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Moisture Studies under Citrus using Tensiometers[1]

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A **YEAR'S** record has been obtained on soil moisture tensiometers at eight depths down to 15 feet under each of two 1 l-year-old navel orange trees budded on sweet stock, one being irrigated twice as often as the other. The trees were located in field *S3* Block Y of the University of California Citrus Experiment Station at Riverside. Irrigation water was applied in a level basin to a depth of 4 inches for each tree at each irrigation. During the irrigation season, tree 3 in row 16 received water every 4 weeks while tree 5 in row 14 received water every 2 weeks. The tensiometers were installed 6 inches apart in a line on the north side of the trees just under the outermost extension of the branches and about midway between the tree trunk and the basin border. The porous tensiometer cups were attached to steel tubes having lengths of 1, 2, 3, 4, 6, 8, 10, and 15 feet and the tops of the steel tubes were set 6 inches above the soil surface.[2] The actual depth of the porous cup in the soil was therefore 4¾ inches less than the corresponding steel tube length. For convenience in the following discussion, the various cups will be referred to by their steel tube lengths.

The trees were located in Ramona sandy loam which is permeable and well drained and the basins were kept weed free with a minimum of hand cultivation. An indication of soil texture is given by the curves inset in Fig. 4. The soil removed from the 15-foot tensiometer holes was composited in 1 foot intervals below the 6-inch depth and the amount of moisture these samples retained at a soil moisture tension of ½ atmosphere (38 centimeters of mercury) is shown plotted against depth. These values approximate the moisture equivalent. The installation of six units under each tree was completed on September 9, 1939. The lo-foot units were added on October 6, and the 15-foot units on November 17. The data shown in the accompanying figures are for the fall of 1939 and spring and summer of 1940.

The curves in Fig. 1 were plotted from daily manometer readings taken between 8 and 9 o'clock in the morning and show the changes occuring in the soil moisture tension at the various depths under the two trees during the fall of 1939. Attention is called to the fact that the vertical scale for the figure is broken into three different sections. The time of irrigation is indicated by tension drops, the wider and more immediate excursions occuring at the shallower depths. The tension

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[1]Joint contribution from the U. S. Regional Salinity Laboratory, Bureau of Plant Industry, and the University of California.

The authors are indebted to William Taggart and William Picker for assistance with installing the tensiometers and taking the readings.

[2]The design of tensiometer used was substantially the same as that described by Richards, Russell, and Neal (2). Spout top porous cups were mounted on steel tubing for convenience in inserting the cup in a King tube hole in the soil. A manuscript entitled "Soil-moisture tensiometer materials and construction" has been prepared for publication and describes instruments now in use at the United States Regional Salinity Laboratory.

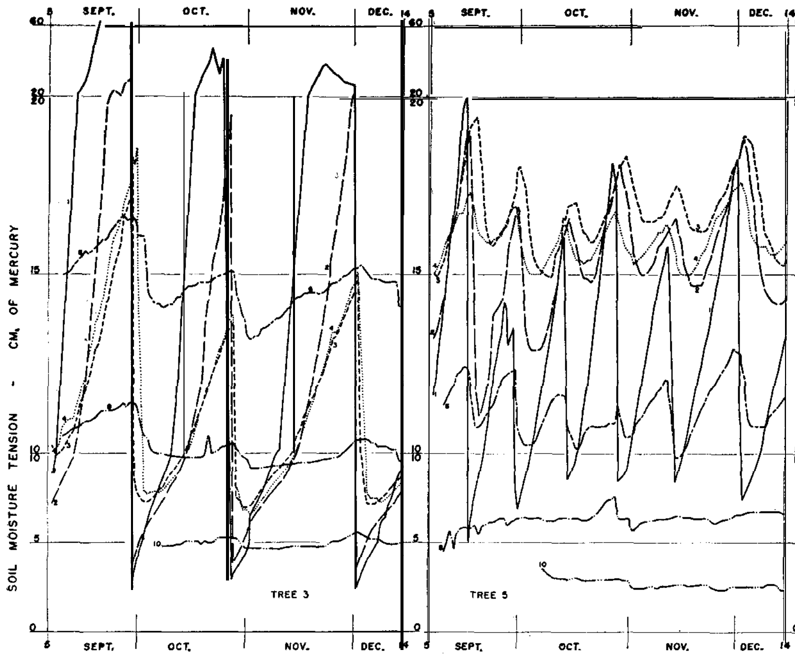

FIG. 1. Soil moisture tensions at eight depths under II-year-old navel orange trees. An irrigation of 4 surface inches was applied every 4 weeks for tree 3 and every 2 weeks for tree 5.

