RELATION OF THE MOISTURE EQUIVALENT OF SOILS TO THE MOISTURE PROPERTIES UNDER FIELD CONDITIONS OF IRRIGATION

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In studies of the water requirement of soils under irrigation, both for land being irrigated and for land for which the construction of irrigation systems is contemplated, some criterion which will furnish an index of the soil moisture properties is needed. Mechanical analyses of the soil are expensive to make and the results, given in the seven grades of soil particles, do not lend themselves to ready comparison except by general soil classes. A criterion is needed which can be expressed as a single factor and which can be determined fairly readily at small expense. The moisture equivalent as suggested by Briggs and McLane is intended to be such an index of the soil moisture properties.

Comparisons of the moisture equivalent with other soil properties have been made, usually under laboratory conditions. The following discussion is a comparison of the moisture equivalent with the critical moisture points of soils under the actual field conditions of irrigation practice, and is based on data secured by the author in the course of various field investigations of the water requirements of different soils and their irrigation practice. This work was done partly while the writer was in the employ of the Irrigation Investigations of the United States Department of Agriculture, but more largely in connection with his general engineering practice. In all cases, the determinations of the moisture equivalents have been made by the Division of Soil Technology of the University of California under the direction of Prof. C. F. Shaw.

The general field method has been to take soil moisture samples before and after irrigation in order to determine the amount of water retained by the soils. Notes on the soil and crop conditions were secured and special samples at wilting taken when feasible. The main purpose of the field work was the study of the water requirements of the soils under irrigation practice. The comparison discussed here was incidental to this main purpose, so that in many cases samples representing only a part of the moisture properties of a particular soil were secured.

The data given were secured from a wide range of soils under varying conditions of practice. In 1913 and 1914, about 7000 individual moisture determinations from 44 fields with 9 moisture equivalents of typical soils were secured, near Billings, Montana. In 1915 about 700 individual soil moisture samples and 14 moisture-equivalent determinations were secured during a study of sandy soils on the Minidoka project in Idaho. The field work in these two investigations was done by the author for the United States Department of Agriculture. In 1917 about 1000 moisture and 54 moisture-equivalent determinations were secured in a study of a wide variety of soils on the Sunnyside project in Washington. In 1917 also about 450 soil-moisture and 50 moisture-equivalent samples were secured from irrigated lands near Reno, Nevada. In addition less extensive results were secured in 1918 on soils near Los Molinos, California and the results obtained by Israelsen (1) for soils in the Sacramento Valley, California, were used. The results discussed cover a total of 136 determinations of moisture equivalents varying in numerical value from 4.1 to 37.6.

Comparisons of four moisture conditions are made both for the surface foot of soil and for the average of the upper 5 feet of soil. These are the maximum field capacity, the normal field capacity, the usual moisture before irrigation and the wilting of the crop. The maximum field capacity applies to soils shortly after irrigation before the moisture distribution is complete or to soils where downward percolation is retarded by heavier soil strata. It does not cover soil saturation but represents a higher moisture content than would be secured under normal conditions. The normal field capacity would apply to soils of uniform character at from 1 to 3 days after irrigation when moisture distribution had become fairly complete, although both evaporation from the soil and deep percolation may be continuing but at a lessened rate. The usual moisture before irrigation represents the minimum moisture under good practice where irrigation would be given just ahead of the actual needs of the crops. The wilting of the crop represents actual injury, practically the minimum to which moisture may be reduced.

In assembling the observations the soil moisture results were expressed in terms of the percentage of the moisture equivalent. The moisture equivalents were grouped by variations of 2.5 per cent. In the figures given the individual results are plotted and also the mean result for each group, the numbers with the means indicating the number of observations included in the mean. As all four soil-moisture points were not determined for the larger proportion of the individual soils, the number of points in the means is less than the total number of moisture-equivalent determinations in each group. This is particularly true for the means for the 5-foot depths of soil, as many soils included in the field work were of shallow depth or variable subsoil which prevented securing means for the full 5 feet.

