

SELECTED ARTICLES

WATER CONDITIONS OF THE SOIL AND IRRIGATION*

THE water condition of the soil is a decisive factor in plant life: the moisture extracted by the plant from the soil forms the main component part of the body of the plant amounting to 90 per cent. of its total weight. Water and its component elements alike form essential parts of the organic compounds of the plant; mineral nutrition can take place only with the active assistance of water, which also helps the process of synthesis, hydrolysis and general metabolism in the plant. Practical investigation of the problem of water supply to citrus trees in Arizona established the fact "that intelligent irrigation" was "of much greater importance than fertilizer practice" and that was "being found to be true in California."

INTER-RELATIONSHIP OF SOIL AND WATER

The content of moisture in the soil, known as "soil moisture", is of great importance in the production of plants. A decrease of the amount of moisture in the soil beyond a certain limit arrests the growth of plants; this characteristic explains the sterility of dry regions and arid lands. Excess moisture, too, hinders and sometimes even arrests growth. This is why artificial irrigation does not mean merely the supply of water to the soil, but should strive to reach a definite optimal content. The degree to which water is bound to the soil or is free to move there, is determined by the mutual attraction of soil and water particles, which can only be explained by the application of physical and chemical laws to these phenomena.

All phenomena of water retention in the soil, its movement inside the soil, and its flow downwards towards the earth, can be explained by the presence of two kinds of forces acting in the environment formed by soil and water: (a) the force of mutual attraction affecting particles of soil and water, (b) the force of gravity exercised by the earth, which affects the movement of water in a vertical direction from the soil to the subsoil and deeper.

Three types of moisture are distinguished in this connection: hygroscopic, capillary and gravitational moisture, though no definite transitional limits can be fixed between them (1: 2). Hygroscopic moisture adheres very strongly to the particles of soil; the pressure necessary to separate it from the particles of soil is fixed at 1,000 atmospheres. Hygroscopic moisture is situated on the surface of hard particles and is not capable to move about in liquid form. At a further increase of the moisture content, water does not come into direct contact with the hard substance of the soil, but with the layer

* By Professor F. Menchikowsky, in *Hadar*, May 1939, Vol. XII, No. 5.

of hygroscopic moisture previously introduced into the soil. The mutual attraction of this additional water and the soil is weaker than that of the preceding supply, so that the new moisture can now move inside the soil in all directions, without yet being subject to the force of gravity exercised by the earth. This moisture, too, is retained by the soil, but a pressure of 5–15 atmospheres suffices to separate it from the soil. Since it is generally assumed that this moisture occupies the capillary spaces in the soil, and maintains itself there partly owing to capillary attraction, it is known as “capillary moisture”. Any further increase of moisture in the soil leads to the accumulation of water retained in the soil with difficulty; this water, therefore, drains down as a result of the terrestrial force of gravity. This water is known as gravitational moisture.

RISE OF WATER IN THE SOIL AND CAPILLARY MOISTURE

If soil comes into contact with a surface of sub-soil water at a certain depth, so that all soil capillaries are filled with water, we enter the domain of physical capillary phenomena. Water rises on its own in the capillary spaces of the soil and reaches a certain level, at which the weight of the rising column of water is counter-balanced by the action of intermolecular soil forces. Physical laws teach us that such capillary rise depends on the diameter of the capillaries in a reversed proportion, the narrower the opening the higher the rise. At the same time, observations prove that in these circumstances capillary moisture attains a maximal rise in loamy soil, a lower rise in sandy-loam, and a minimal rise in sandy soil.

Another feature of the capillary rise in these conditions is that the percentage of capillary moisture decreases with increased height. This circumstance, too, is in strict conformance with the laws of capillarity, and is an extremely important factor in the artificial and natural moistening of the soil.

However, several scholars draw a distinction between the upper and lower zones of capillary moisture (Keen, Versluys, Vageler).

The upper zone of capillary moisture is not completely full with water and the capillary attraction gives, therefore, place to the forces of physico-chemical adhesion.

