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MICROCOPY RESOLUTION TEST CHART
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SUBSOIL MOISTURE UNDER SEMIARID CONDITIONS[1]

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The United States Department of Agriculture, Bureau of Plant Industry, in Cooperation with the Agricultural Experiment Stations of Montana, North Dakota, Nebraska, and Kansas

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INTRODUCTION

Popular belief and many recommendations for economic practice and social organization reflect a lack of knowledge of the water conditions and relations of the soil and subsoil and the material that underlies them in regions of deficient rainfall. There is also little factual information in technical literature on which to build a concept of the conditions that actually obtain.

That the quantity of soil water and its movement under semiarid conditions are different from those under humid conditions is clearly recognized in soil science. Marbut[2] says:

> It can be stated, however, that after mature consideration of all the factors involved it has been decided that the best basis on which soils can be classified into two major groups is that of the presence, in one of the groups (the Pedocal group) of a zone of lime carbonate accumulation in some horizon or layer of the soil profile, regardless of the character or composition of the parent rock, and the absence of such accumulated material in any horizon of the soil profile in the other group (the Pedalfer group). * * * The line across the United States separating these two groups coincides with the western boundary of the prairies. The Pedocalic soils * * * have lost a very small amount of the constituents originally present in their parent materials * * *. The Pedalferic soils * * * are, in general, leached soils. The two groups may be approximately designated as humid soils, the Pedalfers, and subhumid and arid soils, the Pedocals.

[1] Submitted for publication, March 29, 1938.
[2] MARBUT, C. F. SOILS OF THE UNITED STATES. *In* United States Department of Agriculture, Atlas of American Agriculture, Pt. III, Advance Sheets, No. 8, pp. 1-98, illus. 1935. See p. 14.

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The characteristic features of pedalferic soils are acquired through the constant or frequently recurring passage of water downward through them, whereas the characteristics of the Pedocal group indicate the absence or lack of such water movement.

In the absence of such downward movement of water, what is the condition of the subsoil? Is it more or less permanently wet or dry? What changes are brought about by differences in cultivation and cropping and by the normal succession of seasons of above-average precipitation or of drought? It has been stated frequently that a dry subsoil and the absence of a water table result from a precipitation only sufficient to meet the current needs of the vegetation that occupies the soil, and are the conditions that determine dry farming and make its practices necessary. It must be confessed that such statements have been made without presenting the evidence on which they are based. Most publications on soil moisture have been concerned with crop production or with theoretical questions of the water relations of soils, and the contributions they might make to the questions of subsoil water under semiarid conditions have not been developed.

The purpose of this bulletin is to present soil-moisture data selected solely for their bearing on the hydrologic question of subsoil water. Their agricultural significance and lessons can be left for other studies.

When the Division of Dry Land Agriculture was organized under E. C. Chilcott in 1905 to investigate methods of crop production under semiarid conditions, the cooperation of the Biophysical Laboratory under the direction of L. J. Briggs was enlisted to study soil moisture under different crops and methods of tillage. This study has been under way continuously since that time. The methods used have been comparable throughout.

Except for special studies, the determinations of soil moisture presented herewith have been made in units of foot sections of depth. Soil samples were taken with a King soil tube, the cutting edge of which has a diameter of 20 millimeters. Each determination was based on four cores. The samples were weighed and dried to constant weight, then weighed again. The water content was calculated as a percentage of the dry weight of the soil.

During the first seasons, samples were taken to the depth of 3 feet. It was soon discovered that this was not deep enough to measure the seasonal changes in water content, and the standard depth was increased to 6 feet.

This depth has generally been adequate to cover all material changes in soil-moisture content. At a few stations where moisture changes took place to depths greater than 6 feet, the sampling depth was increased to 10 feet or more, and samplings were made to that depth frequently enough to measure the amount of change.

In the charts and tables presented, the wilting coefficient as determined indirectly by Briggs and Shantz,[3] wilting coefficient $=\frac{\text{moisture equivalent}}{1.84}$, is used as a means of showing whether the soil is wet or dry. This wilting point does not represent a critical point in the life of a crop in the field, as crops are able to reduce the soil

[3] Briggs, Lyman J., and Shantz, H. L. THE WILTING COEFFICIENT FOR DIFFERENT PLANTS AND ITS INDIRECT DETERMINATION. Bot. Gaz. 53: 20-37. 1912.

moisture below the wilting point in the zone where crop roots are well disseminated. It does, however, serve as a means of indicating whether a soil is wet or dry, as a soil whose moisture content is below the wilting point is distinctly a dry soil. The wilting coefficient, which is indicative of a dry soil, is used instead of the moisture equivalent, which is indicative of a wet soil, solely as a matter of convenience and space economy in the construction of charts.

STATIONS SELECTED FOR STUDY

The stations chosen for study were selected because they showed some typical hydrologic features, but they do not represent many special soil and moisture conditions found at other stations. The particular features represented by the individual stations are as follows: Havre, Mont., is an example of a loam soil with a medium water-holding capacity under a very low rainfall. Hays, Kans., represents a heavy type of soil with a low infiltration rate under a much heavier rainfall. North Platte, Nebr., represents a soil much lighter and more permeable than that at Hays under a similar but somewhat lower rainfall. Mandan, N. Dak., has both heavy and light soils under the same limited rainfall. Colby, Kans., represents a slightly lighter soil than that at Hays under a lower rainfall. All the stations shown have deep soils in which there is no zone that is impervious to water or roots.

The yearly change in moisture content of the soil at different depths at these stations affords a measure of the extent to which the subsoil at different depths normally functions in crop production, of the extent to which this is changed by the cultivation methods, and of the frequency with which water infiltrates to depths beyond the reach of crop roots.

PRECIPITATION

The precipitation data for the several stations for the years necessary to the study of the soil-moisture records are presented in table 1. It should be borne in mind that the efficiency of rainfall decreases from north to south.

TABLE 1.—*Annual and average precipitation at 5 stations in the Great Plains during the years specified*

Year	Havre	Mandan	North Platte	Colby	Hays	Year	Havre	Mandan	North Platte	Colby	Hays
	Inches	*Inches*	*Inches*	*Inches*	*Inches*		*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1907			17.21			1923	16.03	14.41	26.78	26.54	25.44
1908			21.91		24.56	1924	12.52	16.25	16.10	16.10	13.60
1909			23.01		27.80	1925	17.64	14.06	15.05	15.35	22.15
1910			11.18		15.59	1926	8.00	11.51	14.00	10.58	15.87
1911			16.70		17.03	1927	19.04	20.30	21.16	18.00	26.39
1912			17.85		19.96	1928	11.74	16.85	21.46	19.74	28.70
1913			18.52		22.89	1929	12.25	14.22	17.56	18.06	25.18
1914		23.87	16.59		16.19	1930	8.88	17.38	25.91	24.78	24.02
1915		24.06	34.85	28.99	32.90	1931	8.29	17.44	11.26	14.53	23.81
1916	19.24	15.07	15.26	12.59	16.20	1932	15.29	15.76	18.71	14.86	20.78
1917	11.86	10.31	18.03	19.97	16.08	1933	15.10	11.91	17.75	16.69	14.57
1918	8.35	13.37	15.93	18.91	24.12	1934	9.31	8.13	13.81	7.37	14.72
1919	7.56	13.48	26.56	18.97	25.25	1935	7.72	18.30	23.38	11.49	20.40
1920	11.20	12.69	20.74	27.63	22.62	1936	7.07	6.43	12.43	10.92	15.10
1921	13.37	15.23	15.48	19.37	18.90						
1922	10.26	17.35	19.62	17.54	19.30	Average	12.02	15.15	18.83	17.68	21.35

SELECTION OF DATA

At all the stations only two moisture determinations a year were used. Determinations were generally made at seeding time, at intervals through the growing season, at harvesttime, and in the late fall. Of the two determinations used, one was selected from those made in the spring. The determination was chosen that showed the greatest depth of water penetration before rapid removal by crops had commenced. The second determination was at or near harvest, when the crop had used all the water available to it or needed for its production. The difference between the two determinations represents in a general way the water reduction of the soil during the growth of a crop. In many cases, however, a spring determination was not made at the time that probably represented the greatest water content. The results at the different stations are discussed separately.

RESULTS AT HAVRE, MONT.

The soil at Havre is a medium loam of the Scobey series. The texture of the soil, as expressed by its moisture equivalent, is nearly uniform to a depth of at least 6 feet.

The crop-rotation field at Havre is located on an elevated benchland, lying between Beaver Creek on the east and Big Sandy Creek on the west, both of which are recent streams. Ground water in a well near the rotation field is found at a depth of a little more than 40 feet. It is doubtful whether there is a "sheet" water table under the rotation field, the water apparently being found in preglacial stream channels. Some other wells in the vicinity are more than 200 feet deep.

The crop-rotation field was native short-grass sod until broken in July 1915. The first crop was grown in 1916. The moisture content of the subsoil in the spring of 1916 undoubtedly represents the moisture condition under native sod.

Three plots were selected for these studies. One designated as plot A was continuously cropped to spring wheat on early spring plowing. This is the most productive method of growing wheat continuously at Havre. The other two plots, designated as C and D, were alternately cropped and fallowed. Plot C was fallowed in odd years and cropped in even years. Plot D was fallowed in even years and cropped in odd years. The two plots together give a continuous record of fallowed land cropped to wheat.

The continuously cropped and the alternately cropped plots represent extremes in water penetration. Less water is available for deep penetration under continuous cropping to grain than under a mixed farming system, as small grains use water to a greater depth and usually reduce the water content to a lower point than crops like corn. Fallowed land permits more water penetration than land occupied by a crop, as the crop uses water that is available for deeper penetration in the fallowed land. The two methods represent the upper and lower limits in water penetration that are likely to be encountered under the production of annual crops.

Table 2 and figure 1 show the moisture changes in plot A. The moisture determinations on this plot were made to a depth of 4 feet only, as available moisture was seldom present to that depth.

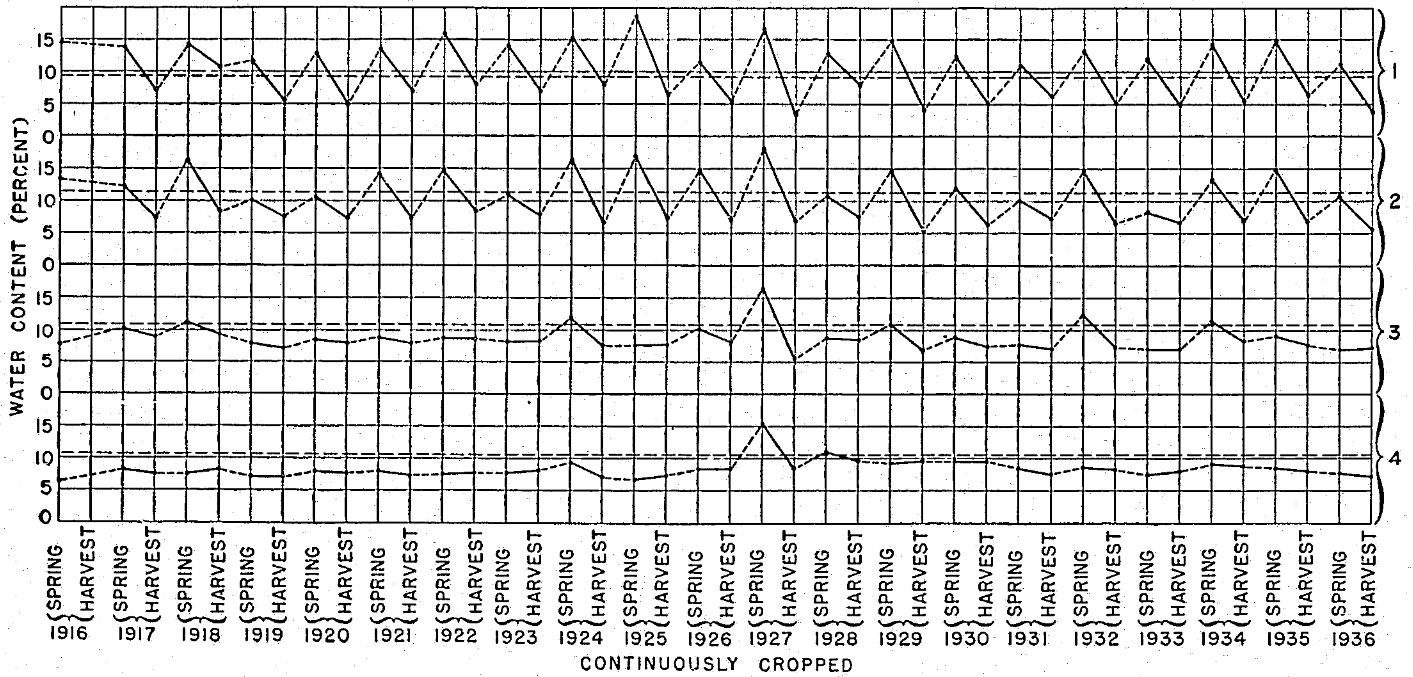

FIGURE 1.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot A at Havre, Mont., continuously cropped to spring wheat, 1916–36. The wilting coefficient of each foot section of soil is indicated by a broken line.

The most striking point exhibited by the figure and the table is the practically complete removal of all available water by the crop each year. In every case when a determination was made at harvesttime, the water content of every foot section of soil was much below the wilting coefficient. In 1918 the soil was undoubtedly dry at the actual harvest date, but no determination was made until fall, when intervening rains had raised the water content of the first foot section. In the few other cases when the surface foot of soil contained as much as 8 percent of moisture at harvesttime, the slightly higher percentage was due to the occurrence of a rain shortly before harvest, and not to lack of complete use of available water by the crop.

The functioning of the different foot sections of soil is shown in figure 1. Lack of change in water content in the lower depths was due to lack of available moisture. When available moisture was present it was used by the crop.

The first foot of soil functioned heavily each year. In every year water above the wilting point was present in the spring and was removed by harvesttime. The actual reduction of water was doubtlessly greater than revealed by the data given, as the spring-determination date selected did not necessarily represent the time when the most available water was present in the first foot.

TABLE 2.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot A at Havre, Mont., continuously cropped to spring wheat, 1916–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																		
		1916	1917		1918		1919		1920		1921		1922		1923		1924		1925	
		Spring	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.3	14.6	13.8	7.0	14.0	10.6	11.6	5.7	13.0	5.0	13.5	7.0	15.9	8.3	14.0	7.1	15.3	8.0	18.9	6.5
2	11.4	13.3	12.2	7.1	16.2	8.1	9.9	7.4	10.5	7.2	14.2	7.1	14.6	8.2	10.8	7.7	16.3	6.4	17.2	7.3
3	10.8	7.8	10.1	8.8	11.2	9.3	7.9	7.0	8.4	7.9	8.8	7.8	8.7	8.6	8.1	8.1	11.8	7.5	7.5	7.7
4	10.5	6.5	8.1	7.5	7.4	8.1	7.1	7.0	7.9	7.6	7.9	7.4	7.6	7.8	7.7	8.0	9.3	7.0	6.6	7.3

Depth (feet)	Wilting coefficient	Moisture content of soil																				
		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.3	11.6	5.4	16.9	3.3	13.1	8.0	14.8	4.2	12.5	5.1	11.0	6.2	13.5	5.2	12.0	4.8	14.2	5.3	14.7	6.3	10.9	3.6
2	11.4	14.9	6.8	18.3	6.7	10.7	7.5	14.6	5.5	12.0	6.2	10.0	7.3	14.6	6.6	8.2	6.4	13.4	6.8	14.8	6.8	10.3	5.3
3	10.8	10.2	8.3	16.4	5.5	8.8	8.4	10.9	6.9	8.9	7.3	7.6	6.8	12.3	7.1	6.8	6.7	11.2	8.0	8.8	7.5	6.8	7.0
4	10.5	8.3	8.2	15.5	8.5	10.8	9.6	9.2	9.4	9.5	9.5	8.2	7.4	8.5	8.2	7.4	7.9	9.0	8.7	8.4	7.9	7.5	7.0

The second foot also functioned heavily in producing wheat, although in several years the amount of water contributed to the crop was small because of the small quantity of available water present. In 7 of the 21 years the water present in the spring did not exceed the wilting coefficient, but in all years there was some reduction in the water content between spring and harvest.

The use of water fell off very rapidly below the second foot. In only 6 of the 21 years did the water content of the third foot section equal or exceed the wilting coefficient. In only 5 years did this foot of soil give up as much as one-half inch (approximately 3 percent) of water to the crop. In nearly half of the years the difference in moisture content between spring and harvest was no greater than the experimental error in making the determinations.

The fourth foot section of soil remained almost constantly dry and contributed very little water to the wheat crop. In only 2 years, 1927 and 1928, did the moisture content of this foot of soil equal or exceed the wilting coefficient. In only 1 year, 1927, did this foot section of soil contribute as much as one-half inch of water to the wheat crop. The reduction of water between spring and harvest in 1927 exceeded that of the other 19 years combined, which indicates how seldom the soil below a depth of 3 feet functions in continuous wheat production under the low rainfall at Havre.

The following conclusions are reached from a study of this plot of soil: The first 2 feet of soil function heavily in the continuous production of wheat. The true extent of the functioning of the first foot of soil is not shown by the selected figures presented, as the supply of moisture in that foot section is frequently replenished by rains and removed by crops several times during the growing season. The second foot did not always function completely because it did not always become thoroughly wet.

Water penetrated to the third foot of soil in over half of the years, but in only a few years was the penetration sufficient to wet the whole foot of soil. In most cases the moisture must have been limited to the upper portion of this foot section. Water penetrated to the fourth foot of soil very seldom, and only once was the penetration sufficient to wet it thoroughly.

The soil in the third and fourth foot sections was dry when the land was broken, and has continued dry ever since except for small additions of water that were removed by crops within the year. The soil has been no drier following the record drought of recent years than it was under native sod.

There is no evidence that water has ever reached the third or the fourth foot sections of soil except from the surface. Each of these foot sections of soil has become wet only in years when all the soil above it has been wet. There is no evidence of moisture movement upward into those foot sections from soil below, and indications are that the subsoil was dry under the native prairie sod and has remained dry under continuous crop production.

The effect of summer fallowing, or leaving the land free from crops in alternate years in order to accumulate moisture, is shown by the moisture history of plots C and D. Tables 3 and 4 present the water content of the soil of these plots on approximately the same dates as for plot A (table 2). The moisture content of these plots was deter-

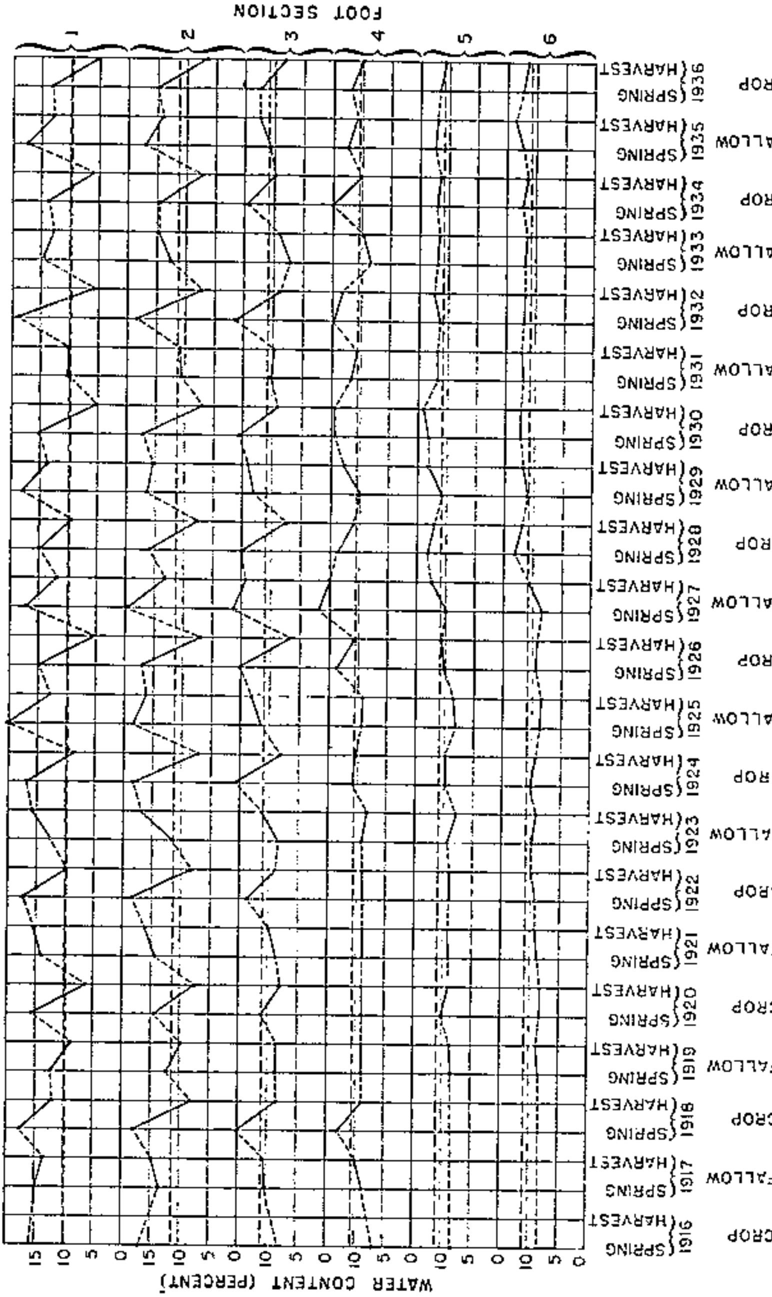

FIGURE 2.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot C, Havre, Mont., cropped to spring wheat in even years and fallowed in odd years, 1916–36. The wilting coefficient of each foot section of soil is indicated by a broken line.

mined to a depth of 6 feet, as moisture changes occurred to greater depths than on the continuously cropped plot. Figure 2 represents the soil-moisture history of plot C. This plot was cropped in even years, and was fallowed in the odd years. The diagram of the companion plot D is not presented because the pattern is much the same.

The most striking feature shown by figure 2 in comparison with figure 1 is the increased functioning of the third and the fourth foot sections of soil brought about by fallowing. Instead of having available moisture present in only half of the years, the third foot of soil was wet practically every crop year, though not always completely filled with water. The average reduction in water content between the spring and harvest samplings for plots C and D was 6.3 percent, as compared with only 2.0 percent for the continuously cropped plot.

