Section 2	...	...	OD	...	PD	...	OD	F	...	...	PD	...	...	...
Section 3	...	...	OD	...	OD	...	OD	F	...	...	OD	...	...	...
Section 4	...	...	OD	...	OD	...	OD	PD	...	...	OD	...	...	...
Section 5	...	...	OD	...	OD	...	OD	PD	...	...	OD	...	...	...
Section 6	...	...	OD	...	OD	...	OD	OD	...	...	OD	...	...	...
Plat B, yield	...	(1)	4.0	(1)	0	(1)	0	9.0	...	(1)	0	...	...	...
Section 1	...	...	PD	...	PD	...	PD	F	...	...	F	...	...	...
Section 2	...	...	PD	...	PD	...	PD	F	...	...	PD	...	...	...
Section 3	...	...	PD	...	OD	...	OD	F	...	...	OD	...	...	...
Section 4	...	...	PD	...	OD	...	OD	F	...	...	OD	...	...	...
Section 5	...	...	OD	...	OD	...	OD	PD	...	...	OD	...	...	...
Section 6	...	...	OD	...	OD	...	OD	OD	...	...	OD	...	...	...
Plat C or D, yield	...	(1)	10.5	(1)	0	(1)	1.3	12.4	...	(1)	...	...	...	...
Section 1	...	...	F	...	F	...	F	F	...	...	...	...	...	...
Section 2	...	...	PW	...	F	...	F	F	...	...	...	...	...	...
Section 3	...	...	F	...	F	...	F	F	...	...	...	...	...	...
Section 4	...	...	F	...	F	...	F	F	...	...	...	...	...	...
Section 5	...	...	F	...	OW	...	PW	F	...	...	...	...	...	...
Section 6	...	...	PW	...	OW	...	OW	OW	...	...	...	...	...	...
Amarillo:														
Plat A, yield	...	...	...	...	7.3	6.3	0	11.0	12.4	3.5	1.7	0	...	...
Section 1	...	...	...	...	F	F	PD	F	F	PD	F	PD	...	...
Section 2	...	...	...	...	PD	F	OD	F	F	PD	PD	PD	...	...
Section 3	...	...	...	...	OD	F	OD	PD	F	OD	OD	OD	...	...
Section 4	...	...	...	...	OD	PD	OD	OD	F	OD	OD	OD	...	...
Section 5	...	...	...	...	OD	OD	OD	OD	OD	OD	OD	OD	...	...
Section 6	...	...	...	...	OD	OD	OD	OD	OD	OD	OD	...	...	...
Plat B, yield	...	...	...	...	10.0	8.5	0	12.8	11.0	7.0	3.8	3.2	...	...
Section 1	...	...	...	...	F	F	PD	F	F	PD	F	F	...	...
Section 2	...	...	...	...	PW	F	OD	F	F	PD	F	F	...	...
Section 3	...	...	...	...	PD	F	OD	PD	F	PD	PD	PD	...	...
Section 4	...	...	...	...	OD	PD	OD	PD	F	PD	OD	OD	...	...
Section 5	...	...	...	...	OD	OD	OD	OD	PD	OD	OD	OD	...	...
Section 6	...	...	...	...	OD	OD	OD	OD	OD	OD	OD	...	...	...
Plat C or D, yield	...	...	...	...	19.0	9.5	9.3	13.8	11.6	4.7	3.5	2.8	...	...
Section 1	...	...	...	...	F	F	PD	F	F	PW	F	F	...	...
Section 2	...	...	...	...	F	F	F	F	F	F	F	F	...	...
Section 3	...	...	...	...	F	F	PD	F	F	F	F	F	...	...
Section 4	...	...	...	...	F	PD	PD	PD	F	F	PD	PD	...	...
Section 5	...	...	...	...	PD	PD	OD	OD	F	PW	OW	OW	...	...
Section 6	...	...	...	...	OD	OD	OD	OD	OW	PW	OW	...	...	...
Tucumcari:														
Plat A, yield	...	...	...	...	...	...	...	13.5	5.6	0	0	...	...	...
Section 1	...	...	...	...	...	...	...	F	F	F	F	...	...	...
Section 2	...	...	...	...	...	...	...	PW	F	PD	PD	...	...	...
Section 3	...	...	...	...	...	...	...	PD	F	OD	OD	...	...	...
Section 4	...	...	...	...	...	...	...	PD	F	OD	OD	...	...	...
Section 5	...	...	...	...	...	...	...	OD	PD	OD	OD	...	...	...
Section 6	...	...	...	...	...	...	...	...	PD	OD	OD	...	...	...
Plat B, yield	...	...	...	...	...	...	...	14.4	5.2	.9	0	...	...	...
Section 1	...	...	...	...	...	...	...	PW	F	F	F	...	...	...
Section 2	...	...	...	...	...	...	...	PW	F	F	PD	...	...	...
Section 3	...	...	...	...	...	...	...	F	F	PD	OD	...	...	...
Section 4	...	...	...	...	...	...	...	PD	F	OD	OD	...	...	...
Section 5	...	...	...	...	...	...	...	OD	PD	OD	OD	...	...	...
Section 6	...	...	...	...	...	...	...	...	PD	OD	OD	...	...	...
Plat C or D, yield	...	...	...	...	...	...	...	14.7	6.2	1.3	0	...	...	...
Section 1	...	...	...	...	...	...	...	PW	F	F	F	...	...	...
Section 2	...	...	...	...	...	...	...	PW	F	F	F	...	...	...
Section 3	...	...	...	...	...	...	...	PW	F	F	PD	...	...	...
Section 4	...	...	...	...	...	...	...	PW	F	PD	OD	...	...	...
Section 5	...	...	...	...	...	...	...	OW	PD	PD	OD	...	...	...
Section 6	...	...	...	...	...	...	...	...	PD	PW	OD	...	...	...

