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SOIL MOISTURE FACTORS OF IMPORTANCE IN CITRUS AND AVOCADO GROVE MANAGEMENT

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In soils of low soluble salt content three factors largely determine the amount of "available moisture" that may be held for an extended period in the soil occupied by the root system of an orchard tree: (1) the field capacity of the soil, (2) the wilting range of the soil, and (3) the volume of soil permeated by the root system. During extended periods without rain or applications of irrigation water, trees on deep, well-drained soils are entirely dependent upon this so-called "available moisture," which is the water held by the soil at moisture contents between field capacity and the permanent wilting point of the soil.

Field Capacity

The "field capacity" is the moisture, expressed as the percentage dry weight of the soil, retained by the soil after rapid drainage has ceased. Field capacity is determined primarily by the texture, that is, by the size of the particles in the soil. In general the higher the proportion of clay and finely divided organic matter in the soil, the higher is the field capacity. Field capacity is not, however, a soil constant, but is affected by variations in texture, structure, and density of the various layers in the soil profile. It also varies slightly with the temperature of the soil water and is higher in winter than in summer. In addition to these factors, the great variability of soil over large areas and the sampling errors resulting from the absorption of water by plants during the drainage period, make field capacity determinations in grove soils at best only approximate values. It is generally assumed that, in sandy soils that are free of dense layers of clay or hardpan, rapid drainage after thorough wetting will be completed in 2 to 4 days and that the moisture content of samples taken at the end of this period represents the approximate field capacity. A more reliable estimation of field capacity may be made from drainage curves which are plotted from data obtained by sampling at intervals for several days after the soil was thoroughly wetted.

