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DETERMINATION OF SOIL MOISTURE CONTENT AT PERMANENT WILTING FOR US IN FIELD STUDIES*

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In ecological investigations of interactions between plants and soil moisture, whether the aim is to determine fundamental plant-environment relationships or primarily to solve immediate plant production problems, the soil moisture content at permanent wilting, expressed as a percentage of the dry weight, is a basic determination. Although there is evidence that this soil moisture value may not represent the exact non-available moisture content of the soil (4, 8) it is generally agreed that it represents the limit of favorable plant growth conditions and will be considered here as non-available soil moisture.

Quantitative determination of the moisture content, is of little value except as it is interpreted in terms of moisture available to the plant. The percentage of moisture remaining in the soil when plants wilt, non-available moisture, is used as the basis for determining the percentage and the quantity of available moisture.

Since the first determination of soil moisture content at permanent wilting by Sachs in the middle of the 19th century, the techniques used, the results obtained and the factors affecting these results have been the subject of much controversy. There has been practically no disagreement over the desirability or even necessity of obtaining a definite value for this determination in order to evaluate the effect of a given soil moisture on the plant.
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The fact that there was so much disagreement with the results of the careful experiments of Briggs and Shantz (4) is evidence that the determination of the soil moisture content at permanent wilting involves techniques which, although apparently easy to understand and manipulate, were not easily repeated. The two chief points of disagreement seemed to be to their conclusions that for any given soil their "wilting coefficient", the moisture content of the soil at wilting, expressed as a percentage of the dry weight, is a constant quantity independent of the kind of plant or of the external conditions under which the plant is grown.

Although their conclusion that the "wilting coefficient" is independent of the kind of plant seemed to their contemporaries to be much at variance with the facts (2, 7), experimental results to refute it were not forthcoming. The chief source of error of previous workers, and one which most technicians still experience, is the development of root systems of different species of plants to an extent that they will come in contact with and absorb the moisture from the entire soil mass. Portions of the soil mass are included in the soil moisture sample which have not been reduced to the wilting per-

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centage. Their second conclusion that the "wilting coefficient" is independent of the external conditions under which the plant is grown was attacked experimentally and otherwise over a long period of time (1, 2, 6, 7) and was considered to need experimental support as late as 1928 (13). The chief source of experimental error here seems to be the inability of workers to determine when the plant has permanently wilted.

The development, by Briggs and his coworkers of a seemingly effective indirect method of determining the wilting percent of soils at the same time that they established the fact that, within experimental limits, the wilting percent is a constant quantity, tended to complicate the wilting percent problem because there was disagreemnt on so many phases of it. There still seems to be more controversy over this phase of the plant-soil moisture problem than over any other. An examination of the current literature dealing with the soil moisture relations of plants discloses that available moisture values in closely related papers vary widely because of the use of different wilting percent criteria.

The senior author has for several years had occasion to evaluate soil moisture data in terms of moisture available to plants in the field. In as much as the results were to be interpreted in terms of plant response, the percentage of moisture remaining in the soil at permanent wilting of the plants seemed the safest criterion. A simple techniue has been developed which is much less elaborate than that used by Briggs and Shantz and yet has proved useable in large numbers of determinations made in connection with ecological studies of native and crop plants. Moisture equivalent and hygroscopic coefficient data have been used from time to time to supplement these wilting percent data but, in case of disagreement of data, reliance has been placed in the wilting percent data, after checking results.

The data presented in this paper are from wilting percent determinations made on a number of soil samples of wide selection, from different experiments, compared with their moisture equivalent and hygroscopic coefficient values. The results of this comparison are presented for the purpose of showing the relationship of the three values obtained by simple procedures which can easily be repeated without the use of extensive or elaborate equipment.

EXPERIMENTAL METHODS

The soil samples used were from both A and B horizons of prairie, oak-hickory, linden-maple, fertile corn field, and soils of different stages of erosion. They thus represented many degrees of fertility as well as five different soil types ranging from fine sandy loam to clay loam. The samples were thoroughly mixed after drying at room temperature.

For the wilting percent studies new number 2 rust-proof vegetable cans were used. The plants, sunflower and corn, were germinated and grown in the cans of soil in the greenhouse after the first of February when light conditions were improved. There were quadruplicates of each kind of plant in each soil. Only three were used in the test, providing an alternate which in three or four cases was needed. Each plant was sturdy and well established in the can and had a well developed root system which filled the soil in the can but was not "pot-bound" before the can was covered. After previously checking results, the cans were covered by tightly tying properly cut and adjusted squares of oilcloth instead of using a melted seal.

When the plants were about four inches high and four weeks of age the cans were covered and the plants were grown without watering. Care was taken to detect the exact time of permanent wilting by checking recovery in a saturated atmosphere. Upon wilting the soil and plant were slipped from the can and a soil sample and a check for moisture determination were taken from among the roots in the center of the root mass. The results within the triplicates were uniform within 5 percent. The extreme of variation is represented by the readings: 8, 8.2, 8.4 percent moisture. The check between the two kinds of plants was good, but only the data from the sunflowers were used.

