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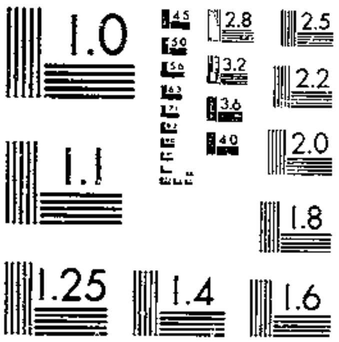

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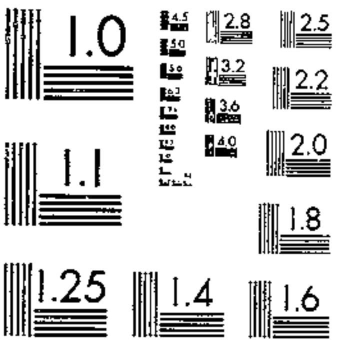

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CONSERVATION AND USE OF SOIL MOISTURE AT MANDAN, N. DAK.[1]

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CONTENTS

INTRODUCTION

In regions of limited rainfall the conservation and use of precipitation in the form of soil moisture has been regarded as one of the most important phases of the problem of crop production. Soil moisture may be conserved through timely tillage, the use of intertilled crops, by means of fallow, or through protection from surface evaporation and run-off by plants and plant residue on the surface. It is lost through plant transpiration, surface evaporation, run-off, and occasionally through seepage.

The extent to which precipitation may be conserved in the soil is dependent largely on the character and amount of individual rainfalls and on the character and surface condition of the soil. Obviously the character and amount of rainfall may not be appreciably modified by human agencies, but the proportion conserved or used is to some extent dependent on the handling, character, and surface condition of the soil and on the kind of crop grown.

[1] Received for publication Oct. 8, 1937.

The art of handling the soil so as to conserve the largest proportion of the rainfall is not new, but conceptions concerning the extent of benefits from such handling have changed. Thirty years ago it was the hope and belief of so-called "dry farmers," that by suitable methods of tillage and rotation of crops the greater part of the water that fell on the land as rain or snow might be conserved for crop use. Much of the information that has since been gathered, indicates that the proportion of the precipitation that may be stored in the soil under the best methods of preparation is comparatively small.

It is the purpose to discuss in greater or less detail in the following pages the results of soil-moisture studies at the Northern Great Plains Field Station, Mandan, N. Dak. These studies have been carried on since the harvest of wheat in 1914 and cover about as wide a range of seasonal weather conditions as has occurred within the past 50 years. Results covering 20 years of continuous investigation bring out significant differences in the comparative use of water by spring wheat and corn, in the quantities saved under different cultural conditions, and in the comparative quantities of water saved during definite parts of and during the whole fallow period. The striking benefit from stubble cover during certain periods is clearly shown by greater savings of water. Two widely different types of soil on the station afford an opportunity to observe under uniform weather, crop, and tillage conditions the comparative effects of light and heavy soils on water use and storage.

EXPERIMENTAL CONDITIONS

CROP AND TILLAGE TREATMENTS

The crop and tillage studies have been confined largely to such fundamental tillage treatments in preparation for wheat and corn,[2] as spring plowing, fall plowing, and fallowing. These treatments are duplicated in two separate fields, one designated as the main field and the other as the south field.

Three conditions of crop treatment have been considered. Two of these, continuous cropping and alternate cropping, include wheat and corn in both fields. The third treatment, wheat on ground fallowed 3 consecutive years, is confined to the main field. The last treatment has not been regarded in this study as one of coordinate importance with other treatments, but has been included as a measure of the limits to benefits from prolonged fallowing. Under continuous cropping the same crop is grown year after year on the same ground both with spring plowing and with fall plowing. Under alternate cropping the crop is alternated with fallow, involving the use of two plots, one cropped and one fallowed each alternate year. Under the third treatment—designated as rotation 570—four plots are used, one cropped and the other three fallowed each 3 years consecutively. Aside from the length of the fallow period and the extra cultivation involved in the last treatment, the handling of the crop and ground has been identical with that of alternate cropping.

[2] The same varieties of wheat and corn have been used continuously throughout these studies, Kubanka No. 1440 and Northwestern Dent, respectively.

CHARACTER OF SOILS IN EXPERIMENT FIELDS

The station farm is located near the eastern margin of the region occupied by the Chestnut group of soils. These soils are characterized by their dark-brown color, prismatic structure of their B horizons, and the presence of a zone of lime accumulation at the bottom of the solum. In normal soils the top of the lime zone is reached at about 20 to 30 inches. These soils have developed under the Plains type of short grasses and extend far west into Montana. A survey in process of publication of the soils of Morton County made by the Soil Survey Division of the Bureau of Chemistry and Soils classifies the soil of the main field as Cheyenne fine sandy loam and that of the south field as Grail silty clay loam.

The difference in texture of the soils of the two fields is shown in mechanical analyses of samples from representative plots in each field (table 1). Comparing the relative amounts of the finer separates of each sample, the percentage of clay and silt in the main field is less than half that in the south field. Wide differences in water-holding capacities are indicated by moisture equivalents and wilting coefficients presented in the last two columns of table 1. These constants for the south field are approximately double those for the main field, which means that the soil of the south field may be expected to retain approximately twice as much water against the pull of gravity and against the pull of plants as the soil of the main field. However, the quality of a soil's capacity for holding water may not be measured entirely by the magnitude of that capacity. If, for example, the moisture equivalent and wilting coefficient may be taken to represent approximate measures of the upper and lower limits of water availability, then the south field could have more water than the main field when the latter was filled to its upper limit and still not have any available for plant use. Furthermore, the heavier soil of the south field presents certain inhibitions to the storage and use of water that are found only to a limited extent in the lighter soils of the main field. It is well known that heavy soils take up water more slowly than light soils, and that in some heavy soils as soon as the surface layers are wet they present an almost impervious barrier (*10*)[3] to further penetration. The soil of the south field, because it presents greater resistance to the penetration of water, must be subject to greater losses by run-off. This resistance to penetration may also account for greater losses through surface evaporation, because water is held nearer to the surface for a longer time. The lighter soil of the main field would naturally be filled to its carrying capacity oftener and to a greater depth. But in years of abundant rainfall, when the soil of the south field reaches its optimum functioning, greater production might be expected because of greater content of organic matter (table 1).

[3] Italic numbers in parentheses refer to Literature Cited, p. 40.

TABLE 1.—*Mechanical analysis,[1] total nitrogen,[1] moisture equivalent,[2] and wilting coefficient[3] of soils from representative plots in the main and south fields at the Northern Great Plains Field Station*

Field treatment, crop, and plot	Depth	Mechanical composition							Total nitrogen	Moisture equivalent	Wilting coefficient
		Fine gravel 2 to 1 mm	Coarse sand 1 to 0.5 mm	Medium sand 0.5 to 0.25 mm	Fine sand 0.25 to 0.1 mm	Very fine sand 0.1 to 0.05 mm	Silt 0.05 to 0.005 mm	Clay 0.005 to 0 mm			
	Feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Main field:											
Continuous, corn, plot A	1	0.3	0.9	1.8	31.0	26.1	30.4	8.3	0.20	17.8	9.7
	2	.2	.9	2.1	36.1	25.4	27.5	7.5	.14	14.6	7.9
	3	.7	.9	2.3	41.5	29.5	17.7	7.0	.11	12.7	6.9
	4	1.7	2.3	2.8	35.3	26.0	22.0	7.6	.07	14.5	7.9
South field:											
Continuous, corn, plot A	1	.2	.4	.2	7.1	17.9	55.6	18.6	.31	31.5	17.1
	2	.1	.4	.5	6.9	17.4	48.4	26.3	.19	29.8	16.2
	3	.0	.2	.6	10.0	18.2	47.2	24.1	.13	28.0	15.2
	4	.1	.3	.0	8.9	18.8	48.0	23.6	.10	29.1	15.8

[1] Analyses by Bureau of Soils, U. S. Department of Agriculture, 1916.
[2] Determinations made by the Division of Biophysics and Genetics, U. S. Department of Agriculture, according to Briggs and McLane (1) method. Each determination was made from a composite sample from all oven-dry soil cores collected from a given layer during the course of 1 season's samplings.
[3] Determined by the indirect method according to Briggs and Shantz (4), dividing the moisture equivalent by the factor 1.84.

METHOD OF STUDY

SOIL-MOISTURE DETERMINATION

The general plan of these studies has called for making soil-moisture determinations at regular intervals during the growing season and once or twice late in the fall. Most of these have been from 1-foot layers of soil to a depth of 6 feet.[4] The determinations used in this study have been for the most part those nearest critical stages in the progress of the season, crop, or treatment. A determination in each case was the average moisture from four samples collected in two separate containers, and so distributed as to be representative of each plot or unit studied. The location of sampling was maintained approximately the same from one sampling to another throughout the study. The moisture was determined by drying the soil sample approximately 24 hours at a temperature of 110° C. The moisture content as first determined was expressed as a percentage of the oven-dry weight of the soil, according to the formula: Percent soil moisture $=\frac{\text{moist soil}}{\text{oven-dry soil}}-1$.

For purposes of relating precipitation water to soil water, and because percentages do not show true comparisons between quantities of water at different levels and in different types of soil, all moisture is presented in inches. The conversion of soil-moisture percentages into inches has been according to the formula: Inches of water per 1-foot layer $=\frac{mw}{5.196}$. In this formula m represents percentage (expressed as a decimal) of soil moisture, and w represents the weight (pounds) per cubic foot of oven-dry soil. The quantity 5.196 is the

[4] During the earlier years a limited number of determinations to a depth of 10 feet were made for the purpose of studying the extent of water movement in lower levels. Results since have demonstrated that the surface 6 feet include the depths of water and root penetration under average prevailing conditions of crop, soil, and moisture.

weight (pounds) of a square foot of water 1 inch deep and at a density of 62.35 pounds per cubic foot—density of water at approximately 60° F. (15.5° C.).

The weight of dry soil per cubic foot has been determined for each 1-foot layer studied and is based on the mean weight of oven-dry soil cores extracted in the course of sampling for moisture during the period covered by the study. The number of cores used to make up the mean has ranged from approximately 50 to 450.

MAJOR AND MINOR PERIODS

For convenience in studying the various relationships between precipitation, water used, and water saved, the year has been divided into two major and four minor periods.

Of the two major periods, one extends from seeding to harvest and the other from harvest to seeding. The former is essentially a water-use or growing period, except in case of summer fallow, and the latter a water-conservation or dormant period. In these studies the growing period begins with the sampling date nearest seeding and ends with that nearest harvest.[6] The dormant period begins with the sampling nearest harvest and ends with that nearest the next seeding. Dates marking the beginnings and endings of major periods and the number of days showing their lengths appear in table 2. Both the seedingtime and the harvesttime dates of sampling have been, for the most part, consistently near to the actual seeding and harvest dates, except for the dates nearest corn planting in 1918, 1920, 1921, and 1934. The dormant periods average approximately two and one-third times the growing periods in length. This is of special interest because the growing period is one of relatively high rainfall, high evaporation, and high water consumption; whereas the dormant period is one of relatively low rainfall, low evaporation, and low water consumption. The average lengths of the growing periods are almost identical for both crops and in both fields, but the growing period for corn is approximately a month later in the season than that for wheat. It is important to keep this in mind when later herein comparisons are made between the efficiencies of wheat and corn in the use of water. It would appear that wheat is grown under more favorable moisture conditions than corn, although corn produces the higher yield.

Of the four minor periods, the first is from seeding to early June, the second from early June to harvest, the third from harvest to late fall, and the fourth from late fall to seeding. This division into minor periods is for the special purpose of allowing a closer scrutiny of the conditions limiting the storage of soil moisture by fallow. The first period may be characterized as one of moderate evaporation, relatively high average rainfall, and moderate use of soil moisture by plants; the second as a period of high evaporation, relatively high average rainfall, and high use of soil moisture by plants; the third as a period of moderate evaporation, moderate rainfall, and low use of soil moisture by plants; and the fourth as a period of low evaporation, low precipitation, and absence of water use by plants. Each period presents a somewhat different condition of soil surface and cover, which appears to have some bearing on the proportions of the precipitation that are

[6] It is obvious that there is weed growth after harvest which continues to remove moisture from the soil until checked by killing frosts or by fall plowing.

saved or lost. The whole fallow period for spring-planted crops covers six minor periods starting with harvest, continuing through the next year, and ending with seeding in the second year. The first three periods present a surface protected by stubble which retards run-off and surface evaporation, and the second three periods present a bare and unprotected surface that favors run-off and surface evaporation.

TABLE 2.—*Annual and average soil-sampling dates nearest seeding and harvest, and annual and average lengths of growth and dormant periods under wheat and corn production, Northern Great Plains Field Station, 1914–34*

Year	Soil sampling date				Length of period			
	Seeding		Harvest		Growth [1]		Dormant [2]	
	Wheat	Corn	Wheat	Corn	Wheat	Corn	Wheat	Corn
					Days	*Days*	*Days*	*Days*
1914			Aug. 1	Aug. 3				
1915	Apr. 19	May 22	Aug. 25	Oct. 25	128	156	261	292
1916	Apr. 24	May 23	Aug. 8	Sept. 28	106	128	243	211
1917	Apr. 21	May 21	Aug. 9	Sept. 25	110	127	256	235
1918	Apr. 22	June 3	Aug. 13	Sept. 23	113	112	256	251
1919	Apr. 25	May 16	July 24	Aug. 29	90	105	255	235
1920	Apr. 23	June 12	Aug. 5	Sept. 4	104	84	274	288
1921	Apr. 22	June 15	July 21	Aug. 27	90	73	260	284
1922	Apr. 21	May 25	Aug. 7	Aug. 29	108	96	274	271
1923	Apr. 27	May 23	July 30	Sept. 7	94	107	263	267
1924	Apr. 18	May 22	Aug. 13	Sept. 29	117	130	263	258
1925	Apr. 8	May 25	Aug. 6	Sept. 5	120	103	238	238
1936	Apr. 17	May 21	Aug. 4	Sept. 15	109	117	254	258
1927	Apr. 18	May 13	Aug. 24	Sept. 23	128	133	257	240
1928	Apr. 14	May 22	Aug. 16	Sept. 8	124	109	234	242
1929	Apr. 18	May 25	Aug. 5	Sept. 9	109	107	245	259
1930	Apr. 23	May 24	July 31	Sept. 2	99	101	261	257
1931	Apr. 16	May 26	Aug. 10	Sept. 9	116	106	259	266
1932	Apr. 15	May 20	July 30	Aug. 27	106	99	249	254
1933	Apr. 22	May 22	Aug. 4	Aug. 25	104	95	266	268
1934	Apr. 24	June 4	July 31	Aug. 23	98	80	263	283
Average	Apr. 20	May 25	Aug. 6	Sept. 10	108	108	257	257

[1] Seeding to harvest. [2] Harvest to seeding.

