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SOME FACTORS AFFECTING THE IRRIGATION REQUIREMENTS OF DECIDUOUS ORCHARDS

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(Contribution from the Division of Irrigation Investigations and Practice coöperating with the Division of Pomology, College of Agriculture, University of California, and with the Division of Agricultural Engineering, Bureau of Public Roads, United States Department of Agriculture, and the Division of Engineering and Irrigation, California State Department of Public Works.)

INTRODUCTION

The relation of water to plant growth is of especial interest to growers of deciduous fruits. Consideration of the relative losses of moisture from irrigated soils by evaporation or transpiration through plants and by means of surface evaporation from the soil is becoming increasingly important. This is especially true in many of the deciduous fruit areas of California, where the cost of irrigation is one of the main items of expense in orchard management. The orchardist growing fruit in an arid or semi-arid region, where irrigation is necessary, supposedly has an advantage over the grower of similar fruit in a humid area, because the supply of moisture in the soil can be controlled to a greater extent. Therefore, it is important to consider the effect of different degrees of soil moisture on the use of water by trees, and the effect of such differences on the kind of fruit produced.

A portion of the California deciduous fruit orchards have been planted in localities where dependence has been placed upon rainfall only. However that irrigation is necessary in many sections of California for the best production of horticultural crops is a fact now coming into recognition. In many of these areas, previously unirrigated, gravity water is not available and recourse must be had to

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pumping from underground supplies. The orchard land awaiting development in California is generally the higher land of the valleys and the adjacent foothill areas. Here, as well as in the pumping areas, water for irrigation is relatively limited. Proper use of the available supply is therefore of vital importance. The older irrigated fruit sections are also confronted with many problems in the use of water. In these sections, the too lavish use of water has probably been the contributing cause of many troubles.

Because of the wide variations in soils in the different deciduous fruit areas of the State and of the extreme differences in topography, irrigation methods must, and do, vary widely. In the citrus groves of the State, irrigation practice has followed certain arbitrary rules. Deciduous orchard irrigation practice, on the other hand, has no semblance of uniformity. Very little definite information is available concerning the efficacy of different practices, especially as to the frequency of irrigation and the amount of water to apply. However, it is not the purpose of the present report to deal directly with methods or practices in deciduous orchard irrigation, but to discuss the results of certain experiments, which, it is believed, will afford a better understanding of their problems.

The experiments fall into four classes and will be discussed in the following order: first, observational data obtained from commercial orchards in the Santa Clara Valley, together with records of moisture conditions in these orchards for a period of four years; second, data obtained from a small block of trees at the Branch of the College of Agriculture, University of California, at Davis; third, studies of the behavior of young trees in potometers or tanks under controlled conditions; and fourth, a comparison of the losses of moisture by evaporation and through transpiration from the same soils, and studies of losses of moisture by evaporation from the soil in tanks and from field plots. The latter studies were supplemented by some experiments on the movement of soil moisture.

Briefly stated then, this report has for its purpose the presentation of certain data relating to soil moisture conditions prevalent in commercial orchards, with an attempt to analyze causes resulting in losses of moisture from irrigated soils.

Studies covering water relations of plants, the movement of moisture through the soil, the losses of moisture from soils, and the control of soil moisture by tillage, probably constitute the bulk of agricultural literature. They are so numerous that only brief mention of pertinent matter can be made in the order of the discussion in this report.

SECTION I

IRRIGATION STUDIES IN SANTA CLARA VALLEY PRUNE ORCHARDS

The Santa Clara Valley of California is one of the oldest and best established deciduous fruit areas of the State. The principal fruit crop is prunes, and for this reason, prune orchards were selected for study. Early in the spring of 1919, a system of soil sampling was begun in a number of mature prune orchards in this valley, in order to study the moisture behavior in response to different irrigation practices.

At present, practically all orchards for which a water supply is available are irrigated. The census of 1910 reports Santa Clara County with an irrigated acreage of 37,637, and the 1920 census reports 71,274 acres, an increase of 89.4 per cent. The mean annual rainfall at San Jose, as computed in 1922, is 16.79 inches, an amount sufficient, on certain types of soil, to produce profitable crops of fruit without irrigation. The fact that trees will not always be permanently injured if irrigation is withheld affords excellent opportunity to study the behavior of trees and the variation of soil moisture through long periods during the growing season, without the necessity of replenishing the moisture supply in order to keep the trees alive.

The rainfall during each of the four years, 1919 to 1922, during which the Santa Clara Valley orchards were under observation, was less than normal. The precipitation at San Jose during 1919 was 11.98 inches. That of 1920 was 8.5 inches; of 1921, 14.59 inches; and of 1922, 16.49 inches. Most of the rain fell during the period from November to March. The amount during the growing season was insignificant. At times during the summer the temperature exceeded 90 degrees Fahrenheit and occasionally temperatures higher than 100 degrees were recorded. Complete climatological records taken at San Jose can be obtained from the annual summaries published by the United States Weather Bureau.

ORCHARDS SELECTED FOR OBSERVATION

A careful canvass of the valley was made and certain mature prune orchards were selected for observation. These orchards, which are comparable as to age and condition, are all located in the central portion of the valley, between San Jose and Saratoga, within about two miles of each other. They are all on a type of soil classed in the soil survey as Yolo clay loam, and locally known as sediment soil, which is considered best for fruit. The orchards which have been selected from among those under observation, and for which data are presented in this bulletin, are listed in table 1. The yields of fruit from some of these orchards had to be ascertained from larger acreages than were intensively sampled to obtain the records of the moisture conditions. In every case, however, the larger acreage received the same irrigation treatment as that in which intensive sampling was done. Sampling was restricted to the smaller acreages in each case because of the difficulty of adequately sampling the larger areas.

The number of producing, young non-bearing, and inferior trees, the blank spaces, and odd varieties are listed in table 1. This was the condition of each orchard at the end of the growing season of 1919.

TABLE 1

SANTA CLARA VALLEY PRUNE ORCHARDS AND THE CONDITION OF TREES AT THE END OF THE GROWING SEASON, 1919

Orchard	Root stock	Date of planting	Acreage intensively sampled for moisture determinations	Acreage from which fruit yields were obtained	Good producing prune trees	Inferior mature prune trees	Young non-bearing prune trees	Vacant spaces in orchard	Trees other than prune trees
1	Almond	1895	15.5	15.5	1251	113	132	4	48
2	Peach	1892	9	14	924	5	27	0	27
3	Almond	1895	10	10	610	90	10	20	10
4	Myrobalan	1893	9	19	645	2	14	1	14
5	Almond	1898	10	10	658	20	41	3	24
6*	Almond	1896	21	25	1804	74	63	68	14

* 80 trees were removed from this orchard at the end of the growing season, 1919.

Orchard No. 1 was selected as a typical unirrigated orchard in the Santa Clara Valley. It had not been irrigated since 1912, and before this time had received only light applications of water at infrequent intervals. The condition of the orchard, as indicated by the number of replants, vacant places, and inferior trees, is indicative of injury which may be partly attributed to drought.

Orchard No. 2 was selected as an example of a winter irrigated orchard. The irrigation treatment in this orchard has not varied for many years. It has always been irrigated during the dormant season if water was available, but never during the summer.

At the time the observations started, orchard No. 3 was essentially a non-irrigated orchard. Water was applied once in 1917, for the first time in seven years, but not in 1918. It was understood when observations were started that orchards No. 1 and No. 3 were not to be irrigated. The owners of these orchards declared they did not believe irrigation was beneficial. However, as will be seen, these orchards were irrigated after the season of 1919.

Orchards No. 4 and No. 5, which are adjacent, were selected as typical irrigated orchards. Orchard No. 4, previous to 1919, usually received one summer irrigation. Subsequently, however, it received two or three applications of water each year. Orchard No. 5, before 1919, had been irrigated at least twice each summer, which was substantially the same practice during the following four years.

Orchard No. 6, up to the year 1917, had been irrigated during the dormant season with gravity water. After the season of 1917, the orchard was summer-irrigated and when it was selected in 1919 it was thought to be a well-irrigated orchard.

Cultural Methods in the Orchards

There were no essential differences in the handling of the trees in the different orchards, with the exception of cultivation and irrigation. Orchard No. 4 was pruned more heavily in the winter of 1920 than any of the other orchards, but in the other years the amount of pruning was substantially the same in all of the orchards. The spray treatments for brown apricot scale and red spider were likewise about the same in each orchard. However, it was observed that orchard No. 5 apparently had more brown apricot scale in the fall of 1922, than any of the others.

On five acres of orchard No. 4, 26 tons of chicken manure were applied in October, 1920. This orchard also received an application of 2 tons of sugar beet lime to the acre during January, 1921. Forty trees in orchard No. 6 received an application or sodium nitrate in February, 1920. No other fertilizer was added during the period of observation.

Cover crops were planted in the fall of each year in each orchard. Sweet clover (*Melilotus indica*) was usually planted, and if the fall irrigation was late, barley was planted with it. In some orchards, owing to the impracticability of planting sweet clover early enough, vetch was used in its place. There were no appreciable differences in the dates of plowing and disking under of the cover crops in the spring of each year. The dates of plowing and disking in the spring for the four years did not materially vary, the earliest date of plowing having been March 25 and the latest date, April 18.