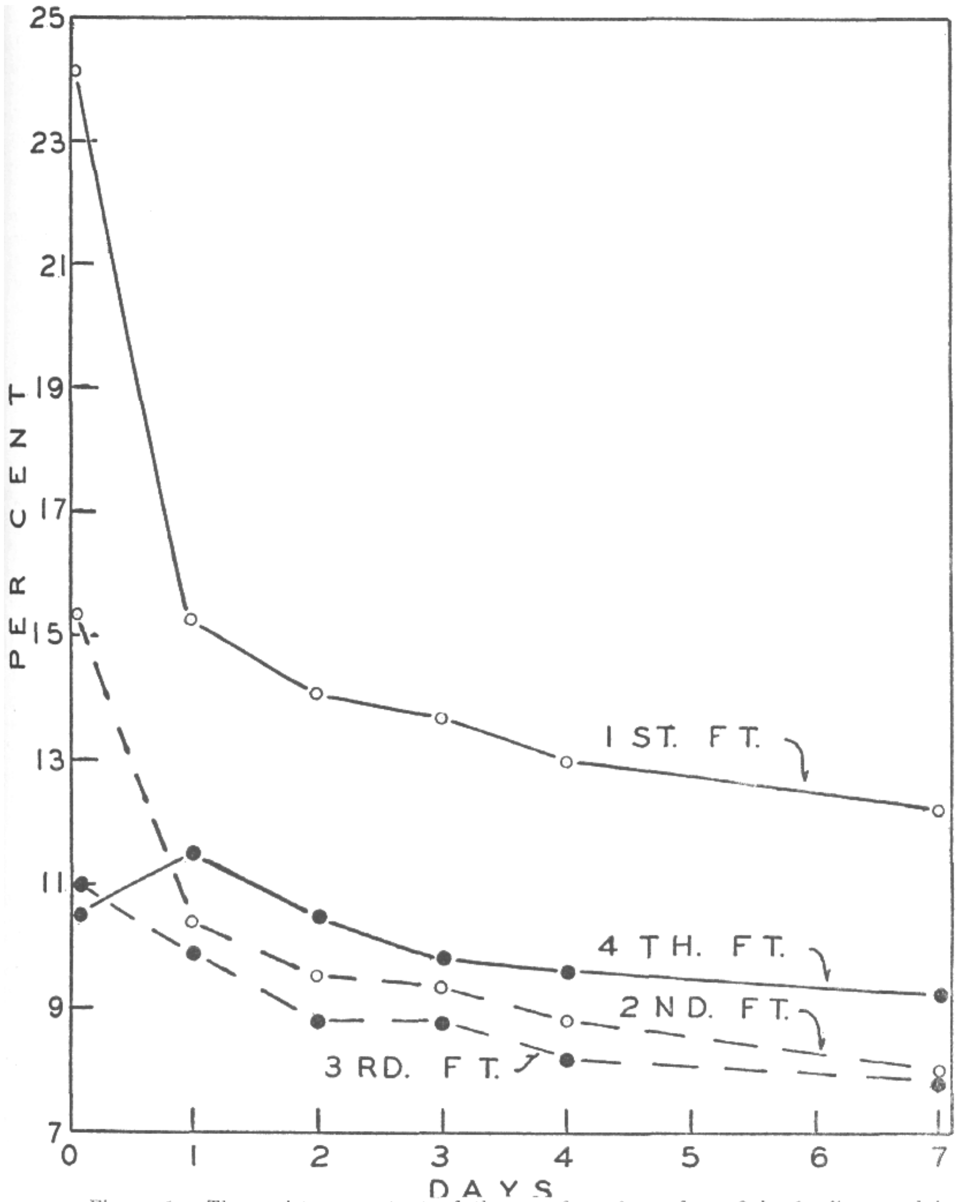

Figure 1. The moisture content of the top four feet of an Orlando fine sand in relation to time after wetting. Sampled after wetting at intervals of: 1 hour; 1, 2, 3, 4, and 7 days.

Drainage curves for the top 4 feet of Orlando fine sand are shown in figure 1. Each value plotted represents the average of samples from 9 stations spaced 3 feet apart. This soil was free of plants, and the surface was covered to prevent evaporation. It is evident that in this soil drainage was slow, probably because of a layer of slightly cemented sand in the fourth foot. Even on the 4th day, the rate of water loss by drainage from this soil was greater than the probable rate of extraction by mature citrus trees. Loss by drainage from the 4-foot profile in acre-inches per acre, calculated from the moisture percentages, was: 1st day, 2:18; 2nd day, 0.62; 3rd day, 0.19; 4th day, 0.31. Since an extraction rate of only 0.05 to 0.13 acre-inches per day by mature, vigorous trees is to be expected, it is clear that in this soil what might be termed "rapid" drainage had not ceased by the 4th day after wetting.

In addition to the uncertainty as to the proper interval to allow for drainage before sampling for field capacity determinations, it is frequently inconvenient to obtain samples at some definite time after the soil has been wetted. A satisfactory method of estimating field capacity from samples taken without regard to moisture conditions is needed. A simple and convenient laboratory method which shows promise of usefulness has been devised, but its reliability has not been thoroughly tested.

This method consists essentially in placing the samples in small metal cylinders on undisturbed soil, wetting samples and soil, allowing two or three days for drainage and determining the moisture content of the samples at the end «of the draining period. The samples and soil were protected from large temperature changes and from loss by evaporation. In a comparison of field capacity a value obtained by the laboratory method and by field sampling excellent agreement was obtained with the top foot samples; but possibly because of incomplete drainage in the field, the field values for the lower depths were appreciably higher than the laboratory values.

The Wilting Point of the Soil

The "first permanent wilting point" of a soil is the soil moisture percentage at which the leaves of plants growing in that soil just fail to recover from wilt in air that is nearly saturated by water vapor. If they recover turgor they were only temporarily wilted. At the first permanent wilting point plants make little or no growth even in very humid air.

The leaves of plants such as the sunflower, which is usually used in wilting point determinations, do not all wilt together; but as the soil dries out, the leaves wilt progressively from base to apex of the stem. At the first permanent wilting point of the soil, only the basal pair of (sunflower) leaves remain wilted in humid air. If placed in the open, the plant will continue to absorb water from the soil as successive leaves up the stem wilt, until finally the small apical leaves are wilted. The moisture content of the soil at which all leaves are completely wilted and fail to recover in nearly saturated air is called the "ultimate wilting point." When this stage is reached the plant soon dies.

The range in soil moisture percentages from the first permanent wilting point to the ultimate wilting point is called the wilting range. In many soils 20 or 25 percent of the total available moisture may be held in the wilting range. In light sands, however, this range is narrow, and in calculating the available moisture capacity of such soils, disregarding the water held at moisture contents below the first permanent wilting point will result in little error.