In figure 1 the relation of soil moisture in the surface foot under field conditions to the moisture equivalent is given for the four moisture points. In order to indicate the variation of the individual results broken lines are drawn which represent 10 per cent variation from the mean curves. The greater

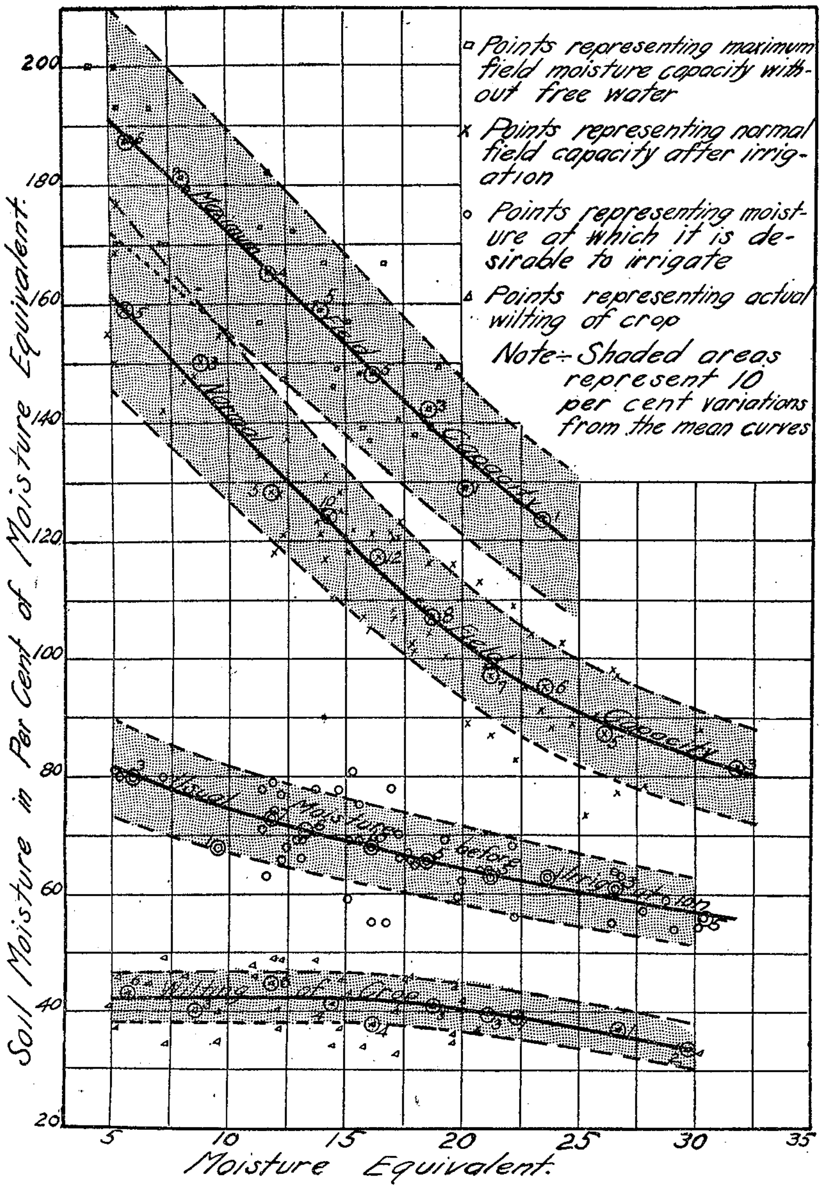

FIG. 1. RELATION OF SOIL MOISTURE IN SURFACE FOOT UNDER FIELD CONDITIONS TO THE MOISTURE EQUIVALENT

proportion of the observations fall within 10 per cent of the mean. The general relationships appears to be fairly consistent.

The variations of individual results may be due either to a lack of consistency of the moisture equivalent as an index of moisture properties or to a lack of accuracy in the selection of soil moisture samples representing the critical moisture points given. In the author's opinion, the latter source of error is the more probable one. The moisture condition at which a soil needs irrigation is not an exact one, particularly when the surface foot only is considered. It will vary for a given soil with the character of crop and its state of growth and with the moisture and soil conditions in the subsoil. Wilting is also a progressive process and the point at which the crop will fail to revive is difficult of actual determination. After irrigation, soil evaporation will continue at diminishing rates over several days, deep percolation may also continue for a considerable period. During this time the crop is withdrawing moisture for its use so that there is no definite point at which soil moisture samples can be expected to give the exact amount of moisture available for crop use.

It is thought that the results as plotted in figure 1 indicate as consistent a relationship between the moisture equivalent and the soil moisture under field conditions as is to be expected under the circumstances under which the observations were made. The purpose of the comparison was to determine whether such a general relationship exists rather than to express the relationship in definite numerical terms, and any specific numerical deductions from these curves, such as those given later in this discussion, should be considered as suggestive only and as subject to modification as additional numerical data may become available.

