Bulletin No. 183 - Water-Holding Capacity of Irrigated Soils

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Water-Holding Capacity of Irrigated Soils

By

ORSON W. ISRAELSEN and FRANK L. WEST

BULLETIN NO. 183

Utah Agricultural College
EXPERIMENT STATION

Logan, Utah November, 1922
UTAH AGRICULTURAL EXPERIMENT STATION

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WATER-HOLDING CAPACITY OF IRRIGATED SOILS

By

ORSON W. ISRAELSEN and FRANK L. WEST

CONTENTS

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory</td>
<td>3</td>
</tr>
<tr>
<td>Water Capacity of Millville Loam Soil, Utah Experiment Station Farm</td>
<td>4</td>
</tr>
<tr>
<td>Investigations by Widtsoe and Associates</td>
<td>4</td>
</tr>
<tr>
<td>Investigations by the Authors</td>
<td>5</td>
</tr>
<tr>
<td>Plan of the Authors' Investigations</td>
<td>5</td>
</tr>
<tr>
<td>Results of the Authors' Investigations</td>
<td>6</td>
</tr>
<tr>
<td>Investigations by Harris and Associates</td>
<td>10</td>
</tr>
<tr>
<td>Other Field Measurements of Water Capacity</td>
<td>14</td>
</tr>
<tr>
<td>Volcanic Loam Water Capacity</td>
<td>16</td>
</tr>
<tr>
<td>Fine Sandy Loam Water Capacity</td>
<td>18</td>
</tr>
<tr>
<td>Purpose of Water-capacity Studies</td>
<td>18</td>
</tr>
<tr>
<td>Some Water-capacity Measurements by Others</td>
<td>22</td>
</tr>
<tr>
<td>Applications of Water-capacity Measurements in Irrigation</td>
<td>23</td>
</tr>
<tr>
<td>Summary and Conclusions</td>
<td></td>
</tr>
</tbody>
</table>

INTRODUCTORY

The expression "Inches Water Applied" as used in this bulletin is the equivalent of so many acre-inches of water applied to one acre of land. One acre-inch of water means one inch in depth over an acre. It is equal approximately to the quantity of water supplied by a stream of one cubic foot per second flowing continuously for one hour.

All information that will enable the irrigator to use water economically is valuable to arid-climate agriculture. In many arid-climate regions, including the western part of the United States, excessive waste of water occurs in the irrigation of highland porous soil areas, as a result of lack of information concerning the capacity of the soil to hold water. Following the waste of water on the uplands by excessive percolation through open soils, vast lowland areas are rendered partially or wholly nonproductive by water-logging. To illustrate, a gravelly bench soil four feet deep, if underlain by a coarse open gravel to a great depth, has the power to hold but a small amount of water. If, to such a soil, a large amount of water is applied in a single irrigation, then unnecessary waste through deep percolation inevitably follows. Furthermore, the wasted water slowly but surely finds its way to low-lying lands from which there is in-
adequate natural drainage, and water-logging results. It is doubtful if an acre of a typical upland soil, four feet deep, would retain more than three acre-inches of irrigation water. If therefore it took six hours adequately to cover an acre with a 2-second-foot stream, the total amount of water applied would be 12 acre-inches an acre, or four times what the soil could retain. Such excessive applications frequently result from the difficulty in getting the water spread uniformly over the surface. In the illustration given above it is clear that 9 acre-inches, of the 12 acre-inches applied to one acre, must be lost to the upland soil and added to the lowland soil, provided of course allowance is made for evaporation losses. The experiments reported in this bulletin were planned to measure the capacity of some soils to retain water, and thereby assist the irrigator better to determine the proper amount of water to apply to such soils in single irrigations.

The capacity of different soils to retain water has been measured in two ways: first, by a study of small samples of soil in the laboratory, and second, by determining the moisture content of the soil in the field before and after heavy irrigations, or special flooding. Only those water-capacity tests, made in the field or in the laboratory under conditions nearly like field conditions, are reported in this bulletin. Field tests are reported first for the deep loam soils of the Utah Experiment Station at Greenville and later for typical irrigated soil in the Gem Valley, Idaho, near Grace and Central, and finally for a typical fine sandy loam in the Sevier Valley, Utah, near Richfield.

For the reader who is especially interested in water-capacity studies there is also presented a summary of water-capacity tests, both field and laboratory, made by other investigators working in various western states. After this summary brief consideration is given to the application of water-capacity studies in irrigation practice.

During the last twenty years numerous moisture-content observations have been made by the Utah Experiment Station. The earlier Utah work was done by Widtsoe and associates and this was followed by Harris and associates. The work of Widtsoe and associates is summarized before presenting the field tests conducted by the authors, after which the work of Harris and associates is reviewed.