Under field conditions the entire soil mass occupied by the root system of a tree does not dry down to the "wilting point" (first permanent wilting point) at the same time. In general, the root concentration is highest in the upper foot or two of soil and within the spread of the branches, and decreases with soil depth and to some extent with distance from the trunk. This distribution of roots results in uneven drying of the soil. As the soil dries out during a prolonged drouth, the soil in the zones of highest root concentration reaches the wilting point, followed successively by soil in zones of lower and lower root concentration. Paradoxical though it may seem, the moisture content of an appreciable part of the soil has been reduced to the wilting point before the tree wilts, and wilting is at first only temporary, so that for some time the leaves may recover turgor during the night. The depth of soil in which the moisture content may be reduced to the wilting point before the tree wilts varies greatly with size of tree, distribution and depth of root system, air temperature and humidity. It probably varies also with planting distance and possibly to some extent with soil texture.

The moisture content of that portion of the soil that is still above the wilting point is almost certainly of importance, for example, if a few inches of soil in the root zone were wetted to field capacity by a rain, the rate of absorption in the wetted zone would almost certainly be higher than in a comparable layer of soil that was just above the wilting point. This has been demonstrated by wetting the soil in a small area under a wilted tree, and determining the rate of extraction from the wetted soil.

Because of the great variability of soil and trees it is not possible to state, even in general terms, the depth to which the soil may be dried to the wilting point before wilting of citrus trees occurs. But trees with a healthy root system are not likely to wilt, even under rather severe weather conditions, until well over half of the small absorbing roots are in soil at moisture contents in the wilting range.

TABLE 1. First Permanent Wilting Point, Field Capacity, and Available Moisture Capacity of a Norfolk Fine Sand Planted to Avocados.

Soil Depth (Feet)	First Permanent Wilting Point (Percent)	Field Capacity (Percent)	Available Moisture Capacity	
			Per depth interval	Per av. foot of depth interval
			(Acre-inches per acre)	
PLOT A				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.0-6.0	1.1	2.7	.46	.23
0.0-6.0	---	---	1.84	.31
PLOT B				
0.0-0.5	2.6	7.0	0.32	0.64
0.5-2.0	1.2	3.5	.50	.33
2.0-4.0	1.1	3.3	.63	.31
4.0-6.0	1.0	2.8	.52	.26
0.0-6.0	---	---	1.97	.33
PLOT C				
0.0-0.5	1.8	5.2	0.24	0.48
0.5-2.0	1.2	3.5	.50	.33
2.0-4.0	1.0	3.2	.63	.31
4.0-6.0	1.1	3.2	.60	.30
0.0-6.0	---	---	1.97	.33

Some writers have stated that if soil in a part of the root zone remains for a considerable period at the wilting point, the roots in this soil will be killed by desiccation. It is true that roots near the surface in soil that is dried below the wilting range by surface evaporation may be killed by desiccation. It is, however, very unlikely that roots in soil in the wilting range are injured by drying so long as the tree as a whole receives adequate moisture from those roots that are in relatively moist soil. There is good evidence that water may move from a root in moist soil to any part of the tree where water shortage occurs.

Thus water lost from roots in soil at moisture contents well below the first permanent wilting: point may be replaced by movement from roots in soil at moisture contents above the wilting point. Under such conditions, roots will stay alive for months in soil in the wilting range and remain capable of active absorption soon after the soil is wetted. If, during a drouth, enough water is applied to soil in some of the root zone to prevent severe wilting of the tree, it is practically certain that nearly all of the roots in the non-wetted as well as the wetted soil will escape injury from cidescation at depths below the influence of surface evaporation.

Available Moisture Content of Some Avocado and Citrus Grove Soils

Table 1 gives the first permanent wilting point, the field capacity, and the available moisture capacity at various depths in the top six feet of soil in three avocado plots on Norfolk fine sand. Field capacity values were obtained by the laboratory method.

The wilting point, the field capacity and the available moisture capacity values of the top six inches of this soil are roughly double the corresponding values for the lower depths. This difference is apparently caused by a relatively high content of organic matter in the top six inches.