The management of the soil varied markedly in the different orchards. Orchard No. 1 was plowed, disked and harrowed in the spring of 1919. It received one cultivation, and the soil was smoothed down before the prunes dropped. In 1920, the orchard was not plowed, but was disked and harrowed just after the irrigation in April, and received one cultivation and smoothing in June. It was disked and harrowed again after the irrigation in October, 1920. It was plowed in April, 1921; and after the irrigation in May, it was disked and harrowed. This orchard received little cultivation other than that necessary to destroy the cover crop, and to prepare the land before and after irrigation.

Orchard No. 2 was the most frequently cultivated of any orchards observed in the Santa Clara Valley. This practice had not varied for many years. After plowing in the spring, the orchard was cultivated at intervals, usually not exceeding 10 days, until the props were placed under the trees and the prunes began to fall. Immediately after the crop was removed, cultivations were again started and continued until the cover crops were planted. The condition of the soil and of the trees is illustrated in figure 1. This photograph was taken on October 4, 1920, and may be compared with figure 2, which was taken in orchard No. 5 on November 1, 1920. The excellent condition of the trees in orchard No. 2, as indicated by the scarcity of replants and inferior trees and the absence of vacant spaces, is proof of the extreme care the owner has bestowed upon them in every way including cultivation. There were no vacant spaces and only five inferior trees in the 14 acres comprising orchard No. 2. The odd varieties were planted around the dwelling, and the replants were made necessary by the construction of a railroad along one side of the orchard.

Fig. 1. Orchard No. 2 on October 4, 1920, showing condition of soil and trees.

Fig. 2. Orchard No. 5 on November 1, 1920.

Orchard No. 3 was poorly cared for up to 1920. The poor condition of the trees indicated the lack of attention for four or five preceding years. This and orchard No. 1 were selected as examples of non-irrigated orchards. They had not been irrigated for a number of years. They were typical of non-irrigated orchards in this location, and showed the effect of drought. Orchard No. 3 was not properly plowed in the spring of 1919. The strips between the trees in the direction of plowing were not disturbed. Later in the season of 1919, an attempt was made to cultivate the orchard and destroy the weeds growing in these areas, but the soil was too dry to be disked. During 1920, 1921, and 1922, the management of orchard No. 3 was entirely changed. The orchard was thoroughly plowed each spring and was cultivated at intervals of a week or ten days until the prunes began to drop.

Orchards Nos. 4, 5, and 6 were given practically the same soil management. The practice was to plow in the spring, usually early in April, and then double disk both ways. In one or two instances the soil was harrowed with a spike-tooth harrow. Before irrigation, levees which formed the basins around each tree were thrown up with a disk, and a supply ditch was constructed. Following irrigation, the levees were leveled with a disk, and the soil disked both ways. Whenever the irrigation was the last one before the crop ripened, the soil was smoothed off with a drag to receive the falling prunes. These orchards were not cultivated if there were no weeds.

IRRIGATION OF THE ORCHARDS

The total amounts of water applied by irrigation, the size of the stream used in irrigation, the total number of hours, the average depth of penetration of the water applied, and the cost of the water is given in table 2.

Orchard No. 2 was irrigated with gravity water, while all the others were irrigated with water pumped from wells. In every case, the depth of water in the wells was in excess of 100 feet, the average pumping lift being about 135 feet. The cost of water under this condition is necessarily high. On some of the other orchards which were under observation, but which are not listed here, the costs for water were even higher than those recorded in table 2. In one instance, water which cost $103.85 an acre foot, was purchased for the irrigation of 25 acres. It is obvious, therefore, that economical use of water is of great importance in this locality.

TABLE 2

AMOUNT OF IRRIGATION WATER APPLIED TO THE SANTA CLARA PRUNE ORCHARDS, WITH COSTS OF THE WATER AND AVERAGE DEPTHS OF PENETRATION

Year	Dates of irrigation		Hours to the acre	Size of stream, gallons per minute	Depth of water applied in inches per acre	Average depth of penetration in feet	Cost of water for each acre in dollars	Cost of water for each acre-foot in dollars
	Begun	Finished						
ORCHARD NO. 1								
1920	Apr. 17	Apr. 24	7.55	225	4.01	5.0	11.32	33.86
	Sept. 28	Oct. 2	3.42	455	3.45	2.0	8.55	29.70
1921	May 6	May 11	6.32	476	6.62	10.5	15.80	28.55
	Nov. 11	Nov. 14	4.65	455	4.65	4.5	11.62	29.95
ORCHARD NO. 2								
1919	Feb. 28	Mar. 2	2.66	2000	12.00	12.0	2.22	2.22
1920	Mar. 22	Mar. 24	2.66	2000	12.00	9.0	2.22	2.22
1921	Feb. 19	Feb. 21	8.00	1500	14.15	10.0	6.66	5.66
1922	Feb. 14	Feb. 16	2.66	2000	12.00	12.0	2.22	2.22
ORCHARD NO. 3								
1919	Nov. 23	Dec. 2	10.70	156	3.68	....	16.05	52.28
1920	Apr. 30	May 5	10.00	130	2.88	6.0	15.00	62.50
	June 20	June 23	3.50	468	3.62	6.5	7.88	26.07
	Oct. 20	Oct. 24	4.25	431	4.50	6.5	8.50	22.65
1921	May 21	May 24	8.70	314	6.04	9.5	13.05	25.95
	Oct. 14	Oct. 17	6.00	304	4.02	3.0	9.00	26.87
1922	May 15	May 18	9.50	306	6.36	10.5	14.35	25.19
	Oct. 16	Oct. 20	7.20	320	5.10	4.5	10.80	25.39
ORCHARD NO. 4								
1919	May 27	June 3	15.75	242	7.73	9.0	23.63	36.70
	Nov. 21	Nov. 29	8.22	314	5.70	....	12.33	25.93
1920	May 20	May 24	11.44	200	5.08	....	17.16	36.50
	June 15	June 19	5.11	432	4.88	12.0	10.22	22.60
	Nov. 1	Nov. 6	5.11	431	4.87	5.0	10.22	22.60
1921	May 20	May 24	5.55	391	4.79	12.0	12.50	28.19
	Oct. 6	Oct. 9	5.55	337	4.13	2.5	8.33	21.80
1922	Apr. 26	May 2	10.00	321	7.06	12.0	15.00	25.52
	June 6	June 12	7.78	323	5.56	12.0	11.66	22.70
	Oct. 10	Oct. 14	7.22	315	5.00	3.0	10.83	25.60

TABLE 2—(*Continued*)

ORCHARD NO. 5

Year	Dates of irrigation		Hours to the acre	Size of stream, gallons per minute	Depth of water applied in inches per acre	Average depth of penetration in feet	Cost of water for each acre in dollars	Cost of water for each acre-foot in dollars
	Begun	Finished						
1919	June 9	June 15	18.6	165	6.80	12.0	27.90	49.46
1920	Mar. 19	Mar. 25	14.65	341	11.10	9.0	29.30	31.68
	Sept. 18	Sept. 20	4.70	431	5.00	4.0	9.40	22.53
1921	May 20	June 2	7.00	391	6.01	8.0	15.75	31.50
	Sept. 25	Sept. 28	6.95	425	6.52	3.0	15.64	28.79
1922	May 29	June 5	8.00	444	7.82	11.0	16.00	24.53
	Oct. 11	Oct. 16	9.00	372	7.38	4.5	18.00	29.25

ORCHARD NO. 6

Year	Begun	Finished	Hours to the acre	Size of stream, gallons per minute	Depth of water applied in inches per acre	Average depth of penetration in feet	Cost of water for each acre in dollars	Cost of water for each acre-foot in dollars
1919	May 2	May 11	8.38	320	5.92	6.0	12.57	25.57
	June 13	June 18	6.97	303	4.34	3.5	9.84	26.85
	Oct. 4	Oct. 14	6.28	303	4.20	3.5	9.43	26.85
1920	Feb. 14	Feb. 23	7.42	341	4.97	4.5	11.14	26.90
	May 6	May 15	10.00	223	4.99	6.0	14.99	36.09
	Sept. 20	Sept. 25	5.43	355	4.25	3.5	9.50	26.82
1921	Apr. 29	May 6	6.28	373	5.17	6.0	11.00	25.55
	Sept. 30	Oct. 6	8.05	320	5.58	3.5	14.08	30.40
1922	May 29	June 17	9.38	321	6.62	9.0	16.89	30.40
	Sept. 25	Oct. 9	7.76	337	5.77	4.5	13.58	28.29

All irrigation was applied by the basin method. The same amount of water was given to each tree, insuring a very uniform distribution of moisture in the soil. The evenness of the application is illustrated in figure 3, which was taken during the irrigation of orchard No. 4, from November 1 to November 6, 1920. The water applied was measured by means of weirs placed in the main delivery ditches, or at the outlets of concrete pipe delivery stands.

YIELDS OF FRUIT FROM THE SANTA CLARA ORCHARDS

The yields of fruit from the orchards are reported in table 3. The fresh and dried fruit yields, the pounds of fresh fruit required to make one pound of dried fruit, the average size of dried prunes, which were calculated from the weight of fruit as graded at the packing house, the yield to the acre, and the yield to the tree are given. The acreage upon which the yields to the acre are based is the total acres in the orchard. The number and the condition of the trees were noted each year. The record of the condition of the orchards at the end of the 1919 season is given in table 1. The inferior trees were carefully noted, and in the final count of the number of trees upon which to base the yield to the tree, these were grouped so that a certain number of inferior trees were taken to be equivalent to one good tree. The estimated yield to the tree, or the yield to 75 trees, the usual number to the acre when planted 24 feet apart, probably will afford a better basis for comparison than the yield to the acre. The trees in orchard No. 1 were planted 20 feet apart. In all of the other orchards the trees were spaced 24 feet apart. The fruit from orchard No. 1, for the years 1921 and 1922, was mixed with that from another orchard. Therefore the yields are not recorded for these years.