AVAILABILITY OF SOIL MOISTURE

In order that the limitations of water use and storage under field conditions may be related to quantities of water in the soil at critical times, it is helpful to present some measure of the availability of water in the soil. It is common knowledge among students of soil-moisture relations that not all the water stored in the soil is available to plants, nor do soils of different textures have equal capacities for holding moisture. The limits of storage and reduction may be indicated by various measures of availability, examples of which are hygroscopic coefficient (*8*), moisture equivalent (*1*), wilting coefficient (*4*), field carrying capacity (*11*), minimum point of exhaustion (*5*), and permanent wilting point (*12*). The field carrying capacity and minimum point of exhaustion represent fair measures of storage and reduction limits of soil moisture under field conditions, but their determination demands conditions of storage and reduction which in these studies have not occurred with sufficient frequency in most cases to establish dependable mean values.

In the present studies the moisture equivalent and the wilting coefficient were at first used as approximate measures of maximum storage and extent of reduction of soil moisture, but numerous observations indicated that they were respectively higher than the field carrying capacity and the minimum point of exhaustion. The unit finally decided upon and used in this bulletin as an approximate measure of the lower limit of available water was one-half the quantity of water represented by the moisture equivalent (expressed in inches). The field-volume weight and the moisture-equivalent percentage of each 1-foot horizon of each plot were used in making the calculations to inches. The unit is designated in this bulletin as the normal point of field reduction. It bears approximately the same relation to the moisture equivalent as does Veihmeyer's permanent wilting percentage, recently described in a paper by Work and Lewis (*12*). It is lower than the wilting coefficient. The writer believes that, at least for the soils with which he is working, it is a satisfactory measure of the normal point to which crops may be expected to reduce the moisture content of the soil at harvesttime. A test of its accuracy is afforded in later pages in the study of the water remaining in the soil at harvesttime.

The normal points of field reduction for the various plots under study are presented in table 3. Considerable differences may be observed between the two fields in the values for plots of corresponding treatment. In the case of wheat in the south field, there is considerable difference between the continuous-cropping and the alternate-cropping plots. There are also significant differences between the three groups of plots in the main field. Normal points of field reduction are given at the bottoms of tables 7, 8, 9, and 10. The difference between the quantity of water in the soil and the normal point of field reduction, is the quantity which in this study has been taken to represent the available water—water in excess of the normal point of field reduction—and which is discussed later under the topic headings, Water Stored in the Soil at Seeding Time, and Water Remaining in the Soil at Harvesttime.

TABLE 3.—*The normal points of field reduction of the surface 6 feet of soil in plots under different conditions of crop and cultural treatment, in the main and south fields, Northern Great Plains Field Station*

Crop and treatment	Plot	Normal point of field reduction	
		Main field	South field
Wheat:			
Continuously cropped:		*Inches*	*Inches*
Spring plowed	A	7.27	14.32
Fall plowed	B	8.66	13.38
Alternately cropped	C	8.68	9.98
	D	8.26	10.55
Cropped after 3 years of continuous fallow (rotation 570)	A	6.81	
	B	6.34	
	C	6.46	
	D	5.20	
Corn:			
Continuously cropped:			
Spring plowed	A	7.23	12.94
Fall plowed	B	7.32	13.00
Alternately cropped	C	7.93	12.69
	D	7.17	12.67

PRECIPITATION AND EVAPORATION

In any study of soil-moisture relationships where weather and crop are concerned, it is important to become familiar with those weather phenomena most closely related to crop production. Precipitation is probably the most important single factor affecting crop production under dry-land conditions. In the present study, precipitation while the crop is growing constitutes the major part of the measurable quantity of water used in the production of crops. Evaporation may be considered as an integration of all other weather phenomena which affect the functioning of soil and crop. It is presented primarily as an aid in the interpretation of certain variations in the use or conservation of soil moisture, not attributable to precipitation, cropping method, or tillage.

In arriving at quantities of water used under various treatments, it is essential to know the quantities of precipitation occurring dur-

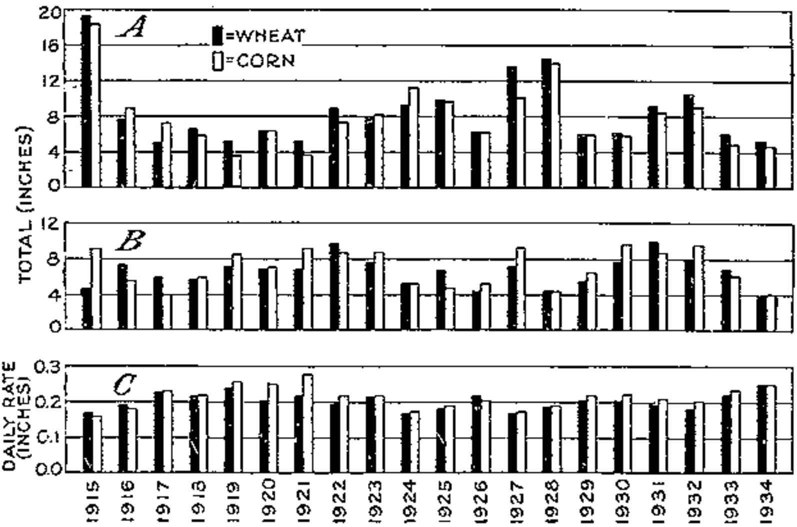

FIGURE 1.—Annual quantities of precipitation during the seeding-to-harvest (*A*) and harvest-to-seeding (*B*) periods of wheat and corn, and the annual daily rate of evaporation (*C*) from a freely exposed water surface during the seeding-to-harvest period of wheat and corn in the main field at Mandan, 1915–34.

ing the periods considered. These have been determined for all periods, but are presented for the major periods only. The annual and average quantities for wheat in the main and the south fields and for corn in the main field only are presented in table 4. There is considerable variation from year to year during the seeding-to-harvest period, but much less variation from year to year during the harvest-to-seeding period. The average quantities for the seeding-to-harvest period are significantly greater than those of the harvest-to-seeding period, notwithstanding the fact that the dormant period is much longer. The highest monthly precipitation occurs during the growing season and the lowest during the dormant season. In order that the precipitation from year to year may be followed more easily, the quantities for the main field are presented graphically in figure 1. The fluctuations of precipitation during each period for both wheat and corn from year to year are quite similar. The years 1917–21 stand out as 5 consecutive years of low precipitation during the growing season. The years 1915, 1927, and 1928 show the highest precipitation during the growing period.

TABLE 4.—*Annual and average quantities of precipitation during the two periods,*[1] *seeding to harvest and harvest to seeding, of wheat and corn in the main and south fields, Northern Great Plains Field Station, 1915–34*

Year	Precipitation					
	Seeding to harvest			Harvest to seeding[2]		
	Wheat		Corn	Wheat		Corn
	Main field	South field	Main field	Main field	South field	Main field
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1915	19.39	18.41	18.32	4.73	5.44	9.12
1916	7.93	7.93	9.03	7.46	7.35	5.56
1917	5.08	4.68	7.35	6.12	6.52	4.13
1918	6.57	4.07	5.51	5.84	5.84	6.09
1919	5.39	5.39	3.66	7.30	9.50	8.65
1920	6.26	6.84	6.39	7.32	7.33	7.53
1921	5.30	5.30	3.73	6.96	10.76	9.10
1922	8.84	8.84	7.16	9.87	9.87	8.59
1923	7.88	7.89	8.21	7.65	7.65	8.78
1924	9.20	9.20	11.32	5.50	5.49	5.45
1925	9.81	9.81	9.55	6.72	6.72	4.80
1926	6.26	6.26	6.23	4.47	4.47	5.34
1927	13.55	14.21	10.08	7.11	7.11	9.34
1928	14.47	14.49	13.88	4.45	3.79	4.65
1929	6.14	6.14	4.97	5.52	5.50	6.64
1930	6.28	6.28	5.90	7.84	7.84	9.65
1931	8.97	8.75	8.45	9.99	10.21	8.86
1932	10.40	9.59	9.05	8.07	8.89	9.66
1933	6.13	6.11	4.55	6.79	6.50	6.25
1934	5.02	5.02	4.65	3.75	3.75	4.06
Average	8.44	8.26	7.93	6.67	7.06	7.12

[1] These periods extend from the soil-sampling dates nearest seeding to those nearest harvest and vice versa.
[2] This period begins at harvest of the preceding year.

It is of special interest to show the monthly distribution of rainfall during the conventional growing and dormant seasons and to point out the comparative amounts for each period. The average monthly amounts for the years 1875–1934 and 1915–34 are presented in table 5. More than three-fourths of the annual precipitation comes during the growing season, with the peak amount falling in June. The averages for 1915–34 are less than those for 1875–1934 for all months except July and September, indicating that the results have been obtained under subnormal precipitation.

Losses of soil water through surface evaporation are not easily measured, but an indication of the influence of weather conditions responsible for such losses may be found in the measurement of evaporation from a freely exposed water surface, records of which have been kept at this station since 1914. Such evaporation is much higher than the evaporation from the soil surface, largely because the surface soil seldom is saturated and frequently is dry, but it is a measure of evaporative power and may be regarded as an important aid to the interpretation of soil-moisture results.

TABLE 5.—*Average monthly distribution of precipitation during the conventional growing and dormant seasons, for the years 1875–1934*[1] *and 1915–34, Northern Great Plains Field Station*

Season and years averaged	April	May	June	July	August	September	Total
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Growing season:							
1875–1934	1.57	2.38	3.36	2.32	1.77	1.32	12.72
1915–34	1.32	2.26	2.84	2.65	1.29	1.38	11.74

Season and years averaged	October	November	December	January	February	March	Total
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Dormant season:							
1875–1934	0.98	0.58	0.52	0.46	0.45	0.91	3.90
1915–34	.91	.52	.43	.32	.36	.72	3.26

[1] Data from U. S. Weather Bureau records for Bismarck to 1914 and from station records thereafter.

The average monthly distribution of evaporation for the conventional growing season, April to September, for the years 1915–34, is shown in table 6. The highest average evaporation for any month is in July, and the lowest is in April. Evaporation for the growing season averages approximately three times as much as the precipitation, the ratios for the different months ranging from about 2:1 to 5:1. The lowest ratio, coming in June, indicates the time of the most favorable combination of these two factors for crop growth; whereas the highest ratio, coming in August, indicates the time of the most unfavorable combination of them.

TABLE 6.—*Average monthly distribution of evaporation from a freely exposed water surface during the conventional growing season and the ratio of evaporation to precipitation*[1] *for the same period, Northern Great Plains Field Station, 1915–34*

Item	April	May	June	July	August	September	Seasonal total
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Evaporation, 1915–34	3.739	5.502	6.214	7.511	6.656	4.559	34.181
Ratio of evaporation to precipitation,[1] 1915–34	2.83	2.43	2.19	2.83	5.16	3.30	2.91

[1] Growing season precipitation, 1915–34, presented in table 5.

The average daily rate of evaporation during the seeding-to-harvest periods for wheat and corn are presented graphically in figure 1, *C*. In general, evaporation increases as precipitation decreases, and decreases as precipitation increases. Evaporation during the growing period for corn runs higher most years than during that for wheat, and during the years when evaporation is higher, precipitation for corn is lower than that for wheat.

From the foregoing it is a reasonable assumption that the growth and development of the wheat crop takes place during more favorable water conditions than does that of the corn crop.

WATER STORED IN THE SOIL AT SEEDING TIME

The determination of quantities of water in the soil at seeding time is an essential primary step in arriving at amounts lost or conserved during major periods. It is of interest, however, to present such quantities for their value as measures of the degree to which soils under different cropping and tillage treatments are functioning within the limits of water availability.