TABLE 3.—*Water content in the spring and at harvesttime, and the wilting coefficient of the soil on plot C at Havre, Mont., fallowed in odd years and cropped to spring wheat in even years, 1916–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1916	1917		1918		1919		1920		1921		1922		1923		1924		1925		
		Spring	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
1	9.7	16.0	14.8	13.4	17.9	12.0	12.3	8.4	15.7	6.1	14.1	15.4	17.3	9.7	12.7	15.9	16.7	8.9	20.3	12.8	
2	11.3	17.0	13.6	14.8	17.9	8.0	12.2	9.6	14.3	7.4	14.4	16.2	18.5	8.1	11.4	16.7	18.1	7.1	18.5	16.2	
3	10.8	8.0	10.2	10.4	15.5	8.4	8.6	8.7	11.0	7.8	8.5	9.9	13.8	8.9	8.4	11.1	15.8	8.1	11.4	13.1	
4	10.5	7.1	8.6	9.8	13.0	8.7	8.9	8.8	8.9	9.1	8.9	9.0	8.9	9.2	9.3	8.1	10.9	10.3	9.4	9.1	
5	10.7	8.1	------	------	8.5	------	8.3	8.7	10.2	8.9	8.9	9.3	8.9	8.8	9.4	7.7	9.7	9.7	8.1	8.5	
6	10.9	8.4	------	------	8.4	------	8.4	8.8	8.4	8.3	8.7	9.3	9.4	9.9	9.9	9.2	10.2	9.3	8.6	8.5	

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.7	14.8	5.2	17.1	11.8	15.0	9.5	18.3	13.6	15.1	5.1	10.3	10.4	19.3	5.9	14.9	12.9	13.9	6.0	17.5	12.9	13.1	5.0
2	11.3	17.2	7.0	19.7	13.1	15.9	7.5	16.6	15.6	17.3	6.9	10.6	10.8	18.5	7.2	12.6	14.7	14.8	7.4	17.0	13.9	14.9	6.4
3	10.8	15.1	6.6	17.5	14.3	15.2	7.5	13.3	14.1	15.7	9.2	10.2	9.7	16.5	8.7	7.2	8.8	14.5	9.9	10.6	12.5	12.2	8.0
4	10.5	13.7	10.7	16.8	15.0	13.9	11.1	9.9	12.7	14.6	14.4	11.5	10.5	14.9	13.4	8.5	9.7	15.0	10.3	12.4	10.9	12.0	9.9
5	10.7	10.1	10.6	9.9	12.4	13.3	12.1	10.7	13.0	13.2	14.0	11.6	11.6	11.3	12.3	11.7	11.5	12.0	11.5	12.4	12.0	11.6	10.5
6	10.9	9.5	9.3	8.4	10.5	13.1	11.8	10.8	11.8	12.4	12.4	11.9	12.2	12.0	11.7	11.9	11.4	12.3	11.2	12.2	13.7	12.4	11.2

TABLE 4.—*Water content in the spring and at harvesttime, and the wilting coefficient of the soil on plot D at Havre, Mont., fallowed in even years and cropped to spring wheat in odd years, 1916–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																		
		1916	1917		1918		1919		1920		1921		1922		1923		1924		1925	
		Spring	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.0	17.1	16.5	7.3	17.6	9.6	12.0	6.2	13.0	13.4	14.4	8.8	16.6	16.0	15.3	6.4	19.4	12.4	21.6	8.4
2	11.2	14.6	17.2	7.3	16.4	8.7	12.8	7.1	15.9	16.8	18.2	8.1	16.9	17.7	16.0	7.2	17.4	15.6	18.5	7.2
3	10.6	11.3	17.2	10.0	14.3	11.9	11.7	9.3	10.2	13.3	14.3	8.3	9.6	11.7	10.9	7.3	9.4	10.0	15.7	7.7
4	10.7	7.3	14.7	12.4	12.8	13.0	11.1	10.7	7.5	9.4	9.8	10.2	8.2	8.5	9.1	7.9	7.9	7.5	9.3	9.6
5	10.8	8.1	12.9	13.0	11.7	------	10.6	10.0	10.4	11.3	9.3	11.1	9.7	9.9	10.0	8.9	9.6	8.5	8.9	9.6
6	10.5	8.6	9.9	9.4	9.3	------	8.9	8.7	10.6	11.1	9.7	10.8	10.4	10.4	10.6	8.7	9.7	9.8	9.8	9.2

Depth (feet)	Wilting coefficient	Moisture content of soil																				
		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.0	13.9	11.6	18.0	3.3	12.1	16.5	17.5	4.2	12.7	9.3	11.1	8.4	20.7	14.1	15.6	6.1	16.8	14.3	18.0	7.0	8.3	5.4
2	11.2	15.6	13.4	19.0	5.7	12.4	15.4	18.0	5.6	12.6	14.3	12.7	9.4	20.2	15.0	18.8	7.7	18.3	16.2	17.3	6.9	8.4	8.2
3	10.6	9.5	10.1	18.7	5.0	9.0	13.4	17.3	6.8	8.6	9.6	11.0	10.6	12.0	13.1	15.7	8.8	14.3	14.3	14.4	9.2	7.7	8.1
4	10.7	9.3	8.4	17.2	8.6	10.4	10.6	14.7	10.3	10.5	9.5	11.2	11.5	9.9	10.3	11.7	11.4	10.3	11.4	12.8	12.8	8.3	7.8
5	10.8	9.2	9.0	10.4	12.5	11.0	11.1	10.9	11.9	12.2	10.8	11.7	11.3	10.2	10.6	12.7	11.1	9.8	9.7	11.6	12.3	10.1	9.9
6	10.5	9.0	9.2	9.5	13.9	10.4	10.6	9.6	11.1	12.3	10.9	11.6	12.2	9.7	11.0	10.4	10.7	10.8	10.3	11.6	11.9	10.2	10.0

On fallowed land the fourth foot of soil provided almost as much water as the third foot of continuously cropped land. It held available water more frequently, but the growing crop was not always able to obtain all of this moisture.

The fifth and sixth foot sections of soil contributed practically no water to wheat. On plot C these two foot sections of soil were dry under the original sod cover and remained dry until 1927. The high rainfall of that year moistened the soil to a depth of at least 6 feet. The soil in these two foot sections has remained moist ever since. In two years, 1934 and 1936, severe drought caused nearly complete failure of the wheat crop on fallowed land. In spite of the need, wheat was unable to reduce the moisture content of the soil at this depth below the wilting point. It is evident that in this soil, wheat is seldom or never able to reduce the fifth and sixth foot sections of soil to a moisture content as low as that under native sod.

It will be noted that in the fourth, fifth, and sixth foot sections a reduction in water content sometimes continued after harvest, as evidenced in the data here presented by a lower water content the following spring. Water reduction at these depths may have been due to weeds in the stubble. The weeds, because of their longer period of growth, were able to remove a small quantity of water that wheat could not get. Even the weeds were unable to reduce the water content to a point comparable with that under the original sod. Evidently the deep-rooted perennials in native sod are able to remove water from the fifth and sixth foot sections to a point not reached by annual crops or weeds.

On the continuously cropped plot there was no infiltration of water beyond the reach of crop roots during the 21 years. On the alternately fallowed plot there was a slight infiltration of water into the fifth and sixth foot sections in 1927. It is doubtful whether the infiltration even in 1927 was beyond the depth of penetration of the deeper-rooted plants present in native sod.

RESULTS AT MANDAN, N. DAK.

The soil in the main field at Mandan is a fine sandy loam, resulting from alluvial deposits on a postglacial terrace. This soil has a high infiltration rate and readily absorbs all the water from ordinary rains. The soil in the south field is a silty clay loam resulting from erosion of glacial deposits. It is a heavy soil, and the surface slope is greater than that in the main field. The wide difference in the character of the two soils is shown by a comparison of their wilting coefficients. 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 in the main field at Mandan as Cheyenne fine sandy loam and that in the south field as Grail silty clay loam. A more detailed description of these soils together with a mechanical analysis and other data are set forth in an earlier publication.[4]

The soil in both fields is variable in the lower depths, particularly on certain plots, and little dependence can be placed on small apparent differences in moisture content at these depths.

[4] THYSELL, J. C. CONSERVATION AND USE OF SOIL MOISTURE AT MANDAN, N. DAK. U. S. Dept. Agr. Tech. Bull. 617, 40 pp., illus. 1938.

Ground water in sheet form probably underlies the area. Wells near the main field and in the pasture 2 miles south show that the depth of this water table is more than 300 feet.

The plots in both fields are on land that was broken and farmed for a few years and then allowed to return to grass. In 1913 the general appearance was that of undisturbed native sod. Both fields were broken in the spring or early summer of 1913, and were cropped in 1914.

The plots selected for study on both fields were the same as those selected at Havre. Plot A was continuously cropped to wheat on spring plowing; plots C and D were alternately cropped and fallowed. Plot C was fallowed in odd years and cropped in even years; plot D was fallowed in even years and cropped in odd years. In addition, data are presented from a lightly grazed native pasture. The soil in the pasture was much the same as that in the south field.

Table 5 and figure 3 show the moisture content of plot A of the main field from 1915 to 1936. It will be noted that the soil in this plot was wet to a depth of 6 feet in 1915. The exceedingly heavy precipitation of 1914 and 1915 was responsible. The precipitation at Bismarck for each of these years exceeded that for any other year from 1877 to 1936. More than 10 inches of rain fell in June 1914, most of which fell slowly enough so that it was absorbed, and it wet the soil thoroughly to a depth of more than 6 feet. The water from the upper foot sections was removed by the wheat crop before harvest, but the fourth, fifth, and sixth foot sections remained wet. The heavy rainfall of 1915 again wet the soil thoroughly to a depth of more than 6 feet. All the available water from the fifth and sixth foot sections was not removed until 1919. Since that time they have remained almost continuously dry. It seems safe to say that since the subsoil became dry in 1919 no measurable quantity of water has penetrated to a depth greater than 6 feet.

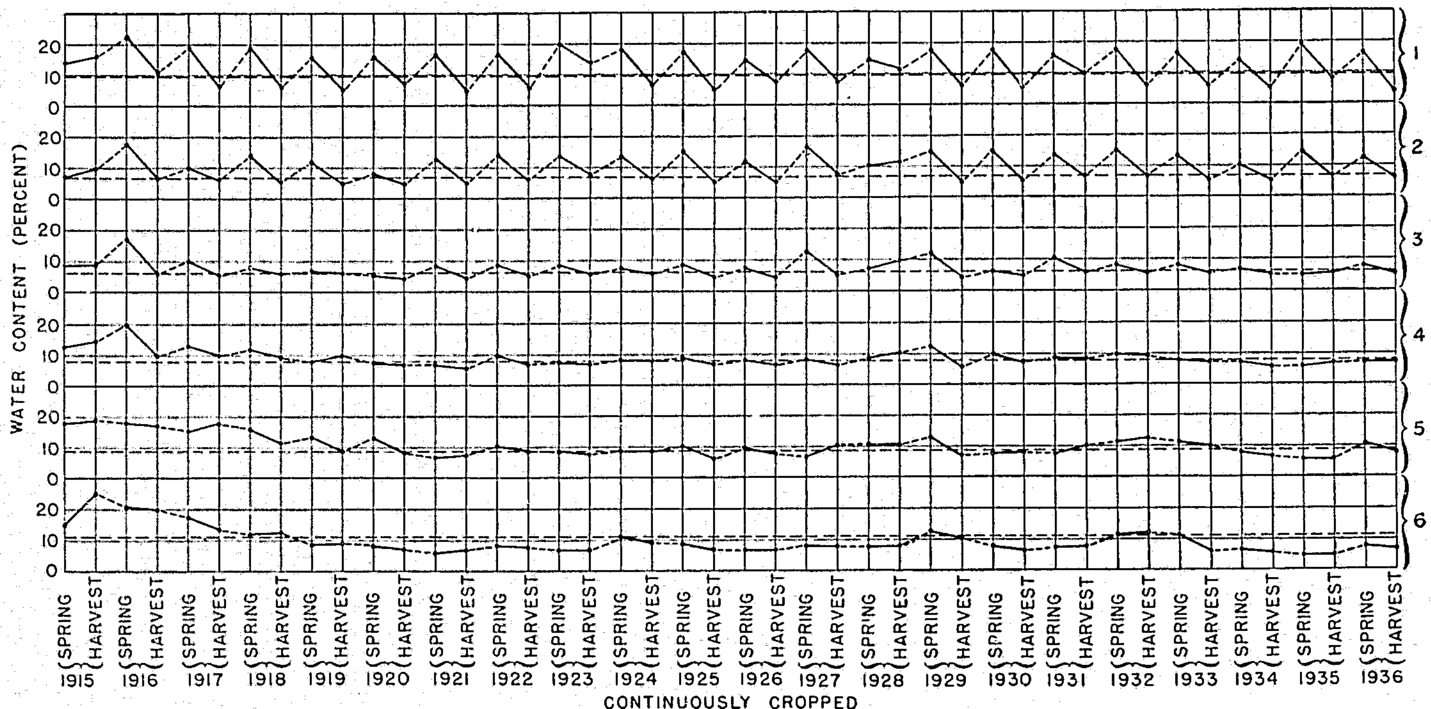

FIGURE 3.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot A in the main field at Mandan, N. Dak., continuously cropped to spring wheat, 1915–36. The wilting coefficient of each foot section of soil is indicated by a broken line.

TABLE 5.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot A in the main field at Mandan, N. Dak., continuously cropped to spring wheat, 1915–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924		1925	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.6	14.3	15.8	22.5	10.9	18.8	6.5	19.3	5.9	15.6	4.8	15.4	7.4	16.7	5.1	17.0	6.3	19.9	14.0	18.4	6.8	17.4	5.0
2	7.0	7.3	9.9	18.3	6.8	10.2	5.9	13.9	5.4	12.0	4.9	7.9	4.8	13.1	5.2	14 0	5.8	14.3	7.9	14.1	6.6	15.4	5.6
3	6.6	8.6	9.3	17.5	6.3	10.0	5.6	7.9	5.7	6.8	5.8	5.4	4.5	8.7	4.6	9.0	5.6	9.2	6.2	7.8	6.1	9.1	5.2
4	8.2	12.6	14.6	10.7	9.8	12.9	10.2	12.2	9.4	7.8	9.7	7.4	6.8	6.9	6.3	9.9	6.8	7.9	7.3	8.6	8.6	8.8	7.1
5	9.2	18.3	19.0	18.3	16.7	15.4	18.3	15.9	11.5	13.4	9.3	12.9	8.5	6.9	7.9	10.6	9.1	8.7	7.9	9.2	9.0	10.4	6.4
6	10.8	15.1	25.1	21.3	20.0	17.5	13.6	12.2	12.5	8.6	9.2	8.4	6.9	6.2	6.7	8.4	8.0	7.0	7.1	10.9	9.6	8.7	7.3
7	3.4	....	....	11.1	7.5	7.3	6.0	18.1	-----	4.6	4.9	5.6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
8	7.0	....	....	14.9	17.3	12.8	17.0	19.3	-----	16.2	14.6	10.4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
9	10.6	....	....	25.2	27.2	24.9	25.9	25.5	-----	22.5	23.8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
10	12.3	....	....	20.6	24.6	28.8	29.2	30.6	-----	24.0	28.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.6	14.7	7.7	18.2	7.9	14.8	12.3	18.2	7.2	18.3	5.7	16.5	10.5	18.0	6.3	16.5	5.7	13.8	4.9	18.9	8.3	16.0	3.3
2	7.0	12.3	5.5	17.0	8.3	11.1	12.1	15.6	5.6	15.5	5.5	14.3	7.0	15.6	6.9	13.5	5.5	9.9	4.8	15.0	6.4	12.3	5.7
3	6.6	8.0	5.0	13.3	6.1	7.9	10.2	11.5	4.8	7.2	5.1	10.4	5.7	8.4	5.8	7.9	5.4	6.7	4.9	4.8	5.5	7.6	5.0
4	8.2	8.6	6.7	8.5	7.0	8.8	10.8	12.7	5.8	9.7	7.6	9.0	8.4	10.2	9.4	8.3	7.6	7.0	5.4	5.9	7.1	7.0	7.2
5	9.2	10.2	8.0	7.5	11.0	10.7	10.8	13.4	7.6	8.3	8.6	7.9	10.5	11.5	13.1	10.8	10.0	8.1	6.8	6.5	6.1	10.4	8.0
6	10.8	6.7	7.0	8.6	8.2	8.2	8.6	12.4	10.6	7.7	7.3	7.9	7.7	11.4	11.9	11.0	6.3	6.6	6.2	5.0	5.0	7.8	6.9

Both the first and the second feet of soil were wet to a point above the wilting coefficient in the spring of every year. Except in a few years they were reduced to below the wilting point at harvesttime. The third foot was wet above the wilting point in nearly every year, but in only 2 years was the moisture content high enough to indicate that the soil was filled with water. In most years the quantity of water contributed to the crop by this foot section was very small and may have been limited to the upper portion of it. The fourth foot, with a few possible exceptions, apparently remained continuously dry from 1919 to 1936. In a few cases a moisture content above the wilting point was recorded, but these may have been due to the experimental error of determinations in the lower foot sections due to lack of uniformity of the soil.

The only case of any material quantity of water moving into the fifth and the sixth foot sections was in 1914 and 1915. The unprecedently heavy rainfall of these 2 years was not duplicated during the period from 1877 to 1936. It appears apparent that only once in 30 or 40 years does water in continuously cropped wheatland penetrate more than 6 feet. The most nearly comparable pair of years in the period from 1877 to 1936 was 1878 and 1879, and the total rainfall for these 2 years was more than 5 inches lower than the rainfall for 1914 and 1915.

Tables 6 and 7 show the soil moisture changes of plots C and D of the main field for the period 1915–36, and figure 4 presents the changes in plot C for that period.

Fallowing permitted the water to penetrate to a depth of at least 4 feet in almost every crop year, and in most cases this was removed or nearly removed by harvesttime. The water content of the fifth and the sixth foot sections of soil remained almost continuously above the wilting coefficient. Wheat used some of this moisture at times, but evidently the quantity of water that could be used from these depths was small. Even in dry years considerable available moisture usually remained in these foot sections. In fact, there was little difference in moisture content of the fifth and sixth foot sections following drought-injured crops and following good crops. Evidently moisture that penetrates into these foot sections is not available to spring wheat except under unusual conditions. It appears likely that with alternate fallow there is some loss of water by infiltration to depths beyond the reach of spring wheat.

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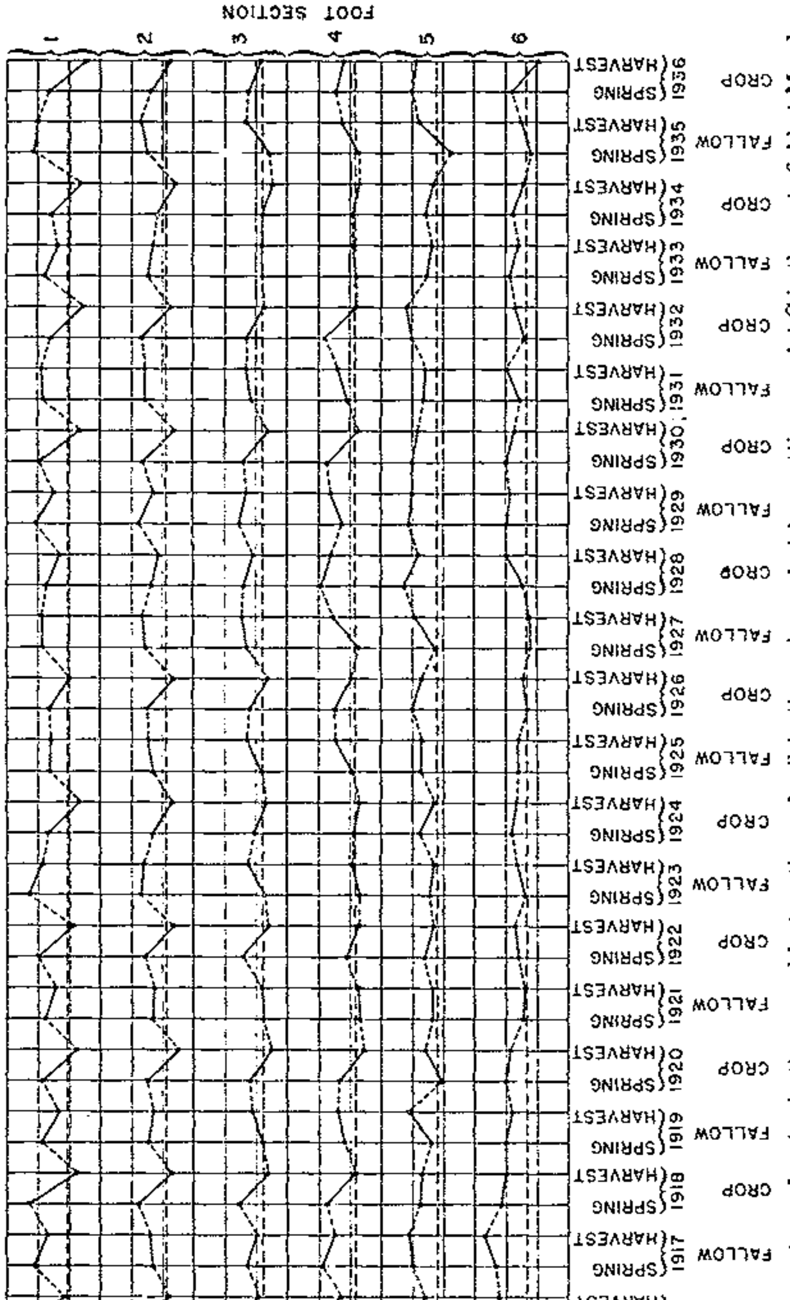

FIGURE 4.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot C in the main field at Mandan, N. Dak., cropped to spring wheat in even years and fallowed in odd years, 1915–36. The wilting coefficient of each foot section of soil is indicated by a broken line.