minima for the l- and 2-foot units were lower under tree 3 than under tree 5, which ***was*** irrigated twice as often. This apparent anomaly is due to reduced permeability of the surface soil under tree 5 caused by surface applications of ammonium sulfate (1). Even though water stood in the basin for many hours after irrigation the reduced infiltration rate coupled with a ready movement of water to lower soil layers did not permit the accumulation of enough water in the soil at the l- and 2-foot cups to reduce the tension below 5 centimeters and 11 centimeters of mercury respectively. The all year tension minima measured in the soil layer between the 1- and S-foot cups was 2.5 centimeters of mercury under tree 3 and 5 centimeters of mercury under tree 5. This indicates definitely that the irrigation did not produce saturation or a perched water table and that soil pores having equivalent diameters larger than 0.1 millimeter for tree 3 and 0.05 millimeter for tree 5 did not fill with water. It is concluded, therefore, that larger soil channels originating from worms, roots or cracks were not factors in conducting water in this soil layer. Only at soil depths below 6 feet was the soil moisture tension consistently lower under the tree with the frequent irrigation and this in spite of the fine textured soil layer occuring at 4.5 feet under tree 5.

The rate of moisture extraction by roots at the various soil depths is indicated by the rate of tension increase. The l-foot unit under tree

3 gave readings above 60 centimeters during the latter part of September and had to be refilled at the time of irrigation. The moisture extraction rate by the roots was about the same at the 4- and S-foot depths and was increasingly higher at the 2- and the l-foot depths. It would seem from the fluctuation in the curves that there was appreciable moisture extraction between irrigations at the 6- and to a lesser extent under tree 3 at the 8- and lo-foot depths also.

The curves in Fig. 2 show the negative pressure of the water in the tensiometer systems at the level of the soil surface instead of the tension

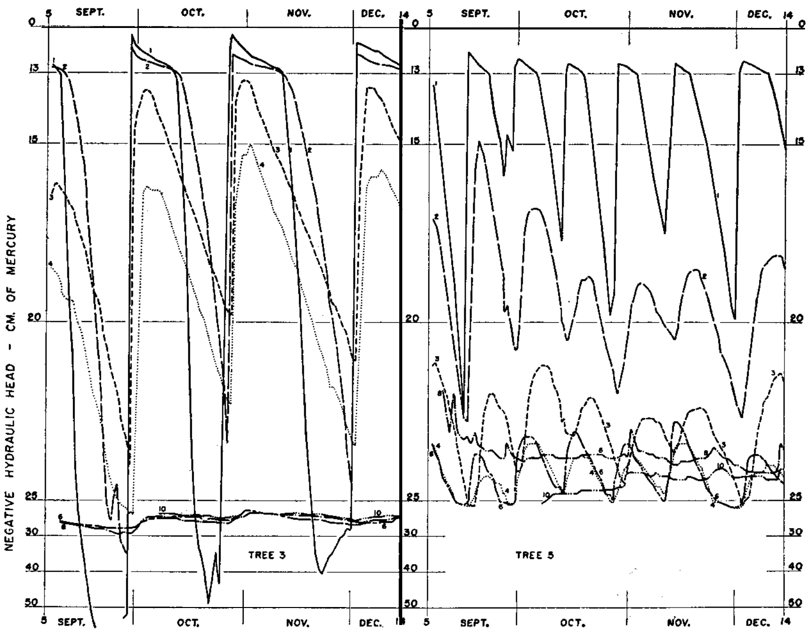

FIG. 2. Hydraulic head curves derived from the curves in Fig. 1.

in the water at the **cup** as in Fig. 1. Being thus measurements of hydraulic head these curves can be used for determining the direction of moisture movement in the soil (3). Flow takes place in the direction of the decrease in hydraulic head and at any given time the magnitude of the hydraulic head at the various cups is indicated by the elevation of the curves in Fig. 2.