The quantities of water in the surface 6 feet of soil at seeding time of wheat and corn under different cultural conditions in both the main and the south fields are given in tables 7 and 8. Quantities are

TABLE 7.—*Annual and average quantities of water in the surface 6 feet of soil at seeding time, and the normal point of field reduction, under different cultural treatments of wheat in the main and south fields, Northern Great Plains Field Station, 1915–34*

Field and year	Quantity of water in the surface 6 feet of soil at seeding time				
	Continuously cropped		Alternately cropped		Cropped after 3 years of fallow (rotation 570)
	Spring-plowed	Fall-plowed	Cropped [1]	Fallowed [2]	
Main field:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1915	12.05	11.84	16.78	12.91	11.49
1916	17.41	19.02	20.65	20.14	12.62
1917	13.24	14.31	16.88	16.76	11.92
1918	12.56	13.92	17.15	14.72	13.65
1919	9.58	11.47	16.28	13.14	15.78
1920	8.83	9.27	13.57	11.87	10.47
1921	7.60	9.32	13.20	10.40	11.75
1922	10.55	9.07	13.98	11.74	10.76
1923	10.09	9.52	13.66	12.15	13.14
1924	12.52	8.06	13.11	11.42	10.52
1925	10.65	9.47	14.56	12.12	12.05
1926	6.91	7.64	14.13	9.68	11.38
1927	7.51	7.00	11.98	10.39	13.31
1928	9.45	7.84	15.75	9.63	11.21
1929	12.60	11.55	15.61	16.46	11.92
1930	10.69	9.20	16.65	12.46	13.20
1931	10.07	9.62	14.43	13.59	(3)
1932	11.53	8.63	15.17	10.71	
1933	10.43	8.55	15.52	12.42	
1934	7.06	5.87	11.75	9.90	
Average:					
1915–21	11.65	12.74	16.36	14.28	12.53
1915–30	10.77	10.59	15.25	12.87	12.20
1915–34	10.62	10.10	15.04	12.63	
Normal point of field reduction	7.27	8.66	[4] 8.47	[4] 8.47	[5] 6.20
South field:					
1915	17.98	15.52	16.54	15.45	
1916	20.04	19.11	19.57	17.35	
1917	17.43	14.54	16.64	13.87	
1918	17.86	16.65	16.27	13.77	
1919	18.30	19.74	15.01	14.17	
1920	16.61	16.05	16.57	11.59	
1921	16.45	13.20	11.17	12.29	
1922	16.22	(6)	13.29	(7)	
1923	15.73		12.23		
1924	15.61		13.54		
1925	15.43		13.03		
1926	14.19		15.83		
1927	14.64		10.64		
1928	14.66		15.72		
1929	16.55		13.14		
1930	15.43		15.80		
1931	16.06		11.57		
1932	15.54		14.14		
1933	15.78		12.72		
1934	15.64		13.61		
Average:					
1915–21	17.82	16.40	15.97	14.07	
1915–30	16.45		14.69		
1915–34	16.31		14.35		
Normal point of field reduction	14.32	13.38	[4] 10.27	[4] 10.27	

[1] This plot, D in the odd-numbered years and C in the even-numbered years, had been fallowed the preceding year.
[2] This plot, C in the odd-numbered years and D in the even-numbered years, had been cropped the preceding year.
[3] Soil samplings discontinued after 1930.
[4] Average of plots C and D.
[5] Average of plots A, B, C, and D.
[6] Soil samplings discontinued after 1921.
[7] Soil samplings discontinued during the fallow period after 1921.

given under five conditions for wheat and four for corn in the main field and under four for wheat and three for corn in the south field. The number of years during which the quantities of water at seeding time have been recorded for the different methods ranges from 4 to 20. In order that these different lengths of period may be compared as to average quantities, three averages are presented. The normal point of field reduction for each field and treatment is given as a means of measuring the water available for crop use.

The averages in tables 7 and 8 show marked differences in the quantities of water under continuous and alternate cropping in the main field but not in the south field. Differences between treatments are more marked with wheat than with corn. The first averages, 1915–21 in the case of wheat and 1915–18 in the case of corn, are significantly higher than the other two, showing the influence of high precipitation in 1915, when all soils were filled to capacity or above. It is apparent that the effect of this abnormal precipitation was carried over into 1916 and 1917, and that the short-time averages for the earlier years are unduly affected.

TABLE 8.—*Annual and average quantities of water in the surface 6 feet of soil at seeding time, and the normal point of field reduction, under different cultural treatments of corn in the main and south fields, Northern Great Plains Field Station, 1915–34*

Field and year	Quantity of water in the surface 6 feet of soil at seeding time			
	Continuously cropped		Alternately cropped	
	Spring-plowed	Fall-plowed	Cropped [1]	Fallowed [2]
Main field:	*Inches*	*Inches*	*Inches*	*Inches*
1915	13.93	14.52	15.12	----------
1916	15.40	15.99	17.78	----------
1917	12.33	12.00	15.35	----------
1918	12.99	13.62	16.91	----------
1919	13.91	14.19	16.52	15.33
1920	10.73	10.44	13.99	10.86
1921	12.34	10.94	12.82	13.00
1922	11.56	12.15	14.70	11.36
1923	12.23	11.94	14.92	15.73
1924	10.86	11.15	15.17	12.26
1925	12.17	11.19	12.78	14.[illegible]
1926	11.94	11.16	15.08	12.49
1927	12.79	12.83	15.38	14.46
1928	10.87	11.73	14.50	12.76
1929	13.71	13.16	13.76	15.08
1930	12.15	12.22	16.16	14.01
1931	10.82	10.75	12.47	14.30
1932	10.80	12.29	15.35	12.56
1933	12.35	12.70	14.17	14.89
1934	9.32	11.06	14.51	11.73
Average:				
1915–18	13.66	14.03	16.29	----------
1919–34	11.78	11.87	14.52	13.45
1915–34	12.16	12.30	14.87	----------
Normal point of field reduction	7.23	7.32	[3] 7.55	[3] 7.55
South field:				
1915	19.11	16.81	20.06	----------
1916	20.58	21.02	22.52	----------
1917	17.62	17.87	19.11	----------
1918	18.02	17.47	19.85	----------
Average	18.83	18.29	20.39	----------
Normal point of field reduction	12.94	13.00	[3] 12.68	----------

[1] This plot, D in the odd-numbered years and C in the even-numbered years, had been fallowed the preceding year.
[2] This plot, C in the odd-numbered years and D in the even-numbered years, had been cropped the preceding year.
[3] Average of plots C and D.

Wide differences in the water-holding capacities of the soils in the two fields make comparisons of water held of little value without some measure of water availability, such as the normal point of field reduction. The average quantities above the normal point of field reduction, at seeding time, are presented in figure 2.

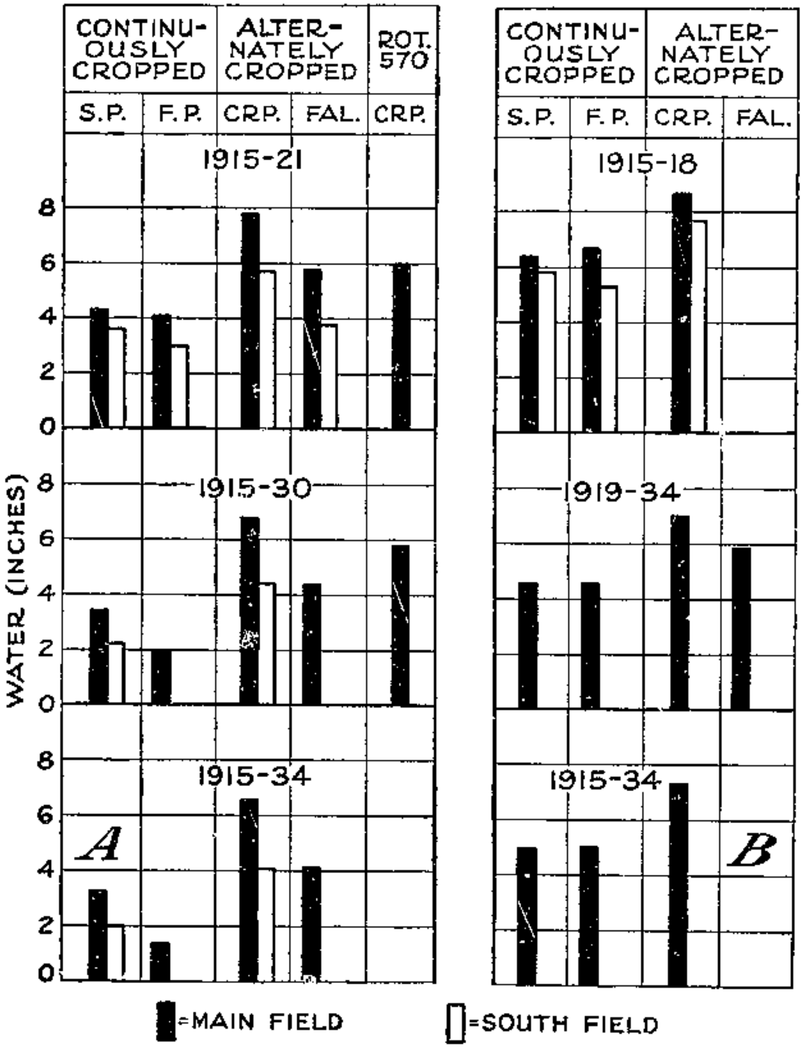

FIGURE 2.—Average quantities of water in the surface 6 feet of soil at seedtime of wheat (*A*) and corn (*B*) in excess of the normal point of field reduction. (S. P.=spring-plowed, F. P.=fall-plowed, CRP.=cropped, and FAL.=fallowed.)

More water is available at seeding time under all treatments of corn in both fields than under corresponding treatments of wheat. A part of the difference in favor of corn is due to the fact that soil samplings at seeding time were approximately 1 month later for corn than for wheat. The precipitation during the interval averaged 2.17 inches.

If all precipitation were saved in the soil, this amount would explain a greater part of the difference in favor of corn. However, studies[6] show that the percentage of precipitation saved during the growing season is relatively small even under the most favorable conditions. It, therefore, seems fair to assume that some of the difference in favor of corn is independent of the time of sampling. Other studies (fig. 3) show that corn on the average does not exhaust the water to as low a point as wheat, particularly in the lower depths, thus indicating a greater residue of available water after corn harvest.

More water is available at seeding time, as indicated by quantities above the normal points of field reduction, in the light soils of the main field than in the heavier soils of the south field. The greater permeability of the main-field soils and their greater tendency to break down into natural mulches, no doubt is responsible for most of the differences in their favor. Greater run-off from the south field is favored by both a finer texture of soils and a greater percentage of surface grade, the main field averaging approximately 2-percent slope and the south field 6 percent.

At seeding time spring-plowed land contains significantly more available water than fall-plowed land, with wheat in both fields and with corn only in the south field (1915–18) average. The stubble remaining on the ground to be spring-plowed without doubt explains the greater quantities of available water in the case of wheat. The results with corn in the south field are for too short a period to be conclusive. Longer time results with corn in the main field show no significant differences between spring-plowed land and fall-plowed land. The absence of a protective cover on the corn ground is a probable explanation of the lack of significant differences between the two treatments.

The average quantities of available water under alternate cropping of both wheat and corn are significantly greater than those under continuous cropping. This is to be expected, as the water-storage period in case of alternate cropping is approximately a year longer than that in case of continuous cropping. The spread between the quantities of available water under alternate cropping and under continuous cropping is greater for wheat than for corn. This is in line with the more complete removal of soil water by wheat than by corn.

There is more available water in the plot to be fallowed under alternate cropping of wheat than there is in the plot that is continuously cropped and spring-plowed. At first thought one would expect them to be alike, for both have the same kind of surface condition—stubble covered—from harvest to the time of plowing in the following spring. However, the plot in the alternate cropping series has the advantage of residual moisture in the lower depths, characteristic of ground alternately cropped and fallowed.

The 3-year fallow in rotation 570 had less available water than 1-year fallow in the alternate cropping, notwithstanding its longer period of water storage. The lower water-holding capacity of the soils in rotation 570 explains this seeming inconsistency. If their water-holding capacity had been higher than that of the soils in the alternate cropping series, their quantities of available water would have been higher.

[6] See discussions under heading, Water Saved by Fallow.

WATER REMAINING IN THE SOIL AT HARVESTTIME

The determination of quantities of water in the soil at harvesttime is as much a part of the process of arriving at quantities of water used or conserved during major periods as is the determination of quantities at seeding time. The presentation of such quantities is important because they mark the extent to which water has been removed during the growing season. Normally it is to be expected that crops, by the time they have matured, will have removed most of the available water from the normal root zone. It is true, however, that more water remains under some conditions at harvesttime than under others.

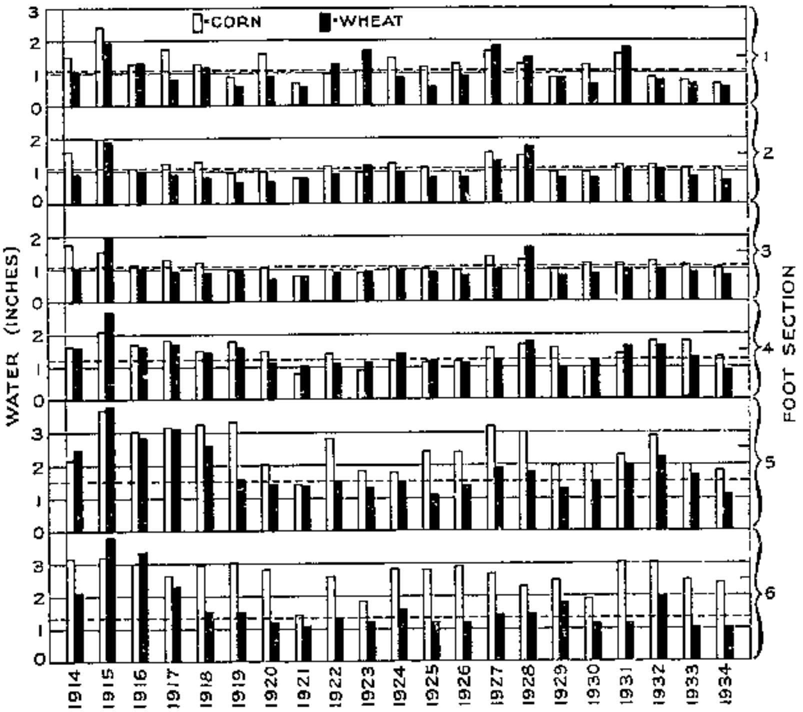

FIGURE 3.—Annual quantities of water at harvesttime of wheat and corn continuously cropped and spring plowed in the main field, and normal point of field reduction for each 1-foot layer of soil to a depth of 6 feet. Mandan, 1914-34.

