# Methods of Measuring Soil Moisture

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We have been concerned for many years with the problems related to soil moisture and its use by plants. Many ideas along these lines have gone through a considerable evolution, especially in the western part of the United States during the past 30 years. In the early years of investigation, many recommendations to farmers were based on the results of laboratory experiments without adequate trials under field conditions. This accounts in part for some of the apparent contradictions and disagreements. We are convinced, from our attempts to carry out detailed and basic work under laboratory conditions, that the results of such work should be regarded only as a temporary step, and should be investigated under field conditions—in other words, on the "proving ground," before too much is recommended to growers. It is, we believe, almost as unsatisfactory to recommend practices to growers merely from field trials since under these conditions it is often difficult to get at the basic factors. In the work we are reporting in this paper, we therefore attempted to carry on our laboratory experiments parallel with the field experiments.

In our work we have recognized two more or less critical moisture contents which are characteristic of any soil, namely, the permanent wilting percentage and the moisture equivalent, the former being the lower limit of moisture content which is sufficiently available to plants to keep them growing normally, and the latter being, for a wide range of soils, the upper limit of moisture content (field capacity) which is found 2 or 3 days after a soil has been irrigated, using a moderate amount of water—say enough to wet it to a depth of 6 feet. We recognize, as do all investigators, that these so-called constants are not absolutely constant for a given soil—they represent narrow ranges of moisture content. The results of experiments conducted by the California Agricultural Experiment Station have demonstrated that the moisture between these two limits is sufficiently available to supply roots at a normal rate, and therefore that plants seem to grow normally as long as the moisture content of the soil containing the major portion of the roots is above the permanent wilting percentage.

The expression "soil-moisture measurement" has been used rather loosely, and one is often not certain as to just what is meant by it. We recognize two qualities of soil moisture in which we are vitally interested. One of these is the amount of water per unit mass of the soil. The other one is the availability of the moisture to the

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plant. This latter quality can be measured by the energy per unit mass required to remove the water from the soil. As water is transpired by a plant, obviously energy must be expended to take moisture from the soil and transpire it. Over the range of moisture content between the field capacity and the permanent wilting percentage, this energy is largely expended in the leaves of the plant, only a small portion of the total energy being required to carry the moisture from the soil into the leaves. However, at moisture contents below the permanent wilting percentage, the amount of energy per unit mass required to remove the water from the soil increases very rapidly as the moisture content decreases. Even though the difference between the energy per unit mass required to remove the water from the soil at field capacity and at permanent wilting is not very great as compared with the total energy required, yet it is sufficient so that it can be measured.

As an index for need of irrigation we could, therefore, use either the amount of water in the soil or its availability; or we might use some device which depends on a combination of these two qualities. There are a number of physical characteristics of soil moisture which might be used to evaluate the magnitude of these two qualities of soil moisture, namely, quantity of water per unit mass of soil and its availability. For example: (1) We might take a soil sample, weigh it wet and weigh it dry. We could, therefore, obviously determine the quantity of moisture in it. (2) Since the heat conductivity of the soil is a function of its moisture content, we should theoretically be able to determine the moisture content by measuring the heat conductivity. (3) Since the electrical conductivity also depends upon the moisture content, it likewise has been suggested as a method of measuring it. (4) If water is placed in a closed porous cup in contact with the soil, the capillary attraction in the soil will tend to decrease the pressure of water in the cup. This ability to decrease the pressure depends upon the moisture content and, therefore, offers a possibility of measurement of soil moisture. (5) Another characteristic of soil moisture is its dielectric constant. This also varies with the moisture content and would seem to offer possibilities for measuring moisture content. All the above characteristics are also possessed by the moisture in any porous material in equilibrium with moist soil. There are other characteristics which might be made use of in the laboratory but seem to offer little possibility for field use.

During the past 2 years, we have made a systematic study of a number of these methods of measuring soil moisture although We do not have the same amount of data on all of them. The one method upon which we have the most data and which seems to offer the most promise at the present time is the two-electrode plaster-of-paris block first suggested by G. J. Bouyoucos.[4] The following report, therefore, gives some of our data on laboratory and field tests, using these blocks.

Some investigations in which one of the authors participated some years ago indicated that when a porous material is placed in a soil of a given moisture content, equilibrium is not established in many cases for a long time.