In figure 2 curves similar to those in figure 1 are given, except that the comparison is based on the mean moisture in the upper 5 feet of soil. The number of points available was less than of those used in figure 1 and the resulting mean curves are in consequence less definite in both their general form and their actual location than those for figure 1.

The curves given indicate that the relationship between field moisture properties and the moisture equivalent is not a linear one except possibly for conditions approaching wilting. Briggs and McLane have derived the formula

Wilting coefficient = moisture equivalent ÷ 1.84.

This formula was based on experiments where the plants were grown in limited volumes of soil rather than under normal field conditions. The above formula is equivalent to the wilting coefficient equalling 54.4 per cent of the moisture equivalent. The results given on figures 1 and 2 indicate that, at least under field conditions, the crops can reduce the soil moisture of both the surface foot and of the mean for the upper 5 feet below this amount. The mean of all observations on wilting for the surface foot of soil is about 40 per cent of the moisture equivalent.

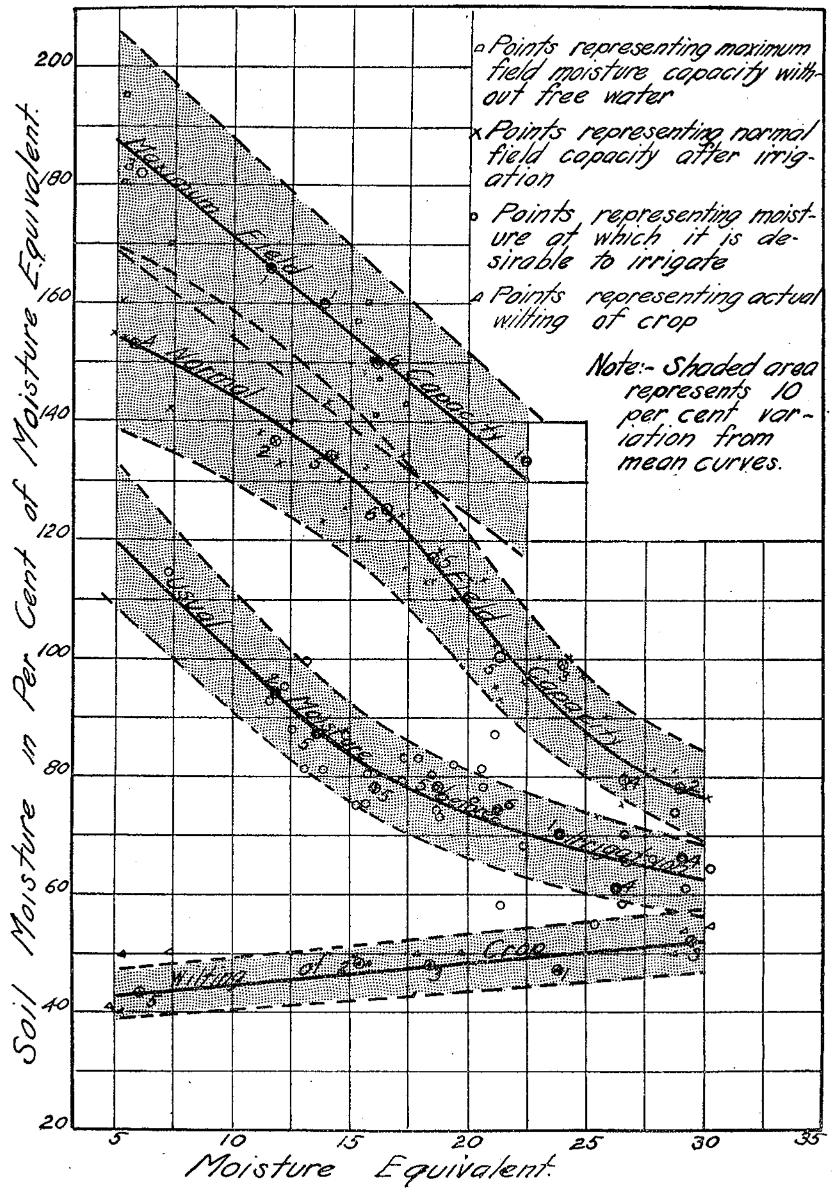

FIG. 2. RELATION OF SOIL MOISTURE IN UPPER 5 FEET OF SOIL UNDER FIELD CONDITIONS TO THE MOISTURE EQUIVALENT

Similarly Briggs and McLane have given the equation

$$\textit{Moisture-holding capacity} = \textit{moisture equivalent} \times 1.57 + 21.$$

The moisture-holding capacity used in this formula is based on the Hilgard short-tube method and exceeds the moisture capacity under field conditions of soils free to drain. In no case does the maximum field capacity reach the amount indicated by this formula.