[1] Damaged by hail.

CONDITIONS AT INDIVIDUAL STATIONS.

The soil at Assinniboine is glacial till and offers no serious physical difficulty to the penetration of moisture or plant roots. All the years for which moisture determinations are given were years of low precipitation, and in these years even in the fallow plats available moisture has never been present in the sixth foot. Neither plat A nor B has had the third foot filled with moisture. It will be noted that in two years out of three plat A has been moist to a greater depth than plat B. All of the available moisture has been removed from the soil on all plats all years except from plat C or D in 1917. In that year the crop, in spite of its need for water, was not able to use all the water from the fourth foot and was unable to remove any moisture from the fifth foot. This year represents a case where the demands of the crop for water were so heavy that the crop roots were unable to extend themselves and take up moisture rapidly enough to maintain life in the crop. The wheat suffered a forced ripening even while available water was present at a depth that could have been reached by the wheat roots under conditions less adverse.

At Huntley the full storage capacity of the soil has never been utilized. This has been due in a large measure to the high water-holding capacity of the soil, which has prevented the limited rainfall at this station from penetrating to any great depth. In addition, there seems to be an increased difficulty of water penetration in the lower depths. That there is no impervious layer of soil that prohibits moisture movement has been shown on other plats which have become wet to a depth of at least 6 feet. All of the available moisture has been removed each year from all plats. Plats A and B have shown very little difference in water storage. Plat C or D has stored the most moisture, but has never stored moisture to a depth where it could not be utilized.

The soil at Sheridan has been easily penetrated by moisture and by roots. Little difference is shown between plats A and B in water storage, and neither of these plats has been wet deep enough to utilize fully the moisture-storage capacity of the soil. Plat C or D has carried available moisture in all 6 feet in two of three years. In 1919 the wheat crop removed all available water from all foot sections of this plat, but the yield was seriously reduced by drought injury. In 1920, when the crop was not seriously injured by drought, it used but did not exhaust the water content of the fifth and sixth foot sections.

At Williston the A and B plats have never had available moisture present below the fourth foot. That this has been due to lack of precipitation rather than to difficulty of soil penetration is indicated by the fact that plat C or D has each year had available water present in all 6 feet of soil. The moisture in plats A and B has always been exhausted by harvest in all depths below the first foot. In a few cases there has been enough rain before harvest to raise the content above the minimum point at that time, though all available moisture had been exhausted earlier in the season. There is little difference between plats A and B in the quantity of water stored, but the difference seems to favor plat A. Plat C or D has each year had available moisture in all foot sections. The extent to which the moisture has been utilized varies to some extent in different years. In the four years of heaviest production the soil-moisture content of the fifth foot section was not reduced to the minimum point. In the two years of low production all of the available moisture was removed from the fifth foot and use was made of the water in the sixth foot. In 1911 the sixth foot of soil was dry at harvest. The indications are that the soil at lower depths is most completely utilized when the crop suffers for moisture.

At Dickinson there has been a great opportunity to study moisture penetration and depth of feeding of crops. The soil at the station is open and water penetrates freely, and the precipitation in some years has been so high that under all the methods of cultivation the soil has been wet to a depth of at least 6 feet. At this station neither plat A nor B has shown to advantage over the other in respect to moisture stored in the soil. These two plats furnish a striking illustration of the fact that roots will not penetrate a dry soil, even though there may be available water below. In 1919 plat A used all of the available moisture in the first 5 feet of soil but not in the sixth foot. In the same year plat B exhausted the available moisture in the first 4 feet, but did not secure that from the fifth and sixth foot sections. The moisture present in the soil in the spring of 1911 and that added by precipitation during the growing season moistened the soil to a depth of less than 2 feet. In spite of severe drought injury no moisture was used below that depth. The dry layer in the third and fourth foot sections prevented the roots from extending to moisture in the fifth and sixth foot sections. The crops of both plats were destroyed by hail in 1912, but the soil did not become wet that year to a depth greater than the fourth foot. In 1913, both plats stored moisture to a depth of 4 feet. This was enough to wet all of the dry layer in plat B, but the fifth foot in plat A still remained dry, as it was left by the crop in 1910. The roots of the wheat crop on plat B in 1913 were able to draw upon the available water in the fifth and sixth foot sections, but in plat A the roots were not able to reach the available water in the sixth foot on account of the dry layer in the fifth foot. The soil in plat C or D shows a deeper storage of moisture in dry years than in plat A or B. In all years except 1920 the plat has held available water in each foot of soil at all depths. In the two years of heaviest production no water was used from below the fourth foot, although there was water present in the fifth and sixth foot sections.