The high organic matter content of the top six inches presumably resulted from the grower's practice, over a period of many years, of applying organic matter and growing cover crops. Doubtless this additional organic matter has been of great value in the nutrition of the trees and has added slightly to the available moisture capacity. These data, however, indicate that it is not practicable to increase very greatly the total available moisture capacity of sandy soils over large areas, such as avocado or citrus groves, by the addition of organic matter. It is in periods of drouth that an increase in the available moisture capacity would be of most value, but during such periods a large part of the water in the top three or four inches of soil is lost by surface evaporation before it can be absorbed by the roots. If we assume that the available moisture capacity of the top six inches was doubled, that is, raised from 0.15 to 0.30 acre-inches per acre by the addition of organic matter, but that the top three inches of soil dried out by evaporation, the net increase of available moisture would be 0.07 acre-inches per acre, probably not over two days' water supply for the mature avocado trees in this grove. The total available capacity of the top six feet of soil in this grove was estimated to be nearly two acre-inches per acre. The samplings for moisture determination on the avocado plots were not timed in such a manner as to permit an accurate calculation of the moisture extraction rate, but an estimate made from the data available suggests that during the last half of March, 1945, the extraction rate was about 0.07 acre-inches per acre per day, or 2.1 inches per month. Under such conditions, starting with the soil at field capacity, the available moisture supply in the top six feet of this soil would be exhausted in about a month.

TABLE 2. First Permanent Wilting Point, Field Capacity, and Available Moisture Capacity of Some Citrus Grove Soils.

Soil Type and Location	Depth (Feet)	First Permanent Wilting Point (Percent)	Field Capacity (Percent)	Available Moisture Capacity: Per depth interval (Acre-inches per acre)	Available Moisture Capacity: Per av. foot of depth interval (Acre-inches per acre)
Norfolk fine sand;	0.0-1.0	1.9	6.1	0.65	0.65
	1.0-3.0	1.4	5.2	1.19	.59
Windermere	0.0-3.0	---	---	1.84	.61
Norfolk fine sand;	0.0-0.5	1.8	4.9	0.24	0.48
	0.5-3.0	1.7	4.7	1.17	.47
Davenport	0.0-3.0	---	---	1.41	.47
Blanton fine sand;	0.0-1.0	2.1	8.0	0.92	0.92
	1.0-3.0	1.9	6.7	1.50	.75
Wiersdale	0.0-3.0	---	---	2.42	.81
Leon fine sand;	0.0-0.5	2.9	9.0	0.48	0.96
	0.5-3.0	2.5	8.0	2.14	.86
Citra	0.0-3.0	---	---	2.62	.87
Blanton fine sand;	0.0-0.5	1.8	7.6	0.45	0.90
	0.5-3.0	1.3	6.5	2.03	.81
Citra	0.0-3.0	---	---	2.48	.83
Norfolk fine sand;	0.0-0.5	1.3	5.0	0.29	0.58
	0.5-3.0	1.0	4.0	1.17	.47
Killarney	0.0-3.0	---	---	1.46	.49
Blanton fine sand;	0.0-0.5	1.5	4.6	0.24	0.48
	0.5-3.0	1.3	4.5	1.25	.50
Windermere	0.0-3.0	---	---	1.49	.50
Blanton fine sand.	0.0-0.5	1.4	4.7	0.26	0.52
	0.5-3.0	1.8	5.5	1.44	0.58
Windermere	0.0-3.0	---	---	1.70	.57
Parkwood fine sand;	0.0-0.5	11.5	23.0	0.90	1.80
	0.5-3.0	5.1	11.0	2.30	0.92
Mims	0.0-3.0	---	---	3.20	1.07
Norfolk fine sand;	0.0-0.5	2.1	7.0	0.38	0.76
	0.5-3.0	1.2	4.0	1.09	.44
Mims	0.0-3.0	---	---	1.47	.49
Norfolk fine sand;	0.0-0.5	2.3	8.0	0.44	0.88
	0.5-3.0	1.3	5.0	1.44	.58
Mims	0.0-3.0	---	---	1.88	.63
Norfolk fine sand;	0.0-0.5	1.9	7.0	0.40	0.80
	0.5-3.0	1.2	4.5	1.29	.52
Merritt Island	0.0-3.0	---	---	1.69	.56
Palm Beach fine sand;	0.0-0.5	2.7	11.0	0.65	1.30
	0.5-3.0	1.4	5.0	1.40	0.56
Wabasso	0.0-3.0	---	---	2.05	.68