TABLE 6.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot C in the main field at Mandan, N. Dak., fallowed in odd years and cropped in even years, 1915–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924		1925	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.4	14.4	22.8	24.3	11.6	20.8	16.7	22.7	7.4	18.5	13.5	19.1	7.9	17.8	14.4	19.9	9.0	22.4	18.9	16.9	7.3	16.5	16.5
2	8.8	8.8	17.9	21.1	7.8	13.2	14.1	17.7	6.7	14.6	13.0	14.8	5.3	13.4	12.8	16.0	6.4	16.9	15.8	13.5	6.8	12.7	15.2
3	7.9	10.0	13.7	19.9	9.5	13.3	9.9	15.6	5.9	8.3	11.2	11.7	4.7	8.3	8.5	14.4	5.7	7.6	12.5	10.6	6.8	7.9	13.1
4	8.4	13.1	16.9	22.3	12.9	18.8	15.1	17.7	8.4	11.7	13.9	13.5	5.4	7.2	7.5	10.7	6.9	6.7	9.2	9.2	6.9	9.2	14.7
5	12.3	18.1	24.6	23.6	16.3	20.1	21.7	17.6	16.7	13.4	21.1	10.4	15.7	13.5	13.6	15.7	13.1	14.5	12.9	17.7	13.0	17.2	16.9
6	13.6	19.2	26.7	23.7	21.9	23.1	25.7	21.5	20.3	20.2	18.2	20.1	18.5	14.8	13.7	15.8	16.9	13.8	16.3	18.2	16.3	16.3	16.2
7	5.4	------	------	14.4	16.0	16.8	17.5	12.6	------	13.4	14.3	16.7	------	------	------	------	------	------	------	------	------	------	------
8	6.0	------	------	13.3	14.4	7.3	9.7	8.1	------	9.6	11.8	11.9	------	------	------	------	------	------	------	------	------	------	------
9	10.3	------	------	25.4	24.0	22.5	22.9	16.6	------	15.5	19.1	------	------	------	------	------	------	------	------	------	------	------	------
10	13.6	------	------	20.1	31.2	25.2	31.0	25.8	------	24.2	27.8	------	------	------	------	------	------	------	------	------	------	------	------

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.4	16.4	10.2	18.7	19.4	17.5	13.6	21.3	15.5	20.3	6.4	18.9	19.1	16.5	6.3	18.0	14.2	16.1	5.9	20.9	20.1	16.4	4.9
2	8.8	15.0	6.6	15.9	17.3	14.2	11.5	18.0	13.6	17.0	6.3	15.7	15.6	16.7	7.4	14.7	12.8	12.0	5.8	15.1	16.7	13.4	7.5
3	7.9	11.8	6.3	12.8	15.0	14.3	10.8	15.5	13.0	14.1	5.9	12.0	12.8	12.9	7.4	7.8	8.6	7.9	5.3	5.4	12.8	12.1	8.3
4	8.4	14.8	9.5	7.0	15.5	19.5	15.7	12.5	15.8	17.6	7.6	11.1	13.8	17.8	8.0	8.1	9.2	9.1	7.0	6.8	12.4	14.3	11.8
5	12.3	20.2	17.1	12.6	19.0	22.4	18.0	21.2	19.8	20.0	18.0	16.5	15.6	20.3	21.6	14.8	13.5	15.5	13.0	7.4	17.9	20.0	18.3
6	13.6	12.9	14.4	12.2	12.5	14.4	20.0	19.7	19.0	20.0	17.6	15.5	19.4	14.6	16.7	18.8	16.2	16.7	14.4	12.1	15.3	17.9	9.9

TABLE 7.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot D in the main field at Mandan, N. Dak., fallowed in even years and cropped in odd years, 1915–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924		1925	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.7	17.0	17.6	26.0	19.8	22.6	7.9	21.1	17.6	20.6	5.1	16.8	15.5	17.7	5.8	19.3	18.0	20.7	17.6	21.3	18.0	17.1	5.9
2	8.3	14.5	10.2	20.5	14.9	16.8	6.5	14.9	13.6	17.6	5.6	6.6	9.8	13.6	5.4	14.2	14.1	16.8	9.6	11.2	14.5	13.4	6.0
3	6.6	13.3	9.3	20.0	12.4	12.9	6.0	6.6	11.0	14.5	5.4	5.3	5.8	9.4	5.0	8.0	9.2	13.0	5.9	6.0	12.4	13.1	5.2
4	8.3	16.7	13.3	17.4	16.3	15.6	9.6	10.8	12.0	11.9	7.0	8.6	10.9	10.3	5.5	9.3	7.5	11.1	8.6	7.7	13.5	14.6	5.8
5	10.7	21.1	18.3	21.6	22.2	17.7	15.7	20.5	17.1	16.6	18.6	15.5	19.4	17.3	14.4	13.6	13.1	11.7	14.5	13.3	17.4	17.3	10.3
6	14.0	26.2	26.5	26.7	24.4	25.3	24.3	23.1	24.0	25.7	18.6	24.8	23.5	20.7	13.9	13.8	14.4	17.4	15.8	16.9	20.2	19.5	20.5
7	5.6	.....	.....	14.1	16.9	15.4	17.4	15.0	.....	11.6	16.2	10.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	4.5	.....	.....	8.0	9.5	7.8	8.7	7.5	.....	6.7	9.6	6.9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	9.4	.....	.....	23.5	16.6	21.9	18.9	18.4	.....	22.3	24.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	12.7	.....	.....	28.3	24.7	28.3	28.5	26.9	.....	23.1	27.9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.7	13.9	14.7	19.1	7.1	14.5	17.9	19.4	7.9	18.2	15.3	17.7	10.5	17.1	17.6	17.4	6.8	14.9	12.2	19.7	10.2	17.1	3.9
2	8.3	10.0	8.7	16.2	8.3	9.7	15.6	16.2	6.0	13.9	13.3	14.8	7.3	14.1	13.2	14.4	6.2	9.9	6.7	10.4	7.6	14.5	8.2
3	6.6	6.8	5.7	14.5	5.2	6.2	13.2	12.4	5.3	6.2	10.9	11.0	6.8	7.1	14.0	12.5	6.1	5.7	6.2	6.0	8.0	8.5	6.9
4	8.3	8.1	6.5	11.2	6.6	6.7	15.4	15.2	8.3	8.4	10.0	12.1	9.0	7.2	13.1	15.1	7.3	7.4	7.3	8.5	10.0	9.2	7.5
5	10.7	12.7	17.7	15.1	10.7	14.2	21.2	16.7	14.5	17.8	19.1	19.1	15.8	12.2	22.5	18.7	17.6	12.2	13.1	12.5	19.7	14.7	14.2
6	14.0	9.3	16.4	17.8	15.9	12.4	22.7	22.4	20.6	17.8	20.8	19.8	20.1	13.6	19.9	23.0	15.8	15.3	14.3	18.3	20.7	14.3	16.2

Table 8 and figure 5 present the moisture data of plot A of spring wheat in the south field. This plot evidently contained available moisture to a depth of at least 5 feet in 1915. The available moisture in the fifth foot was not all removed until 1920. There is no clear-cut evidence that available moisture has been present in the sixth foot of soil at any time during the 21-year period.

The shallowness of water penetration brought about by the heavy soil is evidenced by figure 5. The first foot shows water above the wilting coefficient in all years except 1921. Precipitation records indicate that water was present that year earlier in the season, but not at the time the first determination was made, which was in early June. In all but 4 years the water content of the first foot section was below the wilting point at harvesttime. In three of these years the water content of the soil was undoubtedly below the wilting point before harvesttime, but the moisture supply was replenished by rains shortly in advance of that time. In 1915, a year of heavy summer rains, the water content of the first foot of soil probably remained above the wilting point throughout the growing season.

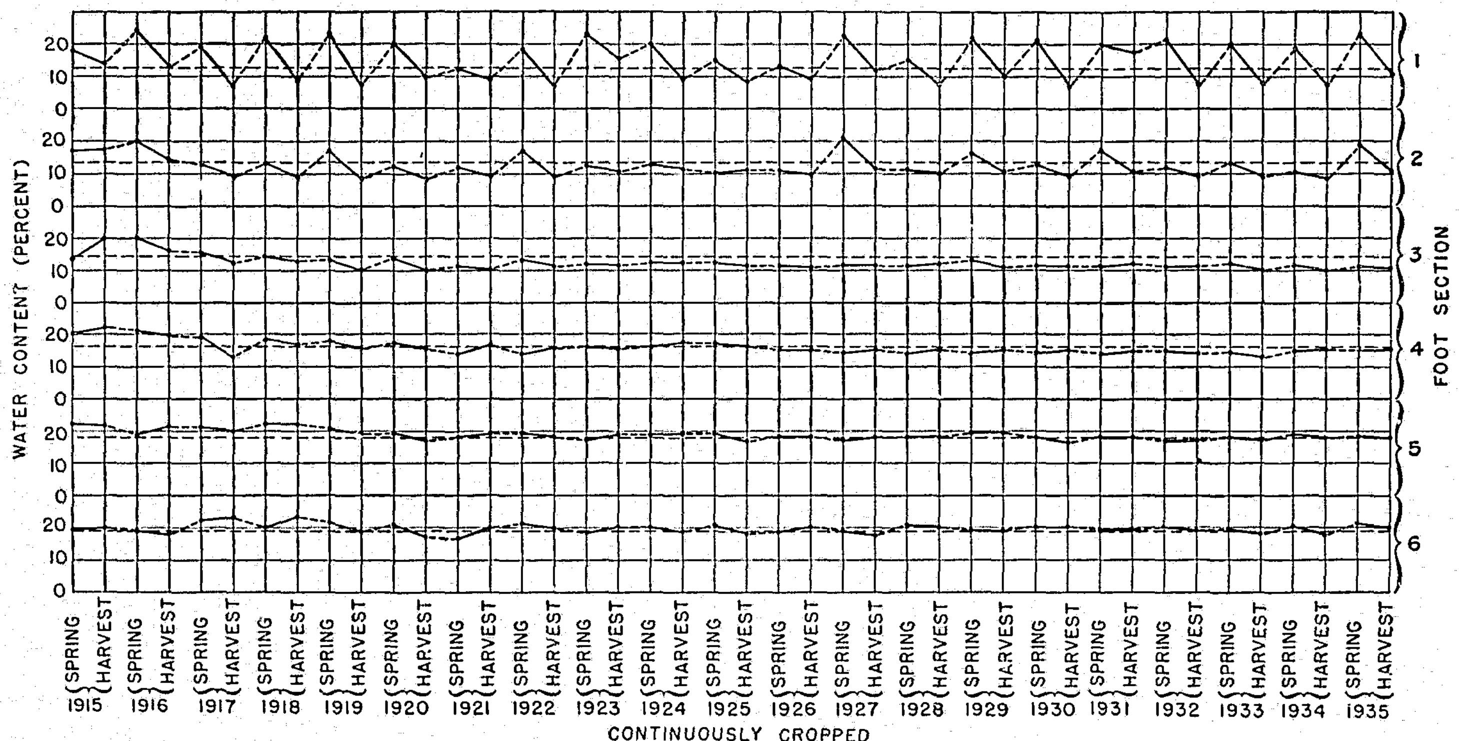

FIGURE 5.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot A in the south field at Mandan, N. Dak., continuously cropped to spring wheat, 1915–35. The wilting coefficient of each foot section of soil is indicated by a broken line.

TABLE 8.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot A in the south field at Mandan, N. Dak., continuously planted to spring wheat, 1915–35*

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924		1925	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	12.6	18.0	14.2	24.5	12.8	18.9	7.2	21.8	8.7	23.3	6.7	19.8	9.6	11.9	9.1	18.4	7.3	22.8	15.5	20.1	8.7	15.3	7.9
2	13.4	16.8	17.6	20.3	14.5	12.6	8.7	13.3	8.9	17.2	8.4	11.7	7.8	11.6	9.1	16.7	8.9	12.0	10.6	12.6	10.8	10.3	10.6
3	14.6	13.5	19.7	20.1	16.1	15.5	12.0	14.2	12.4	13.1	10.1	13.5	10.0	10.5	10.1	12.7	10.8	11.4	10.9	11.8	11.8	11.7	11.1
4	16.6	20.5	21.8	20.7	19.6	19.0	12.7	18.5	17.2	18.0	15.6	17.5	15.3	14.1	16.5	14.0	15.4	15.9	15.6	16.1	17.4	16.7	15.8
5	18.2	21.7	21.5	19.2	20.9	21.0	20.1	21.8	21.8	20.6	18.7	19.0	16.9	18.3	19.2	19.2	18.3	17.0	19.0	18.4	19.2	19.1	16.5
6	19.0	19.4	19.7	19.3	17.8	22.1	23.1	20.2	22.8	21.4	19.0	20.4	17.3	16.6	19.7	20.8	19.6	18.5	20.1	20.2	18.6	20.6	17.7
7	-----	-----	-----	21.0	19.0	22.5	21.8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
8	-----	-----	-----	20.9	21.2	20.6	21.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
9	-----	-----	-----	21.4	20.8	20.2	22.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
10	-----	-----	-----	19.5	19.5	21.5	22.9	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	12.6	12.8	9.1	22.6	11.6	14.8	7.4	21.6	10.3	21.0	7.1	20.2	17.6	21.5	7.4	19.9	8.3	19.3	7.6	23.4	10.9
2	13.4	10.6	9.4	20.5	10.7	10.6	10.3	16.3	10.6	11.8	9.0	16.7	10.6	11.8	9.1	13.4	9.6	10.5	8.4	18.9	11.1
3	14.6	11.1	10.6	11.0	11.2	11.0	12.0	12.4	10.6	10.9	10.9	11.0	11.9	11.1	11.1	12.0	10.1	11.5	9.7	10.9	10.4
4	16.6	15.2	15.2	14.2	15.0	14.0	15.0	14.2	14.9	14.1	15.0	13.9	15.3	14.7	13.8	14.6	13.3	15.3	15.6	14.8	15.4
5	18.2	17.8	17.9	17.2	17.8	18.2	17.8	19.0	19.0	17.9	16.3	17.9	17.9	17.2	17.1	17.9	17.0	18.9	18.1	18.6	17.9
6	19.0	18.5	20.0	18.8	17.6	20.5	20.2	18.9	19.0	19.7	19.8	19.6	19.5	19.8	18.9	19.4	17.7	20.4	18.0	20.8	20.3

In more than half of the years the water content of the second foot of soil did not reach the wilting point, and in several of these years there was apparently no available water present. This is in striking contrast to the continuously cropped plot on the lighter soil of the main field where water above the wilting point was present in the second foot every year.

Water seldom penetrated to a depth greater than 2 feet after the year 1915. The water content of the third foot of soil did not reach the wilting coefficient during the 18-year period, 1918–35. In only 1 year after 1917 did this foot of soil contribute as much as 0.5 inch of water to the wheat crop.

Since the functioning depth of soil is usually limited to 2 feet, and since the sixth foot of soil did not become wet during the unusually wet years of 1914 and 1915, it can be safely stated that no infiltration of water to depths not reached by wheat roots is likely to occur in the heavy soil of the south field under continuous wheat production.

Tables 9 and 10 show the history of the water content of the soil of plots C and D that were alternately cropped and fallowed. Figure 6 diagrams the moisture content of plot C. After the year 1922 moisture determinations were not made on the plot during the year it was fallowed.

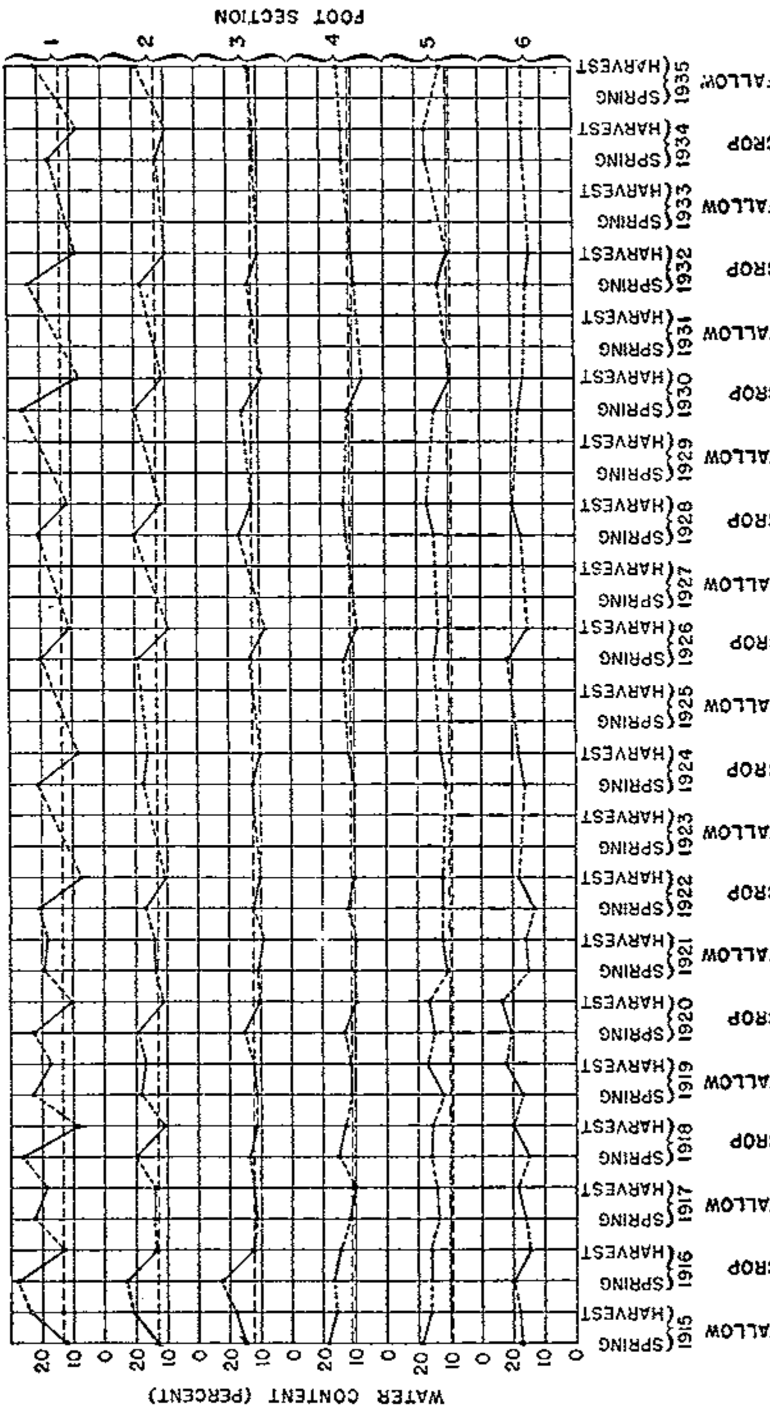

FIGURE 6.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot C in the south field at Mandan, N. Dak., cropped to spring wheat in even years and fallowed in odd years, 1915–35. The wilting coefficient of each foot section of soil is indicated by a broken line.

TABLE 9.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot C in the south field at Mandan, N. Dak., fallowed in odd years and cropped in even years indicated, 1915–35*

Depth (feet)	Wilting coefficient	Moisture content of soil															
		1915		1916		1917		1918		1919		1920		1921		1922	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	13.4	12.6	24.0	28.0	13.3	21.8	18.6	26.1	8.9	22.4	16.9	22.5	10.6	19.1	17.8	20.4	7.6
2	13.2	12.8	21.3	23.0	13.4	14.0	14.0	19.9	11.0	17.9	16.7	19.6	11.0	14.0	14.1	16.8	10.5
3	12.1	15.0	18.3	22.7	12.1	11.2	11.7	13.4	10.9	11.2	11.9	15.3	9.7	10.5	9.0	11.7	10.1
4	10.8	18.5	15.6	16.6	14.6	11.7	10.3	14.9	13.1	10.8	11.3	13.0	9.5	9.7	9.4	12.0	10.6
5	9.6	19.1	16.0	15.8	15.7	13.6	14.6	16.0	15.4	12.2	17.0	14.9	16.6	10.6	12.3	12.0	12.1
6	10.1	17.5	18.0	19.8	14.6	16.3	18.5	15.1	19.8	17.1	21.7	20.5	23.0	15.3	15.5	12.9	18.2
7				20.3	17.8	18.5	20.1										
8				18.7	16.1	17.8	16.2										
9				20.5	18.5	21.3	21.4										
10				23.0	22.3	22.6	23.7										

Depth (feet)	Wilting coefficient	Moisture content of soil													
		1924		1926		1928		1930		1932		1934		1935	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	13.4	21.0	8.4	20.2	10.8	21.0	11.4	26.0	8.2	23.9	8.9	16.7	7.9		21.3
2	13.2	17.6	16.3	19.2	9.4	20.1	11.8	19.8	10.7	17.7	10.0	12.4	9.4		18.7
3	12.1	12.0	10.1	13.3	8.0	16.1	12.2	15.0	9.2	12.8	9.9	11.0	10.8		13.1
4	10.8	10.1	11.6	12.7	8.8	12.0	12.5	10.7	6.7	9.5	9.9	13.0	12.8		14.6
5	9.6	11.1	12.6	14.4	13.2	14.6	16.6	13.7	8.9	13.2	9.8	16.4	16.5		11.7
6	10.1	15.8	17.7	20.8	14.8	16.8	19.4	17.4	16.2	14.8	14.0	16.3	16.2		15.4

TABLE 10.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot D in the south field at Mandan, N. Dak., fallowed in even years and cropped in odd years indicated, 1915–35*

Depth (feet)	Wilting coefficient	Moisture content of soil													
		1915		1916		1917		1918		1919		1920		1921	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	13.8	21.5	18.4	28.0	23.2	24.9	10.8	26.1	19.5	26.9	7.2	23.5	22.7	14.2	8.1
2	13.8	19.2	17.2	21.8	21.0	21.5	10.4	16.8	14.6	21.5	9.0	13.5	15.9	14.3	9.6
3	12.8	17.4	14.3	19.6	19.0	19.7	11.1	11.4	9.9	13.3	8.6	10.6	9.3	10.5	9.2
4	12.1	15.3	15.7	16.3	14.0	17.0	11.2	10.6	11.8	10.6	7.8	9.5	8.1	8.1	8.7
5	11.0	16.7	15.6	15.9	16.0	16.8	15.2	13.5	14.2	12.8	10.1	9.7	7.7	12.1	9.1
6	11.5	18.6	17.0	14.0	18.7	17.3	16.0	14.5	17.1	15.9	14.4	11.7	8.8	14.2	12.2
7				16.2	17.7	19.7	20.0								
8				18.7	18.8	16.8	20.0								
9				15.6	20.3	20.1	21.6								
10				15.5	18.9	17.0	17.6								

Depth (feet)	Wilting coefficient	Moisture content of soil													
		1923		1925		1927		1929		1931		1933		1935	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	13.8	27.8	22.1	21.5	8.4	25.6	16.7	24.1	11.9	22.5	19.6	21.0	9.3	25.4	11.7
2	13.8	20.1	14.2	20.2	10.4	19.3	10.7	19.0	10.4	18.3	11.0	19.1	10.4	21.5	11.1
3	12.8	12.4	9.9	16.1	8.6	15.5	9.2	15.9	9.4	11.6	9.4	16.3	9.5	8.9	10.1
4	12.1	8.2	8.2	11.0	8.9	7.9	8.2	11.2	7.8	8.3	8.1	10.5	8.0	8.0	8.8
5	11.0	7.7	7.6	8.4	9.3	7.1	8.4	8.8	8.0	7.9	8.6	8.3	7.9	8.2	16.1
6	11.5	7.8	9.3	9.9	9.6	7.7	11.2	9.5	7.9	9.7	8.5	9.8	9.3	9.5	9.8

Under an alternate fallow and crop system the second foot section of soil was wet to capacity in almost every crop year. The third foot of soil contained some available water in most crop years, but seldom contained as much as it was capable of holding. The use of water in this foot section was much lower than in the second foot section.