One of the first things we suspected in the use of plaster-of-paris blocks was that there would be a distinct lag in the moisture content of the block behind that of the soil in which it was placed. To test this point, blocks were placed in soils of various moisture contents

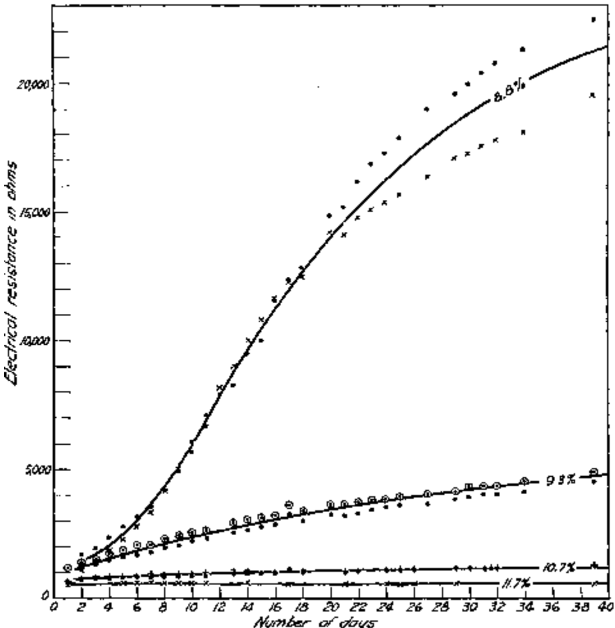


Figure 1.—Electrical resistance as a function of time when blocks are first saturated, and after having the excess water wiped off, are placed in Yolo fine sandy loam of the moisture content shown. The time required for equilibrium is obviously greater for the drier soils, and is appreciable even for higher contents.

[4]Bouyoueos, G. J., and Mick, A. H. An electrical resistance method for the continuous measurement of soil moisture under field conditions. Mich. Agr. Exp. Sta. Tech. Bul. 172:1-38, April, 1940.

from which evaporation was prevented. The resistance of these blocks was read from time to time and the results are shown in figure 1.

It is obvious from the results that the lag is very great, especially in the dryer soils. This simply means that it is impossible to calibrate these blocks by placing them in soils of various moisture contents unless a great length of time is required for the operation. This also would seem to indicate that if placed in soils under field conditions in which plants are growing, the block might be a long way from equilibrium with the soil, and therefore might be regarded as a poor indicator of soil moisture. It has been demonstrated by many investigators that soil moisture moves only very slowly and that one cannot depend upon moisture moving to the roots to supply them with water. The roots must grow into moist soil. This led us to believe that even though there was a big lag when no plants were growing, we might expect much less lag when growing roots permeate the soil surrounding the block. The only way we can test this point is to carry the blocks through what we have (railed several cycles. By a cycle we simply mean the complete series of moisture changes gone through when the soil containing the blocks is wetted and then dried out by the plants.

If electrical resistances are made on the block and the moisture content (of the soil containing transpiring plants) is measured at frequent intervals, one can plot a curve between the two variables, soil moisture, and resistance of the block. One such curve can be made for each cycle. If the curves for the different cycles fall on top of one another, and the rates of transpiration during the different cycles have been differeut, one would conclude that the lag under field conditions is negligible, and therefore, that the electrical resistance of the block might be used as an index of soil moisture. In figure 2 are shown the data for 3 typical blocks placed in soil on which plants were growing under laboratory conditions. Nine such cycles were carried ont during the life of the plant. The small numbers along the curve indicate the cycle from which each determination was made. Since these points fell so close together, it was necessary to indicate the cycle by putting the numbers off the line and connect them to the points by a straight line. It is obvious that the agreement is excellent and we conclude, therefore, from these laboratory results that the lag of the block behind the soil when plants are growing is negligible.