WATER CAPACITY OF MILLVILLE LOAM SOIL, UTAH EXPERIMENT FARM, GREENVILLE

Investigations by Widtsoe and Associates.—The water capacity of Millville loam soil at the Experiment Station Farm
was first investigated by Widtsoe and McLaughlin in 1902 and 1903. Several thousand soil moisture tests were made, and it was found that the maximum amount of water held in the surface foot 24 hours after irrigation was 23.8 per cent of the dry weight of soil, or 3.85\textsuperscript{1} inches of water. In 1902 the maximum increase from 44 trials, in each of which 7\(\frac{1}{2}\) inches of water were applied, was 2.14 inches in the surface foot. The minimum was 0.14 of an inch in the eighth foot, and the average for the upper 8 feet of soil was 0.72 of an inch per foot of soil. In 1903 the average maximum retained from thirty-three 7\(\frac{1}{2}\)-inch irrigations on several plats was 2 inches in the surface foot; the minimum was 0.20 of an inch in the sixth foot; and the average for the upper 6 feet was 0.95 of an inch, or almost 1 inch for each foot depth of soil.

As a result of nearly 3,000 trials\textsuperscript{2} covering five years' work, Widtsoe and McLaughlin found the average maximum moisture content to a depth of 8 feet to be 18 per cent, or 2.82 inches per foot depth of soil. Furthermore, when the moisture content decreased to about 11.5 per cent the plants found great difficulty in obtaining a sufficient water supply. It was therefore necessary to add in a single irrigation the difference between 18 and 11.5 per cent, or 6.5 per cent, which is equal to 1.05 inches of water, for each foot of soil that needs moistening.

Investigations by the Authors.—Attention has been called to the fact that only a few of the many investigations of soil-moisture capacity were applicable to field conditions and consequently of direct value in irrigation practice. The results of some of the more valuable field investigations of moisture capacity are reviewed in the latter part of this bulletin. However, most of the measurements reviewed were made on soils that were growing crops and that were irrigated according to a plan designed to obtain information concerning the duty of water as shown by the amount and quality of the crop produced. In these duty-of-water investigations some plats were given large quantities of water during the season, but seldom if ever were any plats given excessive amounts during any single irrigation. Consequently, there is doubt as to the completeness of soil saturation.


\textsuperscript{1}Based on an apparent specific gravity of 1.35.

authors prepared three rectangular basin plats to which excessive amounts of water were applied. Each plat was 38 feet long and 33 feet wide. Around these plats levees about 2 feet high were built with soil taken from outside of the plats; thus, the soil in the plats was left undisturbed. The plats were numbered A, B, and C. Samples of soil were taken to ascertain the moisture content before irrigation, after which Plat A was given a 12-inch irrigation, Plat B a 24-inch irrigation, and Plat C a 36-inch irrigation.

The borings for moisture samples were made to a depth of 12 feet and the moisture determinations were made in the laboratory by the usual methods, the results being recorded in percent of the weight of the dry soil. In order to make the results of the experiments more intelligible to the irrigator, the moisture percentages by weight have been converted to acre-inches of water per acre-foot of soil, which is clearly very much like percentages on the volume basis. To make this conversion from percent by weight to acre-inches of water per acre-foot of soil, it is necessary to know with a fair degree of accuracy the weight of a given volume of soil—one cubic foot, for example. Determinations of the weight of the soil were carefully made by precise methods which will be described fully in a technical paper. Suffice it to say here that on the basis of these determinations the relative volume of the three component parts of the soil, namely, solid soil particles, water, and air, has been computed. The volumes of solid soil, together with the volumes of air and water before and after irrigation, are shown in Figures 1 and 2.

RESULTS OF THE AUTHORS' INVESTIGATIONS

Column a of Figure 1 shows that Plat A contained more than 6 inches of pore space for each 12 inches of soil. Of the 6 inches' pore space in each foot more than 1 3/4 inches' space was occupied by water that was unavailable to plants and more than 3 3/4 inches by air. The quantities given in Figures 1 and 2 are averages for the upper six feet of soil.

In studying the figures in this bulletin the following notes will be helpful to the reader. The "Solid Soil" represented by the heavy black column indicates the height in inches that one foot (12 inches) of soil would be if it were possible first to heat it enough to drive out all the soil moisture and then compact it under heavy pressure so as to drive out all the air and leave a solid mass having no pore space. Clearly this cannot be accomplished in the field, the soil particles, the moisture, and the air being mixed in one heterogenous mass. The division of the three substances into separate parts helps greatly to understand the volumes occupied by each. For a given soil the air content must clearly decrease as the water increases, and vice versa.
Columns $c$ and $e$ show that Plats $B$ and $C$ contained a little less than $3\frac{1}{2}$ inches of air in each foot of soil. On the basis of $3\frac{1}{2}$ inches of air in each foot of soil, it is clear that the upper 6 feet of soil contained 21 inches of air. If therefore all of the 24 inches applied to Plat $B$ had been held above the 6-foot depth it would have filled all of the air space in the upper 6 feet of soil, i.e., 21 inches, and it would have left $24-21=3$ inches of water on the surface of the ground. Likewise, if all of the 36 inches of
Figure 2.—Water content immediately before and ten days after heavy flooding of three plots on the Utah Experiment Station, Greenville Farm, Logan, Utah. Work by the authors.