The moisture flow pattern under tree 3 during the spring of 1940 is shown by the hydraulic head curves in Fig. 3. The soil was wetted by winter rains to the lo-foot depth and the hydraulic gradient was fairly uniform and downward in the surface 4 feet. Toward the end of February three of the curves coincided, thus indicating the hydraulic gradient was zero in the 6- to lo-foot layer and the soil moisture was at rest under gravity. The slow absorption of moisture by the roots, which is evidenced by the downward trend in the curves, then produced an upward moisture movement in the 6- to IO-foot soil layer. This

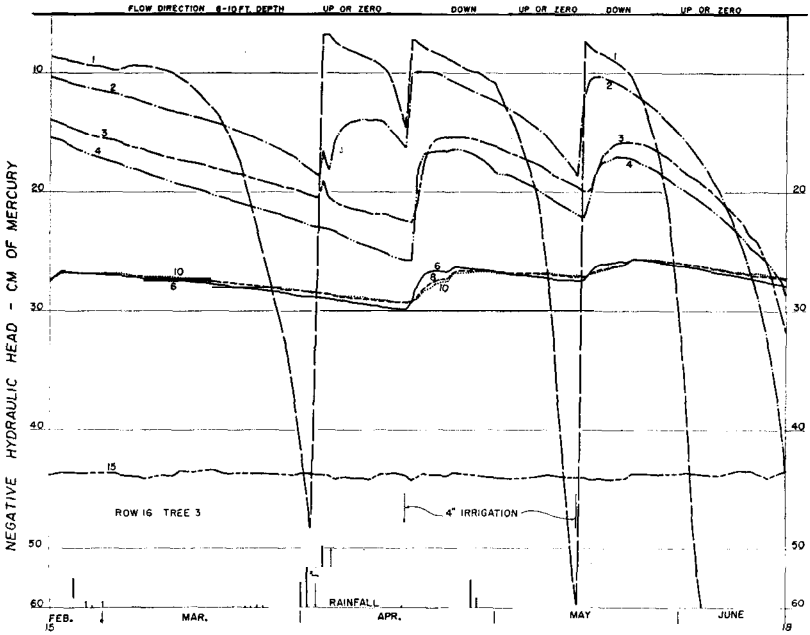

FIG. 3. Hydraulic head curves at eight depths under tree 3. This record starts 2 months after the period shown in Fig. 2. The line at the top of the figure shows the flow direction in the 8- to lo-foot soil layer.

upward flow was indicated by the relative position of the curves and was maintained in the soil layer until after the first irrigation.

Rains at the end of February caused a small rise in the l-foot curve. The warmer weather of March caused a considerable drying out at the depth of the l-foot cup but apparently did not appreciably affect the moisture extraction rate below the 2-foot cup. The 1½ inches of rain at the end of March affected the two surface cups only. The sharp rise in curves 2 and 3 at the time of the rain was caused by a small amount of rain water seeping clown around the steel tube. The 4 inches of irrigation water applied in mid-April produced downward flow and wetting of the soil to below the 10-foot depth, but not to the 15-foot depth. The increasing downward slopes of the curves later in April was caused by the increased transpiration and it is seen that the ¾ inch rainfall of April 25 and 26 scarcely affected the l-foot cup. Early in May the curves for the 1- and 2-foot units crossed each other, indicating the moisture flow direction in the intervening soil layer changed from down to up. At the time of the mid-May irrigation the manometer on the surface unit read nearly 60 centimeters of mercury.”

The mid-May irrigation produced less wetting at the 10-foot depth

‘Centimeter of mercury is not a commonly used unit for expressing hydraulic head. Sewer scales for use on mercury manometers are graduated so as to give soil moisture tension or hydraulic head directly in centimeters of water or centimeters respectively.

than the previous irrigation because the 1- and 2-foot depths were considerably drier than before. The average hydraulic gradient in the 1- to 2-, 2- to 3-, and 3- to 4-foot soil intervals reversed from down to up on May 25, June 8, and June 15 respectively.

In certain irrigated areas good irrigation practice requires at least occasionally that sufficient water be applied to the land to produce root zone leaching and thus prevent the accumulation of a harmful excess of soluble salts. The line at the top of Fig. 3 shows the flow direction in the soil layer 8 to 10 feet below the soil surface. The flow direction is down whenever the line for the lo-foot unit is above the line for the S-foot unit: Table I summarizes flow direction data for this same layer under both trees for a 12 month period.

TABLE I-ONE-YEAR SUMMARY OF MOISTURE FLOW DIRECTION IN THE SOIL LAYER 8 TO 10 FEET BELOW TWO ORANGE TREES

Tree	Irrigation Water* (Surface Inches)	Flow Direction 8- to IO-Foot Depth					
		Days			Per cent of Year		
		Up	Zero	Down	UP	zero	Down
3	36	224	93	49	61.2	25.4	13.4
5	68	86	34	246	23.5	9.3	67.2

*Each tree received in addition 10.8 inches of rainfall.