This is the zone of “open” capillary moisture, the air spaces of which amount to about 24 per cent. of the total soil porosity, which is most favourable to plant life. The following are the types of moisture from soil surface downwards:

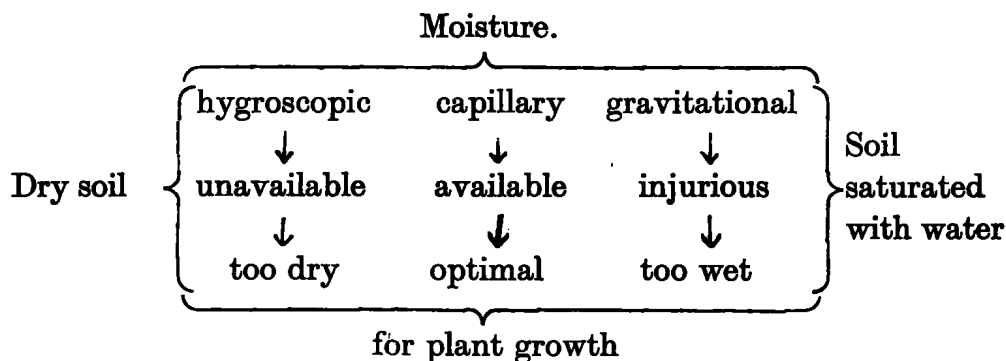
Soil surface
—————
hygroscopic moisture
↓
“ open ” capillary moisture
↓
“ closed ” capillary moisture
—————
sub-soil water.

TYPES OF MOISTURE IN THE SOIL AND WATER REQUIREMENT OF THE PLANT.

As is well known, plants require an uninterrupted supply of water, without which they cannot exist. This supply is assured by the root system, which develops a certain sucking power, that grows as we proceed from the periphery to the centre of the root, and fluctuates between 1 and 10 atmospheres.

Comparing these data with the forces that retain the three above mentioned types of moisture in the soil, we find that the one corresponding to the suction power of the root is the capillary moisture (5-15 atmospheres). As the stock of capillary moisture in the soil decreases, the plant experiences growing difficulties in the extraction of moisture from the soil; the plant begins to wither, and as soon as the amount of moisture falls short of a certain limit, it perishes. At this critical moment the soil still has a certain stock of moisture, but the latter is inaccessible to the plant, since physiologically it forms the "dead moisture" store. This unavailable stock of moisture in the soil corresponds more or less to what we call hygroscopic moisture.

Gravitational moisture fills the non-capillary hollows of the soil, which spaces are as a rule filled with the air necessary for the breathing of roots. The presence of this type of moisture has a bad effect on the physiological conditions indispensable for the life of the roots; and consequently, gravitational moisture is considered detrimental as causing diseases, and sometimes even the death of plants. The following sketch illustrates the relation of the various types of moisture to the water requirements of the plants.



CONSTANTS OF SOIL MOISTURE AND COEFFICIENTS OF PLANT GROWTH

The above shows that a plant has definite requirements as far as moisture content in the soil is concerned. Under certain circumstances, which are optimal for plants, the latter attain maximum growth, while a different content of moisture in the soil brings about the death of plants. Two coefficients of soil moisture, which are biologically important, have been established in this connection. One of these is known as "permanent wilting point"; it designates a physiologically minimal content of moisture in the soil; as soon as this is reached, the plant withers and dies. The second coefficient denotes that moisture content of the soil, which brings about the optimal conditions of growth and development of the plant; it is known as the "optimal moisture content". Successful practising of artificial irrigation requires the determination of these two coefficients for every type of soil. These coefficients of growth can be found with the help of the constants of soil moisture, which

determine the capacity of the soil to retain moisture. Of the several known constants we shall discuss only two, acquaintance with which is indispensable for an elementary comprehension of conditions of soil. One of these is the "hygroscopic content". The determination of this constant aims to find out the amount of water in the soil, at which the latter becomes covered with a thin film of hygroscopic moisture. The second constant, which is very important in practice, is known as "capillary capacity"; it presents the water required to fill a given volume of soil with capillary moisture.

LIMITS OF SOIL MOISTURE AND MOISTURE REQUIRED BY CULTIVATED SOIL

In the absorption of moisture by cultivated plants the amount in the soil decreases till the agriculturer must have recourse to irrigation. This critical moment, when the agriculturer must interfere, can be determined by noticing colour (dark-green colour in lucern) or the first symptoms (drooping leaves). However, a more rational method is to determine the amount of moisture in the soil, the content of which should never fall below the permanent wilting point. This point can be determined within given limits in every type of soil by means of the constants mentioned above. It is impossible to discuss here at great length the complicated method of determining the wilting point evolved by U. S. A. scholars (L. Shantz, F. Veihmeyer, O. Israelsen and others). We shall only mention W. G. Danoff's finding, that the amount of water unavailable to the "dead moisture" store is approximately double the quantity of moisture in air-dry soil.