A comparison of the curves for each of the blocks indicates the agreement between the different blocks. It is evident that they are quite similar. Attention is called to the two vertical lines through the curves. As indicated, the line to the right represents the moisture equivalent for the soil, whereas the line to the left indicates the permanent wilting percentage. It will be noted that the values of the resistances at field capacity are approximately the same for each block and that likewise the resistance at the permanent wilting percentage

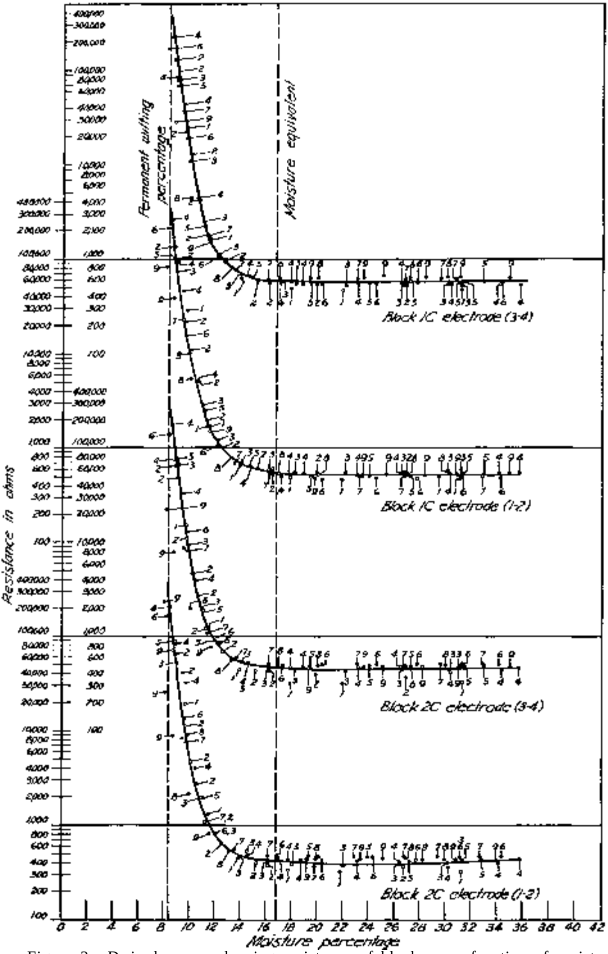


Figure 2.—Derived curves showing resistance of blocks as a function of moisture content when the blocks are placed in Yolo fine sandy loam upon which plants were growing in the laboratory. The numbers distributed along the curve indicate the cycle from which the data were obtained.

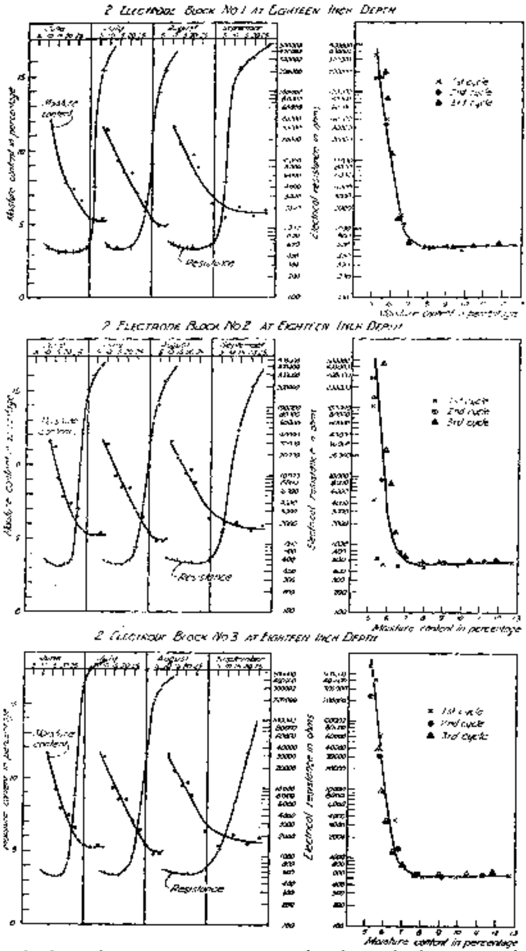


Figure 3—Curves showing moisture content of Yolo sandy loam as a function of tune, and electrical resistance as a function of time, together with the derived curv-e showing the resistance as a function of moisture content for three plaster-of-pans blocks at the 18-inch depth under field conditions.

is approximately the same for all blocks. In the neighborhood of the permanent wilting percentage the resistance increases very rapidly with decrease in moisture content. It is therefore almost impossible to fix an exact value of the resistance corresponding to the permanent wilting percentage.