The moisture equivalent procedure of Briggs and Shants as modified by Russel and Burr (12) was used except that the 24-hour tempering period was used, with the pans covered to prevent evaporation. The layer of soil was 10 mm. thick and the centrifugal force

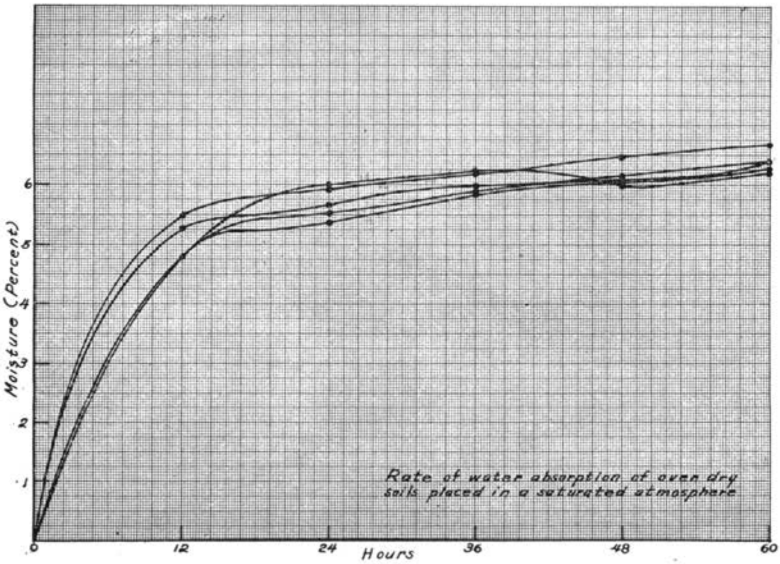

Figure 1. Curve of percentage of hygroscopic moisture plotted on time from which "the hygroscopic co-efficient" reading was made at 36 hours.

was adjusted to 1000 times gravity. The samples were run in duplicate and were repeated in case of failure to check.

The hygroscopic coefficients were determined with oven-dry soil. This was done because it was desired to control the time of exposure in a saturated atmosphere. The nature of the curve of moisture absorption of dry soil is well known. Following absorption at a rapid rate for a period of about 12 hours, absorption continues for an almost indefinite period. Although the use of air-dry soil in hygroscopic determinations would seem to be desirable, previous tests have shown that it is almost impossible to control the time of exposure if the hygroscopic moisture of the sample is not known. Figure 1 shows the rate of water absorption of four similar samples in a saturated atmosphere. On the basis of these and many other data, it was thought desirable to use 36 hours as the time of exposure in these tests.

Puri (11) has presented data to prove that temperature during exposure is a very important factor in the absorption of hygroscopic moisture. At high temperatures, absorption is more rapid but total absorption is greater at low temperatures. Because of other sources of experimental error, in the three tests, no attempt was made to refine these experiments to the extent of exact temperature control. The hygroscopic coefficient determinations were made at a temperature which did not vary by more than 2 degrees each way from 70 degrees Fahrenheit. The weight of the soil sample was approximately 5 grams, oven dry. The samples were spread thin to insure complete absorption of moisture in the moist chamber and they were covered during moving and weighing to prevent loss of moisture.

EXPERIMENTAL RESULTS

In table 1 are given the moisture equivalent and hygroscopic coefficient values and the wilting percentages computed from these values, as compared with actual wilting percentages from plants. Based on the data in the table, the correlation coefficient of the wilting percent values with those computed from the moisture equivalent is .64 and with those computed from the hygroscopic coefficient is .52. These correlations are lower than have often been reported. It must be considered, however, that the results shown in the table were from soils selected from several experiments particularly for their heterogeneity in texture, structure and organic matter content. The aim was not to show how high the correlation may be between the results of indirect and direct methods but how low it can be. The inclusion of samples nearer the extremes of course and fine texture would no doubt have resulted in even lower correlation coefficients. The relation between the compueted values and those obtained by the wilting of plants is shown graphically in figure 2.

TABLE 1. RESULTS OF DETERMINATION OF PERCENTAGE OF SOIL MOISTURE AT PERMANENT WILTING COMPUTED FROM MOISTURE EQUIVALENT AND HYGROSCOPIC COEFFICIENT DATA, COMPARED WITH DATA FROM WILTING PERCENT STUDIES WITH PLANTS.

