GROWTH OF YOUNG WHEAT PLANTS IN AUTO-IRRIGATED SOILS, AS RELATED TO THE WATER-SUPPLYING POWER OF THE SOIL AND TO THE ADJUSTMENT OF THE AUTO-IRRIGATOR

BURTON E. LIVINGSTON, TAKEWO HEMMI AND J. DEAN WILSON

(WITH ONE FIGURE)

Introduction

The auto-irrigator (4, 5) furnishes a convenient means for maintaining approximately constant moisture contents in the soil masses of pot cultures, the maintained moisture content being dependent on the kind of soil used (indicated by its water-holding power, moisture equivalent, etc.), on the packing of the soil, and on the hydrostatic head against which water moves from the irrigator reservoir into the soil mass.

The experiments briefly described below were planned as a preliminary study of the relations between the growth of young wheat plants in auto-irrigated pot cultures and the water-supplying power of the soil about their roots, this dynamic soil feature being itself controlled, for each kind of soil used, by the water content of the soil, controlled in turn by the height of the mercury column introduced between the irrigator reservoir and the water-supplying, porous-porcelain cone. The experiment here reported was carried out by HEMMI in the greenhouse of the Laboratory of Plant Physiology of the Johns Hopkins University, in the winter of 1922-23, and he left his notes with the other authors of this paper when he returned to Japan. The results seem worthy of publication because of the great fundamental importance of the water-supplying power of the soil in plant physiology and plant culture, and because they add considerably to our knowledge of the manner in which the auto-irrigator operates in practice. It seems to be becoming more generally appreciated that the influential conditions of plant environments must be controlled or quantitatively recorded for effective experimentation in plant physiology, and the moisture conditions of the soil are now among the environmental conditions most susceptible of control and satisfactory measurement.

Materials and methods

Three different kinds of soils were used (intended to be like numbers 3, 6, and 9 of LIVINGSTON and KOKETSU's (6) series): a half-and-half sand-
loam mixture with a water-holding power of 39.2 per cent., a fertile loam with a water-holding power of 60.7 per cent., and a half-and-half humus-
loam mixture with a water-holding power of 95.1 per cent., these values being determined by the Hilgard method and expressed on the basis of dry weight. On the basis of dry volume they are 53.5, 57.5, and 78.3 per cent., respectively. Tinned sheet-iron containers were used as pots, 15 cm. in diameter and 20 cm. high, each furnished with an auto-irrigator, employing the porous-porcelain cone after the manner described by Livingstone in 1918. Between the reservoir and the cone was inserted a glass U-tube containing mercury, to introduce hydrostatic head against which all water passing into the soil mass must move. Five containers were used for each kind of soil, with different heights of mercury column in the U-tube, these heights being 2, 10, 20, 30, and 40 cm. The irrigators were allowed to operate preliminarily until the capillary water system of the soil closely approached equilibrium with the mercury column, as shown by the fact that the soil masses ceased practically to gain in weight. Then five wheat seeds were planted in each container and the plants produced were allowed to develop six weeks. During this period the water-supplying power of the soil, at a depth of 6 centimeters, was determined from time to time by the soil point method (6, 7), the results being recorded as milligrams of water absorbed by a single soil point in a two-hour period. (Later work indicates that a one-hour period is better for such determinations, but the results here reported are satisfactory for comparisons within their own series, though they are not comparable with results based upon any other time period.) The standard soil point, of porous porcelain, has an absorbing surface of about 12 sq. cm., and the two-hour indices of water-supplying power here given may consequently be converted so as to refer to a single square centimeter of absorbing surface by dividing each value by 12. No reliable supplying-power value was secured for the soil in equilibrium with the two-
centimeter column of mercury in any case, nor was a reliable value secured for loam in equilibrium with the 10 cm. column, these omissions being due to the use of a shorter time period for the soil-point tests in the cases mentioned. The values were very high in all these cases, surely above the absorbing capacity of the soil point for the soils in equilibrium with the two-centimeter column. The omissions do not detract materially from the value of the results, as will be seen later when the numerical data of the experiment are presented.