Water penetrated into the fourth foot section of soil only intermittently and in limited quantities. It is doubtful whether this foot section was ever filled to capacity after the water that entered it in 1915 was removed. After the fourth foot section became dry in plot D in 1917 and in plot C in 1918, it is doubtful whether moisture ever penetrated through this foot section. It remained dry except for small additions of water from the surface. The soil in the fifth and sixth foot sections remained at an almost uniform moisture content, although some reduction took place in a very few cases. The extent of change in the moisture content of these foot sections is obscured by the high experimental error due to lack of uniformity of the soil at those depths. The soil below the depth of 4 feet apparently remained dry on plot D and moist on plot C. There is no evidence of infiltration of water to depths not reached by wheat roots, other than in the year 1915. It can be safely stated that water is lost from fallow by penetrating beyond the depth reached by wheat roots only in rare cases.

Comparison of the main and south fields brings out some interesting points. The water normally infiltrated to nearly as great a depth under continuous cropping in the light soil of the main field as it did under fallow in the heavier soil of the south field. Under an alternate fallow and crop system water use from the fifth foot section of soil in the main field was greater than from the fourth foot section in the south field.

Table 11 and figure 7 show the water changes in a lightly grazed, native sod pasture during the period 1916–36. Samples were taken several times during each season. For this study, one sample was selected each year during the spring period and one during the late summer or early fall, representing dates when the water content was approximately at the maximum and the minimum, respectively, for the season.

The dominating species of native grasses found in the pastures are described by Sarvis [5] as follows:

> The dominating species are *Bouteloa gracilis* (*B. oliogostachya*) and *Stipa comata*, which form a distinct association. This is an association composed of *Bouteloa gracilis* which is typical of the short-grass formation, and *Stipa comata*, which is a typical long-grass species. This association is dominated by the Bouteloa.

In addition to the principal grasses there are less abundant grasses of both the tall- and short-grass types. A considerable portion of the vegetation is made up of perennial forbs, including several species of *Artemisia*.

[5] SARVIS, J. T. COMPOSITION AND DENSITY OF THE NATIVE VEGETATION IN THE VICINITY OF THE NORTHERN GREAT PLAINS FIELD STATION. Jour. Agr. Research 19: 63–72, illus. 1920. (See p. 65.)

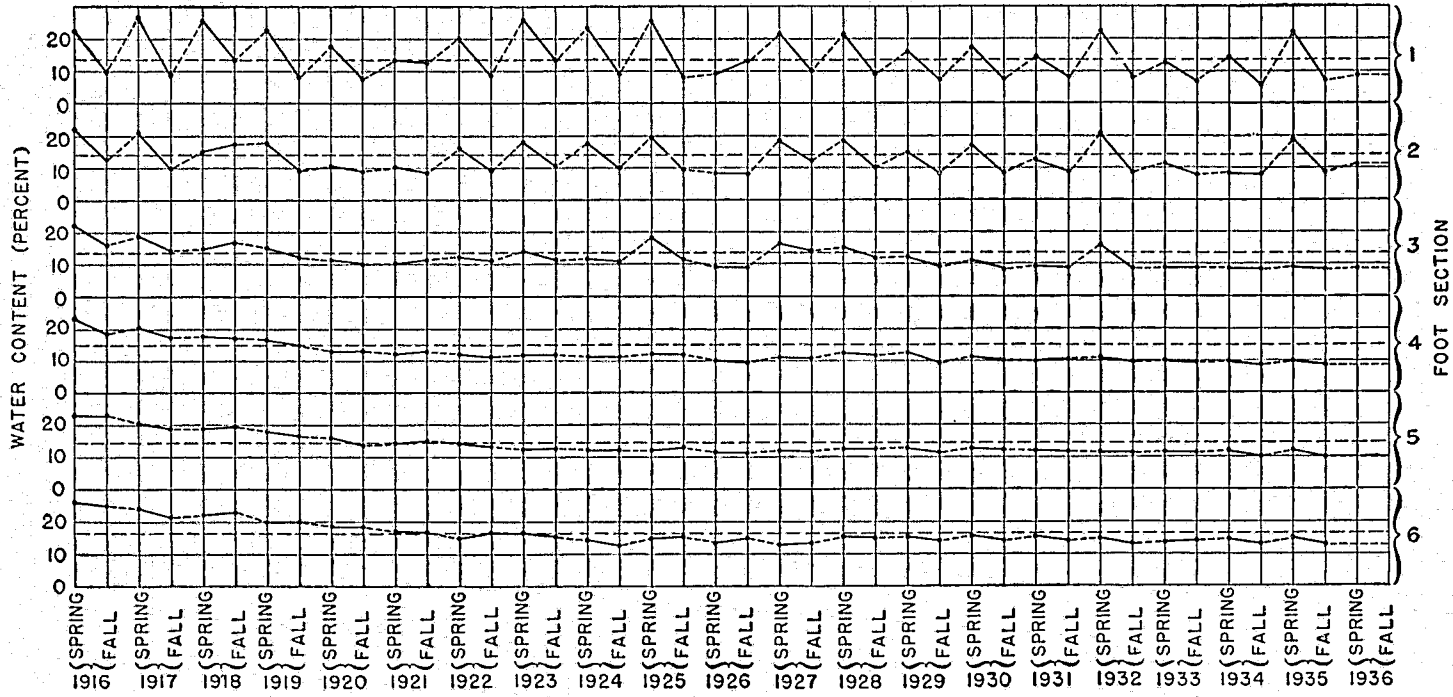

FIGURE 7.—Percentage of water in the several foot sections of soil in the spring and in the early fall on a lightly grazed native pasture at Mandan, N. Dak., 1916–36. The wilting coefficient of each foot section is indicated by a broken line.

TABLE 11.—*Water content in spring and fall and the wilting coefficient of the soil in a lightly grazed, native pasture at Mandan, N. Dak., 1916–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																					
		1916		1917		1918		1919		1920		1921		1922		1923		1924		1925		1926	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	13.6	21.7	10.0	26.4	8.7	25.4	13.4	22.5	8.2	17.4	7.6	12.7	12.1	19.7	8.6	25.7	12.3	22.8	9.0	25.6	8.0	9.2	12.9
2	13.9	22.2	12.5	21.3	9.9	15.4	17.4	17.8	9.5	10.5	8.9	10.1	8.5	15.9	9.2	18.2	10.1	17.8	9.8	19.5	9.4	8.3	7.9
3	13.5	21.8	16.0	18.9	14.5	15.3	16.8	15.1	11.8	10.9	10.3	10.1	11.0	12.0	10.6	13.0	10.5	11.6	10.4	17.8	11.3	8.8	9.1
4	14.8	22.7	18.7	20.4	17.4	17.7	17.6	17.1	14.9	13.1	12.7	11.8	12.7	12.2	11.1	11.9	11.5	10.9	11.1	12.3	11.7	9.8	9.6
5	14.6	23.3	21.8	20.4	19.2	18.7	19.6	18.0	16.5	15.9	13.6	14.2	15.0	14.5	13.1	12.1	12.3	12.2	12.0	11.5	12.5	11.2	10.9
6	16.7	26.0	24.7	23.7	21.2	21.9	23.2	19.9	19.8	18.6	18.6	16.7	16.7	14.7	16.6	16.3	15.2	14.5	12.4	14.5	14.7	13.5	15.0

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	13.6	20.9	9.8	20.8	9.1	16.3	7.6	17.4	7.4	14.3	8.5	22.4	8.5	13.3	7.5	14.5	6.3	21.7	7.7	9.0	------
2	13.9	18.4	12.3	18.4	10.0	15.0	7.9	17.0	8.3	12.5	8.9	20.9	8.7	11.3	8.1	8.5	8.1	19.1	8.8	10.7	------
3	13.5	16.0	13.5	15.0	11.5	11.8	8.7	10.4	8.2	9.4	9.3	16.3	8.9	8.8	8.7	8.7	8.2	9.3	8.5	9.2	------
4	14.8	11.0	10.5	12.2	11.5	12.5	9.4	10.9	10.0	10.0	10.5	10.7	10.2	9.8	9.5	9.9	8.6	9.9	9.1	------	------
5	14.6	11.4	11.1	12.3	11.9	12.5	11.2	12.0	11.7	11.5	11.4	11.5	11.0	11.5	10.9	11.6	10.1	11.7	10.2	------	------
6	16.7	12.6	13.2	15.1	14.6	15.2	13.6	15.4	13.5	14.7	13.7	15.1	13.3	13.4	13.8	14.5	13.3	14.7	12.8	------	------

The 100-acre pasture, from which moisture determinations were selected for this study, has not been grazed heavily enough to reduce the proportion of tall grasses or to increase the number or vigor of unpalatable plants. Its condition is described by Sarvis[6] as follows:

> The 100-acre pasture, which is grazed at the rate of one 2-year-old steer to 10 acres, has produced an abundance of feed each season that the experiment has been in progress. It has not been injured by overgrazing * * *.

The sod land was wet to a depth of 6 feet when first sampled in 1916. This is in contrast with plot A of wheat in the south field, which is located on a similar type of soil. Under continuous cropping with wheat, water did not reach the sixth foot.

In the sod land, there is no evidence that water from the surface has reached the fourth foot section since determinations have been made. Water present in the fourth, fifth, and sixth foot sections in the spring of 1916 was gradually but steadily removed, and by 1923 the moisture content was well below the wilting coefficient and has remained constant ever since. The sod removed water to a lower point in comparison with the wilting coefficient in the lower foot sections than did wheat. The removal of water from the lower foot sections was not accomplished principally in any one year, but was gradual over a term of years. This would appear to indicate that these foot sections of soil are lightly occupied by the roots of deep-rooted perennial plants that do not remove water rapidly in any one year, but because of their continued draft are able to remove the water more completely than those of an annual crop such as spring wheat.

The infiltration of water into the soil to a depth greater than 3 feet took place only following the very wet years of 1914 and 1915. Even a 20-inch precipitation in 1927 wet the soil to a depth of only 3 feet. It is evident that water penetration to depths beyond the reach of roots of plants present in native sod occurs seldom or never. Samples to depths greater than 6 feet have not been taken, but all indications are that the roots of sod plants are able to remove all the water that is able to enter the soil.

The pasture and the continuously cropped wheatland in the south field are alike in that water seldom penetrates to depths greater than 3 feet and that penetration beyond the depth of 2 feet is uncommon. The difference in dates of moisture determinations makes impossible close comparison between land continuously cropped to wheat and land in sod. It appears likely, however, that native grass never uses water as rapidly as wheat does during the period of its rapid growth. Consequently, water falling during the period of most rapid wheat growth may penentrate to a slightly greater depth on the sod. On the other hand, the longer growing season of the sod plants and the deeper rooting systems of some of the plants present in sod contribute to a more complete exhaustion of water on sod than on cropped land.

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[6] SARVIS, J. T. EFFECTS OF DIFFERENT SYSTEMS AND INTENSITIES OF GRAZING UPON THE NATIVE VEGETATION AT THE NORTHERN GREAT PLAINS FIELD STATION. U. S. Dept. Agr. Bull. 1170, 46 pp., illus. 1923. (See p. 40.)

RESULTS AT NORTH PLATTE, NEBR.

The soil at North Platte is described by Zook[7] as follows:

> The soil on the experimental field is designated by the United States Bureau of Chemistry and Soils as Holdredge very fine sandy loam. The high percentage of very fine soil makes tillage easy and permits moisture to penetrate readily.

The soil is reasonably uniform to a depth of 6 feet. Below that depth the water-holding power of the soil, as expressed by its wilting coefficient, becomes gradually lower indicating an increasing degree of sandiness.

The ground water beneath the plots at North Platte is at a depth of approximately 225 feet. Excavations made near the rotation field indicate that the sandy soil is at least 50 feet thick and probably thicker.

The plots selected for study were B, which was continuously cropped to spring wheat, and C and D, which were alternately cropped and fallowed. The fall-plowed plot of continuously cropped spring wheat was selected, because fall plowing for spring wheat is more productive than spring plowing at North Platte. In addition to the wheat plots, moisture determinations from native sod near the experimental plots were used for comparison.

The land on which the plots were located was broken from the native sod in 1887. It was planted continuously to corn for 17 years, and was in oats and barley in 1904 and 1905. Crop-rotation work was started in 1906.

Soil-moisture determinations to a depth of 3 feet were commenced in 1907. Beginning in the fall of 1907, determinations were made to a depth of 6 feet. On the alternately cropped and fallowed plots, the depth was extended to 10 feet in most of the years.

Table 12 and figure 8 show the spring and harvesttime moisture content of plot B from 1908 to 1934, except 1918 when determinations were not made at times suitable for use in this study. The record ends in 1934, because the area occupied by the plots was used for a power-development project.

Even under the heavier rainfall at North Platte, almost all the available water was used each year. In every year except 1932, the water content of the first foot of soil was above the wilting point when the spring determinations were made. The water content was undoubtedly above the wilting point during the spring of that year, but no determination was made at the time when the water content should have been highest. In all but six of the years the water content was below the wilting point at harvesttime. In three of these years the water content of this foot section was undoubtedly below the wilting point at some time near harvest not represented by a determination. In three of the years, 1915, 1923, and 1928, the precipitation was so heavy that the crop did not use all the water.

The second foot section of soil contained water above the wilting coefficient in spring in all but 2 years, and was dried to a point below the wilting point at harvest in all but 4 years.

The third foot section of soil contained available water in only 11 of the 26 years, and was filled to capacity in only a few of these.

[7] ZOOK, L. L. DRY-LAND CROP PRODUCTION AT THE NORTH PLATTE EXPERIMENTAL SUBSTATION. Nebr. Agr. Expt. Sta. Bull. 270, 40 pp., illus. 1933.

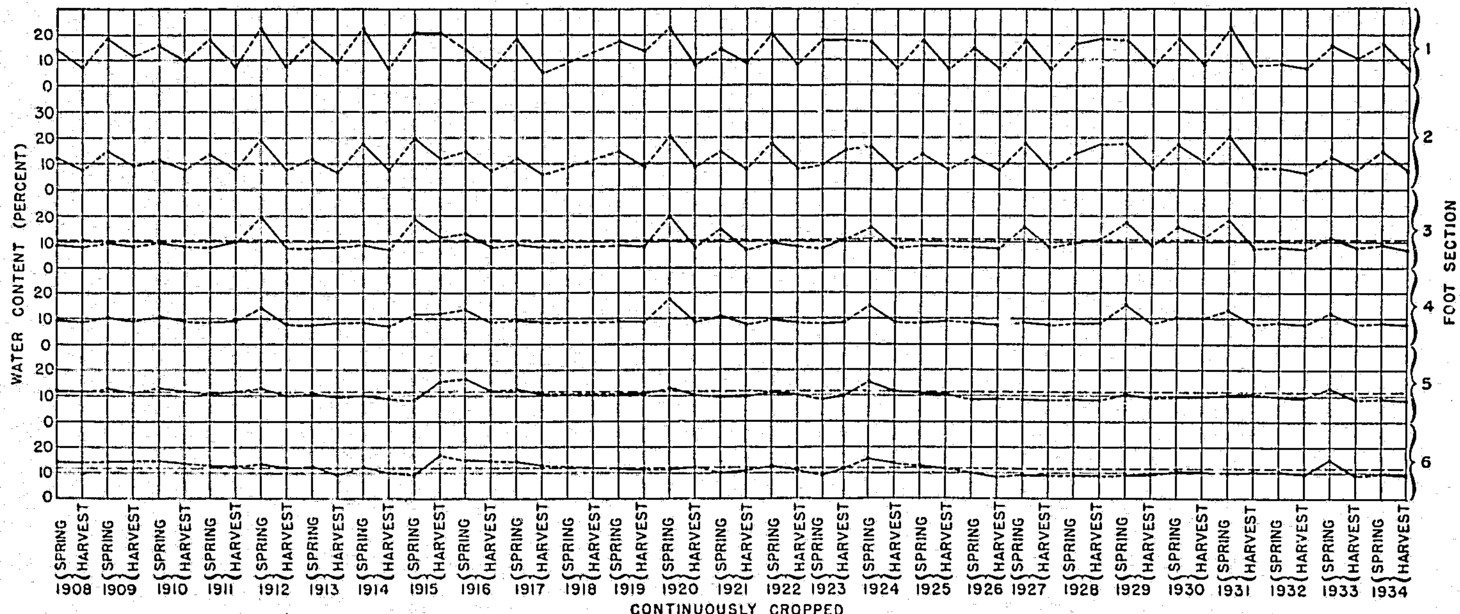

FIGURE 8.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot B, at North Platte, Nebr., continuously cropped to spring wheat, 1908–34. The wilting coefficient of each foot section of soil is indicated by a broken line.

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TABLE 12.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot B at North Platte, Nebr., continuously cropped to spring wheat, 1908–34*

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1908		1909		1910		1911		1912		1913		1914		1915		1916	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.8	14.2	7.3	18.8	11.3	15.8	9.5	18.2	7.2	22.3	7.1	17.4	8.8	22.1	6.2	21.0	20.8	14.0	6.4
2	9.9	12.1	7.7	14.8	9.0	11.2	7.7	13.4	7.8	19.4	7.2	11.2	6.2	17.4	7.4	19.3	11.7	14.3	7.1
3	10.4	8.7	7.7	9.7	8.3	9.8	8.1	7.9	9.7	19.3	7.5	7.7	7.6	8.3	6.8	18.6	11.5	13.0	7.8
4	10.4	9.3	8.7	10.6	9.0	10.9	8.9	8.4	8.8	14.0	7.5	7.6	8.0	8.2	6.8	11.8	11.9	13.1	8.4
5	11.5	12.1	11.3	12.6	10.7	12.8	11.4	10.6	11.3	12.7	9.3	10.3	9.2	9.9	8.5	8.1	15.1	16.2	11.3
6	11.9	14.3	14.1	14.4	14.8	14.9	13.3	12.8	12.6	13.4	11.8	12.2	9.0	12.0	9.9	9.1	16.8	14.9	14.2
7	10.9			13.6	14.0	12.5	12.8	12.1	12.9	12.2	11.0						15.4		
8	9.3			11.7	12.2	11.3	10.7	10.7	10.7	11.1	10.6						12.3		
9	7.8			11.2	11.4	11.1	10.4	10.3	10.5	10.4	10.5						11.4		
10	7.6			10.7	11.2	10.6	10.7	10.0	10.2	10.1	9.8						10.4		

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1917		1919		1920		1921		1922		1923		1924		1925		1926	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.8	18.3	5.6	17.7	13.4	22.9	8.1	13.9	8.7	20.0	8.0	17.8	17.7	17.0	6.8	17.8	6.2	14.6	6.3
2	9.9	11.9	5.9	14.3	8.4	20.2	8.2	14.3	7.6	17.4	7.6	9.0	15.1	16.2	7.6	13.4	7.4	12.2	7.1
3	10.4	8.5	6.8	8.8	8.0	19.5	7.8	14.2	6.9	9.2	7.7	7.2	10.4	15.3	7.5	8.4	8.4	8.0	7.1
4	10.4	9.3	8.3	8.7	8.2	17.0	8.4	10.9	7.2	9.1	8.0	8.0	8.6	14.7	8.4	8.6	9.1	8.2	7.4
5	11.5	12.3	10.5	10.1	10.1	12.6	9.9	9.2	9.4	10.8	9.9	8.2	9.5	15.0	11.7	10.5	10.4	8.5	8.9
6	11.9	14.1	12.4	11.6	11.0	11.2	12.0	9.8	10.9	12.4	10.7	9.0	11.2	15.3	13.5	12.7	11.9	10.2	8.9
7	10.9				10.4	9.8		10.0											
8	9.3				9.3	9.6		8.9											
9	7.8				8.0	9.2		7.0											
10	7.6				8.3	8.7		6.9											

Depth (feet)	Wilting coefficient	Moisture content of soil															
		1927		1928		1929		1930		1931		1932		1933		1934	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.8	17.5	6.4	16.6	18.8	17.9	7.7	18.7	8.2	22.4	7.5	8.4	6.9	15.6	10.7	16.3	6.2
2	9.9	17.5	7.8	13.9	17.5	17.9	8.1	17.2	10.7	20.2	8.3	8.0	7.5	12.5	7.9	14.8	7.1
3	10.4	15.5	7.7	9.4	10.7	17.5	8.3	15.7	11.1	18.3	8.0	8.6	7.8	11.9	8.1	9.2	7.1
4	10.4	8.5	7.3	8.1	8.0	15.6	8.1	10.8	10.6	13.2	7.8	8.9	7.8	12.0	8.0	8.3	7.6
5	11.5	8.4	8.3	8.6	8.3	10.2	9.2	9.8	9.9	10.0	10.6	9.4	9.2	13.0	8.6	9.2	8.4
6	11.9	9.3	9.3	9.2	9.0	9.6	9.7	10.9	10.8	10.0	10.6	10.4	9.9	15.1	9.4	10.0	9.4

Water penetrated to the fourth foot less frequently than to the third foot, and in only a few cases was the soil filled to capacity. When water reached the fourth foot section of soil, it was the result of heavy rains during the calendar year when the crop was growing, or to a carry-over of water from heavy rains of a previous year. The only exception was the year 1912 when there was an unusual concentration of rain in April and May, although the rainfall for the year was below average. In all years except 1915 and 1930, the water content of the fourth foot section of soil was below the wilting point at harvesttime, and in 1930 the content was only a fraction of a percent above the wilting point. It can be safely said that under continuous cropping to wheat, water enters the fourth foot section of soil in not more than 1 year in 3, and that this water with very few exceptions is removed by harvesttime.