Number of Soil Sample	Moisture Equivalent	Wilt Percent from M.E.	Wilt Percent Plants	Wilt Percent from H.C.	Hygro. Coeff.
1	20.17	10.92	8.49	8.76	5.96
2	23.15	12.57	11.16	9.18	6.24
3	18.65	10.12	8.01	7.39	5.02
4	19.78	10.75	7.67	7.58	5.15
5	15.47	8.41	8.52	7.67	5.21
6	16.38	8.91	6.83	5.62	3.83
7	13.22	7.19	4.87	4.60	3.13
8	19.50	10.59	8.85	8.47	5.76
9	17.57	9.51	7.71	8.57	5.83
10	16.88	9.24	9.78	8.17	5.55
11	23.29	12.65	7.06	9.49	6.45
12	24.75	13.45	7.43	8.42	5.72
13	22.04	11.97	6.98	8.10	5.50
14	16.33	8.78	5.50	8.45	5.74
15	20.39	11.07	7.59	10.10	6.88
16	14.61	8.80	6.07	8.06	5.47
17	22.40	12.17	8.28	9.84	6.69
18	14.27	7.75	4.47	7.11	4.83
19	17.57	9.56	5.93	8.96	6.09
20	7.82	4.26	4.07	3.06	2.06
21	17.37	9.44	5.75	8.93	6.03
22	15.44	8.40	5.00	7.95	5.06

An examination of figure 2 discloses the fact that the ratio of moisture equivalent determinations to permanent wilting percentages, for the soils tested is higher than the 1.84 ratio of Briggs and Shantz. Of the 22 soil samples, the wilting percentage value, computed from the moisture equivalent by the use of 1.84 ratio, was higher than the wilting percentage for 18 of the samples and lower for only 4. These results agree with those of Veihmeyer and Hendrickson (15). A greater objection to the use of the 1.84 ratio, or even of the use of moisture equivalents as an indirect method of determining wilting percentages of soils, is the inconsistency of the results. In a comparison of over 100 soils, Veihmeyer and Hendrickson, (15) found that the ratio of moisture equivalents to the permanent wilting percentages ranged from 1.39 to 3.82. For the 22 soil samples (Table 1), the range is from 1.73 to 3.33.

Veihmeyer and Hendrickson (14) have found that the ratios of the moisture equivalents to moisture content at permanent wilting bear no relation to the type of soil, high and low ratios being found with sands, with loams and with clays. The same conclusion could be drawn from the data in table 1. The wilting percentages for the two sandy loams, samples 18 and 20, were 4.47 and 4.07 respectively and the ratios of moisture equivalent to wilting percentage were 3.19 and 1.92. In view of these results, the .64 correlation coefficient of moisture equivalent to wilting percentage obtained from the values in table 1 seems surprisingly high. Rather the conclusion of Olmstead (10) that the permanent wilting percentage bears no definite relation to the moisture equivalent would seem to be valid. The determination of wilting percentages by computation from moisture equivalents could therefore not be safely used in general field studies.

It is obvious from an examination of table 1 and figure 2 that the results from the use of hygroscopic coefficients in determining

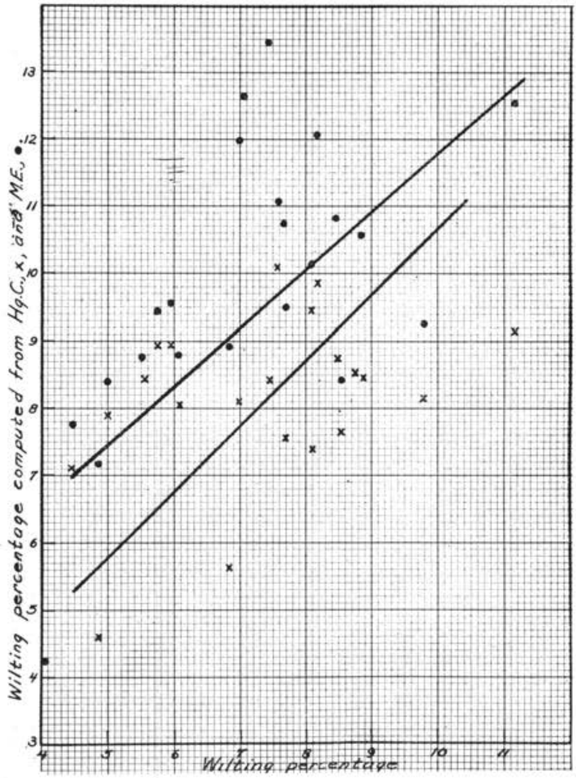

Figure 2. Wilting percentage values of several soils compueted from hygroscopic coefficient and moisture equivalent determinations plotted on wilting percentages obtained by the wilting of plants.

wilting percentages were even more inconsistent than those from the use of the moisture equivalents. This was true in spite of the fact that the moisture content at exposure, recognized as a source of error by Veihmeyer and Hendrickson (15), was corrected by the use of oven dry soils and a definite exposure time was used.

In determining the available moisture content of the soil in field studies, the only safe criterion seems to be the moisture content of the soil at permanent wilting of the plants. Under arid and semiarid conditions this value can sometimes be obtained with a comparative degree of accuracy in the field. However most investigators must depend on growing plants in small containers, wilting them and determining the moisture content of the soil. The simple technique described in this paper is suggested to field workers as a point of departure in developing a useable technique with the facilities available. Because of the elimination of one after another of the short-cut physical methods of determining the soil moisture content at permanent wilting, there seems to be a tendency among field workers to study the effect of soil moisture on the growth and development of the plant with no consideration of the proportion of the field capacity or of the soil moisture content at sampling time that is available to the plant.

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