Fig. 3. Irrigation of orchard No. 4, November 1, 1920. The same amount of water is applied in basins around each tree, insuring a uniform distribution of moisture.

TABLE 3

YIELDS OF FRUIT, FROM THE SANTA CLARA VALLEY PRUNE ORCHARDS, FOR 1919, 1920, 1921, AND 1922

Orchard	Acres in orchard	Fresh fruit, pounds	Dried fruit, pounds	Pounds of fresh fruit to make one pound of dried fruit	Average size in number of dried fruit to the pound	Yield to the acre		Yield to the tree		Yield to 75 trees	
						Fresh fruit, pounds	Dried fruit, pounds	Fresh fruit, pounds	Dried fruit, pounds	Fresh fruit, pounds	Dried fruit, pounds
Yields, 1919											
1	15.5	191,474	96,377	1.99	79	12,353	6,214	150	75.5	11,250	5,662
2	14.0	205,281	97,168	2.11	86	14,663	6,941	221	104.8	16,575	7,860
3	10.0	60,000	35,534	1.69	73	6,000	3,553	95	56.4	7,125	4,230
4	19.0	233,000	115,301	2.02	80	12,363	6,068	195	84.5	14,625	6,337
5	10.0	184,390	61,933	2.98	99	18,439	6,193	276	92.7	20,700	6,953
6	25.0	502,250	200,778	2.50	90	20,090	8,031	273	109.1	20,475	8,182
Yields, 1920											
1	15.5	75,000	34,550	2.17	71	4,837	2,229	59	27.3	4,425	2,047
2	14.0	155,151	68,283	2.27	68	11,082	4,877	168	73.8	12,600	5,535
3	10.0	66,568	27,674	2.41	60	6,657	2,768	105	43.9	7,875	3,293
4	19.0	140,000	65,198	2.15	56	7,369	3,431	98	48.2	7,350	3,615
5	10.0	62,000	27,428	2.26	56	6,200	2,743	94	41.5	7,050	3,113
6	25.0	267,800	107,638	2.49	60	10,712	4,306	150	60.3	11,250	4,522
Yields, 1921											
2	14.0	164,990	74,119	2.23	68	11,785	5,294	179	80.2	13,425	6,015
3	10.0	96,000	42,000	2.29	70	9,600	4,200	152	66.6	11,400	4,995
4	19.0	137,450	67,256	2.04	48	7,234	3,539	95	50.2	7,125	3,765
5	10.0	138,000	58,080	2.38	61	13,800	5,808	212	89.1	15,900	6,683
6	25.0	329,020	144,895	2.27	56	13,160	5,796	184	81.2	13,800	6,090
Yields, 1922											
2	14.0	86,695	44,473	1.95	48	6,193	3,177	94	48.2	7,050	3,615
3	10.0	92,000	24,280	2.64	....	9,200	2,428	146	38.5	10,950	2,888
4	19.0	123,344	63,516	1.94	45	6,492	3,429	111	49.1	8,325	3,682
5	10.0	116,000	49,020	2.37	59	11,600	4,902	180	76.1	13,500	5,707
6	25.0	206,721	99,785	2.04	49	8,269	3,991	116	55.9	8,700	4,192

ANALYSES OF FRESH FRUIT FROM THE SANTA CLARA ORCHARDS

Samples to determine the sugar content of the fresh prunes were taken from each orchard. Since the number of samples and the amount of fruit which could be analyzed were limited, only one sample, of about five pounds of prunes from each orchard, was selected each year. The fruits comprising the sample were picked up in a systematic manner in each orchard. The locations from which the fruits were taken were numerous enough to be representative of the entire orchard. Sound fruits only were selected, and these were picked up from beneath normally producing trees. The prunes were forwarded to the laboratory in wooden cartons and immediately placed in freezing storage until analysis was begun. In some cases analyses were made immediately; in others, the fruit was placed in cans, sealed, and sterilized, the analytical work being done at a later date. The analyses* of the fresh prunes from the different orchards for each of the four years are given in table 4.

The value is, in each case, the average of duplicate portions which agreed closely. The percentages of sugar listed in the table are the percentages of total sugar in the flesh as invert sugar after inversion.

The results obtained from the analyses of fruits for the season of 1919, 1920, and 1921 seem to be fairly uniform. Prunes from orchard No. 5, collected in 1919, seemed to have a greater percentage of sugar in the flesh, calculated on a dry or water-free basis, than prunes from the other orchards. The sugar content of the prunes of 1921, from orchard No. 2, seemed to be low. The 1922 analyses show greater differences in the sugar content.

These differences may be due to unavoidable errors in sampling. Not enough samples were analyzed to determine the variability due to this cause. The difficulty of selecting a representative sample in the field may be so great that errors are introduced. Denny[25] has shown the variation in results obtained in the analyses of 51 fruits taken from one tree, and his work suggests that large numbers of samples must be taken to give assurance that the differences observed are not due to random sampling.

However, it is clear that the differences found in these analyses can not be attributed entirely to the effect of irrigation. The sugar content of the fruit from orchards with low soil moisture during the growing season, in which are included orchards Nos. 1, 2, and 3,

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* The analyses of the samples for the years 1919, 1920 and 1921 were made by Prof. A. W. Christie, and the 1922 analyses were made by Mr. H. Goss, of the University of California.

averaged 70.4 per cent for 1919, 65.6 per cent for 1920, and 66.0 per cent for 1921; while orchards 4, 5, and 6, in which the soil-moisture supply usually was greater, averaged 72.3 per cent, 66.0 per cent, and 67.0 per cent for these years. The differences in these values are no greater than those Denny[25] suggests might be due to random sampling.

TABLE 4

ANALYSES OF FRESH PRUNES FROM THE SANTA CLARA ORCHARDS

Orchard No.	Dates samples collected	Pit, percentage of total weight	Flesh, percentage of total weight	Water in flesh	Sugar in flesh	Sugar in flesh on dry basis
				Per cent	*Per cent*	*Per cent*
1	Sept. 2, 1919......	9.4	90.6	67.6	23.0	71.0
2	Sept. 2, 1919......	9.9	90.1	68.7	21.8	69.3
3	Sept. 2, 1919......	9.4	90.6	66.8	23.5	70.8
4	Sept. 2, 1919......	9.1	90.9	69.6	21.8	71.7
5	Sept. 2, 1919......	8.5	91.5	71.1	21.9	75.8
6	Sept. 2, 1919......	6.9	93.1	70.3	20.9	70.4
1	Sept. 10, 1920...	12.5	87.5	63.7	23.4	64.5
2	Sept. 10, 1920...	9.6	90.4	65.0	23.0	65.7
3	Sept. 10, 1920....	12.0	88.0	64.4	23.7	66.6
4	Sept. 10, 1920....	12.3	87.7	66.1	22.2	65.5
5	Sept. 10, 1920....	12.8	87.2	65.4	22.4	64.7
6	Sept. 10, 1920....	12.3	87.7	63.6	24.7	67.9
1	Sept. 8, 1921......	9.9	90.1	66.45	23.05	68.7
2	Sept. 8, 1921......	10.8	89.2	64.5	22.4	62.95
3	Sept. 8, 1921......	11.0	89.0	66.1	22.5	66.25
4	Sept. 8, 1921......	10.9	89.1	63.95	25.2	69.9
5	Sept. 8, 1921......	9.9	90.1	66.7	22.2	66.6
6	Sept. 8, 1921......	11.2	88.8	66.0	22.8	66.9
2	Sept. 10, 1922....	5.0	95.0	65.9	17.8	52.2
3	Sept. 10, 1922....	4.5	95.5	69.1	15.6	50.5
4	Sept. 10, 1922....	4.5	95.5	64.9	20.9	59.6
5	Sept. 10, 1922....	4.3	95.7	73.3	18.6	69.7
6	Sept. 10, 1922....	4.8	95.2	71.0	17.2	59.3

There appears to be no consistency in the relation of irrigation to sugar content. When the percentages of sugar found are compared with the soil-moisture history of the corresponding orchards, it will be seen that in some years the orchards which had the greatest amount of moisture in the soil had the most sugar in the fruit; but in other years, orchards with less moisture in the soil had the most sugar in the fruit.

SOIL-MOISTURE CONDITIONS IN THE SANTA CLARA ORCHARDS

Before the routine system of soil sampling was inaugurated, a thorough soil survey was made of the orchards. Places where variations in the upper six feet of soil occurred were recorded. The places where the samples were to be taken were then decided upon in relation to these variations in soil in order that they might be representative. At least six places were selected for sampling in each orchard.

Since the variations in the results obtained in sampling orchard soils for moisture content are so great, it is believed that samples taken at random in an orchard will not give comparable results, even though a large number be taken. It was found that comparable results could be obtained, however, if the samplings were confined to definite places in the orchards, such locations being representative of the entire area under observation. In all of the soil-moisture sampling reported herein, the samples were taken from the same places throughout the period of observation. The successive samples were not more than 6 or 8 inches from the previous ones at each location, and at the end of four years the final samples were not more than 3 or 4 feet from the place the first samples were taken. Since the application of water in all of the orchards was very uniform, little variation was found because of irregularities in the wetting of the soil.