The soil at Mandan is easily penetrated by moisture. In 1915, it was wet in all plats to a depth of more than 6 feet. The moisture in the fifth and sixth foot sections of plats A and B was not all removed until the very dry summer of 1919, in spite of the fact that the wheat growing on these plats had suffered from drought injury in the three years preceding. The water of the first 4 feet is utilized freely, but evidently the stress of a long-continued demand for water is precedent to its complete utilization at lower depths.

Edgeley is a striking example of a shallow soil. At this station the soil is a heavy clay that changes into undecomposed shale at a depth of about 2 feet. Even in the second foot pieces of undecomposed shale distributed through the soil are frequent enough to reduce seriously the quantity of available moisture that can be held. The depth of penetration of plant roots seems to be limited to 2 feet. The quantity of rain between harvest and seeding has been large enough to wet thoroughly all the soil on all plats practically every year. This limitation of storage capacity has had the effect of eliminating differences between different cultivation methods in the quantity of moisture conserved. Edgeley is the only station included with such a limited water-storage capacity that it has been practically all utilized each year by all methods of cultivation.

The soil at Belle Fourche is a heavy clay which changes to open partially decomposed shale in the fourth foot. In this soil there is no layer that prohibits moisture penetration, but the soil at the depth of about 2 feet is compact and swells so much when wet that water movement through it is very slow.[6]

Penetration by roots is likewise difficult, and even when available moisture has been present in the lower depths the feeding depth of the wheat crop has been limited to a little less than 3 feet. Evidently the roots penetrate into the third foot only as necessity requires, and they have not been able to reach a depth greater than 3 feet before death or the ripening of the crop occurs. For practical purposes there is no need of considering the soil below the third foot. In spite of the limited water-storage capacity of the soil, there have been only two years when plats A and B have been filled to capacity. There has been practically no difference between the two plats in this respect. Plat C or D has been wet to capacity in all but two years. Belle Fourche represents a station where the demands of the crop for water have been so heavy that the soil moisture has been exhausted in all plats each year at harvest. The only exception is plat C or D in 1911. In that year climatic conditions were so adverse that the crop on the other plats did not germinate and on this plat suffered from drought and heat almost from the time it came up. It made such a limited growth that the roots were not able to extend to a depth of more than 2 feet.

The soil at Ardmore is a heavy clay that changes into fine sand in the fifth and sixth foot sections. The moisture results show that changes in the water content occur below a depth of 4 feet, but the difficulty in sampling the fifth and sixth foot sections has been so great that sampling has been limited to 4 feet in all but one year. As far as the first 4 feet of soil is concerned, there has been practically no difference in the moisture status of plats A and B. The extent to which plat C or D is superior to plats A and B in moisture stored can not be determined, as changes in moisture content evidently have occurred below the fourth foot. The quantity of water used from below the fourth foot, however, can not be large, as plat C or D is little superior to the other plats in point of yield.

Archer represents a station with a soil depth of approximately 4 feet. Below the fourth foot is a bed of gravel that prohibits sampling to a greater depth. It is doubtful whether moisture has penetrated deeper than 4 feet on plats A and B, and in only one year is it probable that water was stored at a depth lower than 4 feet on plat C or D. Plats A and B have approached each other very closely in water stored, utilization of water, and yield. Plat C or D has been little superior to plats A and B in storing moisture. This is re-

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[6] Mathews, O. R. Water penetration in the gumbo soils of the Belle Fourche Reclamation Project. U. S. Dept. Agr. Bul. 447, 12 pp., 4 fig. 1916.

flected in the yield. All available water has been removed from all foot sections of soil in all years under study.

The soil at Scottsbluff is sandy in character. It is easily penetrated by water in the upper depths, but evidently becomes increasingly difficult of penetration in the lower depths. Plat B has never had available water present below a depth of 4 feet, and plat A only once. The maximum depth of penetration of plat C or D has been 6 feet, and this depth has been reached but once. On this soil all available water has been removed from all plats each year. Plats A and B have exhibited only minor differences in the extent to which they have utilized the storage capacity of the soil. Plat C or D has been superior to the others in water stored and in yield. The soil is evidently porous enough to allow root development sufficient to remove all moisture penetrating into it under ordinary conditions.