In Table 2, the wilting point, the field capacity, and the available moisture content of some citrus grove soils are given. Surface soils and sub-soils were taken in separate samples. The field capacity values given for these soils are simply the field moisture contents determined at the time of sampling, and since the samples were taken in the summer, when almost daily rains occurred, most of them are probably somewhat higher than the actual field capacity.

In most of these soils the wilting point of the surface soil is about 2%, and that of the sub-soil, about 1.5%. The available moisture capacity of the top three feet of all but a few lies between about 1.5 and 2.5 acre-inches per acre.

On deep, well-drained soils it is unlikely that trees would wilt before the moisture content of the top three feet of soil has been reduced to about the wilting point, so that on soils similar to those listed here it may be supposed that 1.5 to 2.5 acre-inches per acre would be required to wet them to three feet. In applying irrigation water, of course, not all of the water applied will be retained in the layer of soil that it is intended to wet. Some water will be lost by surface evaporation and run-off, and in sandy soil, probably much more by percolation to depths below the root zone. That is, in low areas, such as middles that have been "dished" out by repeated disking toward the trees, much more water may penetrate the soil than is required to wet it to field capacity, and, if so, will be lost to depths below the root zone.

The efficiency of application, that is, the percentage of water retained in the soil of the root zone, may be affected by rate, uniformity, and amount of the application of water, and by variations in slope, permeability, and "wettability" of the soil. An efficiency of 80% is considered high, and 40% to 65% is probably more usual. Water may be applied with fair to high efficiency as a spray from pipe fitted with sprinklers or as a single stream by the method of flooding from slip-joint pipe on nearly level land or on land of uniform and gentle slope. On land of very irregular or steep slope it is difficult to attain high efficiency by any method, but sprinkling lends itself to higher efficiency than other methods on such land.

It may be fairly assumed that when trees on soils similar to most of those listed here are wilting, the top three feet of soil may be wetted to field capacity by about 2 to 3 acre inches, or 54,308 to 71,462 gallons of wate per acre, if it is applied uniformly over practically the entire surface and does not run oi of the tree rows and collect and penetrat mostly in the middles. In deep sandy soils free from dense layers near the surface, there is very little lateral movement of water, so that nearly all of the water will go straight down at the point of entry

Moisture Extraction as an Indication of Extent and Depth of Citrus Root Systems

To obtain some idea of the depths in light sandy soils at which citrus roots absorb appreciable amounts of water, soil samples were taken during a prolonged dry period to a depth of 8 or 10 feet in several groves on each of two soil types, Orlando fine sand and Norfolk fine sand. Since samples were taken at the "drip" of the tree, the distance from the trunk at which the samples were taken gives and indication of the size of the trees at each site. Moisture determinations and estimates of field capacity by the laboratory method were made on the samples. From these data, the moisture deficiency, that is, the difference between field capacity and the field moisture content at the time of sampling was calculated for each depth sampled. The field capacity, the field moisture content, and the moisture deficiency expressed as percentage dry weight, as acre-inches per acre for the depth interval, and as inches per average foot of the depth interval are given in Table 3.

At most of the sites sampled some rain had fallen a few days before samples were taken. The top foot at Site No. 1 was at about field capacity. At Site No. 4, however, much of the top foot appeared to be air dry. At the other sites rain had probably not penetrated below the top foot, except at Site 6, where the second foot had apparently been partly wetted.

The moisture deficiencies expressed as inches per average foot, which puts findings for depth intervals on a comparable basis, shows little relation to the depth from the soil surface, except at Site No. 2, which may have been irrigated some time before samples were taken. The moisture deficiency was sometimes greatest in the zones of highest field capacity, probably because at certain depths all of the available moisture was exhausted some time before the samples were taken. For example, it would appear from the field capacity values, which in these sands are about 3 times the wilting point values, that certain levels as follows: Site 1, 2-6 foot; Site 2, 1-2 foot; Site 2,1-2 foot; Site 4, 1-4 foot; Site 5, 0-4 foot, were at about the wilting point when sampled.