The fifth foot section was wet less frequently than the fourth foot section, and in all years except 1915 practically all the water in this section was removed by harvesttime.

The sixth foot section of soil rarely received any appreciable quantity of water from the surface, but when water penetrated to that depth, wheat had much difficulty in removing it. In most cases when it did become moist, several years elapsed before all the available water was removed. The only apparent exception is in 1933, and it is believed that the high water content in the spring of that year may represent an experimental error rather than an actual soil condition.

It appears likely that water penetrated below the sixth foot in 1915 and in the spring of 1924.

Samples were taken to a depth of 15 feet on this plot in some of the early years. In all foot sections below the seventh foot, the moisture content of the soil remained above the wilting point almost continuously. In spite of this, there is no evidence that movement of water upward by capillary action into the section occupied by crop roots has ever taken place. There is some evidence that a slow, gradual loss of water may take place from these foot sections probably by vaporization, but the change in water content is too small to be of agricultural importance.

The evidence at hand indicates that on land continuously cropped to spring wheat under the rainfall and soil conditions at North Platte, water sometimes penetrates to depths beyond the reach of the crop roots, but that such an occurrence is infrequent. In the two cases observed, the precipitation for the year responsible for filling the soil to that depth was in excess of 26 inches. During another year with a precipitation higher than 26 inches, water did not reach the sixth foot. Examination of climatic records extending back to 1875 indicates that rainfall in excess of 25 inches occurs approximately once in 10 years. Thus we would expect water to reach a depth of 6 feet under the given cropping conditions not more than once in 10 years. In only extremely rare years, such as 1915, is there likely to be penetration of any material quantity of water to depths not reached by wheat roots. There is only one other year on record in which the precipitation exceeded 30 inches, as it did in 1915.

As stated earlier, the subsoil below the depth of wheat roots apparently remained continuously moist. Whether it was moist under sod or whether it became moist during the 17 years of continuous cropping to corn is not certain. It is certain that the soil within the zone of wheat-root development is normally dry at harvest, and that it remains dry except when wetted from the surface. The rainfall is seldom sufficient to carry water to a depth not reached by wheat roots.

Tables 13 and 14 and figure 9 show the water content on land alternately fallowed and cropped to spring wheat at North Platte. In the alternately fallowed and cropped plots the first 4 feet of soil functioned heavily in wheat production. In all the first four foot sections, available water was present in the spring of the cropped year; and the water content was reduced below or near to the wilting point in all but a few wet years. This is in distinct contrast to the continuously cropped plot, where available water was present in the fourth foot section only 1 year in 3.

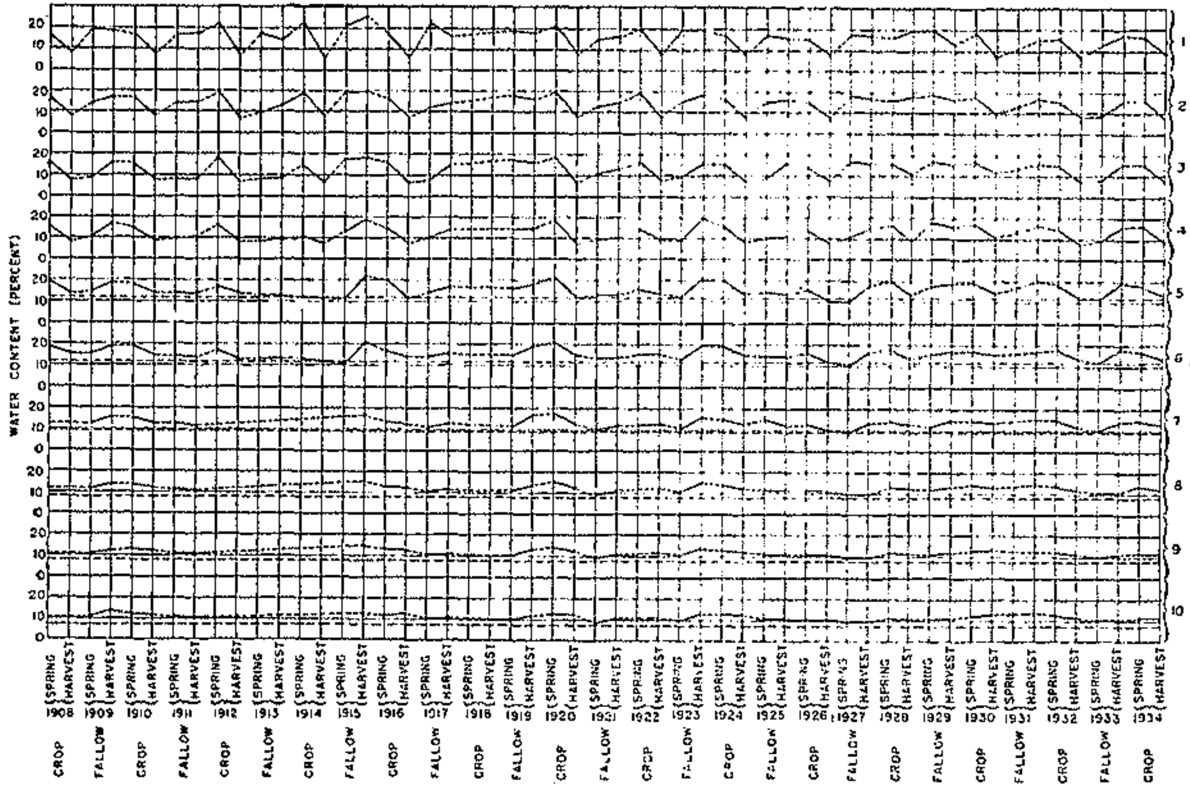

FIGURE 9.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot C at North Platte, Nebr., cropped to spring wheat in even years and fallowed in odd years, 1908–34. The wilting coefficient of each foot section of soil is indicated by a broken line.

TABLE 13.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot C at North Platte, Nebr., fallowed during odd years and cropped to spring wheat during even years, 1908–34*

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1908		1909		1910		1911		1912		1913		1914		1915		1916	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.1	15.9	8.1	19.2	18.0	16.7	7.6	16.8	17.1	22.2	6.9	17.5	14.2	22.5	6.0	21.2	25.4	17.0	6.6
2	10.2	15.7	7.8	14.8	16.9	16.0	7.8	13.8	14.3	19.6	6.8	9.4	13.2	19.2	7.2	19.5	19.7	16.0	7.2
3	10.0	15.4	7.2	8.9	15.8	15.1	7.8	7.6	7.8	18.0	6.6	8.0	8.8	14.7	6.8	17.6	18.2	15.3	6.7
4	9.8	14.9	8.0	10.1	16.7	14.7	8.8	9.6	10.3	16.0	8.2	8.5	9.1	10.6	7.5	12.9	18.8	14.1	7.7
5	11.8	18.9	13.3	14.3	18.8	17.9	13.4	13.7	13.7	16.9	13.4	12.2	12.3	11.6	11.1	10.7	21.6	19.7	11.2
6	11.7	18.0	15.1	15.2	18.4	18.7	14.0	14.1	13.5	16.8	12.8	------	13.2	12.3	12.0	10.5	20.9	16.6	14.1
7	9.3	------	------	12.3	15.1	15.6	12.5	12.8	11.2	13.2	------	------	------	------	------	------	17.2	13.7	12.4
8	8.1	------	------	11.2	13.3	13.4	11.5	11.0	10.8	12.0	------	------	------	------	------	------	15.9	12.8	12.1
9	7.8	------	------	10.6	11.7	12.3	11.8	10.3	10.4	11.3	------	------	------	------	------	------	14.5	12.8	12.3
10	7.4	------	------	10.5	13.5	11.9	11.3	10.4	10.2	11.4	------	------	------	------	------	------	12.8	12.6	12.3

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1917		1919		1920		1921		1922		1923		1924		1925		1926	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.1	22.2	15.3	18.8	17.4	21.0	7.8	14.6	15.8	19.7	7.3	19.7	19.4	16.7	7.3	17.1	15.3	14.8	7.1
2	10.2	12.0	14.0	17.6	15.8	19.7	7.8	[illegible]	14.9	19.1	7.5	15.6	18.6	16.0	8.0	15.0	16.3	14.6	7.4
3	10.0	7.7	14.3	16.7	15.7	18.5	6.9	[illegible]	12.7	16.3	7.5	9.3	15.7	15.2	7.9	9.0	15.9	13.9	7.5
4	9.8	10.1	13.9	14.0	14.9	18.7	7.4	9.4	10.0	14.3	9.6	9.4	19.8	15.5	8.5	9.9	10.8	13.8	7.6
5	11.8	14.2	16.5	15.4	17.9	21.2	12.1	12.5	13.1	15.8	13.1	12.1	20.5	19.7	13.6	14.2	13.0	15.6	10.0
6	11.7	14.2	15.5	14.8	18.6	20.7	14.9	13.3	13.5	15.1	15.1	12.6	19.2	18.7	14.8	14.4	14.0	15.4	11.6
7	9.3	11.1	12.4	11.4	16.8	17.4	12.7	9.9	11.1	------	12.4	10.8	15.8	14.7	12.8	14.9	11.8	12.5	9.9
8	8.1	10.6	11.0	10.7	13.6	15.3	12.2	8.8	10.4	------	11.7	10.2	14.7	13.3	12.1	11.1	11.0	11.0	10.5
9	7.8	10.3	10.9	10.2	13.0	14.1	12.5	9.0	10.3	------	11.4	10.1	13.6	12.9	12.0	10.9	10.9	10.5	10.6
10	7.4	10.1	10.5	10.0	11.9	12.9	12.6	9.1	10.4	------	11.0	9.9	13.0	12.6	12.5	10.7	10.6	10.5	10.1

TABLE 13.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot C at North Platte, Nebr., fallowed during odd years and cropped to spring wheat during even years, 1908–34*—Continued

Depth (feet)	Wilting coefficient	Moisture content of soil															
		1927		1928		1929		1930		1931		1932		1933		1934	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	10.1	17.9	16.2	16.0	19.8	19.7	12.4	18.1	6.8	--------	16.0	15.5	7.2	12.7	17.3	16.4	8.5
2	10.2	18.4	16.5	15.7	17.8	18.9	16.9	17.4	10.0	--------	17.2	15.1	8.2	8.5	16.1	16.3	7.6
3	10.0	16.6	15.6	15.5	11.0	17.0	15.3	16.2	11.2	--------	16.2	15.0	7.3	8.2	15.9	15.5	7.9
4	9.8	11.0	14.9	16.1	9.1	17.5	15.6	17.0	10.5	--------	17.2	14.9	8.0	9.2	15.9	16.3	9.0
5	11.8	10.1	17.5	19.3	13.5	17.1	18.7	19.1	14.3	--------	20.1	18.2	12.1	11.6	19.1	17.8	13.1
6	11.7	10.0	16.6	18.0	13.5	15.5	16.7	17.6	15.3	--------	16.6	17.8	13.4	11.9	18.0	17.2	13.5
7	9.3	9.0	13.1	13.9	12.3	11.2	14.9	14.8	13.4	--------	15.6	14.5	11.6	10.0	13.8	14.6	12.4
8	8.1	9.5	9.8	12.8	12.0	11.4	13.0	14.1	12.8	--------	14.5	13.1	11.6	10.6	10.3	13.5	11.9
9	7.8	9.4	9.5	11.5	11.4	10.9	11.9	12.8	13.3	--------	13.1	12.3	11.5	10.0	11.3	12.0	11.5
10	7.4	9.5	9.4	11.0	11.2	10.9	11.0	12.4	12.9	--------	13.8	12.4	11.4	10.6	10.9	11.3	11.5

TABLE 14.—*Water content in the spring and at harr sttime and the wilting coefficient of the soil on plot D at North Platte, Nebr., fallowed during even years and cropped to spring wheat during odd years, 1908–34*

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1908		1909		1910		1911		1912		1913		1914		1915		1916	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.9	14.6	16.1	19.8	11.1	17.0	15.7	18.8	7.2	22.1	16.2	17.7	9.1	22.4	14.4	21.6	17.6	13.9	17.7
2	10.4	11.8	16.8	16.1	9.7	11.8	13.3	14.9	8.1	19.0	14.8	15.7	8.1	18.2	16.1	20.1	11.6	10.8	16.6
3	10.9	8.8	16.3	15.9	8.5	9.9	10.1	11.4	9.1	16.7	13.5	12.3	7.8	9.6	14.9	18.9	11.2	10.5	15.1
4	10.8	10.7	16.0	16.0	9.0	12.5	12.9	13.0	12.3	13.6	15.9	15.6	10.0	10.6	14.4	19.5	12.2	13.6	17.0
5	13.0	15.5	18.6	19.5	14.3	17.5	16.9	16.4	16.6	15.0	16.4	18.7	14.8	14.8	16.3	22.5	17.1	17.1	19.5
6	12.3	15.0	16.9	17.8	14.9	16.2	15.6	15.2	14.9	14.3	13.3	16.9	13.5	13.6	14.3	20.0	16.8	16.0	17.2
7	9.7	------	------	14.1	13.1	11.9	12.0	11.7	11.6	11.4	11.2	------	------	------	------	------	13.8	12.7	13.2
8	9.1	------	------	13.0	12.0	11.8	10.9	10.8	11.1	11.2	9.8	------	------	------	------	------	13.1	11.8	12.0
9	8.2	------	------	12.2	11.8	11.2	10.4	10.9	10.4	10.1	10.0	------	------	------	------	------	13.5	11.9	11.6
10	7.4	------	------	11.8	11.8	11.2	11.0	10.8	10.6	10.0	9.8	------	------	------	------	------	13.5	11.2	11.2

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1917		1919		1920		1921		1922		1923		1924		1925		1926	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.9	18.8	6.6	19.4	14.3	21.6	17.1	16.5	9.2	19.3	17.4	18.4	17.8	17.1	16.2	18.4	6.4	16.6	16.3
2	10.4	15.6	7.0	17.8	10.4	20.2	15.5	15.1	7.8	13.3	16.8	16.0	14.3	16.9	15.9	17.8	7.8	12.4	14.6
3	10.9	14.6	7.3	16.6	9.6	18.6	15.3	14.4	6.7	7.6	13.7	13.6	9.2	15.8	14.9	16.2	7.8	8.1	9.3
4	10.8	14.9	8.3	15.1	8.8	18.7	17.6	14.5	8.0	9.5	10.0	13.5	9.8	15.5	15.8	15.6	8.5	8.7	8.9
5	13.0	18.0	13.5	17.4	14.7	21.2	20.6	18.5	13.0	13.3	13.2	13.0	15.7	17.0	17.8	18.2	11.5	11.0	11.9
6	12.3	17.1	15.4	17.2	14.8	19.3	19.2	17.2	14.4	13.2	13.6	15.3	15.5	15.5	15.6	14.9	12.4	11.3	12.3
7	9.7	13.5	12.6	14.1	11.5	15.9	15.2	14.2	10.5	------	10.9	12.3	11.9	11.9	12.9	13.1	11.4	10.2	10.4
8	9.1	12.3	12.6	12.2	11.1	13.1	14.2	12.6	10.7	------	10.5	10.3	10.9	11.0	11.6	11.8	11.3	9.6	10.4
9	8.2	11.6	12.2	11.6	10.9	11.2	13.3	12.3	10.2	------	10.5	10.4	11.4	10.7	11.0	11.5	11.2	9.8	9.9
10	7.4	11.4	12.2	11.7	10.6	10.8	13.2	11.6	10.7	------	10.4	9.8	11.0	10.5	10.8	11.0	11.1	9.4	9.9

TABLE 14.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot D at North Platte, Nebr., fallowed during even years and cropped to spring wheat during odd years, 1908–34*—Continued

Depth (feet)	Wilting coefficient	Moisture content of soil															
		1927		1928		1929		1930		1931		1932		1933		1934	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	9.9	18.1	6.2	15.9	20.2	17.9	8.9	18.8	14.9	--------	7.6	13.8	14.5	15.2	12.3	17.0	14.6
2	10.4	18.4	7.4	12.0	19.4	18.4	9.9	17.3	17 3	--------	8.6	8.9	15.5	13.9	8.2	13.8	13.8
3	10.9	17.3	7.0	8.6	17.9	18.2	8.9	14.2	16.2	--------	8.6	8.2	12.6	14.0	8.0	8.6	8.9
4	10.8	16.6	7.2	9.4	18.2	18.7	8.9	11.1	19.7	--------	8.5	10.3	10.8	14.4	8.7	10.4	11.9
5	13.0	15.3	10.0	11.9	17.3	21.3	12.9	14.3	20.8	--------	12.5	13.6	13.3	16.8	12.5	12.6	14.4
6	12.3	11.9	11.9	11.8	14.5	19.5	13.8	12.8	18.1	--------	14.4	13.0	12.6	14.7	13.6	13.5	12.9
7	9.7	10.2	10.6	10.4	10.8	13.3	12.4	11.2	15.4	--------	12.5	10.9	10.5	11.7	11.5	10.9	11.3
8	9.1	10.0	10.2	10.2	9.7	11.6	12.0	11.0	14.6	--------	12.5	11.2	11.0	10.8	11.1	11.0	10.4
9	8.2	10.0	9.7	10.1	9.8	11.0	11.8	10.8	13.3	--------	12.3	11.0	11.9	10.7	11.0	10.9	10.5
10	7.4	9.9	9.9	10.5	10.1	10.7	11.5	11.0	13.5	--------	13.3	11.0	10.7	10.3	11.5	11.0	10.2

In the fifth foot section, available water was present in most years, and most of it was used, although in at least half of the years the water content was not reduced to the wilting point. Evidently roots are not usually disseminated well enough in this foot section to enable the wheat crop to remove all the water. In more than half of the years water appeared to penetrate to the sixth foot section, and in all years, water above the wilting point was present. In spite of need by the wheat crop, the water content of this foot section of soil was seldom reduced to the wilting point. Evidently spring wheat roots do not ordinarily remove much water from the sixth foot section, although in a few instances a material quantity of water was used.

Determinations were made to a depth of 10 feet during most of the years and to a depth of 15 feet in a few years. These determinations show that the soil remained continuously moist at depths greater than 6 feet. Water changes below 7 feet were limited in scope. It is possible that these changes were largely the result of further penetration of excess water, although there are a few instances that indicate there may have been a little used by the crop.

The evidence at hand indicates that under an alternate fallow and crop system with spring wheat there is infiltration of water to depths not reached by wheat roots. After water reaches a depth of more than 5 feet, little of it is recovered by spring wheat. In 1934, when drought reduced the yield of wheat on fallowed land to 3.8 bushels per acre, the crop was unable to reduce the water in the fifth and the sixth foot sections to the wilting point.

Table 15 and figure 10 show the water changes on native sod during the period 1910–34 except 1914 and 1933. Determinations to a depth of 10 feet were made several times but not continuously. The full extent of moisture reduction, particularly in the first and the second foot sections, is not always shown, because determinations were not always made when the soil was at its driest. With sod there is no climax period, such as harvest with wheat, when rapid use of water ceases. Determinations on sod were made when convenience permitted and consequently were not always taken at a period comparable with wheat.

Comparison of figure 10 with figure 8 shows that water penetration on sod was much the same as on continuous wheat. The first two foot sections contained water above the wilting point in most years, and in most years this water was removed. Water penetrated into the third foot section about as frequently on sod as on wheatland, but the water appeared to be removed from sod a little more slowly, but possibly a little more completely. The same is true for the fourth, fifth, and sixth foot sections. There seemed to be a general tendency for the lower foot sections under sod to become a little drier than under wheat.

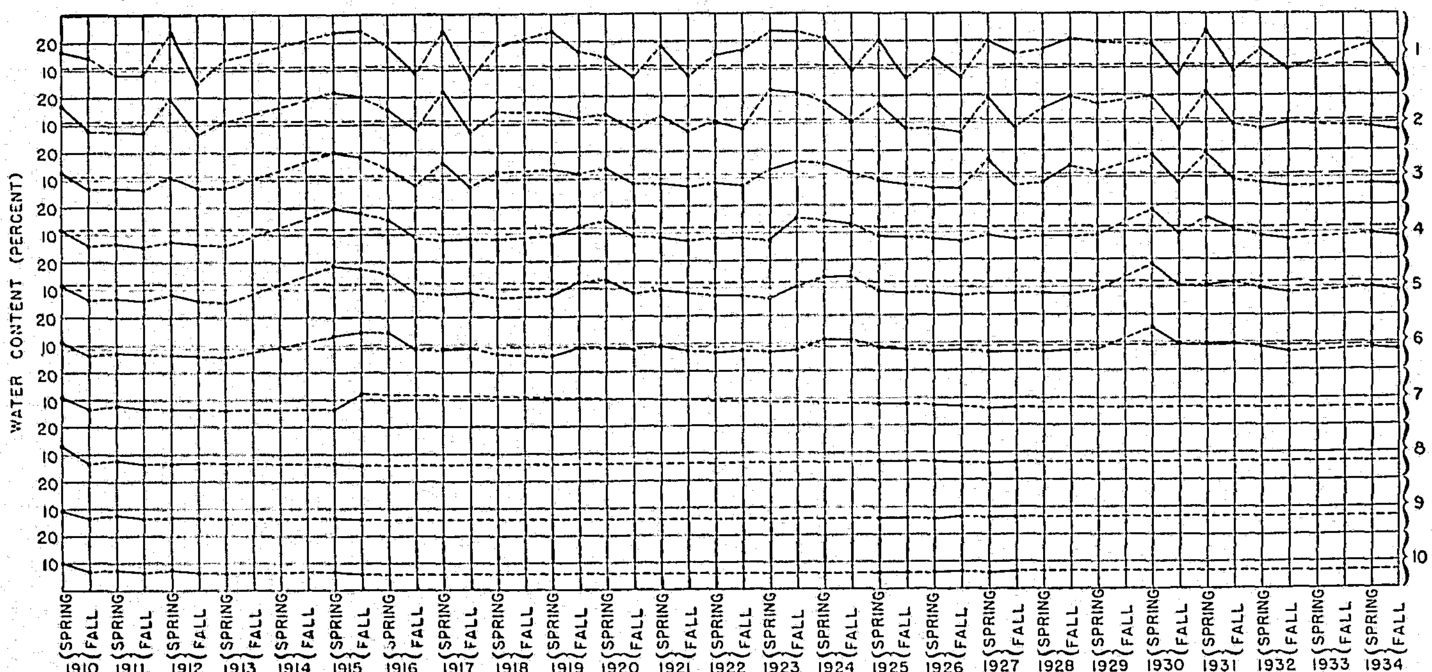

FIGURE 10.—Percentage of water in the several foot sections of soil in the spring and fall on a plot of native sod at North Platte, Nebr., 1910–34, except 1914 and 1933. The wilting coefficients of the first six foot sections are indicated by broken lines.