The soil at North Platte is probably the most uniform of any at these stations on the Plains. It is open and porous and offers a maximum opportunity for penetration of water and roots. The precipitation at this station has been high enough at different times to wet the soil thoroughly to a depth greater than 6 feet. Determinations of soil moisture to a depth of 15 feet have been made at this station, but spring wheat has shown no evidence of feeding to a depth greater than 6 feet. The station record comprises about an equal number of good and poor years. The fact that roots will not penetrate a dry layer of soil to obtain water in moist lower depths is illustrated by plat A in 1908 and by plat B in 1908, 1909, 1911, 1917, and 1919. These two plats exhibit some differences in their moisture relations in individual years, but on an average they show about the same water storage and water utilization. Plat C or D has stored much more moisture than plats A and B. In all years except 1914 it has carried available moisture to a depth of 6 feet, and there is evidence that on several occasions water has penetrated beyond the sixth foot. This water has been lost to the wheat crop, as the roots of wheat do not penetrate the seventh foot section, even in this favorable soil. The season of 1915 at North Platte was one of the wettest on record at any station. All three of the plats contained as much moisture in the first foot at harvest as they had at any time during the growing season, and all foot sections of soil on all plats had available water at harvest. The use of water in the fifth and sixth foot sections of soil has been usual on plat C or D, but only on one occasion has all of the available water been used from these units. Plat C or D in 1911 shows the result of severe climatic conditions in limiting the depth of feeding. In that year the weather was so hot and dry and the demands of the crop for moisture so excessive that the crop died before it was able to extend its roots to the available water in the fourth, fifth, and sixth foot sections.

Under natural conditions and under some conditions of cultivation there is considerable run-off from the soil at Akron. After water penetrates the surface the character of the soil does not definitely limit further penetration or development of the roots. Plat A has shown on an average a deeper water penetration than plat B. In

1911 plat B was moist to a greater depth than plat A, but in all other years when a difference has existed it has favored plat A. The margin of difference was greatest in 1912, 1915, and 1916. Plat C or D generally, but not always, has been moist to a greater depth than the continuously cropped plats. On all the plats the depth of feeding has generally been limited by the depth to which moisture has been present. However, even when moisture has been present in the fifth and sixth feet it has not been entirely used up except in extremely dry years.

At Garden City the character, distribution, and quantity of precipitation have had the effect of limiting the penetration of moisture. Even the fallow plat has rarely been moist to a depth of 6 feet. In plats A and B no available water has been present below the fourth foot. The difference between plats A and B in moisture stored distinctly favors plat B. The storage of moisture in plat C or D has been consistently greater than in plats A and B. All the available moisture was removed from all plats except plat C or D in 1920. The greater storage of water on plat C or D is reflected in a consistently higher yield.

At Dalhart there has been a slight difference between plats A and B, favoring plat B both in water storage and in yield. Neither plat has fully utilized the storage capacity of the soil at any time, and on both plats all of the available moisture in the soil has been removed each year by harvest time. Plat C or D has been filled with available moisture to a depth of 6 feet each year. Crop requirements for water have been so heavy that each year the wheat has suffered for water before harvest. In spite of this all the available moisture in the fifth foot section has been removed only twice in four years, while the moisture present in the sixth foot has never been entirely removed. In three of the four years presented no water was removed from the sixth foot by the crop.

The soil at Amarillo is not easily penetrated by water. In spite of the high precipitation at this station, water has never reached a depth greater than 4 feet in plat A or 5 feet in plat B. At this station there has frequently been a difference between the two in water storage, and in every case where a difference has existed it has been in favor of plat B. The soil in plat C or D did not become wet to a depth of 6 feet until 1915. The crop has never been able to remove all of the water added to the sixth foot of soil that year. In nearly every year plat C or D has stored water to a depth greater than plats A and B, but the difference in most cases has not been large. The soil at Amarillo is an example of one that holds very little available moisture in the lower depths. It is in many cases very difficult to tell whether or not available moisture is present.

The soil at Tucumcari is sandy in the upper foot sections, and moisture is readily taken into it. In the lower depths the soil is of a clay texture, and water penetrates it with difficulty. When wet it holds only a small quantity of available moisture. The wheat crop was able to use all the water to a depth of 6 feet in one year (1915). In the year 1914 the highest yields recorded at this station were obtained on all three plats. In that year no water was used from below the fourth foot on any plat, though available water was present in the fifth foot of plat C or D. There has been very little difference between plats A and B in water stored. Plat C or D has always stored considerably more water than the other two plats.

AVERAGE OF RESULTS FOR ALL STATIONS.

The data from the individual stations demonstrate that the storage and use of water by the wheat crop are somewhat different at the individual stations. There are, however, enough points in common between the different stations to permit general deductions to be made from the data as a whole.

For this purpose the water content and use at all stations, as indicated by the symbols, are brought together in a composite table. It must be recognized that this composite table shows a greater percentage of water use in the lower depths than actually exists. The data on the fifth and sixth foot sections of soil are largely from stations where water has been used to that depth. The inclusion of the lower depths at stations like Edgeley, Belle Fourche, Huntley, and Scottsbluff would greatly increase the number of cases where no water was used in these foot sections, the soil being either wet or dry.

The data from the individual foot sections of soil at the different stations are grouped together in Table 2. In the upper part of the table the data are presented by cases, the figures under each symbol indicating the number of times that symbol was used in Table 1 for the purpose of indicating the water relations of that plat at the depth indicated. In the lower part of the table these figures are reduced to percentages in order to make the different foot sections of soil more directly comparable. For example, plat A has 135 determinations of the first foot and only 72 of the sixth foot. A comparison of the two sections in regard to the proportion of the time a particular symbol has been used is more readily made when they are expressed as percentages.