The conditions are rare under which it would be possible to estimate relative root activity, that is, relative absorption rates at different depths, from a single sampling, and those conditions were not met in this instance. It is apparent, however, that during periods of drouth the amounts of water absorbed by trees on deep light sand at depths below 3 or 4 feet may be very appreciable. In fact, at certain of these sites doubtless very little available moisture remained in the top 3 or 4 feet and yet the trees were not wilted.

The amounts of irrigation water, applied with an efficiency of 80% that would be required to wet these soils to field capacity to the depths sampled appear to be surprisingly high. The amounts calculated in acre-inches vary from 3.2 to 5.1; in gallons per tree, from 1554 to 2469. These data, however, suggest the possibility that on such soils the frequency of irrigation applications might be reduced by wetting as much of the area as possible to a depth of 6 or 8 feet when applications are made, and it would seem to be poor economy indeed to wet these deep soils to less than 4 feet at an application.

TABLE 3. Moisture Deficiency of Some Grove Soils During a Drouth

Site No. Description of Site	Depth (Feet)	Field Capacity (Percent)	Field Moisture Content (Percent)	Moisture Deficiency (Percent)	Moisture Deficiency	Moisture Deficiency Per av. foot
					(Acre-in. per acre)	(Acre-in. per acre)
1. Seedling Orange, 22′ x 22′ Orlando Fine Sand Sampled 11 ft. from Trunk.	0-1	5.3	5.9	0.0	0.0	0.0
	1-2	4.9	2.4	2.5	0.39	0.39
	2-4	3.9	1.0	2.9	0.95	0.47
	4-6	3.7	1.2	2.5	0.78	0.39
	6-8	3.0	2.2	0.8	0.25	0.12
	8-9	13.4	8.4	5.0	0.78	0.78
	9-10	13.7	10.0	3.7	0.58	0.58
	0-10				3.73	0.37
2. Grapefruit, 25′ x 25′ Orlando Fine Sand Sampled 12½ ft. from Trunk.	0-1	7.6	4.3	3.3	0.51	0.51
	1-2	7.2	2.4	4.8	0.75	0.75
	2-4	4.6	2.0	2.6	0.81	0.40
	4-6	3.3	2.8	0.5	0.16	0.08
	6-8	3.2	2.9	0.3	0.09	0.04
	8-9	5.3	3.8	1.5	0.23	0.23
	0-9				2.55	0.28
3. Orange (Parson, Brown), 24′ x 24′ Orlando Fine Sand Sampled 8 ft. from Trunk.	0-1	9.3	4.8	4.5	0.70	0.70
	1-2	6.9	3.2	3.7	0.58	0.58
	2-4	5.0	2.6	2.4	0.75	0.37
	4-6	4.3	2.7	1.6	0.50	0.25
	6-7	5.7	3.3	2.4	0.37	0.37
	7-8	6.5	3.5	3.0	0.47	0.47
	8-9	6.4	3.6	2.8	0.44	0.44
	9-10	5.1	3.5	1.6	0.25	0.25
	0-10				4.06	0.41
4. Grapefruit, 25′ x 25′ Norfolk Fine Sand Sampled 10 ft. from Trunk.	0-1	13.3	1.5	11.8	1.84	1.84
	1-2	3.9	1.2	2.7	.42	.42
	2-4	3.5	1.1	2.4	.75	.37
	4-6	2.8	1.7	1.1	.34	.17
	6-8	3.1	2.2	0.9	.28	.14
	8-10	3.4	2.9	0.5	.16	.08
	0-10				3.79	.38
5. Orange (Parson Brown), 24′ x 24′ Norfolk Fine Sand Sampled 8 ft. from Trunk.	0-1	5.3	1.8	3.5	0.55	0.55
	1-2	4.0	1.2	2.8	.44	.44
	2-4	3.1	0.9	2.2	.69	.34
	4-6	2.4	1.5	0.9	.28	.14
	6-7	17.4	12.6	4.8	.75	.75
	7-8	17.4	11.8	5.6	.87	.87
	0-8				3.58	.45
6. Orange (Hamlin), 24′ x 24′ Norfolk Fine Sand Sampled 6 ft. from Trunk.	0-1	4.6	2.1	2.5	0.39	0.39
	1-2	3.4	2.3	1.1	.17	.17
	2-4	3.2	1.6	1.6	.50	.25
	4-6	2.8	1.3	1.5	.47	.23
	6-7	6.2	3.0	3.2	1.00	1.00
	7-8	7.1	5.1	2.0	.62	.62
	0-8				3.15	.39