Determinations of the water content of each container were also made from time to time, by means of small samples removed with an ordinary cork borer with a diameter of about 1 cm., the holes in the soil being immediately filled with fresh soil of the same kind after each sampling. The
water-content values were recorded as percentages of the volume of the soil and also as percentages of its dry weight.

The several indices of water-supplying power for each container were finally averaged, as were also the several indices of water content. At the end of the experiment the tops of the plants were cut off at the soil surface and their green and dry weights determined, as well as their water contents, as indices of growth vigor. These plant values were recorded as averages per plant six weeks old. The auto-irrigators were read from time to time during the experiment and the total amount of water delivered to the soil of each container during the six-week period was secured by summing the readings.

Results

The data secured from the experiment are shown in table I.

The values given in the table are represented by the graphs of the accompanying figure 1, there being a graph for each of the three kinds of soil.

![Graphs of water-supplying power, water content, and plant growth (green weight of tops of six-week wheat plants), as these were related to the mercury column in the auto-irrigator with which the soil was in equilibrium. Three different soils are represented. The steepest curve is for water-supplying power, the curve for water content has crosses at the points, and that for green weight has circles at the points. Abscissas are heights of mercury column in centimeters. Data are from accompanying table.](image)

Abscissas represent heights of the mercury columns, and ordinates represent supplying-power values (for the steepest curve), water content values (for the lowest curve, marked with crosses at the points), and green weights of tops (for the intermediate curve, marked with circles at the points).
TABLE I
WATER-SUPPLYING POWER AND WATER CONTENT OF AUTO-IRRIGATED SOILS IN EQUILIBRIUM WITH DIFFERENT HEIGHTS OF MERCURY COLUMN, TOGETHER WITH GREEN AND DRY WEIGHTS AND WATER CONTENTS OF TOPS OF WHEAT PLANTS SIX WEEKS OLD THAT HAD GROWN IN THESE SOILS

<table>
<thead>
<tr>
<th>Kind of Soil</th>
<th>Total Amount of Water Delivered to Soil by Irrigator in 6 Weeks</th>
<th>Height of Mercury Column in Irrigator</th>
<th>Average Index of Water-Supplying Power for 2-Hour Period of Exposure</th>
<th>Average Water Content of Soil</th>
<th>Volumetric</th>
<th>Gravimetric (on Dry-Weight Basis)</th>
<th>Average Green Weight of Tops Per Plant</th>
<th>Average Dry Weight of Tops Per Plant</th>
<th>Average Water Content Per Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand-loam</td>
<td>1421 2</td>
<td>10</td>
<td>90</td>
<td>6.2</td>
<td>4.2</td>
<td>254</td>
<td>36</td>
<td>218</td>
<td>180</td>
</tr>
<tr>
<td>Loam</td>
<td>1238 2</td>
<td>10</td>
<td>1580</td>
<td>22.4</td>
<td>16.0</td>
<td>370</td>
<td>44</td>
<td>326</td>
<td>310</td>
</tr>
<tr>
<td>Humus-loam</td>
<td>1031 2</td>
<td>10</td>
<td>1310</td>
<td>33.5</td>
<td>36.1</td>
<td>906</td>
<td>92</td>
<td>814</td>
<td>808</td>
</tr>
</tbody>
</table>

Copyright © 1926 American Society of Plant Biologists. All rights reserved.


Discussion

The following observations may be made here, from the data. The water-supplying power consistently follows the water content in the case of each soil, though these two properties are not proportional. For each soil the water content is determined, within limits, by the height of the mercury column. The water content on an auto-irrigated soil mass may have any value between that which is in equilibrium with the highest mercury column that can be used and that corresponding to the maximum capillary content, but its lower limit is fixed by the physical characteristics of the soil employed. For any soil there is a certain range of water contents and corresponding water-supplying powers that can be established and maintained by the auto-irrigator. The upper limit of this range is the maximum capillary content, with the mercury column just balancing the water column between irrigator cone and reservoir. The lower limit is very low for sandy soils, but high for clays and humus soils, with the highest mercury column that can be applied. For the five heights of mercury column used in this experiment the ranges of water content secured were: from 20 to 5 per cent. for the sand-loam mixture, from 36 to 14 per cent. for the loam soil, and from 47 to 21 per cent. for the humus-loam mixture. The corresponding water-supplying powers ranged from very high values (probably well above 2,500) to 60 for the sand-loam mixture, to 220 for the loam soil, and to 160 for the humus-loam mixture. To secure still lower water contents and supplying-powers, it is at once suggested that still higher mercury columns be employed, but the graphs indicate that increased height of mercury column could have very little effect for the sand-loam or humus-loam mixtures, though a higher mercury column would probably lower the values in question considerably for the loam itself. The present set-up of the auto-irrigator is restricted by the fact that mercury columns higher than about 60 or 65 cm. are not practicable.