TABLE 15.—*Water content in the spring and fall and the wilting coefficient of the soil on a plot of native sod at North Platte, Nebr., 1910–34, except 1914 and 1933*

Depth (feet)	Wilting coeffi-cient	Moisture content of soil													
		1910		1911		1912		1913	1915		1916		1917		1918
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Spring	Fall	Spring	Fall	Spring	Fall	Spring
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	11.0	17.1	14.7	8.0	8.1	24.7	5.0	14.1	24.6	24.1	18.4	8.2	25.3	6.7	18.5
2	11.0	16.6	7.5	7.4	7.1	19.9	6.2	11.1	21.7	19.9	15.4	8.2	21.6	7.2	14.9
3	11.0	12.9	6.6	6.9	6.4	11.0	6.9	7.7	20.2	18.6	14.0	8.0	15.9	7.5	12.4
4	11.7	11.4	6.0	6.8	5.8	7.5	6.1	6.3	19.5	17.9	15.8	8.6	8.1	8.0	8.0
5	11.3	11.0	6.1	6.8	5.8	8.1	5.8	5.4	18.4	17.2	15.9	8.7	8.1	8.8	6.8
6	8.9	11.0	6.2	7.1	6.2	6.4	5.8	6.2	13.4	14.5	14.5	8.7	7.8	8.4	6.5
7		10.8	6.5	7.9	6.5	6.3	6.1	5.9	6.3	12.0					
8		13.4	6.5	8.4	6.4	6.5	6.5	6.7	6.2	6.0					
9		9.5	6.2	7.9	6.3	6.9	6.2	5.7	6.4	5.8					
10		10.5	6.0	7.6	6.1	7.2	6.3	6.2	6.3	5.8					

Depth (feet)	Wilting coeffi-cient	Moisture content of soil													
		1919		1920		1921		1922		1923		1924		1925	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	11.0	25.6	16.4	14.1	7.6	18.8	7.7	15.8	17.4	26.4	25.0	21.9	9.8	20.2	7.3
2	11.0	14.4	12.1	13.5	8.3	13.0	7.2	10.8	8.2	22.4	21.3	18.0	10.8	17.2	8.1
3	11.0	13.6	11.9	14.0	8.6	8.7	7.2	8.9	8.4	13.6	16.4	15.9	12.1	9.5	7.9
4	11.7	9.5	12.4	14.8	9.1	8.9	7.6	8.4	8.5	7.6	15.3	14.9	13.5	8.9	8.9
5	11.3	7.8	12.3	13.1	8.5	9.9	8.3	7.6	7.9	6.9	10.8	14.2	14.2	9.2	8.7
6	8.9	5.8	8.8	8.4	8.0	9.4	7.5	7.0	7.4	7.2	7.4	11.7	11.7	8.6	8.1
7														8.3	7.9
8														7.9	7.2
9														7.6	5.8
10														7.0	6.5

TABLE 15.—*Water content in the spring and fall and the wilting coefficient of the soil on a plot of native sod at North Platte, Nebr., 1910–34, except 1914 and 1933*—Continued

Depth (feet)	Wilting coefficient	Moisture content of soil															
		1926		1927		1928		1929	1930		1931		1932		1934	
		Spring	Fall	Spring	Fall	Spring	Fall	Spring	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	11.0	14.1	7.3	20.6	16.0	17.5	20.5	19.9	19.5	8.0	24.7	9.2	16.9	10.0	18.4	6.2
2	11.0	8.8	7.0	19.3	8.5	15.5	19.6	17.2	19.2	7.7	21.2	9.1	7.7	9.8	8.4	6.8
3	11.0	7.0	6.7	16.9	7.6	8.5	14.0	12.0	18.2	8.1	18.8	9.2	7.7	6.7	7.7	6.9
4	11.7	8.0	7.2	9.5	8.2	8.9	8.8	9.1	18.3	9.6	15.3	10.5	8.9	7.6	9.2	8.4
5	11.3	8.5	7.3	8.0	8.0	8.1	7.9	9.1	18.7	10.5	10.6	11.8	9.6	8.1	10.0	8.2
6	8.9	7.8	7.8	7.2	7.1	7.0	7.2	7.8	15.4	9.9	9.1	9.7	8.7	6.8	8.3	7.2
7	------	7.1	6.5	6.8	6.9	------	------	------	------	------	------	------	------	------	------	------
8	------	6.5	6.2	6.7	6.6	------	------	------	------	------	------	------	------	------	------	------
9	------	6.9	6.5	6.7	6.5	------	------	------	------	------	------	------	------	------	------	------
10	------	6.8	6.3	6.7	6.5	------	------	------	------	------	------	------	------	------	------	------

The 10-foot samples indicate that, under sod, water probably never penetrated to a depth beyond the reach of roots. The soil appeared to contain some moisture to a depth of 10 feet when the first determination was made in 1910. Just why this should be is not certain, as the precipitation for 1909 does not appear to have been sufficient to cause water to penetrate to that depth, and bromegrass sod was dry below a depth of 2 feet. Water, if present, was removed during 1910. The scattered records indicate that moisture did not again extend to such a depth. Even in the very wet year of 1915, water did not appear to reach the eighth foot section. The water entering the seventh foot section in 1915 was removed before deep determinations were again made in 1925.

Moisture-equivalent determinations for the seventh, eighth, ninth, and tenth foot sections are not available. If the soil in these foot sections is approximately the same as on the nearby plots, the soil at depths greater than 7 feet has been continuously dry since 1910. It seems apparent that there is rarely, if ever, any infiltration of water on sod land to depths not reached by the roots of plants present in the native sod.

The soil under native sod has remained drier most of the time than under cropped land. The degree of dryness of the lower foot sections does not appear to be dependent upon the severity of the season.

Winter wheat data are not presented in this bulletin, but enough study of them was made to feel certain that winter wheat makes better use of moisture that reaches the lower foot sections than does spring wheat. Studies of winter wheat on fallowed land show evidence of water use to depths considerably greater than 6 feet. Infiltration of water to depths not reached by the roots of the crops is less frequent where winter wheat is grown than where spring wheat is grown.

RESULTS AT HAYS, KANS.

The soil at Hays is a silty clay loam of the Hays series. Being composed of fine materials its infiltration rate is low. However, it cracks considerably on drying and then is able to take in water rapidly for a short time.

The plots used for study were B, which was continuously cropped to winter wheat on early cultivation, and C and D, which were alternately fallowed and cropped to winter wheat. Winter wheat was used because Hays is south of the area to which spring wheat is adapted. The exact history of the plot rotation field is not available, but it is certain that it had been cropped for a number of years before being acquired for experimental work. It had probably been planted to wheat in most years.

The depth at which ground water may be found under the rotations is doubtful, but is probably about 60 feet. Water was struck at that depth on a field east of the rotation plots. However, less than a mile south of the rotation plots at a place where the surface elevation was about the same, water was not found until a depth of 340 feet was reached. Most wells in the section are located in draws or swales, and water is found at depths of from 36 to 40 feet. The depth to water on the upland is uncertain and variable, but is not likely to be less than 50 feet.

The soil-moisture history of plot B is shown in table 16 and figure 11.

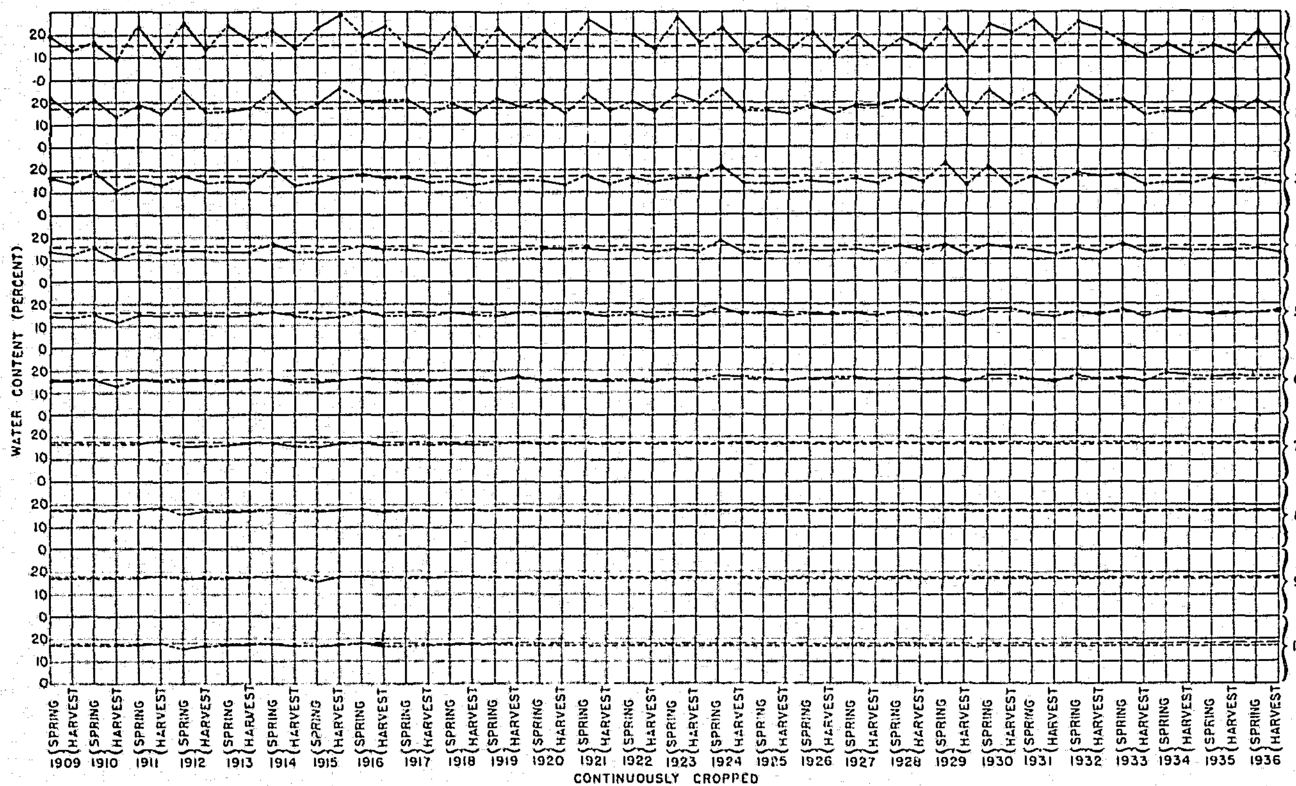

FIGURE 11.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot B at Hays, Kans., continuously cropped to winter wheat, 1909–36. The wilting coefficient of each foot section is indicated by a broken line.

It will be seen at once that in spite of the relatively heavy precipitation at Hays (table 1) the depth of water penetration has been no greater than in lighter soils with lower rainfall. This may be due in part to the nature of the growth of winter wheat. By the time the heavy rains of spring come, winter wheat is making very rapid growth and is using water rapidly. Consequently, the rains are consumed largely in replacing the water used by the wheat crop, and little water is left for further infiltration. The first and second foot sections of soil were filled with water in most years, and in all but a few of these years the water was removed by harvesttime. Water penetrated into the third foot in about half of the years, although that foot section was seldom filled to capacity. In every case the water was removed before harvesttime, although in 1932 heavy rains just preceding harvest replenished this supply slightly.

Water penetrated into the fourth and fifth foot sections in some years, but these sections never contained much available water. The wheat appeared to be able to exhaust the moisture in the fourth foot section about 2 percent below the wilting point. In the fifth foot section, the reduction below the wilting point was smaller.

TABLE 16.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot B at Hays, Kans., continuously cropped to winter wheat, 1909–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1909		1910		1911		1912		1913		1914		1915		1916		1917	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	15.5	19.0	12.3	16.5	8.9	23.2	10.1	25.1	13.0	19.1	17.6	21.9	14.2	23.2	28.9	17.7	24.0	15.2	11.5
2	17.9	22.4	15.1	21.1	13.5	18.9	15.1	24.9	15.5	15.9	17.6	24.9	14.9	19.4	26.6	20.5	21.1	21.1	15.0
3	16.7	16.5	13.8	19.2	11.1	15.1	13.0	17.0	13.9	14.4	14.0	20.4	12.8	14.5	17.3	18.2	16.3	16.1	13.8
4	16.0	13.4	12.3	14.9	9.7	13.3	12.4	13.7	13.5	13.0	13.0	17.0	12.9	12.8	13.5	16.3	14.4	14.1	13.0
5	15.7	14.1	13.4	15.0	11.6	14.7	14.0	14.7	14.6	14.0	14.5	15.9	14.2	13.2	13.9	16.7	14.4	14.7	14.0
6	16.2	15.0	15.0	15.4	12.5	15.6	15.0	15.1	15.5	15.1	15.6	16.2	14.9	14.3	15.5	16.5	16.0	15.2	15.4
7	17.4	------	------	------	------	16.8	18.7	15.6	16.3	16.3	17.4	17.6	15.8	15.6	16.9	17.5	16.5	------	16.6
8	17.2	------	------	------	------	17.5	18.8	16.6	17.2	17.0	17.2	17.9	17.5	16.9	17.5	18.3	17.0	------	17.5
9	17.6	------	------	------	------	17.2	18.5	16.6	17.3	17.0	17.6	18.1	18.0	16.1	17.5	18.2	17.6	------	17.4
10	16.9	------	------	------	------	17.2	18.2	16.4	17.3	17.4	17.6	18.2	17.3	17.0	17.5	18.2	17.0	------	17.0

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1918		1919		1920		1921		1922		1923		1924		1925		1926	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	15.5	22.4	10.3	22.8	13.1	21.1	12.8	25.8	19.9	19.6	13.3	27.6	16.2	22.5	12.0	14.1	12.5	21.2	11.3
2	17.9	19.6	14.9	21.5	17.8	21.2	15.2	23.3	16.1	20.2	15.8	23.0	20.0	25.8	16.3	16.1	15.3	18.9	15.3
3	16.7	14.9	13.2	15.3	14.8	15.3	13.4	16.9	13.5	16.0	14.6	16.2	16.1	20.8	13.6	13.7	13.6	15.2	13.9
4	16.0	14.3	13.2	13.5	14.2	14.2	13.7	14.4	13.3	14.3	12.9	14.4	13.1	18.6	12.8	13.8	13.1	14.1	13.8
5	15.7	15.4	14.3	14.1	15.3	15.3	14.8	14.9	14.1	14.6	13.6	14.7	14.1	18.3	14.9	15.4	14.2	15.5	15.3
6	16.2	16.1	15.6	14.8	16.4	15.1	15.7	14.9	14.7	15.1	14.4	15.4	15.0	17.4	16.7	16.2	15.2	16.6	17.1
7	17.4	17.0	16.6	------	17.3	------	------	------	------	------	------	------	------	------	------	------	------	------	------
8	17.2	17.6	17.5	------	17.3	------	------	------	------	------	------	------	------	------	------	------	------	------	------
9	17.6	17.9	17.4	------	17.1	------	------	------	------	------	------	------	------	------	------	------	------	------	------
10	16.9	17.7	17.6	------	17.1	------	------	------	------	------	------	------	------	------	------	------	------	------	------

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	15.5	19.7	12.2	18.1	13.3	23.2	12.1	24.6	21.0	27.1	17.2	25.6	21.8	15.8	11.3	15.4	11.5	15.5	11.5	22.2	9.6
2	17.9	19.0	18.7	21.1	16.5	27.5	14.6	25.5	18.9	24.1	14.5	27.1	25.5	21.5	14.4	16.3	15.5	20.8	15.9	21.3	15.1
3	16.7	15.8	14.3	18.2	14.5	22.9	12.8	21.5	12.8	17.2	13.0	18.5	16.6	18.2	13.3	14.1	13.7	16.1	14.4	16.2	13.8
4	16.0	14.3	13.5	16.0	13.8	16.7	11.9	16.6	14.8	14.4	12.1	14.7	13.1	16.7	12.7	14.5	14.1	13.9	13.7	14.8	13.3
5	15.7	15.6	14.5	16.1	14.8	16.2	14.2	17.5	17.7	14.7	14.3	16.1	14.4	17.0	14.0	17.0	16.3	14.8	15.5	-------	16.1
6	16.2	16.8	15.9	16.3	15.8	17.0	14.9	18.1	17.7	15.8	15.0	17.7	15.8	17.2	15.3	18.4	17.5	16.2	16.7	-------	17.6

The moisture content of the sixth foot section remained almost constant at a point about equal to the wilting coefficient during the period 1909 to 1930. Heavy rainfall apparently caused a little water to enter the sixth foot in 1930. Since 1930, the moisture content of the sixth foot section has been above the wilting coefficient most of the time. Evidently a little water available to wheat may be present in the sixth foot section of soil. Dryness in other foot sections has made it impossible for roots to remove this water.

Samples to a depth of 10 feet were taken from 1911 to 1919. The soil at depths greater than 6 feet remained constantly dry.

Under continuous wheat production, even under early preparation, the functioning of the soil is limited largely to the first three foot sections. Use of water from depths greater than 3 feet is small because its presence is so infrequent.

There is no evidence that in 28 years water has infiltrated to a depth not reached by wheat roots except for the very small quantity in 1930. Records extending back to 1868 indicate that conditions have been as favorable for deep penetration of water in the 28-year period as in the long-time period. It can be safely stated that at Hays under continuous cropping to winter wheat, no appreciable quantity of water penetrates beyond the reach of wheat roots.

The soil-moisture history of plots C and D is given in tables 17 and 18. Figure 12 shows the moisture history of plot D.

The use of fallow greatly increased the depth to which the soil functioned in the production of wheat. The first four foot sections of soil contained considerable quantities of available water in the spring of nearly all crop years, and in nearly all cases this water was removed by harvesttime. The only time that the fourth foot section was not dry at harvesttime was in 1915, when continuous rains left the soil wetter at harvesttime than it was in the spring. In a few years, sections above it contained available water at harvesttime when that of the fourth foot section had been exhausted. This was the result of rains before harvest sufficient to recharge upper sections but not to penetrate to the fourth foot.

The fifth foot section contained available water in most crop years, and in nearly all of them water was given up to the crop, although the contribution was less than from the fourth foot section.

The sixth foot section contained available water in most years, but much less than the fifth foot. Its contribution to the crop was much smaller than that of the fifth foot section.

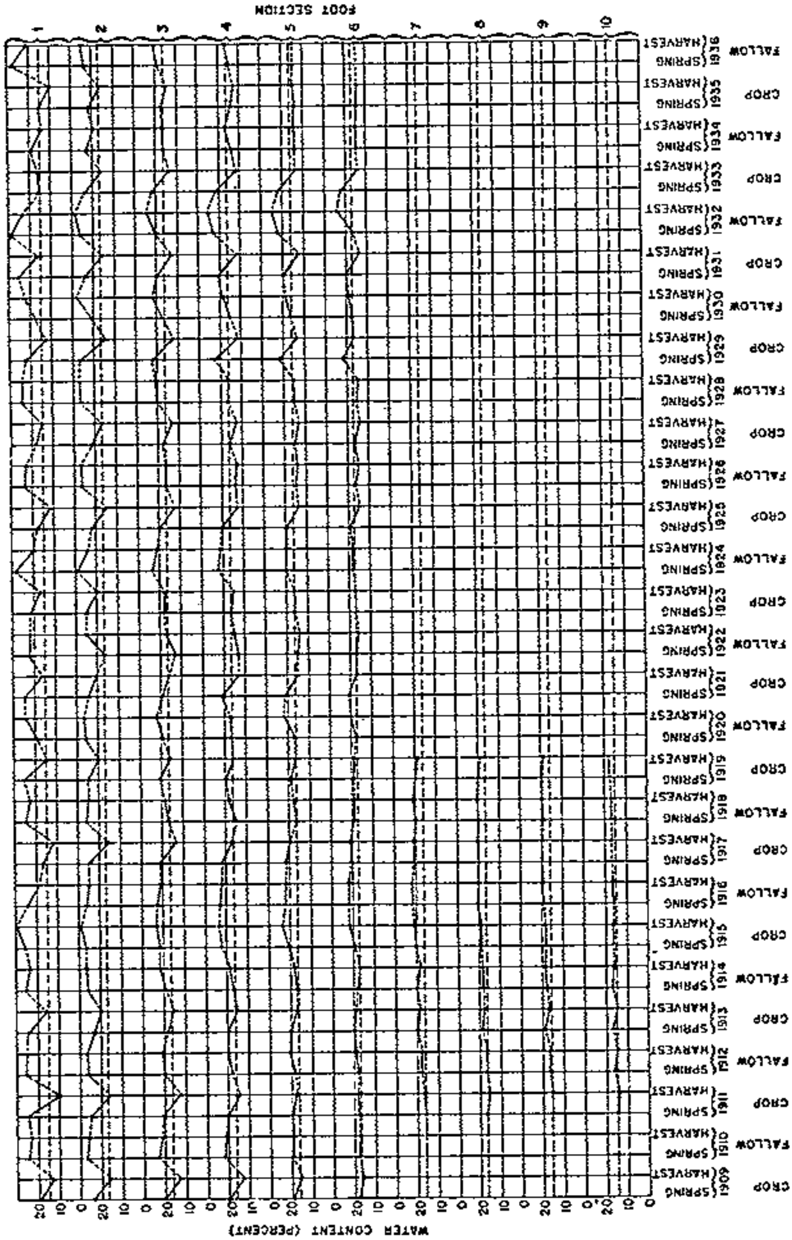

FIGURE 12.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot D at Hays, Kans., cropped to winter wheat in odd years and fallowed in even years, 1909–36. The wilting coefficient of each foot section is indicated by a broken line.