Conclusions and Practical Applications

The practical significance of the fact that a soil has a fairly definite field capacity and wilting point is that: (1) a certain definite amount of water may be held by the soil in a certain depth zone. If more than this amount is applied, the excess will drain out; if less than this amount is applied, all of the soil will not be wetted. (2) Only a certain definite part of the total amount of water that may be held in the soil permeated by the root system of the tree is available to the tree. As the amount of available moisture is reduced throughout the root zone, and exhausted in certain parts of the root zone, the amount of root surface that may function in water absorption is also reduced. As increasing proportions of the absorbing root surface cease to function in water absorption, the water deficit of the trees becomes greater and finally temporary or even permanent wilting results.

Systematic sampling for determination of soil moisture percentages is not practicable for general grove irrigation management. Such work is done merely to obtain a clearer conception of the conditions that affect the trees. With frequent and careful observations in the grove as a basis, the principles of soil moisture control may be applied to practical grove irrigation management. It is essential that the observer be able to tell when the soil at various depths in the root zone is near the wilting point, so as to determine when water should be applied. He should also examine the soil after an irrigation to determine the depth to which it was wetted.

One may become familiar with the appearance and feel of soil of a particular type at about the wilting point by examining such soil where it is thoroughly permeated by roots of plants (large weeds or trees) that are wilting. Soil nearer the surface than six inches should be discarded, since it may have been affected by evaporation. The appearance and feel of soils at the wilting point will vary with color and texture, so that familiarity should be gained with the range of variations that are encountered in the grove. Since the soil usually dries slightly faster at the "drip" of the tree on the south-west quarter (probably because of higher soil temperature), examination in this quarter should give the first indication of need for water. Only from experience is it possible to estimate about how deep the soil may be allowed to dry out in a particular grove before the trees are in danger of wilting. Because of the time required to cover the grove with irrigation water, however, in most situations it will be desirable to start applying water sometime before the trees show any wilting. Water applied as soon as the soil at a depth of 18 to 24 inches is near the wilting point will probably prevent severe water shortage in groves on soils similar to those examined in this study. If it can be avoided, trees should not be allowed to dry out to the point where they show definite wilting. The grower is well aware of the ill effects of prolonged wilting, but even before the trees wilt, fruit growth is gradually reduced as the tree is subjected to increasing water deficit.

To determine how effective an application of irrigation water has been in wetting the soil that was dried out by tree roots, it is necessary to examine the soil in such a manner that variations in distribution of water will be detected. Wherever all of the dry soil was not wetted the line of demarcation between wet and dry soil will be sharp. The soil that is wetted will be wet to field capacity and a few inches below the "wetting front" the soil will be as dry as it was before irrigating water was applied.

The labor and time of examining the soil is greatly reduced by the use of a convenient tool. Either the smallest size of post-hole auger obtainable (2 or 3 inches in diameter), or an auger made by welding a four-foot rod with a crosspiece at the top to a one inch carpenter's bit with the cutting flanges and threaded tip ground off, is a fairly convenient tool. In soils in which it can be used, a probe made of ½ inch rod is very convenient. It is easily thrust through very wet soil but the resistance to penetration increases sharply when the dry soil is encountered. In some soils the probe is useless, either because of too little difference in resistance offered by wet and dry soil or because of hard layers.

Determining the depth of wetting after irrigation gives some idea of the uniformity of distribution with which the water was applied and serves as a basis for estimating the length of time that water should be applied to wet the soil to the desired depth. Without an occasional careful examination of the soil after irrigating, serious faults that might be corrected economically may pass unnoticed.