Comparison of quantities of water remaining in the soil at harvesttime of wheat and corn, is of special interest because of the differences in the closeness and depth of feeding of these two crops. The difference between wheat and corn in depth of feeding under continuous cropping and spring plowed in the main field is shown in figure 3. Both crops behave quite similarly in the degree of reduction of moisture at harvesttime in the first to the fourth-foot layers. However, in the fifth- and sixth-foot layers, corn has hardly ever reduced the moisture to the normal point of field reduction, whereas with wheat from 1918 on, the moisture has been kept around the normal point of field reduction most of the time.

The annual and average quantities of water remaining in the surface 6 feet of soil at harvesttime of wheat and corn under different treatments and the normal point of field reduction of each plot are presented in tables 9 and 10. These tables are similar in every respect to tables 7 and 8, except that they present water at harvesttime instead of at seeding time. To facilitate study, asterisks (*) have been placed against all quantities in tables 9 and 10 which indicate that water has been reduced to or below the normal point of field reduction.

Comparing first the quantities of water remaining at harvest of the two crops, in the case of wheat the water was reduced to or below the normal point of field reduction 74 times in 154 plot years, whereas in the case of corn it was reduced to that point only once in 90 plot years. There is ample reason to believe that the condition of the crop at harvesttime has something to do with this difference in amount of water reduction. Wheat is nearly always fully ripe when harvested, whereas corn is nearly always green as to leaves and stalks when harvested. It would seem a fair assumption that corn, if permitted to ripen as fully as wheat, might show less water in the soil at harvesttime than it does under present conditions of harvest.

Comparing the effect of differences in soil type on the amount of water remaining in the soil at harvesttime, wheat shows a higher percentage of reduction in the south field than in the main field. This is to be expected, because the south-field soils with their higher water-holding capacities have not been able to make as good use of limited rainfall as the main-field soils, and therefore have had much less water in the spring. Removal of this more limited supply naturally takes place sooner and more completely.

TABLE 9.—*Annual and average quantities of water in the surface 6 feet of soil at harvesttime and the normal point of field reduction, under different cultural treatments of wheat in the main and south fields, Northern Great Plains Field Station, 1914–34*

Field and year	Quantity [1] of water in the surface 6 feet of soil at seeding time				
	Continuously cropped		Alternately cropped		Cropped after 3 years of fallow (rotation 570)
	Spring-plowed	Fall-plowed	Cropped [2]	Fallowed [3]	
Main field:	Inches	Inches	Inches	Inches	Inches
1914	9.23	10.35	11.58	16.68	------
1915	16.10	15.13	15.87	18.35	9.57
1916	11.20	12.43	12.46	16.68	6.04
1917	9.73	9.55	10.90	15.91	*5.84
1918	8.42	10.48	10.91	15.38	9.93
1919	*7.04	*7.30	9.52	14.06	*6.71
1920	*6.13	*5.21	8.96	13.05	*5.33
1921	*5.70	*5.72	*7.83	10.68	*6.67
1922	*7.16	*7.62	8.98	11.48	7.11
1923	7.09	8.91	10.98	12.90	8.34
1924	7.43	*7.84	8.89	14.66	5.93
1925	*5.83	*6.50	*8.40	14.18	*6.42
1926	*6.20	*7.78	9.95	10.63	*5.80
1927	8.64	8.85	9.46	15.03	7.89
1928	10.12	*8.50	13.88	16.28	8.44
1929	*6.57	*7.55	9.77	14.92	*6.23
1930	*6.32	*7.16	9.72	13.72	7.07

[1] All quantities marked by an asterisk (*) indicate that water in the soil was reduced to or below the normal point of field reduction of the particular plot.
[2] Even-numbered years plot C and odd-numbered plot D.
[3] Even-numbered years plot D and odd-numbered plot C.

TABLE 9.—*Annual and average quantities of water in the surface 6 feet of soil at harvesttime and the normal point of field reduction, under different cultural treatments of wheat in the main and south fields, Northern Great Plains Field Station, 1914–34*—Continued

Field and year	Quantity of water in the surface 6 feet of soil at seeding time				
	Continuously cropped		Alternately cropped		Cropped after 3 years of fallow (rotation 570)
	Spring-plowed	Fall-plowed	Cropped	Fallowed	
Main field—Continued	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1931	8.79	*8.11	10.25	14.75	(4)
1932	8.57	*7.48	10.63	15.41	
1933	*6.45	*7.37	9.36	11.35	
1934	*5.23	*5.90	*8.06	9.14	
Average:					
1915–21	9.20	9.53	10.93	14.90	7.24
1915–30	8.15	8.72	10.41	14.26	7.12
1915–34	7.97	*8.42	10.24	13.94	
Normal point of field reduction	7.27	8.66	[5] 8.47	[5] 8.47	[6] 6.20
South field:					
1915	18.90	17.90	14.99	17.67	
1916	16.81	14.49	14.38	16.96	
1917	*14.13	*10.81	11.55	13.80	
1918	15.44	*13.12	12.92	13.14	
1919	*13.21	*12.06	*9.19	15.21	
1920	*12.82	*12.21	13.10	*9.63	
1921	*13.99	*11.84	*8.79	12.18	
1922	*13.90	(7)	12.09	(8)	
1923	15.08		*10.45		
1924	14.45		12.43		
1925	*13.30		*8.49		
1926	*13.73		10.44		
1927	14.82		10.23		
1928	*13.80		13.59		
1929	*14.04		*8.39		
1930	*13.12		*9.66		
1931	15.16		*9.64		
1932	*12.97		*10.06		
1933	*12.69		*8.33		
1934	*12.97		12.06		
Average:					
1915–21	15.04	*13.2.	12.13	14.08	
1915–30	14.48		11.30		
1915–34	*14.27		11.04		
Normal point of field reduction	14.32	13.38	[5] 10.27	[5] 10.27	

[4] Soil samplings discontinued after 1930.
[5] Average of plots C and D.
[6] Average of 4 plots.
[7] Soil samplings discontinued after 1921.
[8] Soil samplings discontinued during the fallow period after 1921.

TABLE 10.—*Annual and average quantities of water in the surface 6 feet of soil at harvesttime, and the normal point of field reduction, under different cultural treatments of corn in the main and south fields, Northern Great Plains Field Station, 1914–34*

Field and year	Quantity [1] of water in the surface 6 feet of soil at harvesttime			
	Continuously cropped		Alternately cropped	
	Spring-plowed	Fall-plowed	Cropped [2]	Fallowed [3]
	Inches	*Inches*	*Inches*	*Inches*
Main field:				
1914	11.82	10.62		
1915	14.90	14.18	14.60	
1916	11.33	11.14	12.31	
1917	12.01	12.04	12.48	
1918	11.41	11.38	13.55	
1919	11.04	10.23	10.62	14.56
1920	10.04	10.94	11.77	13.96
1921	*5.91	7.47	8.13	13.15
1922	9.88	9.30	12.01	13.34
1923	7.62	9.34	9.41	14.64
1924	9.67	8.97	11.99	13.93
1925	9.90	11.22	9.18	15.47
1926	9.96	11.01	11.90	12.59
1927	12.13	11.78	13.00	15.28
1928	11.13	12.07	12.65	14.24
1929	8.87	9.85	9.78	14.05
1930	8.53	9.46	10.84	13.43
1931	10.60	10.38	11.58	15.73
1932	11.01	10.55	11.88	14.81
1933	9.37	9.96	9.54	15.23
1934	8.37	9.21	10.78	12.14
Average:				
1915–18	12.41	12.19	13.24	
1919–34	9.63	10.11	10.94	14.16
1915–34	10.18	10.52	11.40	
Normal point of field reduction	7.23	7.32	[4] 7.55	[4] 7.55
South field:				
1915	20.02	19.62	19.22	
1916	16.88	16.50	17.11	
1917	17.42	16.33	18.24	
1918	16.62	16.48	18.07	
Average	17.74	17.23	18.16	
Normal point of field reduction	12.94	13.00	[4] 12.68	

[1] Quantities marked by an asterisk (*) indicate that water in the soil was reduced to or below the normal point of field reduction of the particular plot.
[2] Even-numbered years plot C and odd-numbered plot D.
[3] Even-numbered years plot D and odd-numbered plot C.
[4] Average of plots C and D.

Comparing the effect of the method of cropping, alternate cropping of the light soils of the main field to wheat has not reduced the water to the normal point of field reduction so often as continuous cropping, indicating that the former has provided a more adequate storage of water for crop needs than the latter. In the south field there is not so much difference between the frequency of reduction to the normal point of field reduction under alternate and continuous cropping, which probably indicates that with the heavier soil, storage of water under alternate cropping has been but little more nearly adequate for crop needs than that under continuous cropping.

Comparing the effect of 3 years of continuous fallow in the main field with alternate cropping, water has been reduced to or below the normal point of field reduction oftener under the former system than under the latter. The greater number of reductions under the prolonged fallow in rotation 570, is due mostly to lighter soil which is more easily penetrated by roots, hence there is more complete reduction of water at harvesttime.

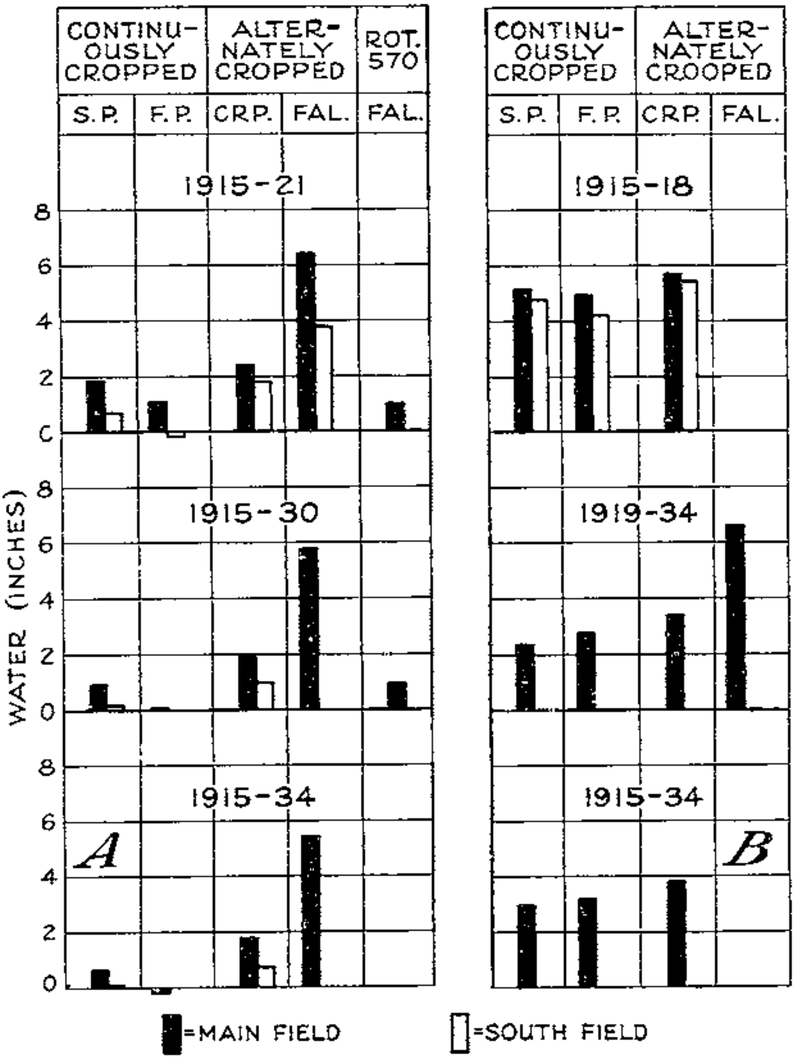

FIGURE 4.—Average quantities of water in the surface 6 feet of soil at harvesttime of wheat (*A*) and corn (*B*), in excess of or less than the normal point of field reduction. (S. P.=spring-plowed, F. P.=fall-plowed, CRP.=cropped, FAL.=fallowed.)

To assist further in the study and interpretation of water remaining in the soil at harvesttime, charts showing the average quantities of water in excess of or below the normal point of field reduction are presented graphically in figure 4. The same general difference in available water between continuous and alternate cropping shows up at harvest as at seeding time. In general more reduction is shown by wheat on fall-plowed land than on spring-plowed land in both fields. The same is true under these treatments of corn with the 1915–18 average, when the effect of the heavy precipitation in 1915 was pronounced. With the longer time averages for corn in the main field, land plowed in the fall showed less reduction than land plowed in the spring.

It is worthy of note in comparing figures 2 and 4, that the average quantities at harvesttime under continuous cropping of corn are for the most part higher than the corresponding average quantities at seeding time under continuous cropping of wheat. This is an important observation, because corn has come to be regarded as a very desirable crop to precede wheat or other small-grain crops in the rotation.

Under alternate cropping of wheat the average quantities of available water in fallow ground at harvesttime are approximately 4 inches higher than those in cropped ground in the main field and approximately 2 inches higher in the south field. It is significant that approximately 2.5 inches more available water is shown at harvesttime under fallow of the light soils in the main field than is shown under fallow in the heavy soils of the south field. At first thought this is not what might be expected upon comparing the relative water-holding capacities of the soils of the two fields indicated in table 1. However, when one considers the greater penetrability of the lighter soil and the greater probable loss from run-off and surface evaporation from the heavier soil, the greater saving of water in the main field is not out of line.

WATER USED[7] IN THE PRODUCTION OF WHEAT AND CORN

The total quantity of water used, whether during the growing period or during the dormant period, is represented by the water in the soil at the beginning of the period, plus the precipitation during the period, less the water in the soil at the end of the period. Its determination is a necessary step in arriving at the relative efficiency of different crops and different methods in the use of soil water. Its presentation and discussion offer in comprehensive terms some conception of the total water used during the growing and dormant periods and its comparative use under different conditions of soil, crop, and tillage.