Plants can grow and extract water from soils over the tension range from zero to about 15 or 16 atmospheres at the wilting point. The range for tensiometers, however, is from zero to somewhat less than one atmosphere. Under the tree with the light irrigation, all tensiometers at depths of 4 feet and below stayed on scale all year. From May to September the l-foot unit usually went off scale before irrigation and during July and August the 2 and 3-foot units went off scale for short periods. Under the tree with heavy irrigation all tensiometers at depths of 3 feet and below stayed on scale all summer. For about a month, August 15 to September 15, the l- and 2-foot depths were off scale preceding irrigations.

The curves in Fig. 4 show the tension variations at the cups nearest the surface that gave continuous records during the irrigation season. Again the times at which the 4-inch irrigations were applied are indicated by the tension drops in the curves. The progressive upward trend and the recession of the curves during and following the rapid transpiration part of the season is of interest. It is noted that while every irrrigation produced a certain amount of wetting, as is indicated by the tension reduction, yet the tension minima were sometimes as high as 24 centimeters of mercury. This indicates that the downward moisture movement took place at comparatively high tension and that the soil was not completely wetted to the depth of penetration of the irrigation water.

Except for minor fluctuations as indicated by the lower curve in Fig. 3 the tension at the 1 S-foot depth under tree 3 remained near 11 centimeters of mercury all year and was unaffected by winter rain, irri-

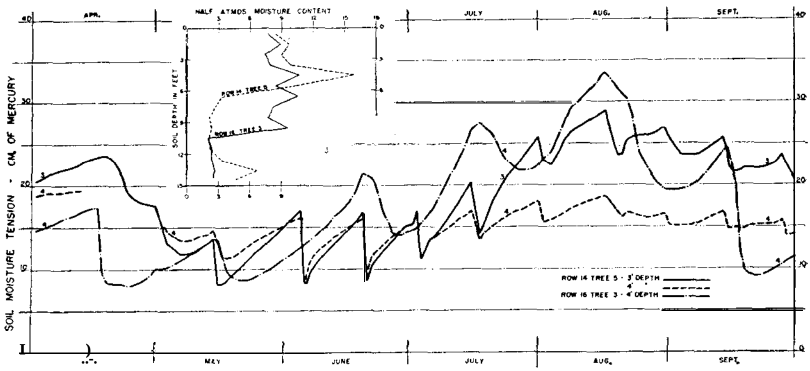

FIG. 4. Soil moisture tension curves at the 3- and 4-foot depths show that tension minima produced by summer irrigations may be as high as 24 centimeters of mercury. The inset curves indicate the variation of soil texture with depth.

gation, or the rapid summer transpiration. Under the tree with the heavy irrigation, however, the tension remained approximately constant at 12.5 centimeters of mercury during the winter but abruptly dropped to a minimum of 1.2 centimeter of mercury immediately following the first irrigation in the spring. During the next 4 months the tension slowly increased to near the former value.

Replicate installations would be required to determine how accurately one set of tensiometers indicates the moisture conditions at other locations around a tree. However, if the water input to the soil surface is relatively uniform, as is the case with level basin irrigation, field experience indicates that the moisture pattern around a tree closely follows radial symmetry for distances from the tree up to about half the tree spacing.

Tensiometers in use require refilling with water as air accumulates in the air trap. The time between refills depends on the soil moisture tension and tension fluctuations and may vary: from several days to several months. The cup water comes to atmospheric pressure or higher during the refilling operation and the equilibrium manometer

TABLE II—TENSIOMETER SCALE READINGS (HYDRAULIC HEAD — CENTIMETER MERCURY) SHOWING TIME REQUIRED TO RETURN TO EQUILIBRIUM AFTER OPENING AIR-TRAPS (EQUILIBRIUM READINGS ARE SHOWN AT ZERO TIME)

Time Minutes	Steel Tube Length (Feet)			
	2	4	8	15
0	16.0	21.6	23.3	43.9
	Air-traps opened and refilled			
5	9.2	19.4	19.8	35.8
55	15.2	21.5	21.8	39.6
105	15.7	21.6	22.2	41.2
135	16.0	21.6	22.3	41.7
255	15.9	21.7	22.6	42.8

reading is again attained by the loss of water from the cup to the soil. The time required to reach equilibrium after refilling is longer when the soil moisture tension is high, especially in coarse soils, but is usually considerably less than 24 hours. The data in Table II were taken on tensiometers under tree 5 and give an indication of the rate of approach to equilibrium.

SUMMARY

A year's record has been obtained on tensiometers at eight depths down to 15 feet under two 1 l-year-old orange trees, one being irrigated twice as often as the other. The data provide information on the rate and depth of moisture penetration, on moisture storage and rate of root extraction at various depths, and on root zone leaching.

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