Trials with devices commonly used to take soil samples showed that the soil tube was the most satisfactory tool to use. Comparative tests between augers and the soil tube indicated that with the use of the latter, maximum amounts of moisture were found in the samples. These trials also indicated that comparable results could be obtained only when all of the soil removed from the hole was used in making the moisture determination. Subdividing the sample usually resulted in inaccuracies. For these reasons all samples from the Santa Clara Valley orchards, and in fact all those used in these investigations after 1918, were taken with the soil tube. This tube had a drive point so shaped that the core of soil could be cut without compacting either the core itself or the soil ahead of the cutting point.

Soil samples for moisture determinations were taken before and after each irrigation and usually at intervals of from two to three weeks during the summer months.

A further source of error in making moisture determinations was found in the incompleteness of the drying of the samples. There was a variation from day to day in weights of soil which supposedly had been thoroughly dried, but which were held in the oven with the expectation of reducing them to a constant weight. In all of the work reported herein, samples were repeatedly check-weighed until it was thought a minimum weight in drying had been obtained. All samples were dried in an electric oven which was regulated to operate between 105 and 110 degrees Centigrade.

Moisture equivalent determinations were made on many of the samples. It was intended to record the moisture percentages as ratios of the moisture equivalent, or of any of its related soil-moisture constants. However, wide variations were found in the moisture equivalent values when repeated determinations were made on the same sample of soil. Some of the causes of these variations have since been discussed by Veihmeyer, Israelsen, and Conrad.[51] These authors found that the value for the moisture equivalent is influenced markedly by the amount of soil used in making the determination. Many of the earlier moisture equivalent determinations, in which the weight of soil used in making the determination varied appreciably from 30 grams, are not sufficiently accurate. A further variation, which was sufficient to affect the results when precision was desired, was noted in the value for the moisture equivalent when samples of the same soil were centrifuged at different times, although other conditions were apparently the same. Therefore, too strict an application of the moisture equivalent to the interpretation of soil-moisture data can not be made until the technique of the method is more thoroughly refined. Furthermore, Puri[43] shows that the hygroscopic coefficient can not be satisfactorily determined even when the method is refined beyond that reasonably possible in routine determinations. It appears, then, that the hygroscopic coefficient can not be used as a satisfactory basis for the measurement of the available water in the soil. However, it must be mentioned that, in spite of the variations in moisture equivalent determinations and consequently in the wilting coefficients which are calculated from them, there was a fairly close agreement between the calculated value and the moisture content of the soil at the time the trees so wilted that they did not recover until water was applied to the soil.

The moisture equivalents listed in the following tables are the averages of numbers of determinations made on 30-gram samples of soils, which were taken from the several orchards at different times. The wilting coefficients and hygroscopic coefficients have been calculated from these moisture equivalent determinations.

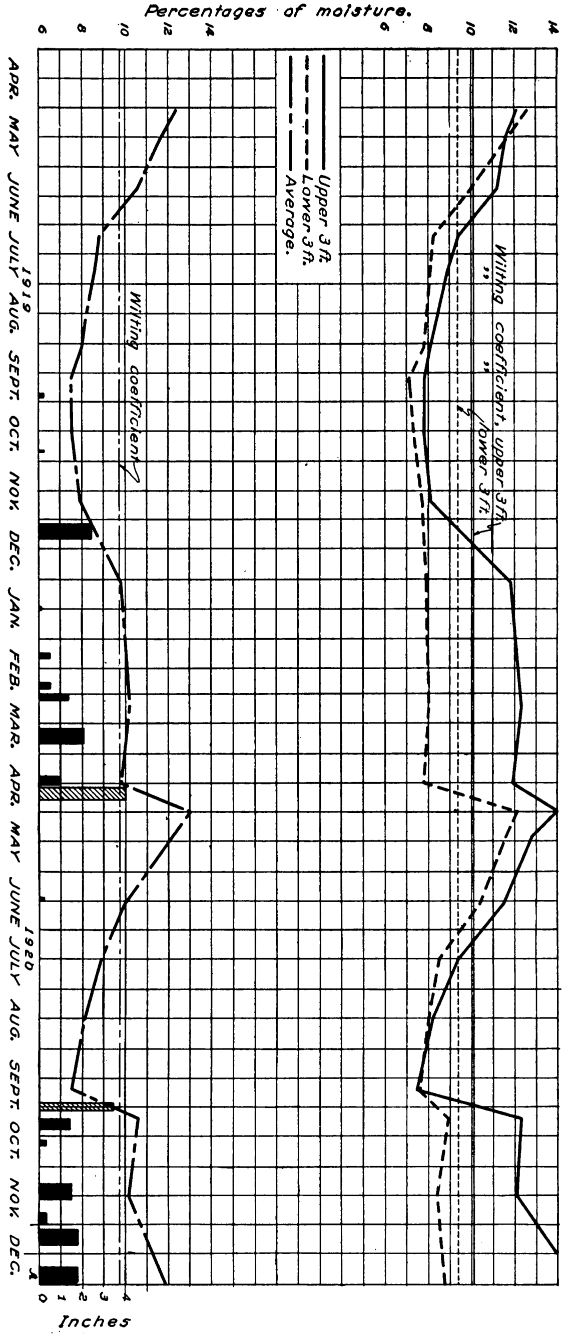

Fig. 4. Soil-moisture conditions in Santa Clara Valley prune orchard No. 1 during 1919 and 1920. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

The percentages of moisture found in the six orchards at different times are graphically illustrated in figures 4 to 15. The average moisture content of the first 3 feet of soil and that of the second 3 feet are shown together with the average moisture content of the first 6 feet. The depth of water in inches applied by irrigation is shown in each case. The heights of the hatched rectangles indicate the total amount of water applied, and the widths of the rectangles, the time it took to apply the water. Rainfall is shown by the solid black rectangles. These show the total rainfall for each month and are placed in a position to indicate the principal dates on which rain fell during the month.

Figures 4 and 5 show that for the years 1919, 1920, and 1921, the soil moisture of the upper 6 feet of soil in orchard No. 1 was reduced below the calculated wilting coefficient for at least two months during the growing season. During the season of 1919, the soil-moisture supply in this depth of soil was reduced below the wilting coefficient about the first of July, and remained dry throughout the remainder of the season. There was no water taken out of the first 6 feet of soil after the middle of September. Apparently the limit of available moisture had been reached by this time. The graph representing the moisture content of the soil to a depth of from 0 to 3 feet is practically parallel with that of the soil from 3 to 6 feet during the summer months of 1919. The soil in this orchard was noted to be very dry at the sampling of July 7, and at all of the subsequent samplings the soil was so dry that great difficulty was encountered in driving the tube into the soil. The trees were decidedly wilted on July 24, 1919. By September 1, it was estimated that about one-half of the leaves of the trees had dropped. The trees were entirely defoliated by November 1. It is a surprising fact that in spite of the low moisture content of the soil to a depth of 6 feet, the trees produced a crop of over 6 tons of green fruit and over 3 tons of dried fruit to the acre. The trees undoubtedly suffered and clearly showed the evidence of lack of water during the latter part of the growing season. When it is remembered that this orchard had undergone this same treatment for many years, the yield is still more surprising. It is true, however, that the yield for 1919 was higher than that usually obtained from this orchard. The average yield up to 1919 had been 3½ tons of green fruit to the acre.

The winter of 1919–1920 was exceptionally dry and the irrigation in April, 1920, of 4.01 acre-inches to the acre, brought the moisture content of the soil up to a point which probably would correspond, at that time of year, to an amount equal to that usually resulting from rain. The moisture in the upper 6 feet of soil was reduced below the wilting coefficient about June 20. The trees were showing evident signs of distress at this time and some of the leaves were dropping. As the season advanced, defoliation continued until about one-half of the leaves had dropped from the trees by September 5.

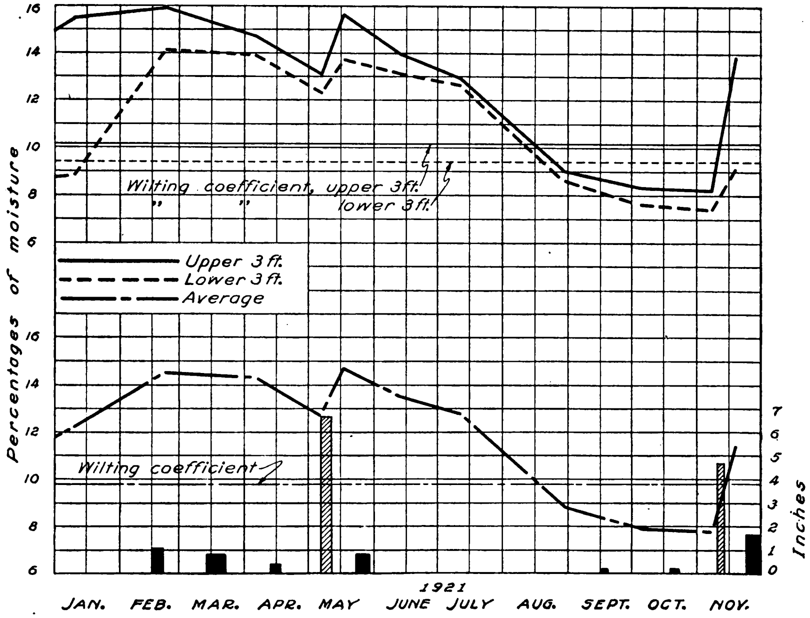

Fig. 5. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 1 during 1921. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

The heavier application of water later in the season of 1921 resulted in prolonging the period in which the soil-moisture supply in orchard No. 1 was above the wilting coefficient. However, the trees were badly wilted by August 30 and were practically defoliated by October 4.

