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Soil Moisture in Relation to Plant Growth

Cecil H. Wadleigh

Growing plants transpire enormous quantities of water which they take from the soil. One cornfield in Iowa transpires enough water during a season to cover the field to a depth of 12 or 16 inches. The production of 1 ton of dry alfalfa hay on the Great Plains may involve the transpiration of 700 tons of water—more or less, depending on the evaporating power of the atmosphere. At a temperature of 75° F. and a relative humidity of 50 percent, a tensional force of approximately 1,000 atmospheres would have to be applied to water to stop evaporation.

Plants lose water continuously. The lowest loss is at night and the highest at midday. But often the soil water is not replenished by rain or irrigation over periods of weeks or months. Hence the soil acts as a moisture reservoir for the plants.

To a Colorado wheat grower, who may harvest 50 bushels an acre or nothing, according to the status of the moisture reservoir in his soil in a given season, it would be difficult to overemphasize the importance of soil moisture in plant growth.

The capacity of the soil moisture reservoir is limited by the field capacity (upper limit) and the permanent wilting percentage (lower limit) of the soil in the effective root zone of a crop. Field capacity is the moisture percentage of a soil, expressed on dry-weight basis, in the field 2 or 3 days after a thorough wetting of the soil profile by rain or irrigation water. Permanent wilting percentage is the moisture percentage of soil at which plants wilt and fail to recover turgidity. It is usually determined by growing dwarf sunflower plants in small containers of the soil under examination. The moisture held by the soil against a displacing force of 15 atmospheres (221 pounds a square inch) is a good estimate of the permanent wilting percentage.

There is a wide disparity between the value of 1,000 atmospheres associated with the evaporating power of the air on a warm, dry day and the 15 atmospheres of soil moisture tension associated with the wilting of plants. Rate of entry of water into the roots is impaired by the prevalence of only a few atmospheres of soil moisture stress, even though the plant can withstand a great drying force at the leaf surfaces.

The permanent wilting percentage of soils may vary from 3 percent for a coarse sandy soil to 23 percent for a fine clay. Comparable figures for the range in field capacity are 8 and 40 percent.

F. J. Veihmeyer and A. H. Hendrickson, of the California Agricultural Experiment Station, have conducted extensive experiments demonstrating the usefulness of these two soil moisture constants in irrigation practice. They designate the moisture held by a soil in the range between field capacity and permanent wilting percentage as the available range. Thus the moisture reservoir constitutes the water in the available range held by the mass of soil in the active root zone.

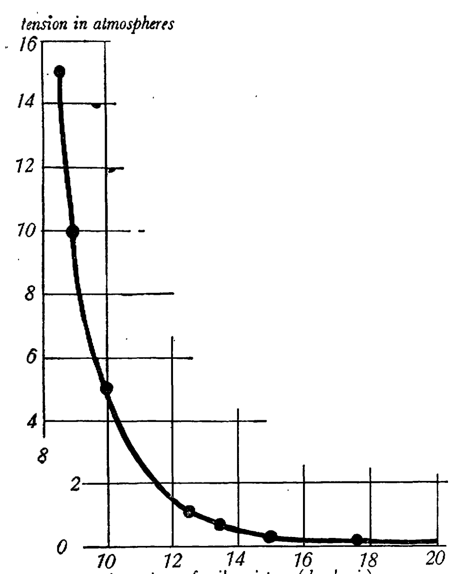
Let us examine the amount of water that may be available in a unit volume of soil, say, 1 cubic foot. A mineral soil is made up of three major components, air, water, and mineral particles. One cubic foot in the dry state will weigh from 65 pounds for clays to 110 pounds for sands. Soil particles have an average density of 2.65, and a cubic foot of soil minerals would weigh 165 pounds. Thus, as much as 60 percent of the volume of a clay soil may be voids filled with air and water. In coarse sands it may be as low as 30 percent.

It is essential for most plants that the voids be only partially filled with water in order to provide necessary aeration.