TABLE 17.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot C at Hays, Kans., fallowed in odd years and cropped to winter wheat in even years, 1909–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1909		1910		1911		1912		1913		1914		1915		1916		1917	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	15.7	25.1	23.2	16.8	10.6	20.9	20.8	25.4	13.2	27.0	24.8	23.8	14.5	27.7	25.3	19.2	23.8	20.3	18.6
2	17.4	23.7	21.6	21.1	13.3	21.3	22.2	27.1	14.4	23.1	25.1	26.7	15.2	26.7	26.5	21.7	26.6	23.0	22.8
3	16.0	17.5	17.2	19.6	11.1	14.7	15.6	2[illegible].2	12.4	14.7	19.0	22.4	12.6	16.3	22.1	19.3	17.5	17.7	18.5
4	16.0	15.1	15.4	21.8	12.0	13.6	13.0	20.0	13.7	14.3	16.7	22.4	12.8	13.8	21.1	20.1	13.5	15.9	15.5
5	16.0	16.2	16.9	22.2	14.2	14.5	13.7	16.6	15.4	14.5	14.3	21.1	15.0	15.4	19.6	20.9	13.2	15.8	14.9
6	16.4	17.2	18.0	21.1	17.1	16.4	15.6	16.6	17.7	16.1	16.2	20.7	16.6	17.7	18.3	21.7	16.3	16.0	16.6
7	17.2					17.7	17.2	16.9	19.4	18.2	19.4	19.9	18.0	18.5	17.9	21.7	17.8		18.5
8	17.0					17.8	17.9	16.9	19.5	18.0	17.7	19.4	18.6	18.0	18.2	21.4	18.3		19.5
9	16.8					17.5	17.8	17.3	18.4	17.7	17.6	19.6	18.6	17.7	17.8	20.1	19.1		19.7
10	16.2					17.2	16.9	16.0	16.7	17.1	16.4	18.1	17.7	16.6	17.7	17.2	16.9		18.3

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1918		1919		1920		1921		1922		1923		1924		1925		1926	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	15.7	23.6	12.0	29.9	22.8	21.7	13.7	28.5	23.8	24.7	14.2	23.9	24.8	25.8	12.0	22.5	29.0	24.4	11.8
2	17.4	26.5	15.0	28.5	26.4	25.1	15.4	28.4	26.7	26.1	18.1	18.2	25.0	26.8	14.6	20.5	23.7	25.3	14.8
3	16.0	21.3	13.3	23.3	22.8	21.4	12.6	21.6	21.6	20.8	13.7	14.1	16.4	23.9	12.2	13.9	12.4	19.7	13.0
4	16.0	19.9	13.5	22.5	23.5	22.2	13.1	18.0	20.3	22.0	13.9	14.2	14.8	22.9	12.1	13.7	15.0	16.8	12.9
5	16.0	17.6	15.6	19.0	24.3	21.9	16.7	17.7	18.6	21.1	16.6	15.8	16.3	21.5	14.9	15.3	15.1	16.6	14.4
6	16.4	17.1	17.0	18.0	23.3	20.8	19.3	18.6	18.6	19.9	17.4	16.5	17.4	18.2	16.9	16.6	15.5	17.3	16.7
7	17.2	18.3	18.3		21.4														
8	17.0	18.1	19.0		20.5														
9	16.8	18.4	19.5		19.2														
10	16.2	18.3	18.2		18.0														

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	15.7	29.1	27.8	17.4	13.0	27.0	18.1	24.7	15.5	25.9	26.0	24.3	24.0	21.8	22.0	17.4	11.7	13.9	22.9	24.1	9.8
2	17.4	28.1	28.0	21.2	16.5	27.6	27.0	27.0	17.4	27.5	26.4	27.9	24.7	24.9	26.5	22.0	15.8	17.0	26.0	27.9	14.6
3	16.0	15.6	22.7	20.0	14.1	19.6	21.3	22.1	14.5	22.3	22.1	24.3	16.6	21.3	22.1	19.8	13.2	14.7	17.7	19.2	13.1
4	16.0	13.9	13.2	18.9	13.9	16.3	17.4	22.8	13.1	21.1	22.1	24.2	15.5	20.8	20.6	19.4	12.5	13.2	15.8	14.4	13.4
5	16.0	14.5	13.3	18.3	14.6	14.1	14.5	22.3	15.3	20.4	20.9	23.7	18.3	21.0	21.5	20.1	13.6	13.6	14.6	------	14.8
6	16.4	16.1	14.3	17.4	15.3	14.7	14.5	21.0	17.0	19.1	20.2	23.0	20.0	21.1	21.5	20.1	15.7	14.7	15.3	------	16.0

TABLE 18.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot D at Hays, Kans., fallowed in even years and cropped to winter wheat in odd years, 1909–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1909		1910		1911		1912		1913		1914		1915		1916		1917	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	14.9	18.9	13.0	24.9	23.9	24.8	10.0	26.3	25.6	25.1	16.5	26.2	23.8	25.8	30.2	24.9	18.8	16.9	12.3
2	16.7	23.8	15.8	26.9	26.2	24.8	15.7	25.8	26.6	23.2	19.7	25.7	26.4	26.5	29.2	26.0	25.1	24.9	15.9
3	16.6	20.6	12.9	22.9	21.1	20.6	12.5	20.0	20.5	18.3	15.4	19.0	22.2	21.6	23.4	22.5	20.5	20.9	13.7
4	16.4	20.0	13.1	21.5	20.8	19.8	14.6	17.9	20.3	19.7	15.6	17.4	19.1	22.4	24.0	23.0	22.3	22.2	17.0
5	16.5	19.5	16.1	19.6	19.2	19.4	17.6	18.1	20.4	19.7	16.9	17.4	17.9	20.4	23.6	21.9	22.0	21.6	20.0
6	16.9	18.1	16.1	18.1	17.5	18.5	18.2	17.8	19.2	19.8	18.9	18.3	17.2	19.5	21.8	22.1	22.2	20.8	21.0
7	16.5	------	------	------	------	16.3	17.0	17.9	17.7	20.3	18.7	19.8	18.3	20.3	21.1	21.6	21.7	------	21.0
8	16.6	------	------	------	------	17.3	15.5	17.2	16.7	18.9	17.9	18.6	18.5	18.9	19.2	20.5	20.3	------	20.5
9	16.3	------	------	------	------	15.4	15.7	16.8	16.6	18.9	16.8	18.1	18.4	17.8	18.4	19.2	19.2	------	19.1
10	15.4	------	------	------	------	14.4	14.0	15.9	14.8	17.2	15.3	16.9	16.4	16.6	16.6	16.3	16.5	------	17.2

TABLE 8.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot D at Hays, Kans., fallowed in even years and cropped to winter wheat in odd years, 1909–36*—Continued

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1918		1919		1920		1921		1922		1923		1924		1925		1926	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	14.9	25.6	22.7	26.2	15.0	19.1	24.9	25.1	17.2	23.3	22.6	21.7	17.6	29.1	20.3	18.4	11.7	24.1	23.6
2	16.7	25.5	25.3	25.0	20.1	25.8	27.2	24.5	20.6	16.6	25.5	24.8	20.0	28.8	23.5	22.2	14.8	26.6	26.8
3	16.6	17.5	19.0	20.7	16.0	19.4	22.5	19.5	16.2	13.0	17.7	18.0	17.7	23.5	21.1	19.7	12.9	16.9	16.7
4	16.4	14.7	18.1	19.6	15.1	17.2	22.4	20.7	13.2	12.8	14.7	16.1	15.2	22.0	20.9	20.5	12.7	13.7	13.3
5	16.5	16.5	18.2	19.1	17.2	17.3	21.7	20.8	15.3	15.0	14.1	16.2	15.9	20.1	19.6	19.5	13.8	15.3	13.9
6	16.9	18.7	19.3	18.7	18.4	17.5	20.2	20.6	17.1	16.7	15.7	16.8	16.8	18.1	18.3	19.3	15.2	16.6	15.1
7	16.5	20.0	20.7		19.3														
8	16.6	20.1	20.6		19.3														
9	16.3	19.0	19.4		18.8														
10	15.4	16.8	17.2		18.0														

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	14.9	18.5	15.5	25.3	24.9	23.0	13.0		23.2	26.3	16.9	20.1	24.2	15.4	16.2	19.1	14.4	15.0	9.8	27.8	21.3
2	16.7	21.5	16.8	27.0	27.5	26.9	15.1		28.0	23.6	16.2	26.3	28.6	23.4	16.1	22.5	19.5	20.8	16.5	24.3	24.9
3	16.6	17.9	13.8	20.1	20.8	23.0	12.4		22.2	20.0	13.1	20.4	24.6	21.9	13.4	16.1	17.1	16.7	14.5	19.0	20.5
4	16.4	15.7	12.7	16.8	16.5	23.0	11.9		19.0	20.5	12.1	23.1	25.4	22.0	12.0	14.0	16.7	14.3	12.5	15.1	17.0
5	16.5	15.2	13.2	15.0	15.5	22.4	14.0		19.0	19.8	12.9	21.8	25.2	22.1	13.5	13.8	14.4	14.1	14.7		14.5
6	16.9	16.6	13.9	15.6	14.8	21.5	16.7		19.0	19.8	13.6	16.7	24.1	22.0	14.0	14.5	14.6	14.4	14.2		14.5

The soil in both the fifth and the sixth foot sections contained available water at harvesttime in a considerable portion of the years. Evidently water at those depths is not used heavily in years when available water is present nearer the surface. Crops are sometimes unable to get the water available in the lower depths in spite of a lack of moisture in the upper foot sections because conditions are so adverse that the wheat dies or comes to a forced maturity before the roots can take up this moisture. In 1911 and 1917, wheat on fallowed land suffered severely from drought and came to a forced maturity with a very low yield without removing the water from the fifth and the sixth foot sections. In 1931, a vigorous growth of wheat producing a high yield removed all the available water to a depth of at least 6 feet. In 1933, a wheat crop that began to suffer from drought early in the spring removed the available water to a depth of more than 6 feet and produced a fair yield. Determinations made on another plot that year showed that the wheat used water to a depth of more than 8 feet.

Determinations to a depth of 10 feet were made during the years 1911–19. The soil moisture of the seventh, eighth, ninth, and tenth foot sections of both plots was approximately at the wilting coefficient when the first samples were taken in 1911. The water content at depths greater than 6 feet on plot D gradually increased to a point considerably above the wilting coefficient. The only year when there appeared to be any material water reduction by the crop was on plot C in 1916, when there was evidence of water being used to a depth of 8 feet. Water use to depths greater than 6 feet occurs at only rare intervals, and it seems likely that there is a slow infiltration of water beyond the reach of winter wheat roots. The quantity of water that reaches these depths must be small. However, deep samples taken in 1935 showed that the water content at depths from 10 to 20 feet was then higher on alternately cropped land than on continuously cropped land.

Numerous determinations of water content have been made on buffalo grass sod at Hays, but the records are not so continuous as those on cultivated land, and there are no moisture-equivalent determinations to serve as indications of the wetness of the soil. If the moisture equivalents of the two fields are approximately the same, it is evident that water penetration to a depth of 6 feet is at least as frequent on sod as on land continuously cropped to wheat. There is also the indication that sod can reduce the moisture content of the fifth and the sixth foot sections to a lower point than wheat can.

RESULTS AT COLBY, KANS.

The soil at Colby, Kans., is a silt loam of the Rosebud series. It is somewhat lighter than the soil at Hays as it contains a higher percentage of silt and a lower percentage of clay. It probably has a higher infiltration rate than the soil at Hays, but does not crack as badly when dry and does not admit as much water through crevices.

The land where the crop rotation field is located was broken from the sod about 1885. It was allowed to go back in the early nineties and was broken again in 1905. During the period 1905–13, the land was farmed continuously. Winter wheat was probably grown in all or nearly all years. The experimental work was commenced in 1914.

In wells dug near the land occupied by the crop rotations no water was encountered until sand was reached at a depth of 108 feet. This sand is overlain by a layer of nearly impervious red clay 52 feet thick. As there is no water accumulation on top of this clay, it can be taken for granted that no water has infiltrated to depths not reached by plant roots.

The plots selected for study were B, which was continuously cropped to winter wheat on early plowing, and C and D, which were alternately fallowed and cropped to winter wheat. Moisture determinations in most years were not made as frequently at Colby as at other stations. Consequently there was less opportunity to select a spring determination showing a maximum water content. There were also a number of years when rain intervened between harvest and the date when the harvest determinations were made.

In 1933, 1935, and 1936 the wheat crop failed, and no soil-moisture determinations were made in the spring or at the time when wheat is normally harvested. Data on the lower foot sections from determinations made at seeding time in the fall are indicated on the figures presented. The dates of determinations are not comparable with those of other years, but the data are presented for the purpose of indicating the change or lack of change in the subsoil water content during these years of extreme drought and heat.

The soil-moisture history of plot B is shown in table 19 and figure 13. In every year and for every foot of soil except the first foot in 1915 and 1923, the moisture content was undoubtedly reduced below the wilting point by harvesttime. The apparent presence of available water in the first foot section at harvesttime in other years was due to rain between the harvest date and the date when the moisture determination was made.

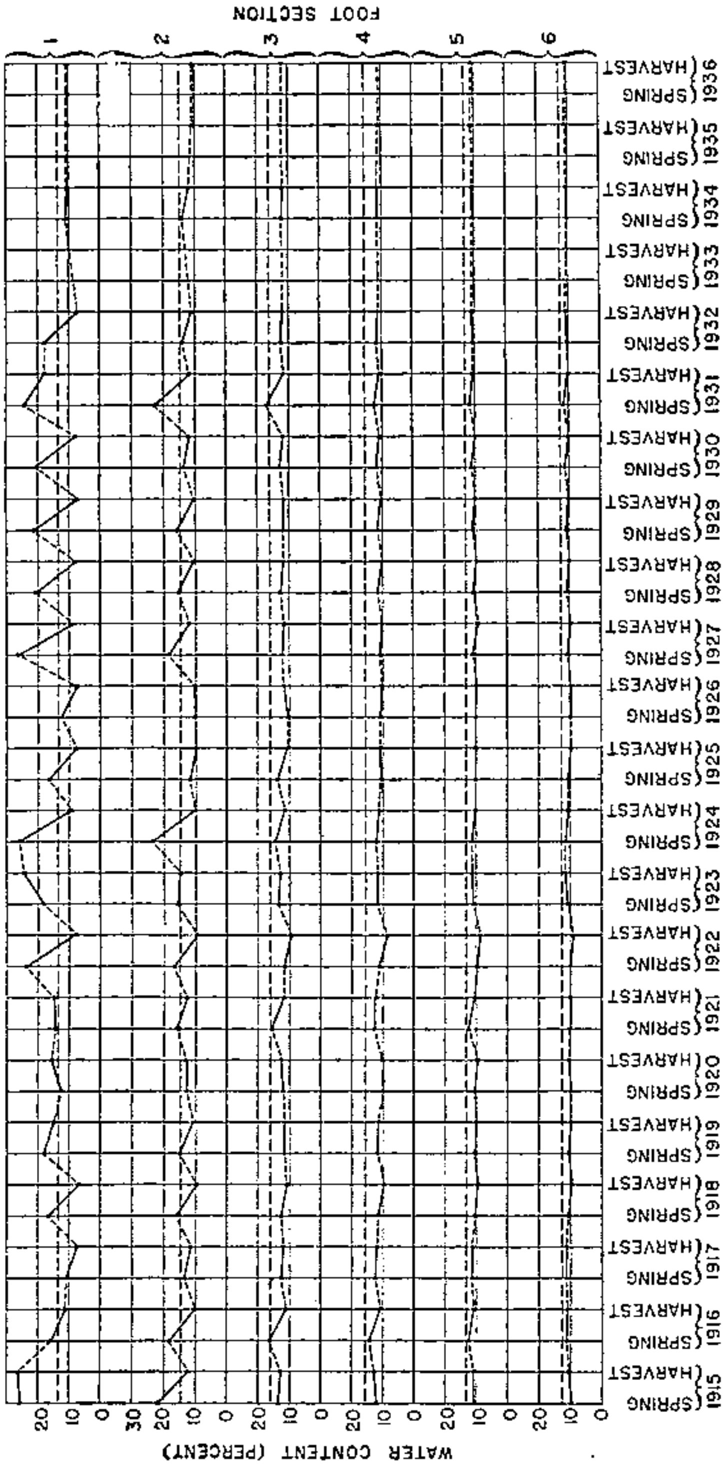

FIGURE 13.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot B at Colby, Kans., continuously cropped to winter wheat, 1915–36. The wilting coefficient of each foot section is indicated by a broken line.

TABLE 19.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot B at Colby, Kans., continuously cropped to winter wheat, 1915–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	13.6	25.8	26.6	15.6	11.0	10.9	7.2	16.5	6.4	18.2	15.1	12.3	15.7	14.0	14.9	23.6	7.5	18.3	24.5	25.9	9.0
2	14.6	21.7	12.6	18.6	10.1	13.5	11.4	16.0	9.7	15.0	10.6	12.9	12.7	15.7	12.3	16.8	9.2	15.1	14.4	23.3	10.2
3	16.1	13.7	13.0	16.7	11.0	12.2	11.9	12.7	10.9	11.6	11.6	11.8	12.3	15.6	11.8	11.8	9.1	13.4	12.7	14.4	11.6
4	15.6	12.0	12.7	14.3	10.9	12.2	11.8	11.0	9.6	11.5	11.2	9.8	10.0	12.8	12.1	11.0	8.6	11.9	11.5	12.0	11.1
5	13.0	10.6	10.9	12.4	10.8	11.3	11.1	10.2	9.3	10.3	9.7	10.0	9.6	12.0	10.1	9.9	8.7	10.9	11.0	11.3	10.3
6	12.8	9.8	10.4	11.4	10.9	11.3	11.3	10.5	9.4	10.3	9.6	9.5	10.1	9.0	9.8	9.8	8.9	10.9	11.6	11.1	10.2

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1925		1926		1927		1928		1929		1930		1931		1932		1934		1935	1936
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Harvest	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	13.6	16.6	7.4	12.2	7.7	26.8	8.9	20.4	7.9	21.5	7.3	20.1	7.9	24.6	10.3	17.6	7.6	11.0	10.3	-------	-------
2	14.6	11.8	9.6	10.1	10.5	18.1	12.0	15.7	10.6	15.7	10.3	13.1	11.3	22.8	11.6	13.8	10.8	13.8	11.8	10.9	10.5
3	16.1	13.6	10.5	10.6	11.3	12.0	11.3	12.3	11.3	11.7	11.5	12.5	11.8	16.9	11.3	12.1	11.7	12.0	11.8	12.0	11.9
4	15.6	10.3	10.5	10.2	10.0	10.9	9.8	11.1	9.9	11.2	10.0	11.1	10.5	12.4	10.6	11.0	10.6	11.0	11.0	10.5	10.8
5	13.0	10.0	9.8	9.8	9.3	10.8	9.0	10.5	9.2	10.9	9.9	10.7	9.4	11.1	9.7	10.2	10.3	9.9	10.1	10.4	10.1
6	12.8	10.2	9.5	9.9	9.4	10.6	9.6	10.6	9.7	10.9	9.9	11.0	9.7	11.6	10.2	10.3	10.6	10.2	10.3	11.0	10.4

The second foot section of soil was dry at harvesttime every year, but it did not function completely in the production of wheat because it was not always filled with water.

Water appeared to enter the third foot section of soil in about one-third of the years. In every year, the water in this section was much below the wilting coefficient at harvesttime. The water content of the third foot section seemed to remain on the average about 4 percent below the wilting point, except when temporarily increased by rain.

Little water penetrated to a depth greater than 3 feet, and the water content of the soil beyond that depth remained almost constantly below the wilting point. It is possible that the fourth and the fifth foot sections of soil have been moist above the wilting coefficient at times not represented by determinations. It is doubtful whether the sixth foot section has at any time contained water above the wilting coefficient.

It can be positively stated that water on this plot has not infiltrated to depths not reached by wheat roots. The fourth, fifth, and sixth foot sections of soil have remained at a uniform level of dryness for more than 20 years, except for temporary additions of water that were in every case removed by the growing crop. The subsoil was fully as dry following good crops as following failures.

The moisture history of the alternately fallowed and cropped plots C and D is given in tables 20 and 21. The soil-moisture history of plot C is shown in figure 14. The use of fallow greatly increased the functioning depth of the soil. Water was present much more frequently and in larger quantities in the lower foot sections than on plot B.