Water that was applied to Plat C had been held above the 6-foot depth it would have filled all of the air space in the soil and left water on the surface to a depth of 36-21=15 inches. However, Figure 1 clearly shows that the soil-air cannot for any considerable time be replaced by water in soil that is naturally well-drained. Note, for example, that one day after irrigation Plat B, which was given twice the amount of water that Plat A received, contained only one-fourth inch more water per foot of soil, or
1½ inches more in the upper 6 feet. Likewise, one day after irrigation Plat C, which was given three times as much as Plat A, contained only one-half inch more water in each foot of soil, or a total of 3 inches more in the upper 6 feet. Moreover, Plats B and C, which were given more than enough water completely to fill all of the air space, contained approximately 2 inches of air in each foot of soil one day after irrigation. It will be noted also that these plats contained approximately 2½ inches of available water one day after irrigation. However, much of this water was still moving slowly downward. Final adjustment had by no means taken place. This is clearly indicated in Figure 2 which shows the amounts of air and water in the respective plats 10 days after irrigation. It will be seen that 10 days after irrigation Plats B and C contained but 1½ inches of available water in each foot of soil, being 1 inch less than the amount held one day after. Immediately after irrigation all of the plats were covered with a heavy straw mulch by means of which surface evaporation was quite largely prevented. Therefore the 1 inch of water lost from each foot of soil between the 1-day tests and the 10-day tests was almost wholly a result of percolation below the 6-foot depth. Moisture determinations after the 10-day tests show very slow losses into the deeper soil, thus indicating that the soil had power to absorb and retain approximately 1½ inches of available water1. The fact that the amounts retained in excess of the amount found before irrigation were relatively small resulted from the large quantities of available water held before irrigation, i. e., about 1 inch of water for each foot of soil.

All observations of the moisture content of field soils show that in order to produce the best growth of crops it is necessary to keep some available water in the soil, i. e., some water above the wilting point. For soils very much like the Millville loams of Greenville about 3 per cent of moisture as a minimum above the wilting point appears to give the best results. This is equivalent approximately to ½ inch of water for each foot of soil. If therefore it is necessary to have a minimum of ½ inch of available water in each foot of soil to assure profitable

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1In the opinion of the authors, the downward movement of the water must continue until equilibrium is established with the water-table. Moisture determinations that were made throughout the summer after the 10-day tests showed a continuous but very slow downward movement of water, thus confirming this opinion. However, after the 16-day tests the rate of movement was so low and the decrease in the amount of water per week so small as to warrant the conclusion that for practical irrigation purposes the tests 10 days after flooding represent the effective water capacity. That the selection of the time period after flooding, which represents the maximum moisture capacity, provided downward movement is still going on, must be made somewhat arbitrarily is fully recognized.
growth of crops and if the soil cannot hold more than $1\frac{1}{2}$ inches of available water in each foot, then clearly it is desirable to apply just enough water at each irrigation to add 1 inch to each foot of soil that needs water. For example, if occasional borings with a soil auger show that the soil needs moistening only to a depth of 6 feet, then 6 inches of water would be sufficient. Likewise if only 3 feet of the soil really needs water, then 3 inches of water would be adequate, and the water applied in excess of this amount would be wasted. To illustrate further, the moisture determinations in Plat C before irrigation indicated that the soil needed little if any moisture below the 6-foot depth. Its needs would therefore have been satisfied by the application of 6 inches. Therefore of the 36 inches applied, about 30 inches, or more than 80 per cent, was wasted by passing below the depth where it was needed. To be sure, it was expected in this case that much of the water would be wasted because an excessive amount was applied in order to ascertain the maximum possible storage capacity of the soil for water.

**Investigations by Harris and Associates.**—During the years 1912 and 1913 Harris and Bracken\(^1\) made numerous observations of the moisture content of Greenville soils before and after different amounts of water were applied in irrigation.

The plats here reported were irrigated as follows:

1. 1 inch of water weekly
2. $2\frac{1}{2}$ inches of water weekly
3. 5 inches of water weekly
4. $7\frac{1}{2}$ inches of water weekly

The average percentages of moisture in the upper 10 feet of soil before and after these irrigations are shown in Figure 3 of Utah Experiment Station Bulletin No. 159. The average amounts of water in each foot of soil to a depth of 6 feet before and after the different irrigation treatments are here presented in Figures 3, 4, and 5. The columns in these figures are prepared on the same plan as those in Figures 1 and 2 representing the moisture content of the soils before and after the authors' experiments. It is important, however, to note one difference in the charts. Figures 1 and 2 present comparisons of moisture content before irrigation with the moisture content of the same plat at different time periods after irrigation. However, columns c and d of Figure 3 and the first four columns in Figures 4 and 5, i.e., columns a, b, c, and d, present comparisons of the moisture content before irrigation of a plat given one irrigation treatment to

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Figure 3.—Water content comparisons between different plats before and after different irrigation treatments on the Utah Experiment Station, Greenville Farm, Logan, Utah.