Plants vary markedly as to rooting habit under favorable soil conditions. Roots of lettuce and spinach penetrate only 12 to 15 inches; those of potatoes and peas, about 2 feet; tomatoes and tobacco, 3 feet; field corn and asparagus, 4 feet; and alfalfa and grapes, down to 8 or 10 feet or more. Potatoes growing in a loam that can hold 1.5 inches of available water per foot of depth would have a total moisture reservoir of 3 inches of water—enough for a vigorously growing potato crop for about 1 to 3 weeks, depending on the evaporation rate.

THERE IS EVIDENCE that the water in the available range of a soil is held equally available to crop plants, even though water at the upper limit, field capacity, is withheld from the plant roots by a tensional force of about only 1.5 pounds a square inch; whereas water at the lower limit, permanent wilting percentage, is withheld by a tensional force of about 200 pounds a square inch. Those values constitute a wide range in tensional force. Why, then, do we find evidence that insofar as plant growth is concerned water is equally available between those limits?

The relationship between soil moisture tension and moisture content provides an answer:



This chart shows the relationship between soil moisture content and tension in Panoche loam.

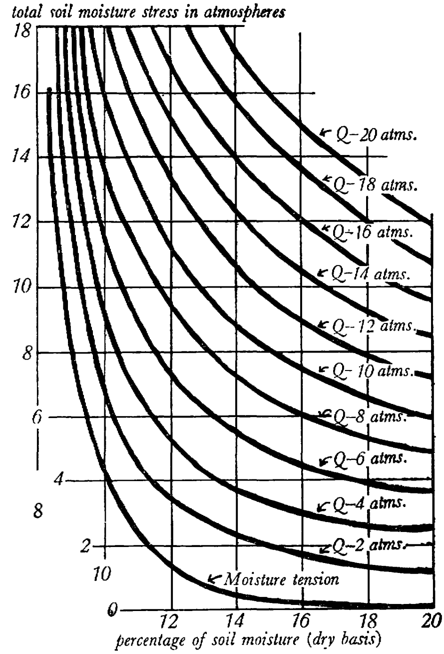
These data were taken on a sample of Panoche loam, a soil found in California. This soil has a field capacity of 18 percent and a permanent wilting percentage of 8.6 percent. It is of key importance to note that the change in moisture tension with a moisture content between these two moisture percentages is not linear, but markedly curvilinear. As the soil dries out toward the permanent wilting percentage, there is but little increase in moisture tension even when two-thirds of the available moisture has been used up. On the other hand, as the permanent wilting percentage is approached, there is an enormous increase in moisture tension associated with a small decrease in moisture content. Thus the shape of the curve explains why there is evidence indicating that, for practical purposes, soil water is essentially equally available almost down to the wilting percentage. Contrary evidence is also prevalent. In general, when two-thirds to three-fourths of the available water has been exhausted from the moisture reservoir, plants may stop growing.

All soils have moisture retention curves similar to the one in the chart, but the shape and locus vary.

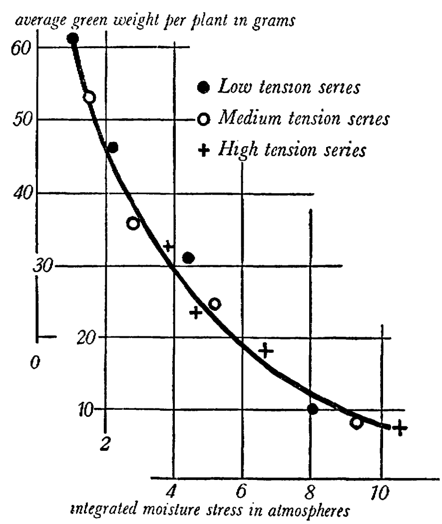
Dissolved salts derived from fertilizers or from natural sources, as in saline soils, also impair the availability of water to plants. Dissolved salts increase the osmotic pressure of a solution, which is measured in terms of atmospheres, as soil moisture tension may be. There is evidence that the effects of moisture tension and osmotic pressure are additive in impeding water availability to roots. The sum of these two forces has been called the total soil moisture stress.