If adequate liquid strain (1, 8) might be developed in the irrigator system the resistance offered to the entrance of water into the soil might be correspondingly increased, but this has not yet been accomplished. Of course a nearly complete atmosphere of opposing pressure might be developed by the use of suction applied in the irrigator reservoir by means of an air pump, but this has not been tried. At best it could generally give resistances corresponding to no more than about 75 cm. of mercury column.

For any height of mercury column in the auto-irrigator the water-supplying power and the water content of the controlled soil were, in general, lowest for the sand-loam mixture and highest for the humus-loam mixture, being intermediate for loam. They are obviously related to the internal surface forces of the several soils, represented by their water-
holding powers. The higher the water-holding power the greater should be the height of the mercury column in the irrigator, to develop and maintain a given water-supplying power in the soil.

With few slight exceptions, the three different growth indices are consistent and consequently only those for green weight of tops are presented in the graphs. For any height of the mercury column the growth of the plants was most vigorous in the humus-loam mixture, least vigorous in the sand-loam mixture, and intermediate in loam. It is notable that the growth values corresponding to the two-centimeter column of mercury are nearly alike for the sand-loam mixture (404) and for loam (406), while the corresponding value for the humus-loam mixture (690) is much greater.

The greatest growth values for the sand-loam mixture were secured with the highest water-supplying power (not measured), with a volumetric water content of 20.2 per cent. and with the shortest mercury column (2 cm.). The twenty-centimeter, thirty-centimeter, and forty-centimeter columns of mercury with the sand-loam mixture were nearly alike as to water-supplying power, water content, and growth index; and all these values were very low. With these mercury columns growth was markedly retarded, but the plants did not succumb, even with the highest mercury column. Growth would probably have ceased altogether with the highest column and the plants would probably have died, if they had been subjected to somewhat more intense conditions of evaporation and sunshine, or even if the cultures had been continued longer, since the water requirement of a plant of course increases as growth progresses, other influential conditions being unchanged.

For the loam soil the highest growth values were secured with the ten-centimeter column of mercury in the irrigator, a slight relative retardation being apparent for the two-centimeter column. This retardation is probably not to be related to water-supplying power, nor directly to watercontent, but rather to the oxygen-supplying power (2, 3) of the soil, which is necessarily lower with higher water contents. With the exception of the two-centimeter mercury column, every one of the columns with loam gave very much greater growth than did any of the columns with the sand-loam mixture; the forty-centimeter column with loam gave nearly twice as much green weight per plant as did the same column with the sand-loam mixture.

A very pronounced retardation in growth is shown for the two-centimeter column with the humus-loam mixture. With this mixture the highest green-weight values were secured (being about alike) with the ten-centimeter and twenty-centimeter columns, and these growth values are by far the highest of the whole experiment. A water-supplying power of 1,310 gave the highest growth value (ten-centimeter column) but one of 240 gave a value nearly as high (twenty-centimeter column). Supplying powers
much greater than 1,300 were apparently attended by growth retardation for this soil, probably related to deficient oxygen supply, as mentioned in connection with the similar case with loam. The two-centimeter column gave nearly as poor growth as did the thirty-centimeter column. Growth was very good with the highest column, better than with any column for either of the other soils. To retard growth as much in this mixture, and in the loam soil also, as much as it was retarded in the sand-loam mixture with the forty-centimeter column of mercury, would, as is indicated above, require a still higher column and might not be attainable with any column that could be applied without actual liquid strain. Only in our most sandy soil was the lower limit of the supplying-power requirement for good growth apparently approached with any of our mercury columns.