The soil-moisture history of orchard No. 2, illustrated in figures 6 and 7, shows that the moisture content of the upper 6 feet of soil in this orchard was reduced below the wilting coefficient in each of the four years between July 1 and July 15. The orchard showed the lack of water during each growing season. Permanent wilting was evidenced at these times by wilting and shedding of the leaves.

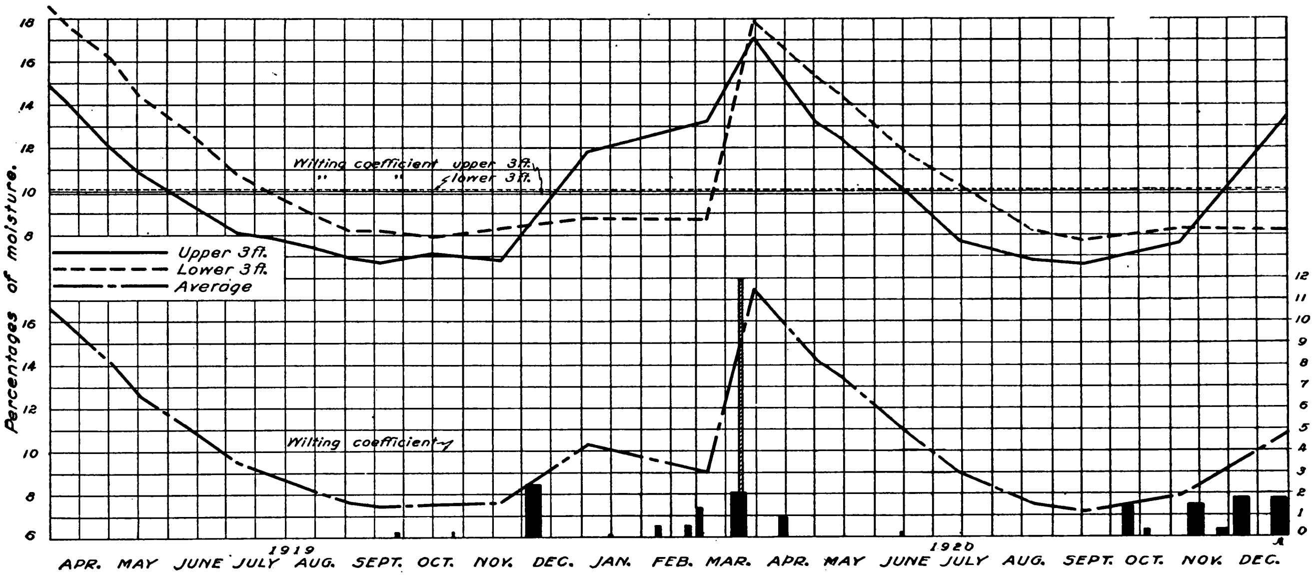

Fig. 6. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 2 during 1919 and 1920. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

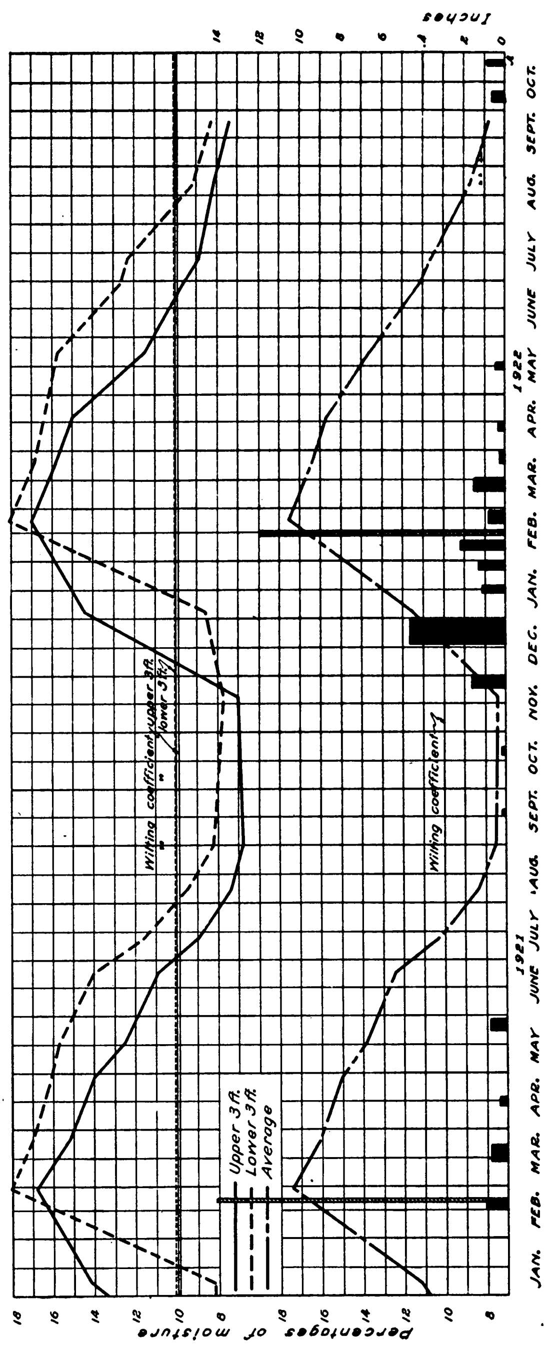

Fig. 7. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 2 during 1921 and 1922. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

The usual condition of the trees in this orchard after the removal of the crop is illustrated in figure 1. It will be noted that the trees were practically defoliated by October 4, 1920. This orchard, except during 1922, bore exceptionally good crops of fruit. The records of yields of fresh fruit from this orchard for the several years preceding 1919 are as follows: 1916, 8,467 pounds to the acre; 1917, 10,956 pounds to the acre; and 1918, 7,969 pounds to the acre. It is, indeed, remarkable that an orchard which unmistakably suffers from lack of water for such long periods of time during each year consistently bears good crops of fruit.

The graphs of the moisture condition in orchard No. 2, when compared with those illustrating conditions in the other orchards which were not winter irrigated, suggest that irrigation in the dormant season does not materally postpone the time in the following growing season during which the moisture supply in the first 6 feet of soil is depleted below the wilting coefficient. A similar condition was found by Batchelor and Reed[6] with mature walnut trees.

On June 20, 1919, the trees in orchard No. 3 showed wilting of leaves resulting in some abscission. The leaves continued to drop as the season advanced, the trees being completely defoliated by October 10. As indicated in figure 8, the moisture supply of the soil to a depth of 6 feet was reduced by the middle of June, 1919, below the wilting coefficient. The unusually low drying ratio of fresh fruit to dried fruit of 1.69 for this year was doubtless due to the partial drying of the fruit on the trees. The condition of the trees during the years 1920, 1921, and 1922 was much better than in 1919. Wilting did not occur so early, and the trees were not defoliated until later in the season. However, the moisture supply in the first six feet of soil was below the wilting coefficient for about two months during the latter part of the growing season each year. (Figures 8 and 9.) The trees were wilted during these periods and were revived on the application of water in the fall. This was especially noticeable in the years when the water was applied early in the fall, and before the majority of the leaves had dropped from the trees.

The yield from orchard No. 3, although much lower than any of the other orchards, was somewhat better than had been obtained for the several preceding seasons. The increase in yields after 1919, as shown in table 3, is a response to better care and to an available supply of soil moisture for a longer time each year.

Fig. 8. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 3 during 1919 and 1920. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

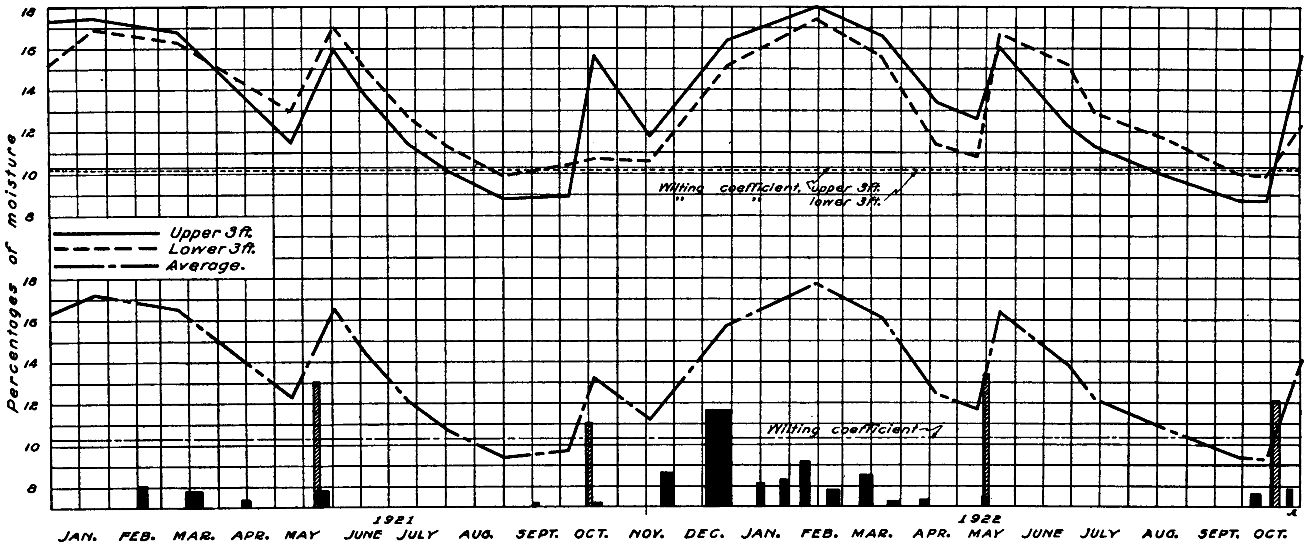

Fig. 9. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 3 during 1921 and 1922. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