The limit of the content of moisture in the soil, which forms a natural boundary beyond which no plant life is possible, closely depends on the composition of soils.

Even sandy soils continue to deliver moisture even when its content is 3 per cent. or less. In loamy soils this limit is reached at 20 per cent. In the loamy soils of our littoral zone the "dead moisture" store according to observations made by the author, between 20.2 and 21.0 per cent. This fluctuation of the amount of moisture available to plants is of great importance to nature, for coarse soils with low capillary capacity enable plants growing in them to utilize almost their entire store of water.

THE EFFECT OF MINERAL ELEMENTS ON THE AVAILABILITY OF SOIL MOISTURE

Irrigation as such forms an interference with the normal course of the soil under natural circumstances; it may, therefore, cause either a better or for worse, as far as the plant is concerned. In irrigating water is introduced annually into the soil a considerable amount of mineral matter in the shape of salts of Na, K, Ca, NH_4 , &c. One part of these salts is in solution thereby increasing the concentration of the soil solution, the other part is absorbed by the soil, as a result of which the physico-chemical properties of the soil undergo a change. It has already been mentioned that irrigation exerts a definite force of binding moisture; as the amount of moisture

in the soil increases, this binding force decreases. The strength of these forces of adherence in the soil plays a very important role in the life of plants, for in the case of soils with a high capacity for binding moisture, sucking roots often experience difficulties and sometimes fail altogether to extract moisture from the soil. Soluble salts are subject to solvatisation, *i.e.* to become covered with an outer "rind" of water particles, thereby decreasing the available amount of moisture in the soil, which the plant is capable of assimilating. These phenomena have formed the subject of investigations made by several scholars. Their observations prove that one and the same amount of water in the soil may supply the plant with systematically decreasing quantities of available moisture, depending on the fact whether the soil had not been fertilized at all, normally fertilized or enriched by a high content of K-salts. In saline soils, or in such as have a tendency to accumulate soluble salts—as a result of climatic, topographical or soil conditions, mineral fertilization may become a factor that hinders growth or even arrests it altogether if intensive mineral fertilization is practised in the case of limited quantities of available moisture. In the agricultural practice of Palestine, where growth depends on rain precipitation, one can observe quite often that the first to suffer at a period of drought are those plots that have been abundantly supplied with chemical fertilizers.

The study of soil from the point of view of its saturation with various mineral bases, proved that physico-chemical properties, too, are conditioned to a large extent by the nature of the absorbed elements. The same is true also with regard to the degree, to which such soil binds moisture. The soil becomes covered with a "rind" of water particles, the formation of which depends on the absorbed elements, their quantity and form.

Consequently, mineral fertilization affects the balance of free moisture, available for assimilation by the plant, not only as a result of the change that takes place in the nutritive solution of the soil, but also as a result of the change that takes place in the soil itself, a change effected by the process of mineral fertilization.

ACCUMULATION OF WATER IN THE SOIL

It has already been stated above that the initial moment of irrigation is connected with the critical stage, at which the plant begins to experience difficulties in its biological activities as a result of the decreasing content of moisture in the soil. The supply of water to the soil at the time of irrigation aims to raise the content of water in the soil to a limit which would represent optimal conditions as far as the plants in question are concerned. Within the scheme of various types of moisture in the soil it means the formation of "capillary moisture". Maximum capillary moisture is known as "field capillary capacity". In practice capillary moisture can be determined in the field by ascertaining—after all gravitational moisture had run off—the percentage of moisture in a given plot protected from evaporation, in which underground water is situated at a considerable depth. (Under laboratory conditions this amount is approximately equal to the "moisture equivalent" *i.e.* the quantity of water, which Briggs and McLane found in a soil-sample after subjecting it to centrifuging for half an hour in a centrifugal machine, the centrifugal force of which is 1,000 times stronger than the force of gravity.

By filling the soil with water up to the above mentioned limit we create in the soil a store of water, which ensures the growth of the plant under optimal conditions during a certain period of time. In this condition some of the soil pores are filled with air. Strict care must be taken not to exceed this limit, since with the introduction of gravitational moisture, which lies beyond the limits of "capillary moisture" conditions become dangerous to the growth of plants.