Work by Harris et al.

the moisture content after irrigation of a different plat which was given a different treatment. The first 2 columns in Figure 3 and the last 2 columns in each of the Figures 3, 4, and 5 compare moisture content before irrigation with the moisture content of the same plat after irrigation. The purpose of comparing the moisture content of some plats before irrigation to that after irrigating in different plats which received different amounts of water is to show how the capacity of a given soil to hold the water applied to it is dependent on the original water content of the soil and on the amount of water applied. Very careful study is essential to a clear understanding of the significance of these comparisons. This will be aided by a comparison of the various columns after attention is again directed to some physical properties of the soils under consideration.
Figure 4.—Water content before and after different irrigation treatments on the Utah Experiment Station, Greenville Farm, Logan, Utah. Work by Harris et al.

It will be noted, as in Figures 1 and 2, that less than one-half of the total 12-inch space occupied by each foot of soil is really solid soil particles, while 6.13 inches of each foot, or more than one-half, is occupied by moisture and air. Columns a and b of Figure 3 show that the plats which were given 1 inch of water weekly had approximately one-half inch of available water before irrigation and only about three-fourths inch after irrigation. The average increase from a 1-inch irrigation was therefore only one-fourth of one inch in each foot depth of soil. The depth of water per foot depth of soil may have been slightly different for a different depth of soil.

In comparing the 1-inch to the 2½-inch irrigation it will be noted by columns c and d of Figure 3 that the increase was about ½ inch for each foot of soil. Those plats which were
Figure 5.—Water content before and after different irrigation treatments on the Utah Experiment Station, Greenville Farm, Logan, Utah. Work by Harris et al.

given a 2½-inch irrigation weekly, as indicated in columns e and f, contained an average of ¾ inch of available water before irrigation, but the actual increase from irrigation was only ¼ inch.

In Figure 4 comparisons are made of the moisture content under the three following conditions: (1) a plat which was given 1-inch applications weekly is compared to one given a 5-inch application; (2) a 2½-inch plat is compared to a 5-inch one; and (3) two 5-inch weekly plats are compared. It will be noted in Figure 4 that the plats which were given 5-inch irrigations contained more than 1½ inches of available water after irrigation. The greatest difference between the moisture content of the various plats occurs in the comparison of columns a and b which
were given 1-inch and 5-inch applications, respectively. Column c shows more soil moisture before the application of 2\(\frac{1}{2}\) inches of water weekly than column e shows before the application of 5 inches weekly.

In Figure 5 comparisons are made between 1-inch and 7\(\frac{1}{2}\)-inch irrigations; 2\(\frac{1}{2}\)- and 7\(\frac{1}{2}\)-inch; and 7\(\frac{1}{2}\)- and 7\(\frac{1}{2}\)-inch irrigations. This figure shows that the plats which received 7\(\frac{1}{2}\) inches weekly contained an average of more than 1\(\frac{3}{4}\) inches of available water after irrigations. As shown in column a the soils which were given 1-inch irrigations had less than \(\frac{1}{2}\) inch of available water before irrigation. The greatest difference occurs between the 1-inch and the 7\(\frac{1}{2}\)-inch irrigations and the smallest difference between the two plats which were given 7\(\frac{1}{2}\) inches weekly. This is shown by comparing column a with column b and column e with column f, respectively. Column a shows that the soil contained less than \(\frac{1}{2}\) inch of available water before the 1-inch irrigations, whereas column e shows that the plats which were given 7\(\frac{1}{2}\) inches contained \(\frac{11}{2}\) inches of available water before irrigation. Furthermore, column b shows an increase resulting from irrigation of \(1\frac{1}{2}\) inches, whereas column f shows an increase of only \(\frac{1}{2}\) inch. Clearly the capacity of a soil to absorb and retain water is greatly dependent on the initial moisture content. Furthermore, the waste which occurred in applying 7\(\frac{1}{2}\) inches to a soil so wet as that represented by column e is clearly shown. Fully 4\(\frac{1}{2}\) inches, or 60 per cent of the 7\(\frac{1}{2}\) inches applied, percolated below the 6-foot depth where it was not needed by the crops because this depth of soil always contained an abundant supply of moisture as a result of rather frequent irrigations.