TABLE 2.—*Recapitulation of Table 1, showing the number of times each symbol was used in describing the use of water in each foot section of each plat.*

[The first part of the table records the number of cases studied; in the second part these are expressed as percentages of the totals.]

Symbol use at depth indicated (foot sections of soil).	Instances of the use of each symbol as indicating the water relations on plats A, B, and C or D.																	
	F.			PW.			PD.			OW.			OD.			Total.		
	A.	B.	C or D.	A.	B.	C or D.	A.	B.	C or D.	A.	B.	C or D.	A.	B.	C or D.	A.	B.	C or D.
Times used:																		
Section 1..	101	98	107	14	14	15	19	22	10	1	1	1	0	0	0	135	135	133
Section 2..	58	57	107	14	17	18	52	47	8	1	0	0	10	14	0	135	135	133
Section 3..	30	27	90	8	8	11	39	45	14	0	0	1	45	42	3	122	122	120
Section 4..	5	9	45	11	7	18	28	26	29	3	3	2	56	57	11	103	102	105
Section 5..	0	3	11	5	3	28	14	11	18	6	13	13	56	52	16	81	82	86
Section 6..	0	1	1	4	1	21	5	5	10	14	17	23	49	48	27	72	72	82
Relation to total, per cent:																		
Section 1..	75	73	80	10	10	11	14	16	8	1	1	1	0	0	0	.....	.....	....
Section 2..	43	42	80	10	13	14	39	35	6	1	0	0	7	10	0	.....	.....	....
Section 3..	24	22	75	7	7	9	32	37	13	0	0	1	37	34	3	.....	.....	....
Section 4..	5	9	43	11	7	17	27	25	28	3	3	2	54	56	10	.....	.....	....
Section 5..	0	4	13	6	4	32	17	13	21	7	16	15	69	63	19	.....	.....	....
Section 6..	0	1	1	6	1	26	7	7	12	19	24	28	68	67	33	.....	.....	....

The differences in the number of cases in the different foot sections are in a large measure the result of the limitation of sampling due to the limitation of depth of feeding in certain soils. If the samples had all been taken to a depth great enough to make the table entirely symmetrical, the condition of the sixth foot would have been expressed by the symbols OW or OD in nearly all of the 63 cases when determinations were made in the first foot section but not in the sixth.

Consideration of the table will be confined largely to the portion where the results are expressed as percentages. The most striking feature of the table is the closeness with which plats A and B approximate each other. In the first foot of soil both were filled to capacity, and all of the water was used about three-fourths of the time. About 10 per cent of the time the soil was not entirely filled with water at any time during the growing season, but all available water was used. In only 1 per cent of the time, which represents the year 1915 at North Platte, was the soil filled with water at harvest. There has never been a case where no available water was present in the first foot during the growing season. In one year, 1911, at Belle Fourche, very little available moisture was present in the first foot of plats A and B. This year was necessarily omitted in Table 1, as the soil was so dry that the wheat did not come up.

Summing up the results for the first foot, it is found by adding the percentages under the symbol PD to those under the symbol F that the available water in both plats A and B was entirely depleted at harvest in 89 per cent of the cases studied; the water content was reduced but not entirely exhausted (the condition represented by the symbol PW) in 10 per cent of the cases; and the soil was still full of water at harvest time (classed as the condition OW) in 1 per cent of the cases.

The second foot section of plats A and B, when compared with the first, shows a sharp reduction in the number of times full use of water was made (F). This is accounted for by the great increase in the percentage of cases when the soil was only partly filled with moisture and all of it used (PD) and in the appearance of a few cases where the soil was dry all the season (OD). The proportion of the time that moisture present in the soil was only partly used (PW) remains nearly constant.

Summing up the results for the second foot section, it is found that it was dry at harvest 89 per cent of the time on plat A and 87 per cent of the time on plat B. This is the sum of the percentages under symbols F, PD, and OD. The moisture content was reduced but not exhausted in 10 per cent of the cases on plat A and in 13 per cent of the cases on plat B. This condition is represented by the symbol PW. There was only 1 per cent of the time on plat A when the moisture content of the soil was not reduced when available moisture was present. This is the condition shown by the symbol OW. All of the available water in the second foot of the two plats was removed practically the same proportion of the time as in the first foot. The aggregate quantity of water obtained by the wheat crop from the second foot must have been considerably less than that obtained from the first foot, as it has been filled with water less frequently.

The third foot section of soil, when compared with the second, shows a material reduction in the full use of water on plats A and B. In this section the soil has been filled to capacity and all the water used (F) only about 25 per cent of the time. This is accounted for by a marked increase in the proportion of cases when no available water was present (OD). There is a slight reduction in the percentage of time the available water was only partly used (PW). Little change is shown in the percentage of cases when the soil was only partly filled with water and all available water used (PD). The reduction in the number of times the soil moisture was reduced but not exhausted (PW) probably represents the fewer number of times that rains near harvest affected the water content of the soil to this depth.