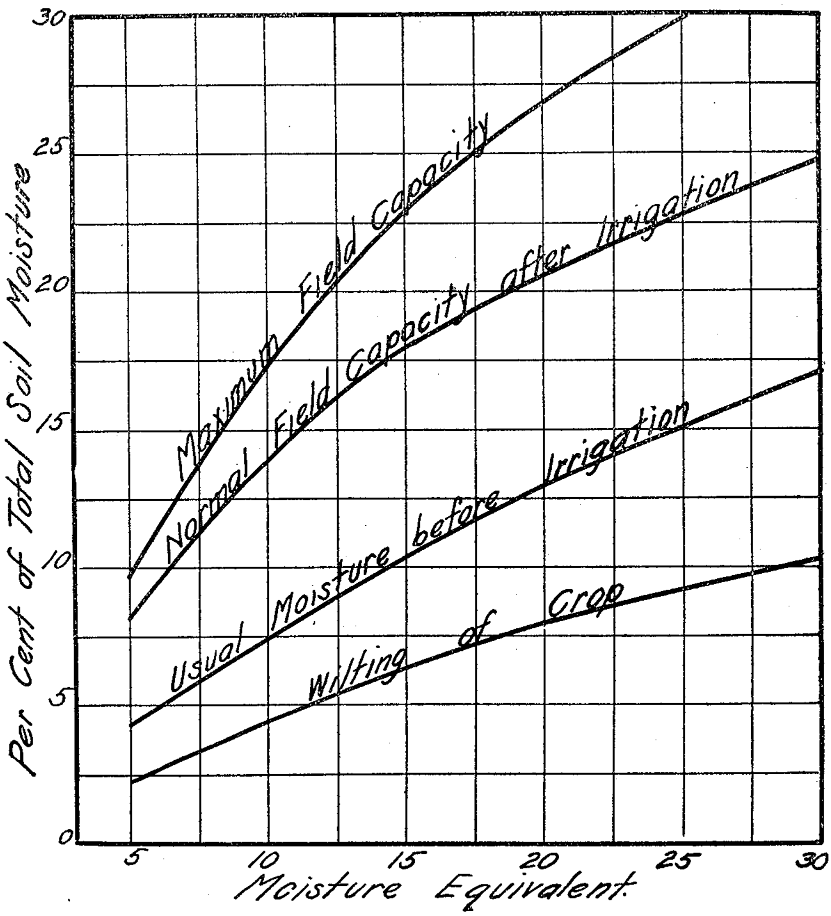

FIG. 3. RELATION OF PER CENT OF TOTAL MOISTURE IN SURFACE FOOT OF SOIL UNDER FIELD CONDITIONS AND MOISTURE EQUIVALENTS

In figures 3 and 4 the mean curves of figures 1 and 2 are redrawn, the percent of soil moisture being used directly instead of as a percentage of the moisture equivalent. These curves indicate the percentages of soil moisture on the oven-dry basis at the different critical-moisture points.

In figures 5 and 6 the curves of figures 3 and 4 are used to give the water added by usual irrigations. In figure 5 is plotted the difference in moisture before and after irrigation as shown for usual practice on figures 3 and 4. This shows the largest moisture capacity for 5 feet of soil in soils of medium texture. The coarse soils having a low moisture equivalent have a relatively small moisture-holding capacity. The heavy soils while having a