As pointed out above, however, laboratory results are not enough upon which to base recommendations for field practice. During the last growing season, a large number of field trials were made on sugar beets and in one case, sudan grass. The blocks were placed in plots of about 100 feet square. Dikes were put up around the edge of each plot so that the irrigation inside the plot could be regulated to give the desired conditions for experimental work. The blocks were placed in the center of the second and fourth-foot sections, three blocks being placed at each depth in each plot. The purpose in using three was to find out the agreement between the different blocks. An effort was made to get as many cycles as possible in the laboratory, namely, to get an indication of the ability of the blocks to replicate themselves. Obviously, it was impossible to get as many cycles under field conditions as it was under laboratory conditions because the volume of soil to which the roots had access was much larger. We were, however, able to get three replications in some of the plots and two in others, for the blocks in the second-foot section. The soil in the fourth-foot section was dried to the permanent wilting percentage in only one case so that the results are not so complete at this depth.

The amount of data obtained from our results is much too extensive to present here in the short space available. We can, however, present the results for the blocks at the center of the 2-foot section, that is, 18 inches below the surface for three textures of soil, namely a sandy loam, a silt loam, and a clay loam, all of the Yolo series. In figures 3, 4, and 5 are presented the complete results for the three blocks at this level for each of the three types of soil. At the left-hand side of the graphs are shown the resistance curves and the moisture-content curves as a function of time. Irrigations are indicated by changes in the moisture-content curve from a low value to a high one, with increasing time. It will be noted that the resistance changes at the same time from a high value to a low value. Attention is called - to the larger number of cycles in the sandy loam soil than the others. This is obviously because of the fact that the available water which this type of soil can hold was much less than in the other types, and it was, therefore, necessary to irrigate it more frequently to keep the beets growing.

To test the replicability of the blocks under these field conditions, the resistance is plotted as a function of moisture content for each cycle on the right-hand side of the figure for each of the three blocks.

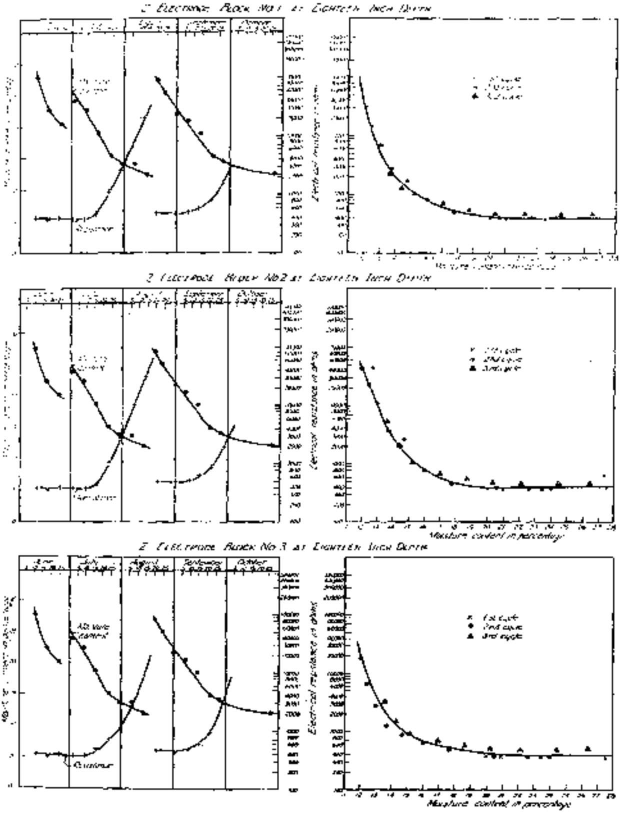

Figure *4.*~Curves showing moisture content of Yolo silt loam as a function of time, and electrical resistance as *a* function of time, together with the derived curve showing the resistance as a function of moisture content for three plaster-of-paris blocks at the 18-inch depth under field conditions.