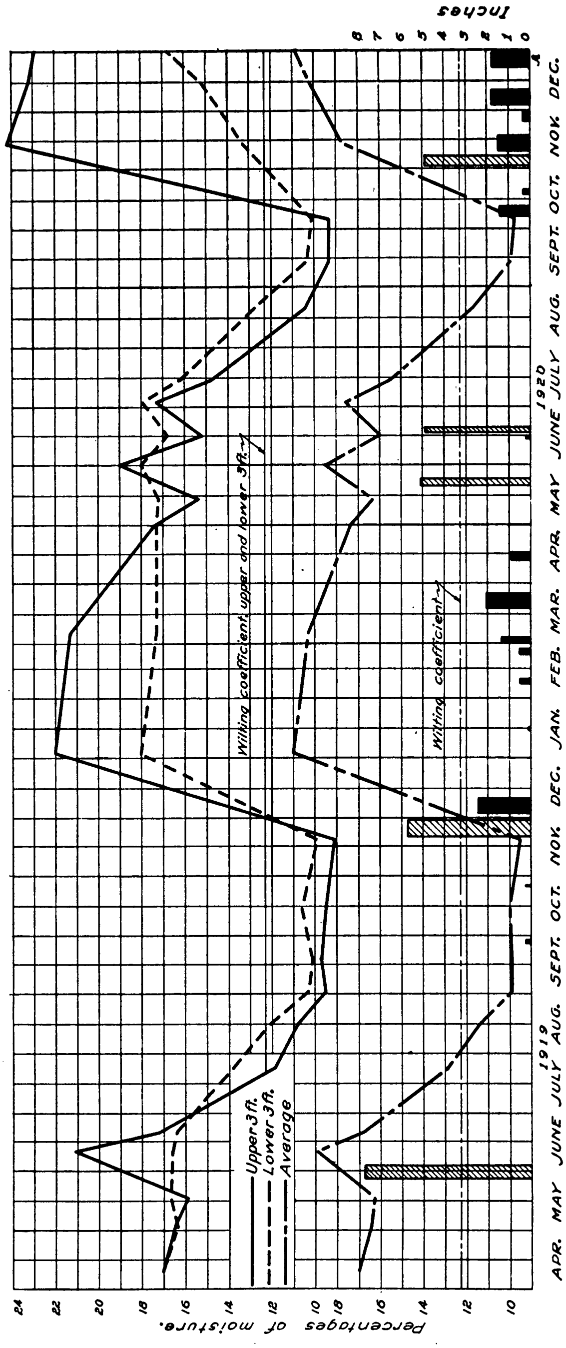

Fig. 10. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 4 during 1919 and 1920. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

Fig. 11. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 4 during 1921 and 1922. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

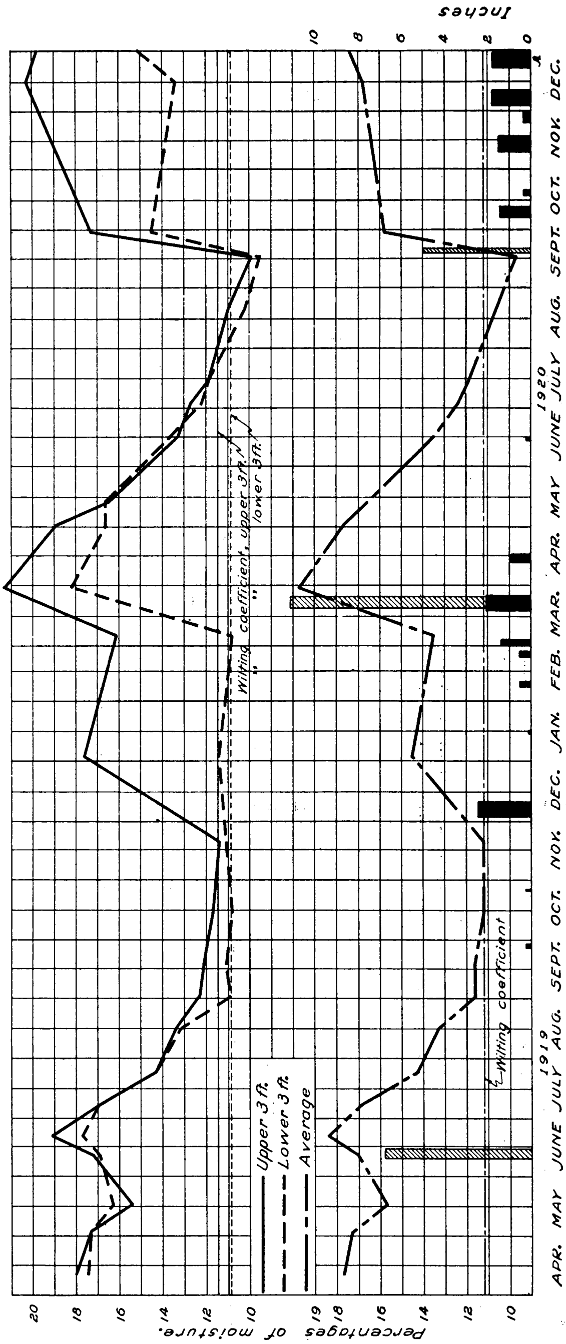

Fig. 12. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 5 during 1919 and 1920. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

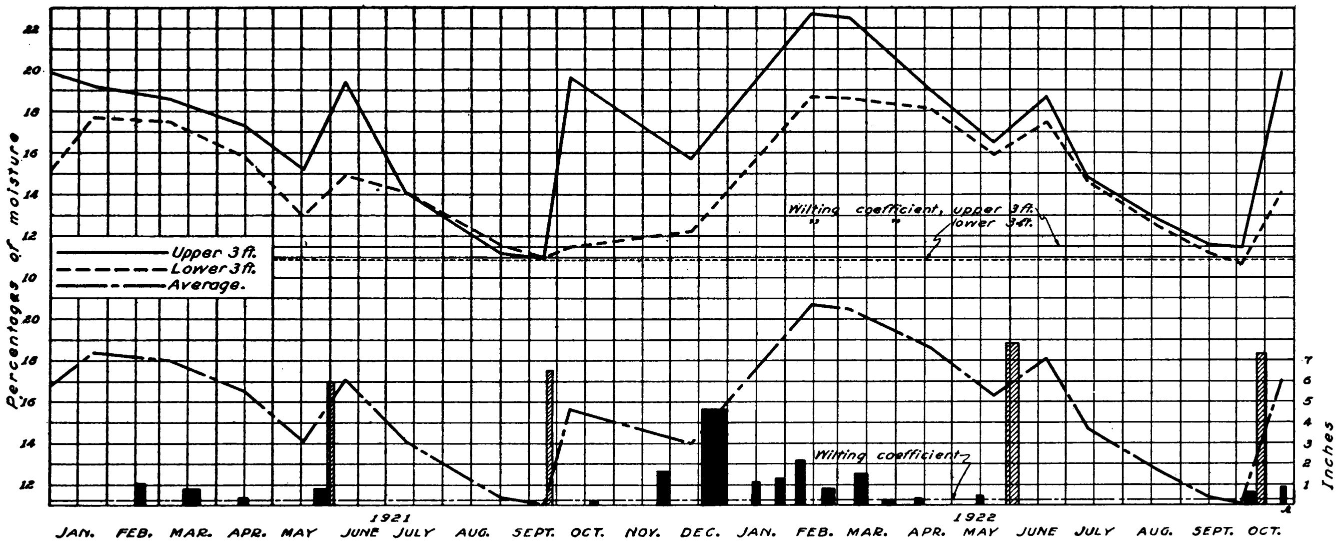

Fig. 13. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 5 during 1921 and 1922. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