OTHER FIELD MEASUREMENTS OF WATER CAPACITY

The investigations of water capacity reported above were all conducted on one type of soil, namely, the Millville loam of the Greenville Experiment Farm. It is therefore considered desirable to report here some investigations of water capacity conducted by one of the authors on a dark-colored, volcanic loam—one plat near Grace, Idaho, and one near Central, Idaho, and in the Redfield fine sandy loam of the Sevier Valley, Utah.

Volcanic Loam Water Capacity.—The soil in Gem Valley, Idaho, is a productive loam derived largely from the weathering of the volcanic material which in late geological time overran Gem Valley. The soil ranges in depth from 4 to 12 feet. It lies on porous lava rock permeated with cracks which form effective
Figure 6.—Water content immediately before, one day after, and six days after heavy flooding of a plat at Central, and a plat at Grace, Idaho. Work by one of the authors.

natural drainage. Water-capacity tests were made at Grace and at Central. In order to determine the water capacity at Grace, a plat 25 feet square was selected. Around this plat a levee was built about 2 feet high. The water that was run into the plat was measured over a triangular steel weir. To this plat, a total

1The soil at Grace has an apparent specific gravity of 1.31 and a pore-space of 52 per cent. The permeability was determined by ascertaining the rate of disappearance of water held in the water-capacity basin. In the Grace soil it was $\frac{1}{2}$ inch to the hour. The wilting point of this soil is 13.2 per cent, computed from the moisture equivalent.
amount of 21 acre-inches was applied. Amounts of water held in the soil before irrigation, one day after irrigation, and six days after irrigation are presented in Figure 6. The amounts are reported in inches of water per foot of soil.

In examining Figure 6 it will be noted that the soil at Central was more compact than the Millville loam of the Utah Experiment Farm at Greenville, having only $5\frac{3}{4}$ inches' pore space for each foot of soil. However, the Grace soil was more open, having over $6\frac{1}{4}$ inches' pore space in 12 inches of soil. Before flooding, the Central soil contained nearly 3 inches of air space and about $2\frac{3}{4}$ inches of water in each foot of soil. One day after flooding it contained only $1\frac{1}{2}$ inches of air and more than 4 inches of water, and 6 days after flooding it contained approximately $1\frac{3}{8}$ inches of air and 4 inches of water. It will be noted also that the available water 6 days after flooding is about $1\frac{1}{4}$ inches greater than before irrigation.

The plat of soil near Grace was more moist before flooding than the Central plat. One day after flooding it held an average of two inches of air. Six days after irrigation it contained a little more than $1\frac{1}{2}$ inches of available soil moisture. The average total amount of water held 6 days after flooding was 3.8 inches per foot as compared to 4.2 one day after. The soil therefore lost 0.4 inch per foot during the 5-day period. The moisture determinations, together with the use of a heavy straw mulch to prevent evaporation, supported the belief that practically all of this lost water, i. e., 0.4 times 6—2.4 inches, passed below the 6-foot depth.

The work at Central and at Grace seems to indicate that under ordinary conditions of irrigation practice on typical loam soils of Gem Valley not more than $1\frac{1}{4}$ to $1\frac{1}{2}$ inches of water per foot of soil may be absorbed and retained from any single irrigation, regardless of quantities in excess of these which are applied.

**Fine Sandy Loam Water Capacity.**—Further determinations of water capacity have been made by one of the authors on a typical farm in Sevier Valley, Utah, the soil of which is a deep, red, fine sandy loam. The Bureau of Soils of the United States Department of Agriculture class this soil as the Redfield fine sandy loam. It comprises about 44,000 acres, or 30 per cent of the arable land in the valley.

To determine the capacity of this soil for water a levee was built around a plat 20 by 20 feet. Soil for the levee, as in other cases, was taken from the outside so as to prevent any disturbance of the surface soil. There was no crop growing on the area. It was cleared of weeds. Soil samples were then taken to
a depth of 6 feet in 6 borings, making a total of 36 samples. The holes were carefully filled and an 18-inch irrigation was applied to the plat. The following day, July 18, a second set of soil samples was taken, and on August 7, twenty days after flooding, a third set was taken. The results are presented in Figure 7. Of the 18.0 inches applied to the plat the upper 6 feet retained one day after flooding, 8.8 inches, or less than one-half. Of the total 8.8 inches held one day after flooding, 5.8 inches, or two-thirds, was held 20 days after flooding.

Immediately after obtaining the first set of soil samples following the flooding, the plat was covered with weeds and straw in order to reduce the evaporation losses to a minimum. It is likely therefore that the major part of the decrease in water content from 8.8 inches, in the upper six feet one day after flooding, to 5.8 inches 20 days after resulted from downward percolation rather than from evaporation. The moisture tests 20 days after flooding show that nearly 6 inches of water can be absorbed and retained from one irrigation, or approximately 1 inch of water per foot depth of soil.