Summing up the results for this foot section, the soil was dry at harvest (F, PD, and OD) 93 per cent of the time on both plats A and B. In the remaining 7 per cent of the cases the water content of the soil was reduced but not exhausted (PW). Thus, it is found that there is no great difference in the first 3 feet of soil in the percentage of the time that harvest finds them without available water, but that the actual use of water is progressively less as the distance from the surface increases, because of the limitation in the extent to which the soil is filled with moisture.

In the fourth foot section of plats A and B the soil has been filled with water and all the water used (F) less than 10 per cent of the time, partly filled with water and all used (PD) in about 25 per cent of the cases, and it has been dry all the season (OD) about 55 per cent of the time. There is little change in the proportion of cases where the moisture has been reduced but not exhausted (PW). A few cases appear on each plat where available water was not reduced (OW).

The percentage of the time when no water was available at harvest remains nearly as high as in the upper 3 feet of soil. But the great proportion of the time that this foot section has been dry or only partly filled with water makes it far less valuable than the third section in supplying moisture to the wheat crop.

Below the fourth foot available water has been present in the soil of these plats in only one-third of the cases. Full use practically ceases, and the number of times the soil has been partly filled with water and all of it used is reduced. On the other hand, the proportion of the time no use is made of available water rises.

Considering the fact that the soil at depths below 4 feet has been moist only infrequently, that the quantity of moisture held when the soil is filled to capacity is not great, and that the wheat crop has been able to use all the available water present only about half the time in the fifth foot and one-third of the time in the sixth foot the conclusion must be drawn that the fifth and sixth foot sections of soil on land continuously cropped to wheat are generally without value so far as crop production is concerned.

In plats A and B it was found that the limitation of the depth to which water was used in the upper sections at least depended so much upon the depth to which moisture was present in the soil that other factors were obscured. In the C or D plat the soil has been wet to a greater depth, as a rule, and it has been possible to compare the individual sections of soil in their water relations without lack of moisture being the determining factor.

In the first foot plat, C or D closely approaches the other plats in its moisture relations. The chief difference has been a slightly greater number of cases where the soil was filled with moisture and all available moisture used (F), and a correspondingly lesser number of cases where the soil was only partly filled with water and all the water used (PD). The soil was dry at harvest practically the same proportion of the time as on the other plats.

The data for the second foot of plat C or D almost duplicate those from the first foot. This seems to indicate that the second foot of soil is normally filled with roots when moisture is present and that water is used as freely from this section as from the soil above it. The difference shown between the second foot of plat C or D and that of the other two plats appears to be solely due to the quantity of moisture present in the soil.

The third foot of soil evidently differs but little from the first and second in regard to the demands which the wheat crop has made upon it for moisture and the extent to which it has responded. It is only slightly lower in the proportion of time that the soil has been filled with water and the water all removed by harvest. This decrease is accounted for by the fact that the soil has not always been moist to a depth of 3 feet even in fallow. The same decrease in the proportion of the time the available water has not all been used is found in this plat as in plats A and B.

In the fourth foot full use of water has taken place only 43 per cent of the time. That this is due to lack of penetration of water rather than to other factors is indicated by the greater percentage of cases, as compared with the upper sections, when the soil was dry or partly dry. There is, however, a small increase in the number of times the available moisture has been only partly exhausted (PW) and a corresponding decrease in the percentage of the time all available moisture has been removed from the soil before harvest.

In the fifth and sixth foot sections full use of the soil is not frequent. There is a marked increase in the proportion of the time the available water has been only partly used (PW) and in the number of times no use has been made of available moisture (OW). There are, too, an increasing number of cases where no available moisture has been present (OD). In the fifth foot sections available water has been present in the soil 81 per cent of the time. In 47 of this 81 per cent the water has been unused or only partly used before harvest. In the sixth foot section available moisture has been present 67 per cent of the time. Only 13 of this 67 per cent represent cases where all available moisture was removed from the soil. The remainder of the time the available water was only partly removed or not used at all.

As a whole, there is a greater use of water in the lower depths of plat C or D than in the other two plats. This is largely due to the fact that water has been present in the fifth and sixth foot sections more frequently. The quantity of water used by the crop from these depths in an average year must be small, since full use of water is so infrequent.

COMPARISON OF CULTURAL METHODS.

The conservation and use of moisture in plats on which different cultural practices have been employed, are sufficiently comparable at the different stations to allow definite deductions to be made.

For the average of all stations, plats A and B show no notable differences in the quantity of moisture conserved. The differences at individual stations are only minor. In the northern section of the Great Plains the advantage of one or the other at the stations where one is superior favors plat A. This is without doubt due to the fact that in most years there is a better opportunity to obtain moisture by holding the winter snow than by conserving the moisture that falls after harvest. The soil at harvest has been shown to be dry approximately 90 per cent of the time; therefore, cultivation at that time usually conserves no moisture, because none is present. By preventing weed growth, fall plowing is better able than spring plowing to conserve the moisture that falls between harvest and winter. However, the moisture that falls after harvest is not usually all used up on land not fall cultivated. The season between harvest and freezing is not long, and the demand of plants for moisture at that time is not high. Where there is sufficient precipitation after harvest to induce weed growth, there is usually enough so that the moisture supply is not exhausted by the time freezing kills the weeds.