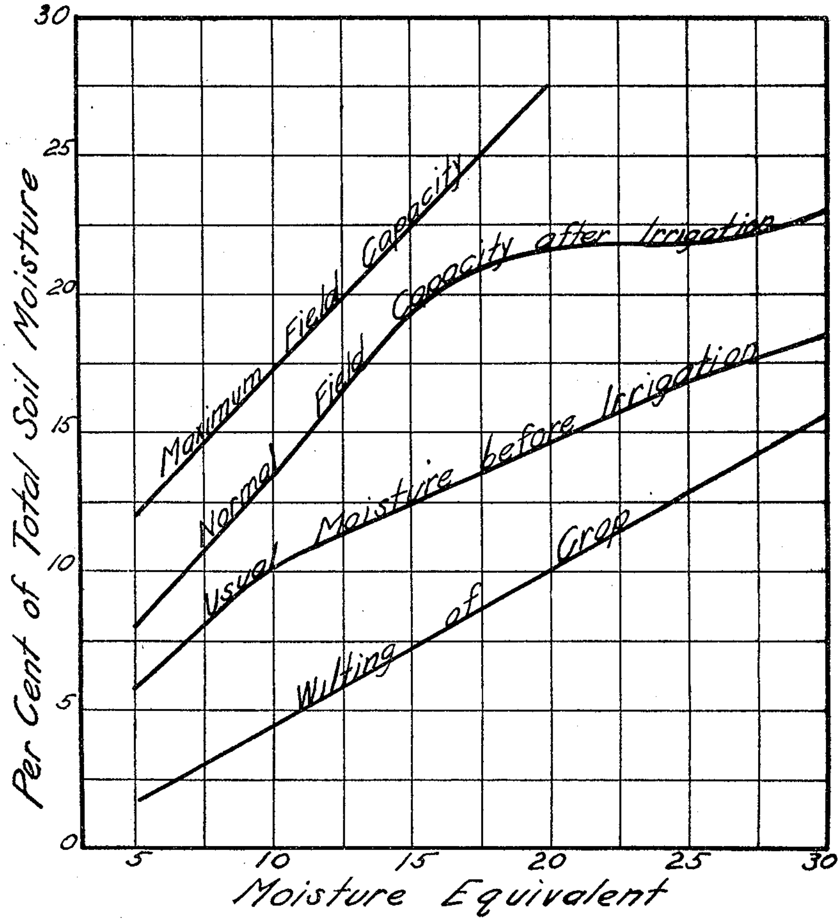

FIG. 4. RELATION OF PER CENT OF TOTAL MOISTURE IN UPPER 5 FEET OF SOIL UNDER FIELD CONDITIONS AND MOISTURE EQUIVALENTS

relatively large moisture-holding capacity, are not able to utilize this capacity to the 5-foot depth, because of the difficulty in getting full penetration. This difficulty in getting full penetration does not affect the surface foot, and the per cent of moisture added from an irrigation continues to increase with an increase in the moisture equivalent.