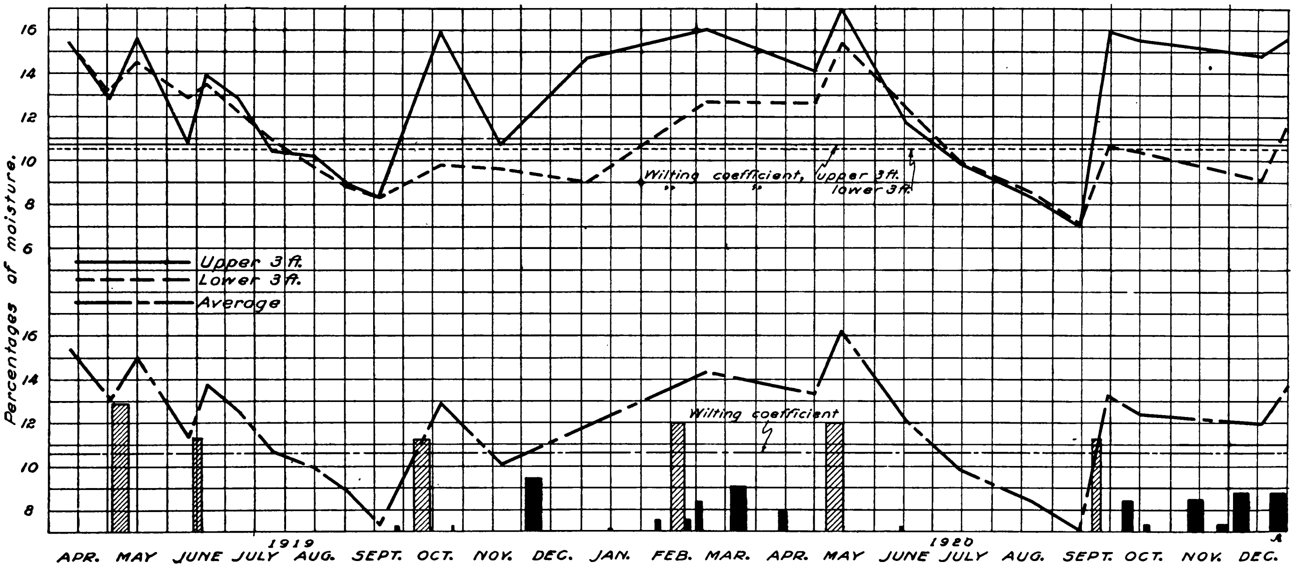

Fig. 14. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 6 during 1919 and 1920. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

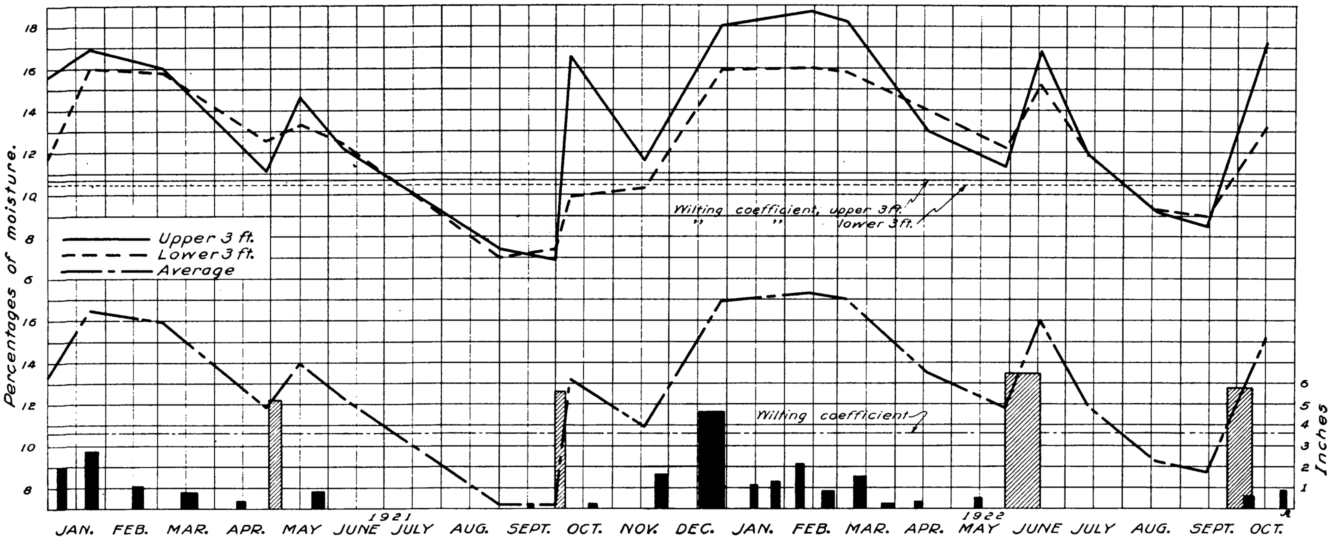

Fig. 15. Soil-moisture conditions in the Santa Clara Valley prune orchard No. 6 during 1921 and 1922. The rainfall is indicated by the heights of the solid black rectangles, and the amount of irrigation water is represented by the cross-hatched rectangles.

Orchards 4 and 6 had the moisture content of the first 6 feet of soil above the wilting coefficient for longer periods during the growing season than orchards 1, 2, and 3, as will be seen from figures 10, 11, 14, and 15. During the four years these orchards were under observation, the moisture content of the upper 6 feet of soil was below the wilting coefficient for periods of from 2 to 4 months during the growing season. These orchards wilted each year, and many of the leaves dropped before the crop was harvested. The condition of the trees in orchard No. 4 on November 1, 1920, is shown in figure 3. This condition was typical also of orchard No. 6. The trees apparently suffered from drought in spite of one or two rather heavy applications of water in the fore part of the season.

The soil-moisture history in orchard No. 5 is shown in figures 12 and 13.

Orchard No. 5 had better moisture conditions in the first 6 feet of soil throughout the four years than any of the other orchards. In one year only, 1920, did the moisture content fall below the theoretical wilting coefficient. In the latter part of the growing seasons of 1919 and 1922, the moisture content was reduced to an amount which was about equal to the wilting coefficient. It is interesting to note that some distress was indicated by the permanent wilting of some of the leaves. It is shown in table 4 that with the exception of the year 1920, this orchard had a higher yield to the tree than any of the other orchards. The striking difference in condition of the trees in orchard No. 4 and of those in orchard No. 5 could be noted easily since they were adjoining orchards. The border line of orchard No. 5 could clearly be distinguished from that of orchard No. 4 by the better appearance of the trees.

Orchard No. 5 had yielded good crops consistently before 1919. In 1916 the yield of fresh fruit to the acre was about 11,000 pounds; in 1917, 7,000 pounds; in 1918, 9,000 pounds. Orchard No. 4 had not been a good producer, the average yield of fresh fruit previous to 1919 having been about 4,400 pounds to the acre. Orchard No. 6 had not produced good crops up to 1919. The yield of fresh fruit to the acre in 1915 was 2,600 pounds, and in 1916, 6,435 pounds. In 1917 it was reduced to 2,918 pounds.

EXTRACTION OF MOISTURE BY THE TREE ROOTS FROM DEPTHS OF SOIL BELOW SIX FEET

Samples of soils for moisture determinations were taken to depths of 12 feet during the four years of observation. In each orchard the soil below 6 feet contained considerable gravel; the labor of taking samples, especially when the soil was dry, was so great that only a few sets of samples were taken each season. These determinations, though few in number, indicate that in every year during which soil moisture was available, some moisture was taken from the soil by the trees to the full depth of 12 feet. The extraction of moisture from the depth of 6 to 9 feet was at a slower rate than that from the first 6 feet. The extraction from the 9 to 12-foot depth was at a slower rate than from the 6 to 9-foot depth. The amounts of water taken from the soil by the trees from the four 3-foot layers of soil are given in table 5. These records show the extraction of moisture after the last irrigation was applied in the summer, or after the last rains, and before the first application of water in the fall, or at the end of the growing season. The values, expressed in acre-inches, are the amounts of water in 3 feet of soil, equivalent to the designated depth of water in inches. The amount of water in the soil in the fore part of the summer is given as the amount above the calculated hygroscopic coefficient. The values will convey some idea of the supply of water available for growth. However, it is to be noted from table 5 that in one instance only all of the water above the hygroscopic coefficient was used by the trees. This is the 0 to 3-foot depth of soil in orchard No. 6, during the summer of 1921. There was an amount of water equivalent to 3.68 acre-inches to the acre in this depth of soil on May 16, 1921, and 3.88 acre-inches to the acre was removed by the trees. The soil-moisture content in this orchard also was reduced to the hygroscopic coefficient in the fall of 1920. The moisture content of the upper 3 feet of soil in orchard No. 2 was usually reduced almost to the calculated hygroscopic coefficient in the fall of each year.