The results of these field measurements of water capacity in Gem Valley, Idaho, and Sevier Valley, Utah, are considered sufficiently accurate to form a valuable guide in the determination of the amounts of water to apply to the respective soils in single irrigations. They are, however, less accurate than the determinations on the Millville loam of the Greenville Experiment Farm heretofore considered.

![Diagram](image-url)

Figure 7.—Water content immediately before, one day after, and twenty days after heavy flooding of a plat on the Utah Experiment Station Farm, in the Sevier Valley, Richfield, Utah.

Work by one of the authors.
Purpose of Water-Capacity Studies.—The application of these water-capacity measurements in irrigation practice is clearly the purpose of the investigations. A complete study of the methods of irrigation with special reference to the preparation of land, the size of irrigation stream best suited to the particular soil, the distance to run water over the land, together with careful observation by each irrigator and thorough acquaintance with his soil—all these additional factors must be fully considered and understood before the water capacity measurements reported here can be intelligently applied.

The importance of application together with some illustrations of how to apply these experiments is further considered on page 22 to which the practical irrigator is now referred. For the student of soils who is desirous of examining the results of water-capacity studies by others, a brief review of some of the outstanding investigations is now given.

SOME WATER-CAPACITY MEASUREMENTS BY OTHERS

For the reader who may be especially interested in the water capacity of soils there is given below a brief abstract of the results of water-capacity measurements by others together with references which may be of assistance to the reader in obtaining original reports in order more fully to examine the work. The year in which the work of other investigators was reported is given in connection with the several references.

King pioneered the study of the field-water capacity of soil as early as 1889. By driving 6-inch iron cylinders in the surface foot of soil, removing the cylinder and excavating down to the second foot, then driving the cylinder into the second foot, and so on down, he obtained a sample from each of the upper 5-foot sections. After removal, the lower end of each cylinder was covered with a perforated sheet of tin. The samples were placed in a tank of water for five days after which they were taken out of the tank and drained 4 days. The moisture content or water capacity was then determined. The surface foot held 4.6 inches of water, the second-, third-, and fourth-foot sections, consisting of a reddish clay, held approximately 4.3 inches each, and the fifth foot, a fine sand, held 3.8 inches. These are the total amounts of water, hygroscopic and capillary.

King found also, as reported in his book on irrigation and drainage, that in order to bring the soil moisture "from the lower limit of the best productive stage of water content to the upper limit requires an application of 4.5 inches of water for the

upper 4 feet of soil”. This is equal to a little more than 1.1 inches of water for each foot of soil. Other experiments by King show that if the soil has been permitted to become excessively dry, it may require approximately 10 inches of water to bring the moisture content of 5 feet of soil to the upper limit of retentive capacity.

The water capacity of various field plats of soil was studied by Willard and Humbert¹ in New Mexico during the years 1910 and 1911. Their first method of studying water capacity was by means of applying small amounts of water to the lower end of tanks by sub-irrigation. The tanks were 42 inches high. One tank in a period of 200 days rose in moisture from 1.02 inches of water in the surface foot to 2.80 inches, indicating thus a power to raise and retain 1.78 inches of water from an irrigation of 5.61 inches. In a second tank 1.57 inches were lifted from an irrigation of 4.7 inches.

Further light concerning the capacity of the New Mexico soil to retain water was obtained by measuring in three soil-moisture determinations the amount of water that was lost by percolation below 6 feet depth of soil during the season 1910. Percolation losses in the soil below 6 feet were measured on plats in natural condition which received a number of irrigation treatments. To illustrate these results, the percolation losses, from plats which received in irrigation during the season total depths of 8, 13, 16, and 20 inches, are reported below. The plats which received 8 inches were given eight 1-inch irrigations; those receiving 13 inches were given four 3¼-inch irrigations; those that received 16 inches were given in general four 4-inch irrigations; and those which received 20 inches were given five 4-inch applications. The plats which had a total of 8 inches lost 1.89 inches by percolation below a depth of 6 feet; those which had 13.0 inches lost 4.56 inches; those that received 16 inches lost 5.05 inches; and those which received 20 inches lost 7.33 inches. These results indicate that the following losses occurred from each of the different irrigations: from the 1-inch irrigation, 0.24 inches passed below 6 feet; from the 3¼-inch irrigation, 1.14 went below 6 feet; from the 4-inch irrigation, 1.26 inches went below 6 feet; and from the 5-inch applications 1.46 inches went below the 6-foot plane.

As a result of 6 years’ investigation of the water capacity of a uniform sandy loam soil in Nebraska, Burr² found that this

soil would retain from 16 to 18 per cent of its dry weight and that 7 to 8 per cent was available to the plants. This is equivalent to approximately 1 1/4 inches of water to each foot of soil.