QUANTITIES OF WATER USED DURING THE GROWING SEASON

The annual and average quantities of water used from seeding to harvest of wheat and corn, under different soil and cultural conditions, are presented in table 11.

That less water was used in the south field than in the main field is evident from the fact that only 25 percent of the cases of spring plowing and 10 percent of the cases of alternate cropping show more water used in the south field. Owing to the limited number of cases when soil-moisture data were available for corn in the south field, no definite conclusions may be drawn in regard to the comparative behavior of the soils of the two fields in the quantity of water used in corn production. The differences between the average quantities used in the two fields are small. The fact that less water was usually

[7] The term "used" as it appears in this and similar connections in this bulletin, signifies all water removed from the soil, whether consumed directly by the crop or lost by run-off, surface evaporation, or seepage. Obviously it is impossible in the field to measure separately the quantities thus removed from the soil.

stored in the heavier soil of the south field explains in part the lesser amounts used in that field.

Table 11.—*Annual and average quantities of water used from seeding to harvest of wheat and corn under different cultural treatments in the main and the south fields, Northern Great Plains Field Station, 1915–34*

Field and year	Quantity[1] of water used from seeding to harvest: Continuously cropped: Spring-plowed: Wheat	Continuously cropped: Spring-plowed: Corn	Continuously cropped: Fall-plowed: Wheat	Continuously cropped: Fall-plowed: Corn	Alternately cropped: Wheat on fallowed land	Alternately cropped: Corn on fallowed land	Wheat on land fallowed 3 years (rotation 570)
Main field:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1915	15.34	*17.35	16.10	*18.66	20.30	18.84	20.22
1916	14.08	13.10	14.52	13.88	16.12	14.50	13.91
1917	8.59	7.67	9.81	7.31	11.00	10.22	10.63
1918	10.71	7.39	10.01	8.05	12.81	9.17	10.29
1919	8.23	6.53	9.56	7.62	12.15	9.56	12.46
1920	8.96	7.08	7.32	5.89	10.87	8.61	11.99
1921	7.20	*10.16	8.90	7.20	10.67	8.42	10.38
1922	12.23	8.81	10.29	10.01	13.84	9.85	12.49
1923	10.28	*12.82	8.49	*10.81	10.65	*13.72	12.68
1924	12.29	*12.51	9.42	*13.50	13.42	*11.50	13.70
1925	14.63	11.82	12.78	9.52	15.97	13.15	15.44
1926	6.91	*8.21	6.12	*6.38	10.44	9.41	12.82
1927	12.42	10.74	12.60	11.13	16.07	12.46	18.97
1928	13.80	13.62	13.81	13.54	16.34	15.73	17.24
1929	12.56	9.81	10.14	8.28	11.98	8.95	12.03
1930	10.05	9.52	8.32	*8.66	13.21	11.22	12.41
1931	10.25	8.67	10.48	8.82	13.15	9.34	......
1932	13.36	8.81	11.55	10.79	14.04	12.52	......
1933	10.11	7.83	7.31	*7.59	12.30	9.48	......
1934	7.75	5.60	4.99	*6.50	8.71	8.38	......
Average:							
1915–18	12.18	11.38	12.62	11.98	15.06	13.18	13.76
1915–21	10.44	9.90	10.89	9.80	13.42	11.33	12.84
1915–30	11.14	10.45	10.51	10.03	13.49	11.77	13.61
1915–34	10.99	9.91	10.13	9.71	13.25	11.40	......
South field:							
1915	17.49	*17.61	15.97	15.71	19.96	19.36	......
1916	11.16	*12.73	12.55	*13.55	13.12	*14.41	......
1917	7.98	7.55	8.41	*8.89	9.77	8.22	......
1918	6.49	*7.21	7.60	6.80	7.42	*7.59	......
1919	10.57		13.07		11.21		
1920	10.63		10.68		10.31		
1921	7.76		6.66		7.68		
1922	11.16				10.01		
1923	8.54				9.64		
1924	10.36				10.31		
1925	11.94				11.35		
1926	6.72				11.65		
1927	14.03				11.62		
1928	15.29				16.62		
1929	8.65				10.89		
1930	8.59				12.42		
1931	9.65				10.68		
1932	12.16				13.67		
1933	9.20				10.50		
1934	7.69				6.57		
Average:							
1915–18	10.78	11.28	11.13	11.21	12.57	12.40	
1915–21	10.30		10.71		11.35		
1915–30	10.46				11.88		
1915–34	10.30				11.57		

[1] Quantities marked by an asterisk (*) indicate years when corn used more water than wheat, under the same treatment.

Less water was used in the production of corn in most cases than in the production of wheat. Years when corn used more water than wheat are indicated by asterisks (*) before the quantities. No adequate reason can be offered at this time why corn in these cases used more water than wheat. The preponderance of cases when corn used less water than wheat establishes beyond question the position of corn as more economical in the use of water. The fact that the yields of corn have been significantly higher than those of wheat makes the position of corn even stronger.

Results show that in nearly every case, more water was used under alternate cropping by both wheat and corn than under continuous cropping, largely because more water was stored under alternate cropping.

More water was used under fall plowing than under spring plowing of land for both wheat and corn in both fields during the early years of the experiments, when the effect of the abnormally high precipitation in 1915 was carried over into the next few successive years. The longer time averages in the main field, however, show greater quantities used on land plowed in the spring than on land plowed in the fall.

QUANTITIES OF WATER USED DURING THE DORMANT SEASON

The annual and average quantities of water used from harvest to seeding of wheat and corn under different soil and cultural conditions are presented in table 12.

TABLE 12.—*Annual and average quantities of water used from harvest to seeding of wheat and corn under different cultural treatments in the main and south fields, Northern Great Plains Field Station, 1915–34*

Year	Quantity [1] of water used from harvest to seeding [2]						
	Continuously cropped					Alternately cropped, main field	
	Main field				South field, spring-plowed, wheat		
	Spring-plowed		Fall-plowed				
	Wheat	Corn	Wheat	Corn		Wheat stubble to be fallowed	Fallow to be sown to wheat
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1915	1.91	7.01	*3.24	5.22	(3)	3.40	4.63
1916	6.15	5.06	3.57	3.75	6.21	3.19	5.19
1917	4.14	3.13	*4.24	*3.27	5.90	1.82	6.10
1918	3.01	5.11	1.47	4.51	2.11	2.08	4.60
1919	5.84	6.15	*6.31	5.84	6.85	5.07	6.40
1920	5.53	7.84	5.35	7.32	3.93	4.97	7.81
1921	5.49	6.80	*5.85	*9.10	7.13	5.52	6.81
1922	5.02	3.24	*6.52	*4.21	7.64	5.96	6.57
1923	4.72	6.43	*5.57	6.14	5.82	4.48	5.47
1924	2.67	2.21	6.35	3.04	4.90	4.97	5.29
1925	3.50	2.30	*5.09	*2.58	5.74	3.49	6.62
1926	3.39	3.30	3.33	*5.40	3.58	3.19	4.50
1927	5.86	6.51	*6.90	*7.52	6.20	6.67	5.76
1928	3.64	5.81	*5.46	4.60	3.95	4.28	3.73
1929	2.65	4.06	2.47	*5.55	2.81	2.94	6.19
1930	4.32	6.37	*6.19	*7.28	6.45	5.15	6.11
1931	6.24	8.59	*7.53	*7.59	7.27	8.12	9.28
1932	5.33	9.46	*7.55	7.75	8.51	7.61	7.85
1933	4.93	4.91	*5.72	4.10	3.99	5.00	6.67
1934	2.24	4.11	*5.25	2.98	.80	3.21	3.35
Average	4.33	5.32	5.21	5.42	5.26	4.46	5.95

[1] Quantities marked by an asterisk (*) indicate years when more water was used under fall plowing than under spring plowing.
[2] This period begins with the harvest of the preceding year.
[3] No soil samplings at harvesttime in 1914.

The lowest average use of water during the dormant season was in the main field under wheat continuously cropped on spring-plowed land, and the next lowest was on the plot to be fallowed in the pair alternately cropped to wheat.

With both of these cropping treatments, the ground remained covered with stubble during the entire dormant period. Continuous wheat on spring-plowed land in the south field showed nearly an inch greater water use than the corresponding treatment in the main field. In this case the difference was due to soil difference and not to surface condition. Corn on spring-plowed and on fall-plowed land and wheat on fall-plowed land in the main field were approximately alike in the average quantities of water used during the dormant season. The fact that the ground surface under these treatments is similar no doubt accounts for their uniformity in water use.

The highest average use of water by any crop or treatment during the dormant period was from ground in fallow under alternate cropping.

Comparing the two extremes of water use, it appears that the surface condition plays an important part in the conservation or use of soil water. Stubble left on the ground throughout the dormant season is a positive help in checking surface losses. Bare ground, whether fallow, fall-plowed, or corn stubble, shows higher average use of water than ground covered with a grain stubble. Stubble reduces run-off and surface evaporation and holds snow. The moisture saving which it effects overshadows the loss of water that may result from weed growth after harvest.

The fact that there is a greater use of water from fallow than from other bare ground, such as that plowed in the fall or in corn stubble, suggests the probability that fallow, having a higher water content in the surface layer, has more water to lose through surface evaporation; and because it has a higher water content it presents greater resistance to the penetration of precipitation, and losses through run-off are consequently increased.

RATIO OF PRECIPITATION TO WATER USED

The proportion of water used, expressed as a percentage of the precipitation occurring during the period considered, is discussed because it gives some idea of the adequacy or inadequacy of seasonal rainfall as the source of water supply for current needs during the growing season and as a source of water supply for future needs, in case of the dormant season.

PERCENTAGE USED DURING THE GROWING SEASON

The quantities of water used during the growing season, expressed as percentages of the precipitation during that period, are given in table 13. The percentages in nearly every case indicate that all the precipitation during the growing season and probably most of the available water stored in the soil at the beginning of the period were used. Wheat and corn on land plowed in the spring in the main field are practically alike in the average percentage used, as are wheat and corn on land plowed in the fall in the main field and wheat on spring-plowed land in the south field.

TABLE 13.—*Annual and average quantities of water used*[1] *from seeding to harvest of wheat and corn under different cultural treatments in the main and south fields, Northern Great Plains Field Station, 1915–34*

Field and year	Quantity of water used						
	Continuously cropped				Alternately cropped		Wheat on land fallowed 3 years (rotation 570)
	Spring-plowed		Fall-plowed		Wheat on fallowed land	Corn on fallowed land	
	Wheat	Corn	Wheat	Corn			
Main field:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1915	79	95	83	102	105	103	111
1916	178	145	183	154	203	161	175
1917	169	104	194	99	217	139	234
1918	163	127	152	130	195	158	157
1919	153	178	178	208	226	261	231
1920	143	111	117	92	174	135	175
1921	136	272	169	193	201	226	196
1922	138	123	117	141	157	138	141
1923	131	156	108	132	135	167	161
1924	134	111	102	119	140	128	150
1925	140	124	130	100	163	138	157
1926	110	132	98	102	167	151	177
1927	92	107	93	110	118	124	140
1928	95	98	95	98	113	113	119
1929	205	197	165	107	195	180	190
1930	160	161	133	147	210	190	198
1931	114	103	117	104	147	111	
1932	128	98	111	110	144	138	
1933	165	161	119	156	201	195	
1934	154	120	99	140	173	180	
Average:							
1915–18	147	118	153	124	180	140	169
1915–21	146	147	154	141	189	169	183
1915–30	140	140	132	131	170	157	170
1915–34	140	136	128	131	170	157	
South field:							
1915	95	95	87	85	108	104	
1916	141	141	158	150	165	160	
1917	171	103	180	121	209	112	
1918	160	124	187	117	182	131	
1919	196		242		208		
1920	156		150		151		
1921	146		126		145		
1922	126				114		
1923	108				122		
1924	113				112		
1925	122				146		
1926	107				186		
1927	99				103		
1928	105				115		
1929	141				177		
1930	137				198		
1931	110				122		
1932	127				143		
1933	151				172		
1934	153				131		
Average:							
1915–18	142	116	153	118	166	127	
1915–21	152		162		167		
1915–30	133				153		
1915–34	133				150		

[1] Expressed as percentages of the precipitation from seeding to harvest.

PERCENTAGE USED DURING THE DORMANT SEASON

The quantities of water used during the dormant season, under different surface and cultural conditions and expressed as percentages of the precipitation, are presented in table 14.

During the dormant season all tillage treatments of both wheat and corn ground showed average percentages of water used ranging from

64 to 90. There were, however, occasional years when some treatments showed percentages above 100, indicating that the quantities of water used during such years were greater than the precipitation, notwithstanding the fact that the dormant season is ordinarily considered a moisture-conservation period. Under alternate cropping, fallow shows the highest percentage of precipitation used. Wheat stubble on land to be spring-plowed, whether continuously or alternately cropped in the main field, showed the lowest average percentage of water use, indicating a relation between low water use and stubble cover. Spring-plowed wheat in the south field showed a somewhat greater percentage than the same treatment in the main field, which is largely explained by the heavier soil and greater slope of the ground in the south field. Corn under both treatments of continuous cropping showed a higher percentage of water use than wheat on spring-plowed land in either field, thus again demonstrating the effect of stubble in checking the loss of water from the surface soil.