In years with a heavy precipitation after harvest, plat B usually conserves more moisture than plat A. The greater number of times that plat A possesses the higher moisture content in the spring shows the superiority of catching snow over retaining fall precipitation in conserving moisture at the northern stations.

At the southern stations the difference between the two methods in conserving moisture when a difference exists has been in favor of plat B. In this region there is little snow; consequently, the superiority of plat A in catching snow is of little importance. There is also an earlier harvest and a later fall than at the northern stations. This gives plat B a longer period for moisture storage and also gives the weeds on plat A a greater chance to remove the moisture that falls after harvest. In spite of this, the difference between the two plats in the quantity of moisture stored has generally been small.

That the greater depth of plowing practiced on plat B has not increased the root development of this plat over that of plat A is indicated by the fact that the two plats have been practically duplicates in the utilization of the moisture present.

Unfortunately, the slight superiority of one plat over the other in moisture storage in different sections of the Great Plains is such that it is not possible to benefit greatly from it in farm practice. The southern stations, where plat B has conserved more moisture than plat A, are particularly subject to soil blowing during the winter months. This operates against the use of fall cultivation on an extended scale.

At the northern stations, where plat A has been slightly superior to plat B, there is a practical limit to the spring work that can be done without unduly delaying seeding. In that region the earlier seeding that may be practiced on fall plowing frequently more than makes up for any superiority of spring plowing in the quantity of moisture conserved.

Certainly the greater quantity of moisture stored by either method in any section is not enough to counterbalance other factors such as timeliness of work, control of weeds, and prevention of soil blowing.

Plat C or D has been markedly superior to the other two plats in moisture storage at all stations except those with a limited water-storage capacity. At Edgeley, it will be remembered, the soil is so shallow that practically all of it has been filled to capacity for all methods of cultivation each year between harvest and seeding; consequently, little difference between methods has existed. At some other stations, such as Archer and Ardmore, the difference in favor of plat C or D has been small. The superiority of C or D over A and B in individual years has depended upon the quantity of rainfall as well as the character of the soil. The demand of the wheat crop for moisture differs in the several portions of the Plains,[7] and a given quantity of stored water may be of more value at one station than another. When translated into bushels of yield 4 inches of water stored at Assinniboine would probably be much more valuable than the same quantity of water at Amarillo. The superiority of plat C or D over the other plats in conserving moisture must be considered in terms of increase in bushels per acre to determine the value of fallowing as a farm practice.

Alternate cropping and summer fallowing practiced in these experiments has in all but the driest years stored moisture in the entire zone of natural development of the roots of the wheat crop. It is evident from this that any extension of the fallow period for the purpose of increasing the quantity of moisture stored would not often be effective in increasing the yields of wheat. The more likely result in most years would be the storage of moisture at a depth where its recovery by the wheat crop would be extremely doubtful.

The three plats taken together indicate that moisture is the controlling factor in crop production in the Great Plains and that differences in yield generally are due to differences in the water supply. Plats A and B have produced yields almost or quite equal to those on plat C or D in years when they have contained the same quantity of water.

GENERAL CONCLUSIONS.

Under dry-farming conditions there is present in the soil no ground water or other source of free water. Below the zone of a few feet near the surface, which the present study shows may be wetted and dried during the cycle from harvest to harvest, the soil is either dry or does not contain water above its field carrying capacity. Under these conditions no water moves upward through appreciable distances to replace the water removed by the roots. Water is supplied to the roots only by such part of the soil as they occupy, and only that part of the soil suffers exhaustion or reduction of its water content.

The development of the roots of the wheat plant is indicated by the depth and extent to which the soil water is used. The usual depth of development is indicated by the results given in detail in Table 1 and summarized in Table 2. It appears that at stations

[7] Cole, John S., and Mathews, O. R. Use of water by spring wheat on the Great Plains. U. S. Dept. Agr. Bul. 1004, 34 p., 10 fig. 1923.

where the character of the soil permits easy penetration of water and plant roots, the natural zone of development of wheat roots is the first 4 feet of soil. In many years, particularly on plats A and B, lack of moisture prohibits root growth to that depth, but where moisture is present in the first 4 feet of soil the evidence at hand points to a nearly uniform utilization of moisture within these 4 feet. The use of water below the fourth foot section of soil depends primarily upon the character of the season. In years when moisture is present in all 6 feet of soil, little or no use of water below the fourth foot is shown if there is at all times a supply of available moisture present in the first 4 feet. Development of any considerable number of roots in the fifth and sixth foot sections of soil seems to be made only under stress of a shortage of moisture, either temporary or continued. The extent to which the moisture in these depths is used depends largely upon the length of time that the crop suffers for moisture without drying up or ripening prematurely. The complete utilization of water at these depths seems to require a fair growth of crop and an extended period of time when the crop needs water but does not actually die or come to a forced maturity. The quantity of available moisture held in the fifth and sixth foot sections of soil is usually small, and its complete or nearly complete utilization necessitates conditions so severe that the yield of the crop is almost always seriously compromised. So far as actual benefit to the crop in ordinary years is concerned, the moisture held in the soil below the fourth foot is of no importance. In a few years the moisture at these lower depths has maintained life in a crop and has enabled it to take advantage of favorable conditions later in the season.