In field experiments concerning methods of preparing the seed bed for winter wheat in Kansas, Call found for the typical season of 1912-1913 that the upper four feet of dark brown silt loam surface soil and a reddish-brown silty loam held at seeding time a maximum of 20.6 per cent, a minimum of 17.8 per cent, and an average of 19.1 per cent. The greatest amount available to plants was 6.8 per cent, the smallest amount 4.5 per cent, and the average amount was 5.8 per cent.

In Texas Fraps studied the water capacity of six soils, ranging in texture from a sandy loam to a clay. He found the average water capacity of soils in field tanks 18 inches deep at the end of wet periods to be 58 per cent of the water capacity as measured in the laboratory. The maximum in the field was 69 per cent of the laboratory capacity. Expressed in inches of water for each foot depth of soil he found the average maximum water content at the end of wet periods and the minimum water content at the driest period of an average year as presented in tabular form below.

<table>
<thead>
<tr>
<th>Time</th>
<th>Sandy Loam</th>
<th>Loam</th>
<th>Loam</th>
<th>Clay Loam</th>
<th>Clay</th>
<th>Clay</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>END OF WET PERIOD</td>
<td>2.28</td>
<td>2.78</td>
<td>3.43</td>
<td>4.38</td>
<td>4.47</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>END OF DRY PERIOD</td>
<td>1.79</td>
<td>2.02</td>
<td>1.73</td>
<td>2.34</td>
<td>2.45</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>DIFFERENCE, OR WATER AVAILABLE TO CROPS</td>
<td>0.48</td>
<td>0.76</td>
<td>1.70</td>
<td>2.04</td>
<td>2.02</td>
<td>1.50</td>
<td></td>
</tr>
</tbody>
</table>

It will be noted from the work done by Fraps that the sandy soil had capacity to absorb and retain approximately one-half inch of water to one foot depth of soil, whereas the clay loam and one of the clays had capacity to absorb and retain more than 2 inches of water in each foot of soil.

3The authors have converted moisture percentages to inches of water for each foot depth of soil. The apparent specific gravity of the soil was assumed to be 1.30.
Working on the sandy soils of the Umatilla project in Oregon, Allen\(^1\) found that the soil is capable of holding against gravity "only 4 inches of water in the surface 4 feet of soil". After making this finding, only 4 inches of water was applied in each irrigation. Because of the excessive losses of water from the sandy soil of the Umatilla Project through deep percolation, the capacity of the soils to hold water was carefully studied. Soil was placed in concrete tanks a little over 3 feet square inside and 6 feet deep. The tanks were placed in large pits with their tops even with the soil surface. Measurements were made of all of the water applied and also of all that percolated through the soil. In 1915 Dean, reporting to Allen\(^2\), applied water to the soil in the concrete tanks in 1½-inch and 3-inch irrigations, the totals for the year being 37 inches. Of this amount 13 inches, or a little more than one-third, percolated through the 6 feet of soil in the 2 tanks which were growing alfalfa. More than two-thirds percolated through the tank in which no crop was growing.

Conducting soil moisture studies on typical dry-farm soils in Juab Valley, Harris and Jones\(^3\) found that fallow land at seeding time contained about 6.4 inches of available water in the upper 6 feet of soil. They found also that probably never more than 10 inches of water in the upper 6 feet of soil is available to plants.

Harding\(^4\) made numerous determinations of moisture in typical mountain soils before and after irrigation during the years 1913 and 1914. He studied also some of the typical sandy soils of the Minidoka Project in Idaho, the Sunnyside Project in Washington, and the irrigated lands near Reno, Nevada. He concludes that "the maximum depth of water per foot depth of soil which can be retained under favorable conditions for the upper 5 feet of soil is about 1.25 inches, which indicates that the depths of single irrigations in excess of 6 to 8 inches, even under favorable soil conditions, will not be retained in the upper 5 or 6 feet of soil".

The methods whereby the water-capacity studies may be applied in irrigation practice, together with the extent to which they may be applied, are now briefly considered.


\(^2\)Ibid.