TABLE 14.—*Annual and average quantities of water used,*[1] *and surface condition of the soil, from harvest to seeding of wheat and corn under different cultural treatments in the main and south fields, Northern Great Plains Field Station, 1915–34*

Year	Quantity of water used						
	Continuously cropped					Alternately cropped, main field	
	Main field				South field, spring-plowed, wheat [2]		
	Spring-plowed		Fall-plowed				
	Wheat [2]	Corn [3]	Wheat [3]	Corn [3]		Wheat stubble to be fallowed [2]	Fallow to be sown to wheat [3]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1915	40	77	69	57	------	72	98
1916	83	91	48	67	85	43	70
1917	56	76	60	79	91	30	100
1918	52	84	25	74	30	36	79
1919	80	71	87	68	70	69	88
1920	76	104	73	97	54	68	107
1921	79	75	84	100	66	79	98
1922	51	36	66	47	77	60	67
1923	62	73	75	70	76	59	72
1924	49	41	115	67	90	90	96
1925	52	48	76	54	85	52	102
1926	76	62	75	101	80	71	101
1927	82	70	95	81	87	94	81
1928	92	128	123	101	104	96	84
1929	48	61	45	84	51	53	112
1930	55	66	79	75	82	68	78
1931	63	74	75	85	71	61	93
1932	66	98	94	80	98	94	95
1933	73	79	84	66	59	74	93
1934	60	101	140	73	21	86	89
Average	64	76	80	76	73	68	90

[1] Expressed as percentages of the precipitation from harvest to seeding time
[2] Surface in stubble during this period.
[3] Surface bare during this period.

CROP YIELDS

In order that the discussion of the use of water in the production of spring wheat and corn may be related to production, the yields under various treatments in the main and the south fields are presented in table 15. Total production only has been considered, as it marks better than grain yield the full relative use of water by the crop.

In this study the total crop is all of that portion of wheat that is harvested with the ordinary grain binder and of corn that is harvested with the row binder. In the case of wheat it includes weeds as well as crop yield. The weights are in pounds of field-cured matter per one-tenth acre.

TABLE 15.—*Annual and average yields*[1] *of spring wheat and corn under different cultural treatments in the main and the south fields, Northern Great Plains Field Station, 1915–34*

Field and year	Continuously cropped				Alternately cropped		Wheat on land fallowed 3 years (rotation 570)
	Spring-plowed		Fall-plowed		Wheat on fallowed land	Corn on fallowed land	
	Wheat	Corn	Wheat	Corn			
Main field:	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1915	395	550	450	485	670	455	680
1916	325	635	345	745	480	515	450
1917	215	410	220	360	320	400	325
1918	215	680	225	615	400	640	385
1919	115	405	85	370	235	380	195
1920	70	331	75	347	415	675	425
1921	102	326	165	284	206	397	297
1922	276	545	200	400	430	570	480
1923	135	610	85	695	240	745	230
1924	340	607	225	606	560	648	610
1925	280	362	190	303	525	316	580
1926	68	370	0	387	221	520	247
1927	285	546	305	515	385	414	260
1928	310	432	320	363	535	363	425
1929	190	322	115	341	345	348	330
1930	185	301	100	416	375	404	275
1931	270	454	120	456	335	490	300
1932	380	372	290	353	540	330	(2)
1933	95	286	0	296	150	360	----------
1934	154	185	0	160	345	225	----------
Average:							
1915–18	288	500	310	551	468	510	460
1915–21	205	477	224	458	389	409	394
1915–31	[3] 244	471	209	464	403	463	358
1915–34	219	441	176	432	386	461	----------
South field:							
1915	395	535	440	*570	*795	*560	----------
1916	200	550	320	605	440	385	----------
1917	105	210	100	270	255	390	----------
1918	0	655	0	420	150	400	----------
1919	100	310	*115	295	215	370	----------
1920	0	250	0	253	345	517	----------
1921	22	158	42	161	117	321	----------
1922	230	310	*235	355	285	525	----------
1923	105	473	*105	512	*245	699	----------
1924	215	407	135	415	295	*679	----------
1925	120	293	150	346	455	*419	----------
1926	0	154	0	124	142	335	----------
1927	245	456	255	494	*415	*500	----------
1928	140	351	150	*414	*540	*391	----------
1929	65	215	20	153	240	270	----------
1930	80	256	60	266	240	373	----------
1931	80	287	88	265	280	377	----------
1932	250	*403	280	*407	440	*462	----------
1933	0	140	0	120	*170	309	----------
1934	0	85	0	65	45	190	----------
Average:							
1915–18	190	488	215	466	418	434	----------
1915–21	126	381	145	368	335	420	----------
1915–31	[3] 154	348	158	366	346	447	----------
1915–34	121	328	124	326	307	424	----------

[1] Yields are in total pounds of field-cured matter per tenth-acre plot. In case of wheat, total yield includes everything (both crop and weeds) harvested with a grain binder. In most cases of failure the growth, whether weeds or crop, was too poor to harvest with a binder. In most such cases the plot was mowed, but no weights were taken. Quantities marked with an asterisk (*) indicate years when yields were higher in the south field than under the same treatment in the main field.

[2] This experiment was discontinued after 1931.

[3] All averages 1915–31 are for the 14 years within that period, when wheat yields were obtained from continuous cropping in the south field, and when soil-moisture data were obtained from rotation 570.

In most cases the yields from similar treatments are higher in the main field than in the south field. Out of 120 plot years, yields have been higher in the south field under corresponding treatments only 18 times (table 15). Under continuous cropping there was only one case in which the yields from land plowed in the spring in the south field were higher than yields from the same treatment in the main field. The differences in favor of the main field are somewhat greater under continuous cropping than under alternate cropping. In general it may be said that crop production was higher in the main field because there was more soil water to use in that field. The yields under different treatments increased with the lengthening of the moisture-storage period. However, this increase was small between the alternate cropping series and rotation 570 in the main field. Apparently the length of the moisture-storage period has a profound effect on the yield up to the point where the soil to the normal depth of feeding is filled to its field carrying capacity, but beyond that little or nothing is to be gained by lengthening this period. It is evident that the desirable length of the storage period depends in some degree on the soil type, a heavier soil requiring a longer time to fill than a lighter one. It is possible that a greater difference might have resulted if the soil of rotation 570 had been as heavy as that of the alternate cropping series or of the heavier type prevailing in the south field.

The average differences in yield between the plots plowed in the spring and those plowed in the fall in the continuous cropping series are not greatly significant in either field. During the early years when the effect of the abnormally high precipitation of 1915 was pronounced, plowing in the fall produced higher yields than plowing in the spring in the main field. The longer time averages show yields from plowing in the spring to be higher than those from plowing in the fall.

FIELD WATER REQUIREMENT

The determination of the water requirement of plants has been the subject of much study and experimentation. Perhaps the most exhaustive of such investigations were carried on by Briggs and Shantz (*2*). Their results point to a wide variation in the relative efficiency of different plants in the use of water. A lengthy review of literature on the subject by these investigators (*3*) emphasized the fact that most such determinations had been made from pot cultures under certain conditions of control which do not prevail in the field. They cited only three instances of determinations made under field conditions. One of these was under irrigation, and the other two were under dry-land conditions. They concluded that—

> The measurement of water requirement under field conditions is uncertain, owing to the difficulty of determining what proportion of rainfall during the growing season is actually used by the crop. This uncertainty arises from the lack of knowledge regarding the amount of run-off and the amount of rainfall that is evaporated from the soil surface without being available to the crop.

This conclusion is essentially correct, if we are concerned with the physiological differences of different plants under controlled conditions. If, however, the subject is to be approached from the basis of field conditions, where run-off and direct evaporation from the soil are of more or less regular occurrence, it seems reasonable that these items should be considered a part of the water requirement under such conditions.

Burr (*5*) in 1914 reported the field water requirement of cane (sorgo), corn, spring wheat, and winter wheat. He suggested in that connection that "the method of procedure was too crude to give it much technical value." Though the technical value of Burr's study may have seemed small, it nevertheless represented the actual use of water in connection with the field production of these crops.

Cole and Mathews (*6*) have made by far the most significant contribution to the fund of information concerning field water requirement. Their study dealt with the use of water by spring wheat at some 20 different stations in the Great Plains for periods from 2 to 10 years, and took into consideration two treatments, continuous cropping and alternate cropping. They did not, however, exhaust the possibilities for study of the field water requirement of wheat nor did they touch on such a study with other crops. It is, therefore, with the thought of extending information on this subject that results under a greater number of conditions are presented in the following pages.

METHOD OF DETERMINATION OF FIELD WATER REQUIREMENT

The method by which the field water requirement of wheat and corn was determined in this study is essentially as follows: The moisture content of the soil was determined at the beginning and at the end of the growth period. The difference between the water in the soil at seeding time and that at harvesttime, added to the total precipitation during the interval, constituted the total water used. The ratio of water used to the total yield of field-cured matter constituted the field water requirement.

The method of determination is essentially the same as that followed by Cole and Mathews except for some minor differences. Their initial determination of soil moisture was the sampling nearest the date of coming up, whereas in most cases this bulletin deals with the sampling nearest the seeding date. Though the sampling nearest the date of coming up is probably the better point from which to calculate the water used during the period of actual growth, the one nearest seeding has been a more constant sampling date from year to year in this particular study. It is highly improbable that the choice of either point materially modifies the results. As to the depths of sampling which have been used for field water-requirement studies, Cole and Mathews used samplings to a depth only which seemed to include the operation of plant roots, whereas in the present study samplings to a depth of 6 feet have been used throughout. This has little effect on the results, as changes in water content below the depth of feeding are not significant.

The field-water-requirement ratio in the present study differs from others in that it is expressed as the number of inches of water used in the production of 1,000 pounds per acre of field-cured matter, instead of pounds of water used per pound of dry matter produced. It has the advantage of being readily related to quantities of precipitation and clearly shows the quantity of water used. The ratio may be expressed in inches of water per pound of field-cured matter, by simply changing the decimal point, or should it be desired to express the ratio in inches of water per ton of field-cured matter per acre, it is only a matter of multiplying by two the values in table 16.

EFFECT OF CROP, SOIL, AND TILLAGE ON THE FIELD WATER REQUIREMENT

Briggs and Shantz, in their review of the literature (*3*) on the water requirement of plants, pointed out that the economy of water use by crops may be modified by the method of soil preparation or by variation of the soil type, although many of the results which they reviewed were not conclusive.

In the present study, field water requirements have been determined for wheat under four conditions of soil preparation and for corn under three conditions of soil preparation, and for both crops under two soil types. The ratios of field water requirement under these conditions are presented in inches of water per 1,000 pounds of field-cured matter per acre in table 16.

In most cases the lower ratios were obtained from the lighter soils of the main field. Years and averages when ratios were lower in the south field are indicated by an asterisk (*). There is a tendency for the heavier soil in the south field to show greater efficiency under the more favorable moisture conditions provided under alternate cropping.

Corn shows lower ratios in most cases than wheat. Under continuous cropping the ratios for wheat are approximately double those for corn, whereas under alternate cropping the ratios are not greatly different. There are several instances under alternate cropping when the ratios for corn were higher than those for wheat, which suggests in case of corn that there are other influences than amplitude of water which affect the economy of water use.

TABLE 16.—*Annual and average field water requirements [1] of wheat and corn under different treatments in the main and south fields, Northern Great Plains Field Station, 1915–34*

Field and year	Continuously cropped				Alternately cropped		Wheat on land fallowed 3 years (rotation 570)
	Spring-plowed		Fall-plowed		Wheat on fallowed land	Corn on fallowed land	
	Wheat	Corn	Wheat	Corn			
Main field:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1915	3.88	3.15	3.58	3.85	3.03	4.14	2.97
1916	4.33	2.06	4.21	1.86	3.36	2.66	3.09
1917	4.00	1.87	4.47	2.03	3.44	2.56	3.27
1918	4.96	1.09	4.45	1.31	3.20	1.43	2.67
1919	7.17	1.61	11.25	2.06	5.17	2.52	6.39
1920	12.80	2.14	9.76	1.70	2.62	1.28	2.82
1921	7.06	3.12	5.39	2.54	5.18	2.12	3.49
1922	4.53	1.62	5.15	2.04	3.22	1.73	2.60
1923	7.61	2.10	9.90	1.56	4.44	1.84	5.51
1924	3.61	2.06	4.19	2.23	2.40	2.24	2.26
1925	5.23	3.27	6.73	2.62	3.04	4.16	2.66
1926	10.16	2.22	(2)	1.65	4.72	1.81	5.19
1927	4.36	1.97	4.13	2.16	4.17	3.01	7.30
1928	4.45	3.15	4.32	3.75	3.05	4.33	4.06
1929	6.61	3.05	8.62	2.43	3.47	2.57	3.65
1930	5.43	2.43	8.32	2.08	3.52	2.78	4.51
1931	3.80	1.91	8.73	1.93	3.93	1.91	(3)
1932	3.71	2.38	3.98	3.06	2.77	3.79	----------
1933	10.04	2.74	(2)	2.56	5.20	2.63	----------
1934	5.03	3.03	(2)	4.06	2.53	3.72	----------
Average:							
1915–17	4.07	2.36	4.09	2.58	3.28	3.12	3.11
1915–18	4.30	2.04	4.16	2.28	3.26	2.70	3.00
1915–30 [4]	5.10	2.36	6.26	2.39	3.53	2.88	4.02
1915–34	5.97	2.35	----------	2.37	3.77	2.66	----------

See footnotes at end of table.