The second chart shows the effects of various levels of added salts, expressed in atmospheres of osmotic pressure, on the total soil moisture stress of the soil having the tension curve shown in the first chart. Increased levels (Q values) of added salts decrease the availability of soil water.

An experiment exemplifying the lat-



The relationship between total soil moisture stress and moisture content of a Panoche loam with various increments in osmotic pressure of the soil solution induced by added salt.



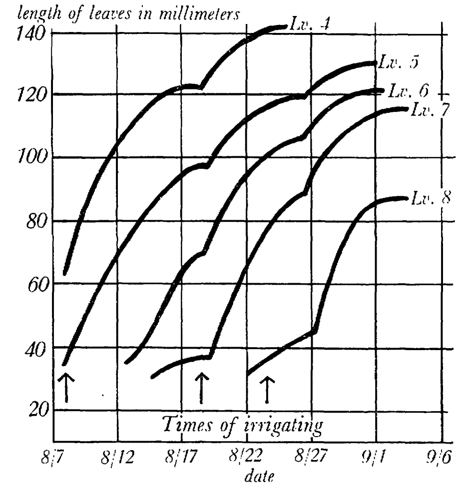
Accumulated growth of bean plants as related to total soil moisture stress arising from various combinations of moisture tension and osmotic pressure.

ter statement is illustrated by the data in the third chart. Cotton plants were grown in oil drums filled with soil to which 0.1 percent of sodium chloride was added to make it slightly saline. (Q equalled about 6 atmospheres at 12 percent moisture.) The moisture content of the soil was determined daily by weighing the drums, and the length of each leaf was measured at 8 o'clock every morning. When 90 percent of the theoretical amount of available water was exhausted, the soil was irrigated, as shown by the arrows. Nearly every leaf stopped growing a day or two prior to the irrigations, even though the plants did not wilt. Calculations revealed that the total soil moisture stress associated with complete cessation of leaf growth was 14 atmospheres.

The foregoing effects on diurnal leaf growth are additive through time. This is further shown by the data presented in the chart, (page 360) showing the total soil moisture stress on bean plants grown to maturity in soil contained in oil drums and varying as to salinity (osmotic pressure effect) by adding 0, 0.1, 0.2, and 0.4 percent sodium chloride to different batches of the soil used. Some of the soil cultures were kept quite moist (low tension series); others were irrigated when two-thirds of the available water was used (medium tension series); and others were allowed to dry down almost to the wilting percentage (high tension series). Growth of the bean plants was closely related to total soil moisture stress, regardless of whether the stress arose from salinity or moisture tension.

Plant growth is primarily the result of two major processes: Cell division (production of new cells) and cell enlargement. Intensive investigations on sugar beets by D. J. Watson of the Rothamsted Experimental Station in England indicated that soil moisture deficits affect growth mainly by inhibiting cell enlargement, rather than by affecting cell division.

A plant cell is a living osmometer in



Growth of leaves of a cotton plant as related to soil moisture depletion and replenishment.

which the contained solution tends to absorb water from its surroundings, thereby effecting an internal hydrostatic pressure on the cell wall—turgor pressure. This turgor pressure is the force that brings about cell enlargement, and its effectiveness is controlled by the action of a substance within the cell known as auxin. Thus, the plant growth is directly related to degree and duration of turgescence of plant tissues.

Water loss from plants by transpiration brings about a tensional stress within the plant that is counteractive to the prevalence of turgor pressures in expanding cells. This internal tensional stress is eased by water absorbed from the soil. Conditions such as poor soil aeration, high moisture tension, or salinity may impair the capacity of roots to absorb water so that moisture tension in the plant is not adequately alleviated. This may reach the state where the plants lose turgidity.

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