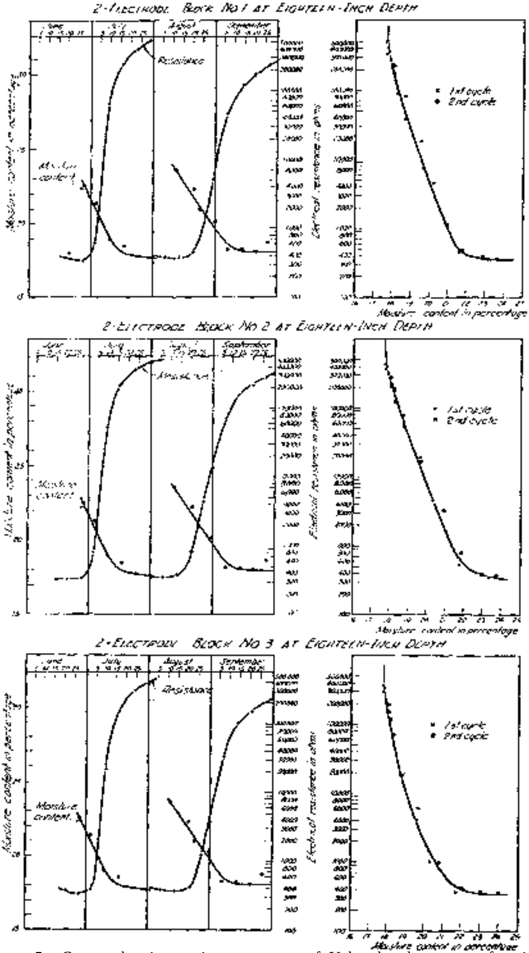


Figure 5.—Curves showing moisture content of Yolo clay loam as a function of time, and electrical resistance, as a function of time, together with the derived curve showing' the resistance as a function of moisture content for three plaster-of-paris blocks at the 18-inch depth under field conditions.

It will be noted that the replicability is quite satisfactory. This simply means that under the field conditions experienced, the blocks were fairly good indicators of the moisture conditions in the soil.

*At* field capacity and higher-moisture contents for all the soils the resistances of the blocks are nearly constant between 400 and 600 ohms, while the resistance when all the available moisture is used might go as high as 500,000 ohms as in figures 3 and 5. The crop on the plot from which the data for figure 4 were blamed did not use ail the available water.

From our work we conclude that the blocks have approximately the same resistance in different soils when all the available moisture is used, and also have approximately the same resistance at the moisture equivalent in different soils. This was to be expected since for reasons which would require too long to discuss at this point, we believe that the resistance of the block, is a measure of the energy per unit mass required to extract the water from the soil. From previous work we know that the energy per unit mass required to remove the water from the soil is approximately the same for all soils tested at the permanent wilting percentage, and for most soils at the field capacity, although there are some exceptions in the latter case.

The fact that the blocks have approximately the same resistance in all soils which we have tested at the permanent wilting percentage makes them especially useful as an indicator of need for irrigation. It will be noted from the figures, as mentioned earlier, that the resistance increases very rapidly as the moisture decreases in the neighborhood of the permanent wilting percentage. A knowledge of the way the resistance of the block is changing as time progresses, therefore, makes it possible for the operator to anticipate the nearness of the approach of the permanent wilting percentage.

For field practice, therefore, in irrigation procedure we have recommended that when the resistance of the block is about 10,000 ohms it is a warning that the moisture in contact with the block is almost exhausted. At this resistance there is still some moisture available, the amount of which depends upon the soil. Of course, the block if placed near the surface may reach this value long before the beets need irrigation because *they* would have their roots where water is available at lower depths. Since sugar beets seem to grow normally as long as there is available water in the top 4 feet of soil, it is possible to place these blocks at levels such that when they indicate that the permanent wilting percentage has been reached, there is still some water available at depths below where *the* block is placed and hence safety can be obtained by regulating the depth at which the block is placed. Also, as mentioned above, if one desires to he can have another safety in the use of the block by simply irrigating a little before the permanent wilting percentage is approached as indicated by the block.

These studies were carried out on fertile alluvial soils on the alkaline rather than the acid type and of fairly low salt content. The conclusions drawn here, therefore, may not always be valid under the latter conditions, and furthermore the tests were carried out with only relatively fine-textured soils of the Yolo series. We feel, however, that for the soils studied the two-electrode blocks made in the manner which we used are fairly reliable guides upon which to base a rational irrigation practice. We feel that further tests should be made with these blocks before they can be recommended for general use on all soils.