Table 16.—*Annual and average field water requirements of wheat and corn under different treatments in the main and south fields, Northern Great Plains Field Station, 1915–34*—Continued

Field and year	Continuously cropped				Alternately cropped		Wheat on land fallowed 3 years (rotation 570)
	Spring-plowed		Fall-plowed		Wheat on fallowed land	Corn on fallowed land	
	Wheat	Corn	Wheat	Corn			
South field:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1915	4.43	3.29	3.63	*2.76	*2.51	*3.46	
1916	*4.20	2.31	*3.92	2.24	*2.98	3.75	
1917	7.60	3.60	8.41	3.20	*3.43	*2.11	
1918	(2)	1.10	(2)	1.62	4.95	1.90	
1919	10.57	(5)	11.37	(5)	5.21	(5)	
1920	(2)		(2)		2.99		
1921	(2)		(2)		6.56		
1922	4.85		(6)		3.52		
1923	8.13				*3.93		
1924	4.82				3.49		
1925	9.95				3.15		
1926	(2)				8.20		
1927	5.73				*3.52		
1928	10.92				3.08		
1929	13.31				4.54		
1930	10.74				5.18		
1931	12.06				*3.81		
1932	4.86				3.11		
1933	(2)				*6.18		
1934	(2)				14.60		
Average:							
1915–17	5.44	3.07	5.32	2.76	*2.97	*3.11	
1915–18		2.58		2.48	3.47	2.81	
1915–30[4]	7.95				3.71		
1915–34					4.75		

[1] Expressed as a ratio of the quantity of water (acre inches) used per 1,000 pounds field-cured matter produced per acre. An asterisk (*) indicates years when the treatment showed greater economy of water use in the south field than in the main field.
[2] Crop failure.
[3] Soil samplings discontinued after 1930.
[4] Average of 12 years during 1915–30 when total yields of wheat were obtained from spring-plowed continuous cropping in the south field, and when soil-moisture results were obtained in rotation 570 in the main field.
[5] Soil samplings discontinued after 1918.
[6] Soil samplings discontinued after 1921.

Comparing the effect of the system of cropping, the ratios for wheat under alternate cropping are consistently lower than those under continuous cropping, but with corn the ratios under alternate cropping average higher than those under continuous cropping. This reversal in the economy of water use under alternate cropping of wheat and corn may possibly be due to a depressing effect of fallow on corn which is sometimes observed.

Comparing the effects of plowing in the spring and in the fall under continuous cropping, the ratios are lower under one treatment about as often as under the other. The averages with wheat show slightly better economy during the earlier years on fall-plowed land than on spring-plowed land, but in the longer-time averages the reverse was true. The average ratios for corn on fall-plowed land are slightly higher than those for corn on spring-plowed land in the main field, but are lower in the south field.

Comparing the ratios for wheat under alternate cropping with those under the 3-year fallow treatment, the longer-time averages show the greater economy under alternate cropping. Part of this difference in the economy of water use may be due to the fact that the 3-year fallow treatment is located on soil of lighter texture, which undoubtedly has been responsible for the more complete removal of water under that treatment (table 8).

With the longer-time averages there is a higher percentage of dry years. As a result the average ratios for wheat tend to increase, whereas the average ratios for corn remain about the same, or if anything decrease slightly

FIELD WATER REQUIREMENT COMPARED WITH POT-CULTURE WATER REQUIREMENT

A comparison of the water requirements of wheat under field conditions, with those obtained from pot cultures, is presented in table 17. Comparisons are given for those years, 1919–22, when wheat was grown under the same general conditions both in the field and in pot cultures. The soil used in the pot cultures approximated that in the main field. Climatic conditions, so far as the surface part of the plants was concerned, were identical. The effects of rainfall and surface evaporation were of necessity different. In the pot cultures, water was supplied at a rate to maintain the soil in a uniformly optimum moisture condition, and the surfaces of the pots were sealed so the only escape of water was by transpiration. Under field conditions water was supplied from rain, and part of the water used was the result of surface evaporation. Ratios are expressed in pounds of water required in the production of a pound of field-cured matter in the case of the field water requirement, and of pounds of oven-dry matter in the case of the pot-culture water requirement. It is a fair assumption from numerous moisture determinations that the field-cured matter did not carry more than 15 to 20 percent of moisture.

A comparison of the ratios of average field water requirement under various treatments in the main and the south fields to average pot-culture water requirement, is shown at the bottom of table 17. The average of all ratios under alternate cropping and under rotation 570, is slightly more than double the pot-culture average ratio, and the average ratios under continuous cropping in the main field are approximately four times the average pot-culture ratio.

Comparisons of daily rate of evaporation (fig. 1) with field water requirements under alternate cropping and with pot-culture water requirements for the years 1919–22 (table 17) show that both water requirement and evaporation rise and fall together. This would seem to indicate that under conditions approaching a sufficiency of water supply in the soil, evaporation exercises a marked control over the economy of water use.

WATER SAVED BY FALLOW

Much has been said concerning the benefits from summer fallowing as a method of conserving soil moisture. Yet little has been presented to show its efficiency at different stages or how much the time of initial tillage affects the amount of water conserved or the amount of crop produced.

Fallow as discussed in this bulletin begins with the harvest of one crop, extends through a dormant period, a growing period, and a second dormant period, and ends with the seeding of another crop. As explained on page 5, the growing period extends from seeding to harvest and the dormant period from harvest to seeding. Comparing fallow with continuous cropping in regard to the length of the time during which moisture may be conserved before the seeding of a crop, fallow conserves moisture for approximately a year longer than continuous cropping, or the equivalent of one growing and one dormant period.

TABLE 17.—*Comparison of field and pot-culture water requirements of wheat at the Northern Great Plains Field Station, 1919–22*

Year	Field water requirement[1]							Pot-culture water requirement[2]
	Main field				South field			
	Continuously cropped		Alternately cropped	Fallowed 3 years	Continuously cropped		Alternately cropped	
	Spring-plowed	Fall-plowed			Spring-plowed	Fall-plowed		
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1919	1,623	2,546	1,170	1,446	2,392	2,573	1,179	520
1920	2,897	2,200	593	638	(3)	(3)	677	340
1921	1,598	1,220	1,172	790	(3)	(3)	1,485	531
1922	1,025	1,166	729	588	1,098	(4)	797	372
Average	1,786	1,785	916	866			1,035	441
Ratio of average field water requirement to average pot-culture water requirement	4.05	4.05	2.08	1.06			2.35	1.00

[1] Expressed in pounds of water used in the production of 1-pound field-cured matter.
[2] Determined by Dillman (7), physiologist in charge of Alkali and Drought Resistant Plant Investigations, at the Northern Great Plains Field Station for the years indicated.
[3] Crop failure.
[4] No soil-moisture data for this treatment in 1922.

The method of handling ground to be fallowed has been to leave it in stubble from harvest until the first of June the following year, when it is plowed and harrowed. Throughout the remainder of the fallow period, the ground is kept free from vegetation by cultivation with a duck-foot cultivator. The number of such cultivations varies from one to four during the growing season. The following spring the land is given one cultivation just before seeding.

In the discussion of results with fallow, consideration is given both to major and to minor periods in relation to precipitation and in relation to water saved or lost. Division into major periods permits study of the proportion of water saved or lost during crop-producing and noncrop-producing periods, whereas division into minor periods permits a closer scrutiny of the factors affecting the losses or gains that may be identified with certain specific stages in the advance of the season, the development of the crop, or the handling of the soil.

QUANTITIES OF WATER AND PERCENTAGES OF THE PRECIPITATION SAVED DURING MAJOR PERIODS

The quantities of precipitation and the quantities and percentages of the precipitation saved during major parts of and during the whole fallow period are given in table 18. Nineteen fallow periods are considered, 1914–16 to 1932–34. The fallow period is divided into three major divisions, harvest to seeding, seeding to harvest, and harvest to seeding. The quantity of water saved was determined by subtracting the quantity in the soil at the beginning of the period from that in the soil at the end of the period. Negative quantities indicate losses. The surface condition during each of the three periods is given in footnotes.

TABLE 18.—*Annual and average quantities of precipitation during the major parts of and during the whole fallow period under alternate cropping of wheat in the main field, and the quantities and percentages of it saved in the surface 6 feet of soil for the fallow periods 1914–16 to 1932–34, Northern Great Plains Field Station*

[Minus sign (−) indicates loss of stored water]

Fallow period	Precipitation				Water saved in the soil							
	Harvest to seeding	Seeding to harvest	Harvest to seeding	Whole fallow period	Harvest to seeding [1]	Seeding to harvest [2]	Harvest to seeding [3]	Whole fallow period	Harvest to seeding [1]	Seeding to harvest [2]	Harvest to seeding [3]	Whole fallow period
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Percent*	*Percent*	*Percent*	*Percent*
1914–16	4.73	19.39	7.46	31.58	1.33	5.47	2.27	9.07	28	28	30	29
1915–17	7.46	7.43	6.12	21.51	4.27	−3.28	.02	1.01	57	−41	0	5
1916–18	6.12	5.08	5.84	17.04	4.30	−.85	1.24	4.69	70	−17	21	28
1917–19	5.84	6.57	7.30	19.71	3.76	.66	.90	5.32	64	10	12	27
1918–20	7.30	5.39	7.32	20.01	2.23	.92	−.49	2.66	31	17	−7	13
1919–21	7.32	6.26	6.96	20.54	2.35	1.17	.16	3.68	32	19	2	18
1920–22	6.96	5.30	9.87	22.13	1.44	.28	3.30	5.02	21	5	33	23
1921–23	9.87	8.78	7.65	26.30	3.91	−.26	2.18	5.83	40	−3	28	22
1922–24	7.65	7.88	5.50	21.03	3.17	.75	.21	4.13	41	10	4	20
1923–25	5.50	9.20	6.72	21.42	.53	3.24	−.10	3.67	10	35	−1	17
1924–26	6.72	9.81	4.47	21.00	3.23	2.04	−.03	5.24	48	21	−1	25
1925–27	4.47	6.26	7.11	17.84	1.28	.95	1.35	3.58	29	15	19	20
1926–28	7.11	13.55	4.45	25.11	.44	4.64	.72	5.80	6	34	16	23
1927–29	4.45	14.47	5.52	24.44	.17	6.65	−.67	6.15	4	46	−12	25
1928–30	5.52	6.14	7.84	19.50	2.58	−1.54	1.73	2.77	47	−25	22	14
1929–31	7.84	6.28	9.99	24.11	2.69	1.26	.71	4.66	34	20	7	19
1930–32	9.99	8.97	8.07	27.03	3.87	1.16	.42	5.45	39	13	5	20
1931–33	8.07	10.40	6.79	25.26	.46	4.70	.12	5.28	6	45	2	21
1932–34	6.79	6.13	3.75	16.67	1.79	−1.07	.40	1.12	26	−17	11	7
Average	6.83	8.62	6.78	22.23	2.31	1.42	.76	4.48	34	16	11	20

[1] The surface was in stubble during this period.
[2] The surface was in stubble until the plowing date, June 1, and bare thereafter during this period.
[3] The surface was bare during this period.

An average of nearly 2 inches more precipitation falls during the growing period (seeding to harvest) than during the dormant period (harvest to seeding), notwithstanding the shorter duration of the former. However, there were eight times during each dormant period when the precipitation was greater than that of the growing period with which it was connected.

During the first major period the quantities saved range from 0.17 to 4.30 inches, with an average saving of 2.31 inches for the 19 fallow periods. There was an actual loss of water from the soil during five of the second major periods. In the first of these cases, 1915–17, a considerable part of the loss was no doubt due to seepage below the 6-foot level. In this case the soil at the beginning of the period was filled to more than double the normal point of field reduction (see table 7, 1916, under cropped). In the other four cases the loss from the soil was most likely due in greater part to surface evaporation. The average saving for the second period was 1.42 inches. During the third major period there was a loss of water four times during the period of study. The average saving for this period was 0.76 inch.

The first major period shows a greater average saving than the other two periods combined. Some of this greater saving is probably due to the presence of stubble cover, which retards evaporation and aids in holding snow during this period. Comparing the first and the third periods—identical as to time of occurrence, but different as to surface condition and water content of the soil—the average quantity of water saved during the first period is three times as great as that saved during the third period. The soil was comparatively dry most years at the beginning of the first period (see table 9 under cropped) but not at the beginning of the third period (see table 9 under fallowed). At the end of the second period there were 4 inches or more of water saved (the sum of quantities in the first and second periods) in the soil seven times. In only one of these cases was an inch of water saved during the third period, indicating that the presence of water already stored in the soil, as well as the lack of stubble protection, contributes to the comparatively low amount of water saved in the third period.

After land has been in fallow for some time and is partly filled with water near the surface, it presents increased resistance to further penetration, hence run-off is greater than from ground soon after the crop is harvested. Letteer (*9*) in a study of run-off from fallowed ground concluded that—

> In most cases after heavy rains, the proportion of run-off from heavy rains was greater on land which had been fallow for several months than on land which had been fallowed for a comparatively short time.

Letteer showed that 87.1 percent of a 2.9-inch fall of rain was lost by run-off from ground which had been fallow for 15 months, compared with 32.6 percent lost from oat ground. There is little doubt that greater losses by run-off occur from ground which has been in fallow for some time than occur from ground in fallow for a shorter time, but it must be kept in mind that a considerable part of the precipitation in this section comes in small increments which pass readily into the surface soil with a minimum of run-off, and that the surface of bare ground is usually dried out enough to receive readily such amounts of rainfall, even though subsurface horizons are filled to their carrying capacity. In the present case it is a reasonable assumption, supported by observation, that the high rate of surface losses in the late stages of fallow are in the main the result of surface evaporation.

It is quite evident from the percentages of water saved, as shown in table 18, that the proportion of water saved during fallow is relatively small, even during the period of greatest rainfall. The average savings for the major divisions of the fallow period range from 34 percent in the first to 11 percent in the third. The average for the whole fallow period is 20 percent.

QUANTITIES OF WATER AND PERCENTAGES OF THE PRECIPITATION SAVED DURING MINOR PERIODS

Inasmuch as the fallow period covers seasonal conditions that vary from time to time within its major divisions, it is of interest to study the comparative water savings within smaller divisions. Such a study is presented in table 19, in which quantities of water saved or lost during each minor division of the fallow period are compared in their various relations to precipitation and to surface cover; and in the case of the second and third divisions, they are contrasted with the quantities saved or lost during the same time on fallowed land being cropped to wheat. The fallow period is divided into six minor parts, and the cropping period into two minor parts. Stated in the order in which they occur in the fallow period they are harvest to late fall, late fall to seeding, seeding to early June, early June to harvest, harvest to late fall, and late fall to seeding. The quantity of water saved was obtained by subtracting the quantity in the soil at the beginning of the period from the quantity in the soil at the end of the period. Negative quantities indicate losses from the soil. At the bottom of table 19 are given the average precipitation and the percentage of it saved or lost during each minor period. The results given in table 19 are for 14 fallow periods only, hence the averages are not for the same period of years as those presented in table 18. During the fallow period the ground is in stubble during the first three minor divisions and is bare during the remaining three minor divisions. During the cropping period the ground is covered with crop during both minor divisions, but the major part of the growth of the wheat crop takes place during the second division. From the following discussions each minor division appears to be identified with some condition of surface cover or soil that affects the proportion of water saved or lost.