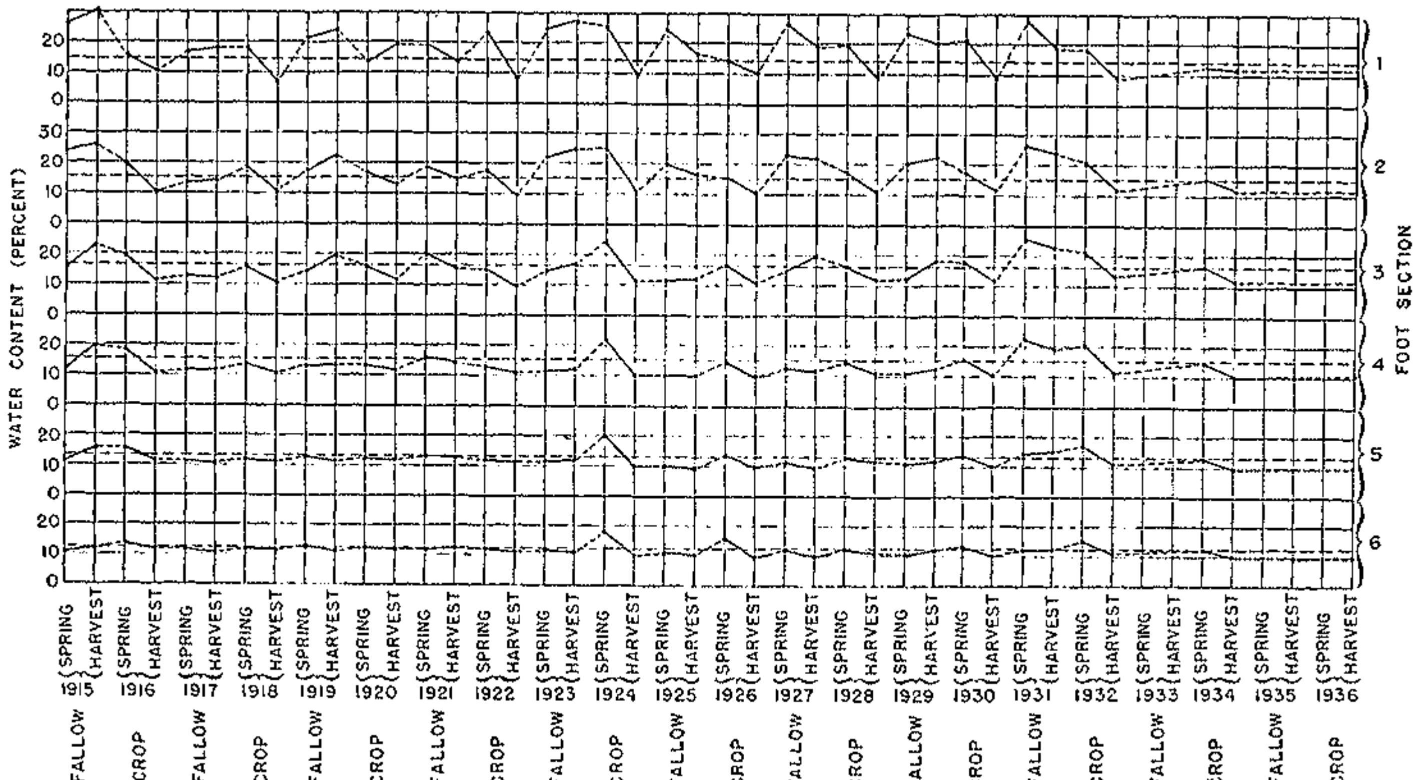

FIGURE 14.—Percentage of water in the several foot sections of soil in the spring and at harvesttime on plot C at Colby, Kans., cropped to winter wheat in even years and fallowed in odd years, 1915–36.

TABLE 20.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot C at Colby, Kans., fallowed in odd years and cropped to winter wheat in even years, 1915–36*

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	14.5	26.1	30.8	14.5	10.5	16.8	18.1	18.1	6.6	21.7	24.0	13.5	19.1	19.0	13.2	23.0	7.5	24.5	27.0	25.5	9.8
2	15.3	23.8	25.7	19.5	10.6	13.3	14.0	18.6	10.5	17.2	22.8	16.5	13.0	18.6	14.6	17.1	9.0	22.0	24.5	24.9	10.8
3	16.7	15.4	23.0	19.4	11.5	12.5	12.0	15.7	10.2	14.3	19.3	16.0	11.7	20.3	14.1	14.1	9.3	14.5	16.8	24.2	11.2
4	15.5	12.1	19.8	18.1	10.9	11.5	11.8	13.5	10.4	13.2	13.2	13.5	11.7	15.8	14.1	12.7	10.6	11.1	11.8	21.9	10.0
5	13.4	11.1	15.8	15.6	11.3	11.2	10.6	11.7	11.0	13.0	11.1	12.4	11.8	13.1	12.8	11.6	11.1	11.2	11.6	19.7	9.5
6	12.7	10.9	11.9	13.6	11.1	11.7	10.8	11.8	11.5	12.9	10.0	12.1	11.8	11.8	12.5	11.8	10.9	11.2	10.7	17.8	9.9

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1925		1926		1927		1928		1929		1930		1931		1932		1934		1935	1936
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Harvest	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	14.5	24.1	16.9	14.1	10.1	26.9	18.7	19.6	8.4	23.9	20.2	20.9	8.6	27.8	18.7	18.3	8.3	12.4	11.7		
2	15.3	19.8	16.4	15.3	10.3	23.0	21.5	17.0	10.6	20.1	22.0	16.4	11.2	26.2	23.4	20.8	11.9	15.1	11.3		
3	16.7	11.4	12.1	16.6	10.7	15.9	19.3	16.1	11.9	12.1	18.2	17.3	11.4	25.3	22.3	21.1	13.0	16.1	11.9		
4	15.5	10 1	10.3	14.7	9.7	12.4	11.2	14.3	10.9	10.9	12.6	15.2	10.1	22.5	19.0	20.2	11.1	14.8	10.3	10.1	10.6
5	13.4	9.9	9.1	13.5	9.6	10.9	9.4	12.2	11.3	10.4	11.9	13.3	9.8	14.2	15.0	17.0	10.6	12.4	9.5	9.4	9.7
6	12.7	11.0	10.1	13.0	9.2	11.5	9.5	11.9	10.4	10.5	11.7	12.7	9.8	11.4	12.1	15.1	11.0	12.1	9.8	9.5	9.5

TABLE 21.—*Water content in the spring and at harvesttime and the wilting coefficient of the soil on plot D at Colby, Kans., fallowed in even years and cropped to winter wheat in odd years, 1915–34*

Depth (feet)	Wilting coefficient	Moisture content of soil																			
		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	13.8	25.4	28.0	18.3	15.3	14.0	8.2	19.9	7.4	19.8	16.4	18.6	23.9	12.5	12.1	23.0	20.5	20.0	25.4	28.2	13.3
2	15.8	24.6	15.1	19.0	13.8	15.3	12.2	16.3	10.6	16.6	12.5	18.3	20.8	16.0	12.9	21.4	22.0	20.7	21.7	25.7	18.7
3	17.1	19.7	13.0	17.7	13.7	14.5	13.7	12.0	9.4	11.7	10.7	15.2	17.4	18.2	11.6	15.4	19.1	20.3	19.9	25.1	20.1
4	14.8	13.4	11.6	13.6	11.8	12.2	11.3	9.0	8.6	9.1	9.5	7.4	13.3	17.3	9.8	9.6	15.6	16.8	16.6	19.2	16.7
5	13.0	11.2	10.4	11.0	10.3	10.7	9.8	8.9	8.4	8.8	9.3	7.9	11.2	15.4	9.6	9.6	12.4	14.4	14.1	13.0	13.6
6	11.9	9.1	9.2	9.5	9.4	10.6	9.3	8.9	8.3	7.9	8.8	7.4	11.3	13.6	9.1	8.8	12.1	12.1	11.5	11.8	12.5

Depth (feet)	Wilting coefficient	Moisture content of soil																	
		1925		1926		1927		1928		1929		1930		1931		1932		1934	
		Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest	Spring	Harvest
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	13.8	18.6	7.8	23.6	14.5	25.7	7.9	24.9	21.4	23.4	9.3	28.2	21.8	24.6	13.5	25.0	16.5	22.3	15.1
2	15.8	18.7	10.9	14.2	12.7	19.1	12.0	24.4	23.4	24.1	12.2	26.3	23.0	25.0	12.1	23.6	21.6	17.4	16.9
3	17.1	19.4	10.7	11.5	10.7	13.3	12.0	17.9	22.2	21.4	11.7	24.0	23.9	24.4	11.5	19.1	21.7	11.0	12.4
4	14.8	17.2	9.2	10.0	9.4	12.6	9.5	12.8	15.6	17.7	12.6	16.9	22.7	21.6	9.5	10.4	16.3	9.7	10.0
5	13.0	14.8	9.0	9.6	9.8	11.5	9.5	12.5	12.0	15.3	13.9	12.6	19.1	19.1	9.4	9.5	10.5	9.3	9.9
6	11.9	12.4	9.0	10.0	10.5	11.6	9.7	12.0	11.0	13.7	12.9	12.1	15.7	17.2	9.2	9.8	10.1	8.9	9.8

The first three foot sections of soil were filled nearly to capacity in most crop years, and in all but a few exceptional cases practically all the water was removed by harvesttime.

The fourth foot section of soil was filled to capacity in only a few years, but it practically always contributed some water to the crop. In some years it contributed heavily. As much water was used from the fourth foot section under alternate fallowing and cropping as from the second foot section under continuous cropping.

The fifth and the sixth foot sections contributed material quantities of water to the crop in some years, but in most years the quantity was limited, because the soil at those depths was not filled. There was, however, more water used from the sixth foot of land that had been fallowed than from the third foot of continuously cropped land.

In all the lower foot sections, the crop removed the water in most years to as low a point on fallowed land as on continuously cropped land, indicating the complete occupation of the soil by wheat roots to the depth of 6 feet, when available water was present to that depth.

In a few years, water undoubtedly penetrated to depths greater than the depth of the determinations. The complete removal of water to a depth of 6 feet would indicate that wheat roots penetrate more than 6 feet. The possibility that during the course of these experiments water infiltrated beyond the depth reached by wheat roots appears to be remote.

AVERAGE REDUCTION IN WATER CONTENT FROM SPRING TO HARVESTTIME

Table 22 presents the average reduction in water content of the different foot sections of soil between spring and harvesttime on continuously cropped, alternately fallowed, and sod plots. These figures do not represent the full amount of water used, as determinations were seldom made at the exact time when the soil held its maximum quantity of water, and sometimes were not made when the soil was at its driest. They do serve, however, as good indications of the extent to which the different foot sections of soil function in the production of wheat and native grass, and as measures of the changes brought about by tillage practices.

It can be noted from the table how the use of water from the different foot sections is influenced by the cropping practice, by soil type, by vegetative cover, and by precipitation.

TABLE 22.—*Average reduction of the water content of the soil from spring to harvesttime at 5 stations in the Great Plains for depths, cropping practices, and number of years specified*

Depth (feet)	Havre—spring wheat		Mandan—spring wheat					North Platte				Hays—winter wheat		Colby—winter wheat	
			Main field		South field			Spring wheat		Winter wheat					
	Continuous cropping, 20 years	Alternate fallow, 19 years	Continuous cropping, 22 years	Alternate fallow, 22 years	Continuous cropping, 21 years	Alternate fallow, 21 years	Native sod, 20 years	Continuous cropping, 26 years	Alternate fallow, 25 years [1]	Alternate fallow, 21 years [2]	Native sod, 20 years	Continuous cropping, 28 years [3]	Alternate fallow, 28 years [3]	Continuous cropping, 19 years	Alternate fallow, 19 years
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	7.6	9.0	9.6	10.1	9.9	11.5	10.4	8.4	8.8	6.7	7.4	6.5	7.2	7.3	7.1
2	6.3	9.5	6.8	8.2	3.9	7.7	6.2	6.2	8.0	7.7	5.6	4.7	7.1	4.8	6.9
3	2.0	6.3	3.0	6.1	.8	4.2	2.2	3.0	7.4	7.1	3.2	2.9	6.3	1.5	5.9
4	.6	1.7	1.4	5.4	.2	1.4	1.9	2.2	6.5	6.5	1.6	1.6	6.3	.8	4.8
5	--------	.0	1.0	1.7	.3	.5	.6	.8	4.7	5.4	1.3	.9	4.1	.8	3.2
6	--------	.0	.3	1.5	.5	.0	.6	.5	2.7	3.5	.9	.5	2.3	.5	2.4
7	--------	--------	--------	--------	--------	--------	--------	--------	1.7	2.4	--------	-.3	.5	--------	--------
8	--------	--------	--------	--------	--------	--------	--------	--------	.8	1.6	--------	-.1	.4	--------	--------
9	--------	--------	--------	--------	--------	--------	--------	--------	.3	1.1	--------	-.4	.1	--------	--------
10	--------	--------	--------	--------	--------	--------	--------	--------	.0	.8	--------	-.1	.3	--------	--------

[1] Data for the seventh to tenth foot are for 19 years.
[2] Data for the seventh to tenth foot are for 11 years.
[3] Data for the seventh to tenth foot are for 7 years.

Under continuous wheat production, the water reduction was much the same at Havre under a 12-inch precipitation, in the south field at Mandan under a 15.2-inch precipitation, and at Colby under a 17.7-inch precipitation. At these three locations, heavy use of water was confined to the first two foot sections. Below a depth of 3 feet, the average reduction in water content was less than 1 percent in any foot section. The low average rate in the lower foot sections was usually the result of considerable use in a few years rather than a small use each year. The similarity of use at Mandan and Havre under different precipitations is due to a difference in soil type. A larger quantity of precipitation reached the third foot section of soil at Havre than reached the third foot section in the heavy soil of the south field at Mandan under a heavier rainfall. The similarity of use at Colby is probably due to the nature of the crop as well as to the soil type. Winter wheat begins to use water heavily by the time spring rains usually occur, and the consequent drying of the soil in the upper foot sections results in the water from spring precipitation being used to replace the water removed by the crop instead of being available for deeper penetration.

The effect of soil texture is particularly evident in the two fields at Mandan. Water reduction was as great in the fifth foot section of the light soil in the main field as in the third foot section in the south field. Reductions in the fourth, fifth, and sixth foot sections on continuously cropped land in the main field were greater than from the same foot sections on fallowed land in the south field. The water reduction in the fourth foot section of the continuously cropped plot in the main field at Mandan under a 15.2-inch precipitation was about as great as in the same section of a similarly cropped plot at Hays under a 22-inch precipitation. Much of this difference in the efficiency of the precipitation undoubtedly can be attributed to the difference in the texture of the soils, although there are other contributing factors.

At the two stations where results from sod are available, water reduction on sod land was much the same as on continuously cropped wheatland. There was, however, a tendency for more complete use of available water in the fifth and the sixth foot sections under sod than under wheat.

The use of fallow greatly extended the average depth of soil normally functioning in the production of wheat. At Havre, the active feeding range of wheat was increased 1 foot by the use of fallow. On the south field at Mandan it was increased a little more than a foot. On the main field, the active feeding range of spring wheat was increased nearly 2 feet by the use of fallow, and at North Platte it was increased by more than 2 feet. In both of these cases, full advantage of all the water provided by fallow could not be taken because the normal root development of spring wheat did not allow the crop to remove all the available water in the lower foot sections. Winter wheat at North Platte made more use of water available at depths greater than 4 feet than did spring wheat.

At Hays and Colby, fallowing increased the normal feeding range of winter wheat by about 3 feet. At Hays, due to the relatively heavy rainfall, water probably infiltrated to depths not reached by wheat roots. At Colby there has probably been no such loss.

In general, the increased depth of active feeding brought about by the use of fallow is proportional to the rainfall during the fallow year.

An even closer relationship might be shown if wheat were able always to take advantage of the water provided by fallow. In many cases, however, it was not. The roots of wheat do not develop to their possible maximum depth when all the water needed to mature the crop can be obtained from the upper foot sections. Neither does wheat root so deeply when the need for water is so great that the crop is badly stunted, or when the need arises suddenly, late in the life of the crop. Deep feeding is induced by a need for water continued over a long period but at no time so severe as seriously to inhibit the growth of the crop.

EXTENT OF INFILTRATION OF WATER TO THE WATER TABLE

In general it may be said that under sod or under continuous cropping to small grains, infiltration of water to depths not reached by roots has been so rare and so limited at the stations under study that the addition of any appreciable quantity of water to the water table is a matter of centuries.

At Havre, Colby, Hays, and on the south field at Mandan it is questionable whether water has ever penetrated beyond the reach of wheat roots on land continuously cropped to wheat. At North Platte and on the main field at Mandan, water has penetrated beyond the reach of wheat roots. At Mandan, this occurred only once in 25 years, and then under a precipitation not duplicated during the period 1878 to 1936. At North Platte the indications are that it is not likely to occur as often as once in 10 years.

At both North Platte and Mandan the indications are that under native sod water seldom penetrates to depths beyond the reach of the deep-rooted perennial plants that make up a part of the vegetation.

Under a system of alternate fallow and crop, water infiltrated to depths greater than under continuous cropping, but even under this system infiltration beyond the reach of crop roots was very limited and infrequent. At Havre and Colby, there was little or no infiltration beyond the reach of wheat roots. At Hays, North Platte, and on the main field at Mandan, there was infiltration beyond the reach of roots, and after the soil below the feeding range of crop roots became wet it remained continuously so. At Hays, soil-moisture determinations made to a depth of 20 feet in 1935 showed that the soil at depths between 10 and 20 feet was much wetter on alternately cropped than on continuously cropped land. Even under an alternate fallow and crop system it would require many years for water to reach the water table.

The conclusion must be reached that, at the stations under study, material additions of water to the water table are not made by penetration of surface water on the upland. The existing water tables or channels must be due to infiltration of water from streams or other places of water concentration, or to the penetration through permeable strata probably located long distances away from the points under study. At Colby, the well water probably entered the ground hundreds of miles away.

It is of particular interest that at the two locations where under continuous cropping water penetrated beyond the reach of wheat roots, the water table is several hundred feet below the surface and is at the approximate level of nearby rivers.

In all the locations the water table was so far from the surface that it could not possibly influence the growth of crops. The very meager penetration of surface water to depths beyond the reach of roots indicates that at the locations studied annual fluctuations of rainfall could have no effect upon the water table, except that the drying up of streams may severely limit water penetration along watercourses.

If very wet years occurred successively, the extent of infiltration into the subsoil would be materially increased. The residue of water remaining after harvest, as it does in the wettest years at some stations, would reduce the quantity of water necessary to saturate the section of soil occupied by crop roots, and more water would be available for deeper penetration. As a general rule, however, wet years occur following years when the crop has exhausted all the moisture within reach of its roots. The entire dry zone must be saturated before water penetrates below it. This explains why a higher rainfall for a single year is required to wet the soil to a given depth under dry-land conditions than is required under more humid conditions where a residue of moisture is left in the soil at harvesttime. Years wet enough to leave a residue of moisture in the soil at harvest do not often occur under dry-land conditions.

The depth of the water table does not appear to have any effect on the water content of the soil within the range of crop roots. The soil within this zone is normally dry at harvesttime and remains dry except when water reaches it from the surface. Whether the subsoil is wet or dry below the zone of root growth of annual crops does not affect these crops, as there appears to be no evidence of water movement upward. The presence of a wet subsoil is of temporary importance to deep-rooted crops like alfalfa. Such crops are able to send their roots down many feet and use water not available to annual crops. When such crops have dried the soil to the limit of their root development, they in turn are dependent upon the annual rainfall. The subsoil once dried out, remains dry except as surface water penetrates below the roots of crops.

The recharge of the subsoil is an extremely slow process. In sections east of the one under study, where the rainfall is somewhat heavier, the water removed from the subsoil many years ago by alfalfa crops has not yet been replaced. The University of Nebraska, in studying why alfalfa in the vicinity of Lincoln never appeared to do well again on land once planted to alfalfa, found that the cause lay in the exhaustion of subsoil moisture by the first crop.

While water infiltration beyond the reach of crop roots does not often occur on the heavier agricultural soils of the Great Plains, it does occur on sandy soils. Such lands are easily permeable and have low water-holding capacities. Consequently, a given quantity of rain wets deeper than on soils with more silt and clay in their structure, and more water penetrates beyond the reach of roots. The typical deep-rooted vegetation on sandy soils is an indication that this occurs. It can be safely said, however, that on the short-grass land of the Great Plains there is no penetration of upland surface water to the water table.

East of the short-grass area, even on pedocalic soils, water penetration to the water table occurs at times. At Brookings, S. Dak., during the period 1904–8, an average increase in precipitation of approximately 4 inches above the mean caused a rise in the water table that brought it into the basements of many houses. With the recurrence of more normal rainfall, the water table receded to its former level, and the droughts of recent years have caused it to recede still further.

While there is no evidence of upward movement of water by capillary action in the soils studied, there does appear to be a tendency for the soil at lower depths to be a little more moist in the spring than at harvesttime. The change in water content is not pronounced enough to be positive, and is so limited in scope that, if it occurs, it is not of agricultural importance, and is probably due to vaporization and recondensation.

CONCLUSIONS

Under semiarid conditions, the soil within the zone of normal wheat-root development is usually dry at harvesttime. Under continuous grain production, there is an annual cycle of water accumulation and discharge. Rains that fall after harvest, unless dissipated by weeds, and precipitation during the winter and spring build up the supply of available water in the soil. The building-up process continues in the spring until the crop reaches a stage of development where the rate of discharge from the soil by plants exceeds the rate of recharge by precipitation. From then on the water content of the soil decreases, and complete removal of available water usually occurs at or near maturity of the crop. The rate of water discharge by a rapidly growing grain crop exceeds the rate of recharge by precipitation in all but very exceptional cases.

The depth to which water penetrates depends upon the quantity and type of precipitation and the character of the soil. As a general rule, the entire annual cycle of charge and discharge is confined to only a portion of the zone where roots can develop freely, and no water reaches the underlying subsoil. In a few exceptional years at a few stations the entire root zone fills with water and a small quantity penetrates beyond the reach of wheat roots.

The addition of fallow to the cropping system lengthens the period of water accumulation by a year, permits the wetting of the entire root zone in more cases than under continuous cropping, and increases the number of times when water reaches the underlying subsoil.

Water charge and discharge are much the same under sod as under continuous grain production, although available water is removed completely to a lower depth under sod than under grain, probably because of the presence of deep-rooted perennial plants in native sod. The time element limits the depth to which the roots of annual crops can remove all the available water.

Breaking up the upland sod in the Great Plains has not decreased the quantity of water in the subsoil. The subsoil is no drier and is generally not so dry under continuous grain production as under sod. Where fallow or a cultivated crop enters into the cropping system, the subsoil is wetter than under sod in most cases. The net result of the production of annual crops in the semiarid section has been an increase rather than a decrease in subsoil water.

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