The amounts of water delivered to the soil masses show somewhat the same relations to the heights of the mercury columns and to growth as do the water contents and water-supplying powers. These rates of delivery of water from the irrigator to the soil are of course largely dependent on the rate of evaporation from the soil surface and on the rate of water absorption by the plants.

It is of special interest and importance to call attention to the observation that the growth of the wheat plants in this experiment was clearly and profoundly influenced in some cases by some variable or variables other than the water-supplying power of the soil. With soils having very high water-supplying powers it is probable, as has been mentioned, that growth retardation is brought about by deficiency in the oxygen-supplying power of the soil. This might explain why a water-supplying power of 1,580 (loam with a twenty-centimeter mercury column) gave a green-weight value of but 370, while a water-supplying power of only 160 (humus-loam mixture with a forty-centimeter mercury column) gave a green-weight value of 504. Other considerations would need to be taken up, however, for a rational and general interpretation of such results. For example, a supplying-power of 1,310 (humus-loam mixture with a ten-centimeter mercury column) gave the highest growth value of the entire series (906 for green weight of tops), while a water-supplying power of only 240 (the same mixture with a twenty-centimeter mercury column) gave practically the same growth index (904). Other apparently anomalous cases may be found in our table.

Other chemical conditions of the soil, aside from its oxygen-supplying power, may of course have exerted influence on the growth of the plants. The loam used is known to have been a productive soil, and the two mixtures used were each half loam. It consequently does not appear likely that any of our plants were retarded by inadequacy in the supply of the necessary inorganic salts and ions. That the humus may have introduced special and
perhaps influential chemical conditions is of course possible, but no consistent interpretation of our results seems to emerge from a study of the data with this possibility in mind. It seems likely that we are here dealing with a matter of considerable complexity, one that will require much further study. It may well be that the water-absorbing powers of the root systems were different for the different treatments, with resulting differences in the ratio of water-absorbing power to transpiring power in the plants themselves. Such a suggestion leads to many possibilities, an a priori consideration of which would, however, be premature with our present very limited experimental data. At any rate, the problem of the water relations between plant and soil is worthy of much more serious attention than has thus far been devoted to it. The auto-irrigator, the soil point method, and the method for determining the oxygen-supplying power of the soil should all be valuable in the development of this very important portion of the field of plant physiology and physiological ecology.

In spite of the considerations suggested in the last paragraph, it remains clear that the water-supplying power of the soil was, in general, of primary importance in determining the growth of our wheat plants. If the fifteen different treatments are arranged in the descending order of green-weight values it becomes clear that the highest five growth indices are for the range of water-supplying powers from very high to 160 (humus-loam mixture), while the lowest four growth indices are for the range of water-supplying powers from 170 to 60 (sand-loam mixture).

To avoid possible partial misunderstandings or unjustified deductions, it may be mentioned that our data and interpretations refer to a Baltimore greenhouse in the winter months, to wheat plants grown for six weeks from seed, to the three specific soils used, to auto-irrigators of the type employed, and to standard soil points exposed to the soil at a depth of 6 centimeters for a period of two hours. Other plants, other treatments, and other instrumentation may be expected to give in some cases more or less different results; but the general principles here noted may be expected to obtain.

LABORATORY OF PLANT PHYSIOLOGY,
THE JOHNS HOPKINS UNIVERSITY

LITERATURE CITED
2. HUTCHINS, LEE M. Studies on the oxygen-supplying power of the soil as indicated by color changes in alkaline pyrogallop solution, together with quantitative observations on the oxygen-supplying
1926.

3. ————, and LIVINGSTON, B. E. Oxygen-supplying power of the
soil as indicated by color changes in alkaline pyrogallol solution.

4. LIVINGSTON, B. E. Porous clay cones for the auto-irrigation of potted

5. ————, and HAWKINS, Lon A. The water relation between plant
and soil. Carnegie Inst. Publ. no. 204: 1–48. 1915. Washing-
ton, D. C.

6. ————, and KOKETSU, RICHIRO. The water-supplying power of
the soil as related to the wilting of plants. Soil Sci. 9: 469–485.
1920.

7. ————, and OHGA, ICHIRO. The summer march of soil moisture

8. URSPRUNG, A. Dritter Beitrag zur Demonstration der Flüssigkeitsko-