TABLE 19.—*Water saved or lost in the upper 6 feet of soil of 2 plots during the minor parts of the fallow and cropping periods, under alternate fallow and wheat in the main field, the average precipitation, percentages of water saved or lost, and surface condition of the soil, Northern Great Plains Field Station, 1919–34*

[Minus sign (−) indicates loss from the soil]

Years and plot	Fallow period: Harvest to late fall[1]	Fallow period: Late fall to seeding[1]	Fallow period: Seeding to early June[1]	Fallow period: Early June to harvest[2]	Fallow period: Harvest to late fall[2]	Fallow period: Late fall to seeding[2]	Cropping period: Year and plot	Cropping period: Seeding to early June[3]	Cropping period: Early June to harvest[3]
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*		*Inches*	*Inches*
1919-21, D	2.07	0.28	−0.54	1.71	0.69	−0.74	1920, C	0.93	−5.54
1920-22, C	.06	1.48	−.58	.86	1.80	1.70	1921, D	−.86	−4.53
1921-23, D	1.82	2.09	.66	.93	3.22	−1.01	1922, C	.03	−5.03
1922-24, C	2.91	.23	−.11	1.86	.08	.29	1923, D	−1.21	−1.56
1923-25, D	−2.08	2.61	1.04	2.20	1.29	−1.39	1924, C	.10	−4.32
1924-26, C	1.40	1.83	.21	2.28	−.22	.19	1925, D	−.81	−5.36
1925-27, D	−.59	1.87	−.49	1.44	.06	1.20	1926, C	−.18	−4.00
1926-28, C	−.22	.66	2.89	1.75	.32	.40	1927, D	2.51	−5.04
1927-29, D	.88	.71	.11	6.53	−1.11	.44	1928, C	−1.48	−.39
1928-30, C	−1.19	3.77	−2.50	.96	1.65	.05	1929, D	−.91	−4.95
1929-31, D	1.50	1.19	.67	.59	1.94	−1.23	1930, C	−.49	−6.44
1930-32, C	1.62	2.25	−.83	1.99	1.36	−.94	1931, D	−.16	−4.02
1931-33, D	.71	−.25	3.91	.79	1.12	−1.00	1932, C	1.65	−6.19
1932-34, C	1.64	.15	−.10	−.88	1.54	−1.14	1933, D	−2.02	−4.15
Average	.75	1.21	.20	1.51	.97	−.22		−.21	−4.39
Average precipitation	3.71	3.31	3.00	5.53	3.56	3.20		3.00	5.53
Precipitation saved or lost ... percent	20	37	7	27	27	−7	----	−7	−79

[1] The surface was in stubble during this period.
[2] The surface was bare during this period.
[3] The surface was in crop during this period.

Comparing the first and the fifth minor divisions of the fallow period, each a harvest-to-late-fall division, less water is saved during the first division than during the fifth, notwithstanding the stubble cover in the first, and the absence of it in the fifth. The stubble during the first period includes live plants, weeds, and volunteer crops that continue to use moisture until killed by frost or by fall plowing; hence the reason for the greater saving during the second harvest-to-late-fall period when the ground is bare.

Comparing the second and the sixth divisions, each a late-fall-to-seeding division, there is an average gain of 1.24 inches in the former and an average loss of 0.22 inch in the latter. It is obvious that little if any water is used by plants during these periods, as the ground is frozen most of the time. Losses during the sixth period, therefore, must be largely due to surface evaporation and to run-off when the snow melts in the spring. It is impossible to state at this time what proportion of this loss is due to evaporation and what to run-off. The soil at the beginning of the sixth period contained an average of nearly 4 inches more water than it did at the beginning of the second period, and consequently it must have presented greater resistance to the infiltration of water. However, on page 13 it was shown in a system of continuous wheat (fig. 2), that more water was stored when the land was plowed in the spring than when it was plowed in the fall. In that case it could not be said that the lower saving in bare ground was due to retarded infiltration by higher moisture content of the surface soil.

During the seeding-to-early-June period in fallow, there is a drop in the saving of water as compared with the periods immediately before and after. This drop is very likely caused by weed growth up to the time of plowing, about June 1, and the drying-out effect of the plowing itself. More cases showed losses than gains during this period. This suggests a possible benefit from plowing fallow somewhat earlier than June 1, in order to prevent moisture loss from weed growth the latter part of May, and to get the benefit from plowing at a time when the rate of evaporation is lower.

Summer fallow, so far as checking the use of water by plants is concerned, begins with the plowing or other initial cultivation. Losses of water after that are due to surface evaporation and run-off. The early-June-to-harvest period shows the highest average quantity of water saved during any minor period. It is during the first part of this period that the heaviest precipitation occurs; hence the importance of starting the cultivation of fallow by June 1 or earlier.

During the fallow period the proportion of water saved or lost during minor divisions ranges from a loss of stored water equivalent to 7 percent of the precipitation during the second late-fall-to-seeding division, to a gain of 37 percent during the first late-fall-to-seeding division. During the cropping period the greatest loss occurred during the early-June-to-harvest period, which includes the major portion of the growth of the wheat crop. Not only was all the precipitation used during this period, but stored water equal to 79 percent of the precipitation was also used.

EFFECT OF THE TIME OF PLOWING FALLOW ON THE QUANTITY OF WATER SAVED AND ON THE SUBSEQUENT WHEAT YIELD

It has long been apparent in certain experiments with methods of fallow at this station that the time of plowing summer fallow has a marked effect on the subsequent yields of wheat. In one of these experiments summer fallow plowed June 1 is compared with that plowed July 1, plowing being the initial cultivation. In the 20 years during which these methods of fallowing have been studied, there was no instance when the yield of wheat on fallow plowed July 1 exceeded that on fallow plowed June 1. The average yields for the entire period were in favor of the latter by 6.6 bushels per acre.

Soil-moisture data in connection with these methods are available for only the 1930–34 period. The results for this short period are given in table 20. Briefly, they show that an average saving of 1 inch of water in the surface 6 feet of soil for the 5 years 1930–34 from plowing fallow June 1 as compared with July 1 made a net return of wheat crop of 1,420 pounds of total field-cured matter per acre, or of grain, 6.6 bushels per acre.

TABLE 20.—*Effect of time of plowing fallow on the amount of soil moisture saved and on the subsequent yield of wheat*

[Averages for the 5-year period 1930–34]

Time of plowing	Soil moisture in the surface 6 feet of soil at seeding time of wheat	Yield per acre (field-cured matter)	
		Total	Grain
	Inches	*Pounds*	*Bushels*
June 1	11.42	3,470	16.6
July 1	10.42	2,050	10.0
Gain from early plowing	1.00	1,420	6.6

It has not been an uncommon practice among farmers to delay plowing for summer fallow until the middle of the summer, the assumption being that the chief benefit from summer fallowing was in the resting of the land or in the green-manure effect of the weeds plowed under. Very little thought apparently was given to the fact that the consumption of water by weeds during June, the month of highest rainfall, might be as great as that by a crop. Nor was consideration given to the fact that most of the rainfall after the middle of the summer is in smaller quantities which do not often penetrate beyond the surface 6 inches, and which for the most part are subject to loss by evaporation before succeeding rains occur. The heaviest rainfall in this section occurs during May, June, and July. It constitutes approximately half the precipitation for the year, and practically all of it falls during the normal growing period of wheat. It should be apparent, therefore, that the greatest saving of water through plowing for summer fallow, may be attained by performing that plowing early in this period.

SUMMARY

The use and conservation of water under dry-land production of spring wheat and corn have been studied under continuous cropping on land plowed in the spring and on land plowed in the fall, under alternate cropping, under a system of cropping to wheat after 3 years of continuous fallow, and with two soils of widely different texture and water-holding capacities.

Soil moisture has been determined in 1-foot layers to a depth of 6 feet and is first expressed as a percentage of the dry weight of soil and then converted into inches by the following formula in which m is the percentage of moisture and w is the weight of a cubic foot of soil:

$$\text{Inches of water per 1-foot layer} = \frac{mw}{5.196}.$$

For convenience in study the year is divided into major and minor periods. The major periods are designated as growing and dormant periods, and to some extent they are considered as periods of water use and water conservation, respectively. The minor periods are four in number and are fixed by definite stages in the progress of the season, or of crop growth, or by the time of tillage operations. Beginning with the seeding of the crop they are designated as seeding to early June, early June to harvest, harvest to late fall, and late fall to seeding.

The normal point of field reduction has been devised as a means of measuring the amount of water available for crop use. Available water is determined by subtracting the normal point of field reduction from the amount of water present in the soil.

Precipitation while crops are growing constitutes the major part of the water used in their production under dry-land culture in the Great Plains. More than three-fourths of the annual amount falls during the conventional growing season (April to September), and one-half during May, June, and July, with the peak amount coming in June.

The highest evaporation during the growing season is in July, and the lowest is in April. The ratio of evaporation to precipitation during the growing season is lowest in June and highest in August, indicating that the growth of the wheat crop takes place under a more favorable combination of precipitation and evaporation than does that of corn.

The quantity of water available for crop use in the soil at seeding time is directly related to the length of the water-storage period, to the type of soil, to the depth of root feeding of the preceding crop, and to the presence or absence of stubble cover on the surface. From 2 to 5 inches more water is available under alternate cropping than under continuous cropping. From 1 to 2 inches more water is available under all conditions in the light soils of the main field than in the heavy soils of the south field. More available water is shown under all treatments of corn than under the same treatments of wheat. Land that goes through the winter in wheat stubble and is plowed in the spring contains more available water than land that is plowed in the fall and goes through the winter bare. There is no significant difference in the amount of available water between land plowed in the spring and land plowed in the fall where continuously cropped to corn, owing to the absence of effective stubble cover in the case of spring plowing.

A greater residue of available water remains in the soil after corn harvest than after wheat harvest. The difference in the depth and closeness of feeding of these crops, and their comparative degree of ripeness at the time of harvest, account for the greater residue in the case of corn. Soil moisture at harvesttime has been reduced to the normal point of field reduction oftener under continuous cropping than under alternate cropping in the main field, oftener in the heavy soils of the south field than in the light soils of the main field, and oftener under wheat cropping than under corn cropping.

The quantity of water used in the production of wheat and corn appears to be governed by the amount stored in the soil at the beginning of the growing period and the water requirement of the crop. More water has been used under wheat production than under corn production; more has been used under alternate cropping than under continuous cropping; more has been used from the light soils of the main field than from the heavy soils of the south field; and more has been used from land plowed in the spring than from land plowed in the fall, largely because there has been more to use.

Approximately one-half as much water is used during the dormant period as is used during the growing period. The lowest average use comes under treatments having stubble cover, and the highest use comes under treatments where the ground surface remains bare, such as fall plowing, corn ground, and summer fallow. When ground during the dormant period is covered with wheat stubble, from 64 to 68 percent of the precipitation is used. Under corn stubble and on fall-plowed corn ground, 76 percent of the precipitation is used. On fall-plowed wheatland, 80 percent is used. and under fallow, 90 percent is used.

Out of 120 plot years yields have been higher 102 times in the main field where the soil is a light sandy loam than yields under corresponding treatments in the south field where the soil is a silty clay loam.

Field water requirement is stated in terms of acre-inches of water used in the production of 1,000 pounds of field-cured matter. Average field water requirements under continuous cropping of corn are less than half those under continuous cropping of wheat. Under alternate cropping there is not so much difference, the requirements sometimes being higher for corn than for wheat. The field water requirement of corn tends to increase with approach of sufficiency of water supply, whereas the reverse is true in the case of wheat. The average differences in the requirements on land plowed in the spring or in the fall are not significant. On the whole, the field water requirement in the light soil of the main field is less than under corresponding treatments in the heavy soil of the south field.

The average field water requirement under continuous cropping of wheat in the main field is approximately four times the average requirement under pot-culture conditions. Under alternate cropping of wheat, the average field water requirement is approximately twice the pot-culture requirement. On the heavy soil in the south field, the average field water requirement under alternate cropping is approximately two and one-third times the pot-culture requirement. Water requirements, both under pot culture and under fallow in the field, rise and fall with evaporation, indicating that under conditions approaching sufficiency of water in the soil, evaporation is a dominant control factor in the economy of water use.

During the whole fallow period 20 percent of the precipitation is saved. During the first major division of the period, harvest to seeding of wheat, the ground is covered with stubble, and 34 percent of the precipitation is saved. During the second major division, seeding to harvest, the ground is covered with stubble until plowed (June 1), and 16 percent of the precipitation is saved. During the third major division, harvest to seeding, the surface of the ground is bare throughout the period, and only 11 percent of the precipitation is saved. During the minor division periods the average proportion of the precipitation saved or lost under fallow ranged from a saving of 37 percent during the first late-fall-to-seeding period to a loss of 7 percent during the second late-fall-to-seeding period. The gain or loss during minor periods appears to be definitely identified with specific conditions of surface cover or soil.

Methods of fallow experiments show that an average saving of 1 inch of water by plowing fallow June 1 instead of July 1 meant a net gain of wheat crop of 1,420 pounds of total field-cured matter per acre, or in terms of grain, 6.6 bushels per acre.

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