In exceptionally severe years, such as 1911 at Belle Fourche and North Platte, the demands for moisture by the wheat crop have been so excessive that the plants dried up without feeding deeply because the roots could not extend themselves rapidly enough to obtain a supply of moisture sufficient to maintain life. The limitation of root development was caused not by lack of water or by lack of demand for water, but by a demand for water so great that it could not be met. This condition is rare, but an approximation of it late in the life of the crop has often been responsible for a forced ripening without the roots reaching their fullest development.

The fact that moisture is normally exhausted in the first 4 feet of soil does not indicate that the moisture is exhausted simultaneously in the different foot sections. In general, the several foot sections are reduced to the minimum point successively in the order of their distance from the surface. There is very little margin between the first and second foot sections of soil in the time at which they become dry. The principal reason for this is doubtless that the roots become well disseminated through at least this much soil before the wheat reaches a stage of growth where its demands for moisture become heavy. There is, in addition, the fact that the exhaustion of the moisture content of the first foot of soil is frequently delayed by precipitation. Reduction of soil moisture in the third and fourth foot sections commences before the moisture in the first 2 feet of soil is exhausted. However, the minimum point is reached distinctly later in the third foot section than in the second and distinctly later in the fourth than in the third.

The fact that all the available moisture present is utilized about the same proportion of the time in each of the first 4 feet of soil indicates that when water is present the roots of the wheat crop usually completely occupy the soil to about that depth before the plants reach maturity.

This does not indicate that water held at lower depths is not usually valuable. In most years all available moisture within reach of the roots of grain crops is needed, and the plat that carries the greater quantity of moisture in the zone of normal development of roots generally makes the higher yield.

The value of moisture-storage capacity in a soil depends largely upon the precipitation. Thus, at Williston, where the soil is of sufficient depth to permit the storage of moisture to a depth of 6 feet, plats A and B have only occasionally been filled with moisture to a depth of 3 feet, and in some years the second foot of soil has not been filled to its carrying capacity. In spite of its greater moisture-storage capacity, it is doubtful whether, in the aggregate, more moisture has been stored in these plats than in the corresponding plats at Edgeley, where the shallow soil has been filled to capacity each year. Stations like Dickinson, that combine a high storage capacity with a relatively large precipitation, are able to utilize moisture to a greater extent.

Another evident fact is that the utilization of a large soil mass is not essential to a high yield. The yield depends more upon the maintenance of a constant supply of available moisture at a depth where it can be easily absorbed by the roots than it does upon the mass of soil involved. The highest yields recorded at any station were produced at Belle Fourche in 1915, when the soil was at no time wet to a depth greater than 2 feet. At the same station in 1920, when all the soil was filled to capacity with moisture and the crop prospects were even better than in 1915, the yield was reduced below that of 1915 because the available moisture was exhausted too long a time before harvest. Yields of wheat on the shallow soil at Edgeley under favorable conditions have been as high or higher than at stations where a much greater soil mass has been occupied by the roots.

SUMMARY.

With knowledge of the field carrying capacity and the minimum point of exhaustion of each soil unit the soil-moisture data have been utilized to classify into five groups the extent to which each foot section of soil has functioned each year in the production of spring wheat by three distinct cultural methods at 17 field stations on the Great Plains.

On land producing a crop each year differences in cultural methods are not sufficient to cause major differences in the depth to which water is stored and from which it is recovered. Alternate fallowing and cropping results, on the average, in the utilization of a somewhat greater volume of soil.

The depth to which available water is stored may be limited by the shallowness of the soil. When not limited by soil character the surface 6 feet of soil may function in the growth of spring wheat. Except on soils of limited storage capacity, the depth to which water is stored in the Great Plains is more often determined by the

quantity and character of the precipitation than by the storage capacity of the soil.

Available water, when present in the soil, is removed with about the same degree of frequency from each of the first 4 feet. The aggregate quantity of water contributed by each foot section becomes progressively less with increasing distance from the surface, both because each successive foot section is less frequently filled with water and because the quantity of available water that may be held in each successive unit is less. The fifth and sixth foot sections hold still less available water, and the full use of their limited capacity is not frequent. They contribute very little to the total quantity of water used by the crop, but under certain conditions this contribution may be important.

In about 90 per cent of the years covered by these investigations the soil within the zone of normal root development was dry at harvest time.

The utilization of a large soil mass is not essential to a high yield. The yield depends more upon the maintenance of a constant supply of available moisture to the depth at which it can be easily obtained than upon the mass of soil involved.

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