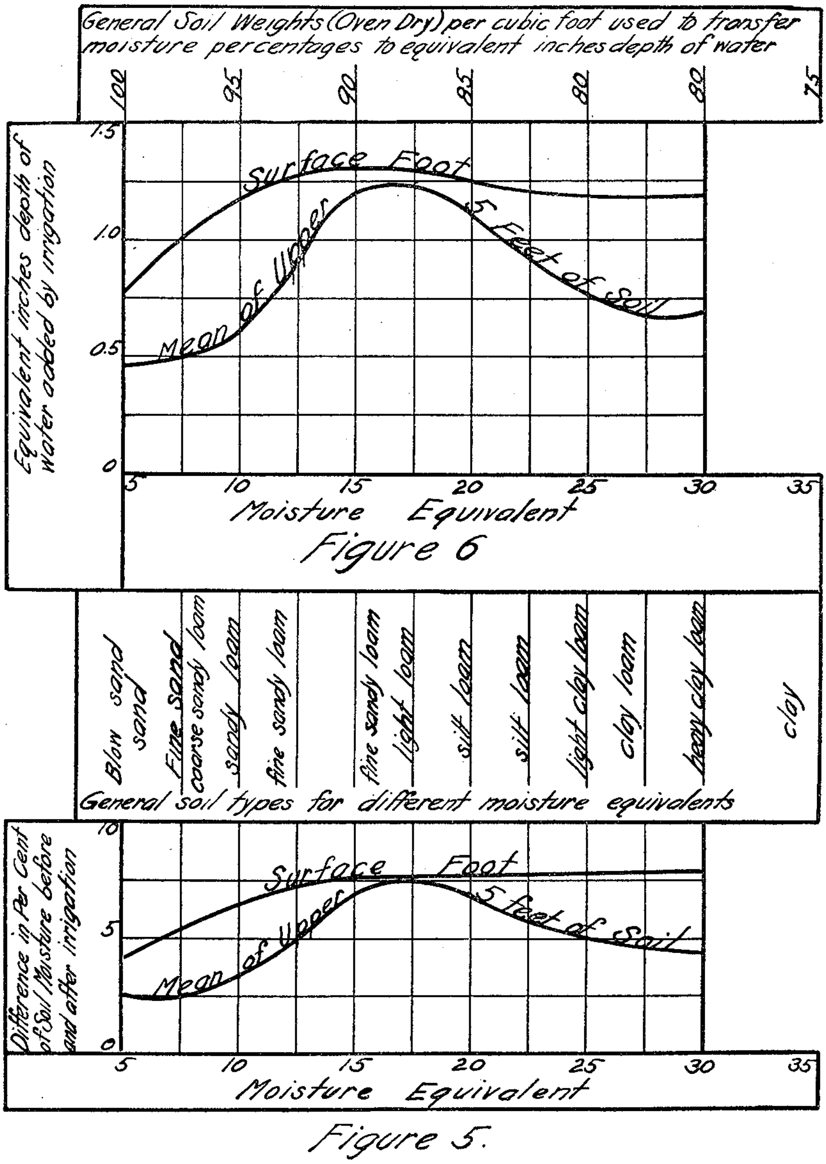

Fig. 5. Relation of Per Cent of Moisture Added by Irrigation Under Field Conditions and the Moisture Equivalents

Fig. 6. Relation of Equivalent Inches Depth of Water Retained per Foot Depth of Soil from an Irrigation and the Moisture Equivalent

In figure 6 the curves shown are similar to those in figure 5, the vertical ordinates in figure 6 being equivalent inches depth of water per foot depth of soil instead of soil moisture percentages as in figure 5. The general soil weights by which figure 5 is converted to figure 6 are shown at the top of the figure.

In addition the general soil types corresponding to the different values of the moisture equivalent have been written between figures 5 and 6 for convenience in reference.

In considering figures 3 to 6 the same statements regarding numerical accuracy will, of course, apply as were made regarding figures 1 and 2 from which they are derived. Caution should be used in applying figures 5 and 6, as further data will probably change the location of these curves. The general form of these curves is in agreement with general observations under field conditions and, in the author's opinion, they represent the nature of the relation of the moisture capacity of soils under field conditions to the soil texture. Further investigations might change the numerical values of points on such curves rather than their general form.

The form of the curves shown in figure 6 is in accord with general conditions of irrigation practice. Coarse soils, such as those having moisture equivalents of less than 10, are able to retain only limited amounts of water and consequently even where of good depth require frequent irrigations. In order to prevent excessive deep percolation losses on such soils the methods of irrigation must be adapted to covering them quickly so that the amount absorbed will not materially exceed the depth of water they are able to retain. On such types frequent irrigations are usually required, alfalfa generally receiving from two to three irrigations per cutting.

Soils having moisture equivalents of from 15 to 18 where of good depth are the most favorable of any in their moisture properties under irrigation. These combine a large moisture-storing capacity with a rate of absorption which permits them to be irrigated by such methods as will enable the moisture capacity to be utilized without excessive deep percolation losses. Such soils will usually carry alfalfa on one irrigation per cutting. Where properly handled very good economy in the utilization of irrigation supplies can be secured on these soils; where not properly prepared or where the water is not carefully handled they are sufficiently light to permit large percolation losses with consequent low efficiency in the application of water.

The heavy soils absorb water so slowly that it is usually not practicable to utilize the moisture capacity to the 5-foot depth without permitting the water to run sufficiently long so that other injuries such as scalding of the crop will occur. Frequently on such soils the moisture penetration will not exceed 2 feet in depth, with the result that frequent light applications must be made. This condition may cause a lower efficiency in the use of water and of the labor of its application than on soils of somewhat lighter texture.

The data presented, while subject to the limitations of extent and of accuracy covered in the above discussion, are thought to warrant the following general conclusions. All conclusions are limited in their application to field conditions under actual irrigation practice.

1. There is a fairly consistent relationship between the moisture equivalent and the various moisture properties of soils, which appears to offer promise of usefulness in determining moisture properties and probable irrigation practice of soils whose irrigation is contemplated, particularly as to the probable depth of water which will be retained from an irrigation with its effect on the depth to be applied and the necessary frequency of application.

2. The data presented, while indicating the general nature of the relationship of soil moisture capacity and soil texture, are not sufficient to fix the numerical values of such relationships except in a very general way.

3. The relationship of the soil-moisture properties to the moisture equivalent does not appear to be linear except in the case of the wilting of the crop.

4. 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 depths of single irrigation in excess of 6 to 8 inches, even under favorable soil conditions, will not be retained in the upper five or six feet of soil. This conclusion is in accord with the results of general field observations from many sources.

REFERENCE

(1) ISRAELSEN, O. W. 1918 Studies on capacities of soils for irrigation water and on a new method of determining volume weight. *In* Jour. Agr. Res., v. 13, no. 1, p. 1–36.