APPLICATION OF WATER-CAPACITY MEASUREMENTS IN IRRIGATION

If the irrigator has dependable information concerning the capacity of the soil to retain water he can apply this to his irrigation practice as outlined below. Suppose, for example, that he has 20 acres of a sandy loam soil having an average depth of 4 feet and that below the 4-foot depth the material is a coarse gravel that will hold very little water. Suppose also that water-capacity measurements on a soil like the one in question indicate that each foot of soil containing the amount of moisture ordinarily found before irrigation, will absorb and retain $\frac{3}{4}$ of an inch of irrigation water. Under these conditions, to satisfy the moisture capacity of each acre, it would be necessary to use $\frac{3}{4}$ times 4, or 3 acre-inches per acre. When one remembers that a stream of 1 cubic foot of water per second running 1 hour will deliver enough water to cover 1 acre 1 inch deep, or in other words, will deliver 1 acre-inch of water an hour, and further that in the example under consideration it would be necessary to have 3 acre-inches to the acre, he would clearly have to run a 1-second-foot stream 3 hours for each acre, or 60 hours for the 20 acres. But in actual practice he may find this length of time to be entirely inadequate. It is important to note that the time required as above given assumes that the water is spread uniformly over the land surface. It is, however, extremely difficult to obtain uniformity in distribution of the water, especially on open porous soil or on land that is uneven and poorly prepared for irrigation. The investigations of water capacity reported here will not lessen the irrigator's difficulty in obtaining uniform distribution nor will they point the method toward removing this difficulty. They do, however, form a basis for measuring approximately the degree of economy that is being obtained. For example, under the conditions of water capacity above considered, if it is found necessary to run a 1-second-foot stream of water 6 hours for each acre in order to get it over the entire surface of the land, then clearly some parts of the field are being over-irrigated with the result that half of the water applied is being lost by percolation into the gravel. Such conditions frequently occur. They emphasize the need for so improving the method of applying water that the entire land surface can be irrigated without excessive loss of water. This will assure approximate uniformity in distribution.

The irrigation methods by which deep percolation can be avoided cannot be considered here. Some experiments are under
way on this problem, the results of which will, if significant, be reported at some future time.

SUMMARY AND CONCLUSIONS

(1) This bulletin concerns the capacity of soils in the natural field condition to absorb and retain irrigation water.

(2) Most water-capacity tests have been made with soils under laboratory conditions, the results of which, tho valuable as a means of soil study, do not apply accurately to the needs of irrigation practice.

(3) A review of water-capacity measurements made by 10 investigators in 8 states and on 20 different classes of soil shows that the amount of water absorbed by the soil when in need of irrigation varied from 1/2 inch of water to 1 foot of soil in a sand, to 2.25 inches of water to 1 foot in a clay loam soil.

(4) A typical deep volcanic loam near Grace, Idaho, one day after flooding held more than 2 inches in the surface foot and nearly 1 1/2 inch in the sixth foot in excess of the amount of water held before irrigation. The same soil 6 days after irrigation held only 1 1/2 inches in the first foot and less than one-fifth inch in the sixth foot.

(5) A typical shallow volcanic loam soil near Central, Idaho, held over 2 inches in the surface foot one day after irrigation and more than 1 3/4 inches in the fourth foot in excess of the amount held before flooding. Six days after irrigation the first foot of the shallow soil held 1 2/3 inches and the fourth foot held 1 1/2 inches more than the amount held before irrigation.

(6) A fine sandy loam of the Sevier Valley, Utah, retained nearly 2 1/4 inches in the surface foot 1 day after flooding and about 1 inch in the sixth foot. Twenty days after flooding, the surface foot held 1 inch and the sixth foot held 0.9 of an inch more than was held before the irrigation.

(7) As an average of nearly 3000 trials Widtsoe and McLaughlin found that the upper 6 feet of the Greenville loam soil retained a little more than 1 inch of water for each foot of soil about 24 hours after irrigation.

(8) Investigations by Harris and Bracken show that plats on the Greenville Farm to which 1 inch of water was applied weekly held about 1/4 inch of available water per foot of soil immediately before irrigation. The plats which were given 2 1/2 inches weekly held 3/4 of an inch of available water before irrigation, and those which were given 7 1/2 inches weekly held a minimum of 1 1/2 inches of available water per foot of soil. In
addition, about 60 per cent of the 7½ inches applied weekly percolated below the depth of 6 feet where it was probably lost to the use of plants.

(9) Much of the work on water capacity has been done on soil which was growing crops and therefore has been based on the application of water in irrigation. This method has left some doubt as to the completeness of soil saturation.

(10) The authors' work was done on plats which were not growing crops. Moreover, excessive amounts of water were applied and completeness of capillary saturation was thus assured.

(11) The authors' work showed that one day after irrigation the plat which was given 36 inches of water held 1/3 inch more per foot of soil than the plat which was given 12 inches, also that the 24-inch plat held ¼ inch more water per foot of soil than the 12-inch plat.

(12) Ten days after the heavy irrigations were applied by the authors each of the plats held the same amount of available water, namely, about 1½ inches per foot in the upper 6 feet.

(13) The moisture-capacity investigations here reported show that as a general rule soils have the capacity to absorb from ½ to 1½ inches of water to each foot depth of soil that needs moistening, the actual capacity for a given soil depending on its texture and structure. Sandy or gravelly soils retain the smaller amounts and clay loam soils retain the larger amounts.

(14) Information concerning the water capacity of soils made available by the investigations here reported, and by other similar studies, form the basis for intelligent determination of the amounts of water to apply to various soils in single irrigations, but they do not assist the irrigator to obtain uniformity in the lateral distribution of water. This must be accomplished by careful preparation of land and proper adjustment of the size of stream used to the soil irrigated.

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