By measuring the amount of moisture in the soil up to a certain depth at which maximum capillary capacity is achieved, and deducting the percentage of moisture in the soil at the initial moment of wilting, we find that store of water in the soil may and must contain under normal conditions of

the duration of the period, in which this store is exhausted by the plants. This depends on the type of plants, their age, climatic conditions and the rate of evaporation on the surface of the soil (11).

FACTORS OF DELIVERY OF MOISTURE FROM THE SOIL TO THE PLANTS

The efficiency of the delivery of available capillary moisture to the plants is less important than the total quantity of delivered moisture and the limit of this delivery. The fundamental factor that determines the water economy in the soil, is probably that absorptive capacity of the soil particles, which is determined by their chemical composition. This is known as sorption. This property to form more or less of water particles round particles of soil is responsible not only for the total amount of all types of moisture in the soil and their distribution, but also for the process of water delivery to plants. The study of the process shows that it is not uniform. At first the delivery of water is rapid, then it slows down, and finally, as the hygroscopic coefficient draws nearer, it almost stops. The following scheme illustrates this process in different types of soil :

	<u>loam</u>	<u>sandy-loam</u>	<u>sand</u>
rate of delivery of moisture	high	middle	low
rate of evaporation	slow	middle	quick

FACTORS OF EVAPORATION AND CONSERVATION OF SOIL MOISTURE

Evaporation was considered to be one of the factors effecting a decrease in the total store of moisture in the soil. This opinion rested on the assumption that capillary moisture filled all capillary spaces in the soil, and that as the upper layer of the soil was dried, the moisture stored in the lower layers ascended towards the surface. Had this assumption of the capillary moisture been correct, the latter should have filled all spaces in the soil, without leaving any space at all, or only very little space. In fact, however, a somewhat similar state of affairs is to be found only where the water table is close to the surface, when a type of "closed" capillary moisture is present, as we have had occasion to notice above. Under normal

conditions capillary ways are interrupted by air bubbles and the movement of moisture meets with difficulties. Observations made by F. J. Veihmeyer in California showed that loss of moisture by evaporation affected only 15 cm. of the surface layer of soil. Deeper strata do not lose any moisture as a consequence of this phenomenon. This assumption has been confirmed both in soil-tests in the laboratory as well as observations in the field. At the same time these observations showed that cultivation of the soil does not affect the conservation of moisture, contrary to former suppositions that mechanical cultivation destroys capillary connections in the soil.

The loss of moisture in uncultivated soil should be ascribed exclusively to the evaporating properties of weeds that cover the surface of such soils. Cultivation helps to decrease evaporation only in that sense that it destroys the cover of field-weeds.

THE CONTROL OF WATER RELATION IN LOCAL SOILS AND IRRIGATION

Local climatic conditions render artificial irrigation indispensable, if a certain degree of soil-fertility is to be maintained. Consequently, it is necessary to take into consideration all factors affecting moisture in the various types of local soils. The usual system of irrigation does not always satisfy the requirements of plants, for it sometimes allows moisture to fall below the above mentioned critical limit, or else it enriches the soil with water far beyond the limits of capillary moisture. Citrus trees belong to that category of plants which are extremely sensitive to both deficiency and excess of moisture in the soil; a large number of diseases of citrus trees and seedlings is to be ascribed to either of these deviations from the standard. On determining the stock of optimally absorbable water, which corresponds to capillary moisture, and establishing the water requirement of the trees in the plantation, we can find out and fix the suitable interval of time between two consequent waterings. In the campaign against faulty irrigation one more factor plays a decisive role, namely the exact knowledge of the level of uppermost sub-soil waters, which may create a non-uniform distribution of moisture in the soil, more especially in deeper strata that lie near the level of these underground waters, where "open" capillary moisture turns into "closed" capillary moisture poor in air. Such unfavourable conditions prevail under local conditions in saturated plots lying in the vicinity of "wadis."

The problem of water delivery from the soil to the roots of plants has not been sufficiently considered as yet. It had been assumed that the flow of moisture to the roots was uniform, while in practice immediately after a watering the plant requires less efforts to obtain the requisite moisture than it does before a new watering. Another factor that is to be taken into consideration in this respect is the nature of chemical fertilization, for it affects the degree to which soil binds moisture or renders it available.

In the light of our present knowledge of soil moisture and its relation to plants, irrigation of plantations can be successfully achieved only if it is guided by a control of the interrelation of moisture and soil.