The smaller amounts of water taken from the 6 to 9-foot depth, and the still smaller amounts taken from the 9 to 12-foot depths of soil, is clearly brought out in table 5. These records, together with the graphs of moisture conditions, indicate that if the losses of moisture from below the surface layers of soils are attributed solely to that caused by transpiration through the trees, an assumption

TABLE 5

AMOUNTS OF MOISTURE TAKEN BY TREES FROM DIFFERENT DEPTHS OF SOIL BETWEEN IRRIGATIONS IN SUMMER AND FALL*

Orchard	Date of sampling	Acre-inches per acre available above hygroscopic coefficient				Depth of soil wet from previous irrigation	Samples taken before irrigation. Date	Acre-inches to the acre taken from different depths of soil				Percentage taken of total amount available			
		0-3 foot depth	3-6 foot depth	6-9 foot depth	9-12 foot depth			0-3 foot depth	3-6 foot depth	6-9 foot depth	9-12 foot depth	0-3 foot depth	3-6 foot depth	6-9 foot depth	9-12 foot depth
1	May 16, 1921	4.39	3.68	2.84	2.47	10.5 feet	Oct. 4, 1921	3.86	3.07	2.32	1.81	87.8	83.5	81.8	73.3†
2	Apr. 28, 1921	3.63	4.64	4.29	3.03	Below 12 feet	Nov. 18, 1921	3.53	4.24	3.35	1.26	97.2	91.4	78.0	41.6
2	Apr. 17, 1922	4.13	4.79	4.84	4.18	Below 12 feet	Sept. 28, 1922	3.83	4.08	3.73	1.59	92.7	85.3	78.7	38.9
3	June 1, 1921	4.54	5.04	3.56	2.52	9.5 feet	Oct. 4, 1921	3.58	3.33	2.55	1.71	78.8	66.1	71.7	67.8†
3	June 28, 1922	2.82	4.14	2.72	1.64	10.5 feet	Sept. 28, 1922	1.97	2.62	1.49	1.17	69.9	63.3	56.8	71.3†
4	June 1, 1921	6.50	6.04	4.78	2.67	Below 12 feet	Oct. 1, 1921	6.04	5.74	3.27	0.60	93.0	95.0	68.4	22.5
4	June 28, 1922	5.80	5.74	4.69	4.79	Below 12 feet	Sept. 27, 1922	5.24	4.29	1.94	0.98	90.2	74.7	41.3	20.5
5	June 19, 1922	5.50	5.09	3.68	2.92	Below 12 feet	Sept. 15, 1922	3.58	3.07	1.92	1.16	65.1	60.4	52.2	39.7
6	May 16, 1921	3.68	3.13	1.87	1.18	6.5 feet	Oct. 1, 1921	3.88	2.97	1.56	1.06	105.4	94.9	83.5	89.9†
6	June 17, 1922	4.79	4.08	2.97	1.56	9.0 feet	Sept. 14, 1922	4.18	3.13	2.17	1.21	87.4	76.6	73.1	77.5†

* The water table under each of these orchards was over 100 feet from surface.

† It should be noted that the soil from 9 to 12 feet was not fully wet from previous irrigation.

which will be shown to be substantially true in the latter part of this report, most of the roots are distributed rather uniformly throughout the upper 6 feet of soil, there are a few roots in the 6 to 9-foot depth, and still fewer in the 9 to 12-foot depth.

In orchard No. 4, very little moisture was taken from the 9 to 12-foot depth even though there were large amounts available. The soil to this depth was noticeably moist at all times during the last three years of the period of observation. In spite of this, the trees in this orchard showed permanent wilting and defoliation of leaves during the growing season. This suggests that the distribution of Myrobalan roots, on which these trees were grown, was largely limited to the upper 9 feet of soil.

DISCUSSION OF RESULTS

The graphs of the soil-moisture conditions in the Santa Clara Valley prune orchards show the fluctuations in soil moisture prevalent in mature commercial orchard. These suggest that the maintenance of even an approximately uniform soil-moisture content is impossible. Mature prune orchards are different from other deciduous orchards in that there is a long period when surface applications of water can not be made. Usually the trees are propped for about two months during the latter part of the summer, and the fruit is on the ground for a long time.

Orchard No. 5 had the best moisture conditions of any of those under observation. An irrigation was given in June of each year, except in 1920, and the orchard was irrigated as early as possible in the fall. The soil moisture was reduced appreciably below the wilting coefficient only in 1920. Orchards No. 4 and No. 6 showed greater reductions of the soil-moisture supply than No. 5. Orchards No. 1 and No. 2 were wilted for longer periods than the other orchards, except No. 3, during 1919 and 1920. Orchard No. 3 showed much less wilting during the season of 1921 and 1922. It ranks with orchard No. 4 in this respect.

There seems to be no relation between the yield and the soil-moisture content in the different orchards. Also the size of dried prunes bore no relation to soil-moisture content. The number of pounds of fresh fruit required to make one pound of dried fruit, given in table 4, can not be used to judge strictly the amount of water in the fresh fruit from the different orchards. The time the fruit was allowed to remain on the ground and the condition of dryness of the fruit probably were not the same for the different orchards. As previously pointed out, the low drying ratio for the fruit from orchard No. 3 in 1919 was due to the fact that much of the fruit dried on the trees. However, the drying ratios recorded represent what may be expected from commercial orchards and indicate no consistent relation between soil moisture and water content of the fruit. This is further illustrated in the percentages of water found in the flesh of the fruit samples collected from the different orchards and reported in table 4. As previously discussed, it is also thought that the differences in amounts of sugar found in these samples can not be attributed to the differences in irrigation.

No differences could be recognized in the condition of trees growing on soil with a high moisture content in the upper 6 feet and those on soils with low moisture content in the same depth until the soil-moisture supply had been reduced to the wilting coefficient. Wilting, without recovery until water was again added to the soil, always resulted when the moisture content of the upper 6 feet of soil had been reduced to a condition closely approximating the calculated wilting coefficient. This will be discussed further in the following sections.

Since the trees did not seem to be affected until the soil-moisture content had been reduced to the wilting coefficient, the necessity for irrigation early in the summer, when there was considerable residual soil moisture either from rains or previous irrigations, is not apparent. The irrigation practice in all of these prune orchards could have been bettered if the spring irrigations were delayed and the water applied later in the season when the moisture content of the upper 6 feet of soil was further reduced. Many of the early irrigations resulted in penetration of water below the 6-foot depth. The same amount of water applied later would delay wilting and shorten the time the trees would remain in this condition. The soil moisture more nearly approached this condition in orchard No. 5 than in any of the other orchards.

The graphs depicting the soil-moisture conditions (figures 4–15) do not indicate a more rapid use of water by the trees on soil with high moisture content than by those on soil with low moisture content. This is evidenced by a comparison of the slopes of the portion of the graphs following irrigation with the portions near the wilting coefficient.

Some of the graphs do show a steeper slope immediately following the application of water. For example, the graphs in figure 10 for the 0 to 3-foot depth and the 0 to 6-foot depth are steeper following the irrigation of May 27 to June 3, 1919. However, this as well as other cases which can be noted in the graphs may be due to the rapid loss by evaporation from the surface layer of soil immediately following irrigation and to downward movement which carried some of the water below the upper 6 feet of soil. In many cases soil samples were taken immediately after irrigation and before the water was distributed throughout the soil. The samples included the surface layer from which rapid loss from evaporation followed irrigation. The loss of water from below the surface of the soil is assumed to be almost entirely due to transpiration, and the slope of the graphs to indicate the rate of extraction by the roots. These considerations will be more fully dealt with in later sections of this report. The rate of extraction of soil moisture seemed to be as rapid from the 0 to 3-foot depth of soil as it was from the 3 to 6-foot depth.

The condition of the trees seemed to be governed by the moisture content of the upper 6 feet of soil. When the moisture in this depth of soil had been reduced to the wilting coefficient, wilting always resulted and the trees did not recover until water was added to the soil, even though the soil below the sixth foot had a much higher moisture content.

Further information concerning the use of water by mature deciduous fruit trees is given in the following section.

SECTION II

IRRIGATION STUDIES OF PEACHES

Studies similar to those made in the Santa Clara prune orchards were made on the effect of irrigation on peaches. An orchard consisting of one block of Muir peaches, on peach root, located at the Branch of the College of Agriculture of the University of California, at Davis, was selected.

This locality is a semi-arid region. There are no fogs during the growing season, and between the first of May and the latter part of September there are few clouds. The area is typical of the hot, dry interior-valley climate of California, except that the night temperatures are lower than are usual farther north in the Sacramento Valley and in the southern part of the San Joaquin Valley. The normal rainfall at Davis, calculated up to 1923, is 17.41 inches. Practically no rain falls during the summer months. During the six years these studies were conducted, the rainfall was less than normal except during the season of 1918–1919. The rainfall in inches given in the following tabulation, is for each season from September 1 of one year to September 1 of the following year.

1916–1917	14.09	1919–1920	8.98
1917–1918	9.66	1920–1921	17.13
1918–1919	19.40	1921–1922	16.63

The soil in this area is classed as Yolo loam. In some places the surface soil verges into a silty loam or a fine sandy loam. The subsoil is somewhat lighter in texture than the surface soil, and there are occasional pockets of sand and gravel.

The distance to the underground water surface under the orchard during the years the observations were made was about 18 feet. The normal rainfall at Davis is usually sufficient to wet the soil, if it is dry in the fall, to a depth of about 8 feet. Results of soil sampling indicate that this moisture is exhausted by mature peach trees at the end of the growing season of each year. It is possible that the roots of the trees, in the area under observation, were sufficiently deep to extract moisture from the moist soil immediately above the water-table. However, in the principal peach growing sections of California, the water-table is generally higher than that at Davis, and it was thought that the results obtained in a study of the effect of the variation of the moisture supply in the upper 6 feet of soil, would be applicable to other peach growing areas in the State.

On February 16, 1912, the trees, which were excellent two-year-old nursery stock, selected for uniform size, were planted in the orchard. The irrigation and cultural treatments were the same throughout the orchard until the beginning of the growing season of 1917, when differential irrigation treatments began.

The tree rows were numbered 1, 2, 3, ... beginning on the south side, and so on to 16 on the north end. The trees in each row were numbered 1 to 6, beginning with number 1, on the east side, and ending with number 6, on the west side. The trees were spaced 20 feet in the rows and the rows were 20 feet apart.

The schedule of irrigation treatment which was followed during 1917 and 1918 was as follows: All even numbered rows (rows 2, 4, 6, 8, 10, 12, 14, and 16) received no irrigation when there was normal rainfall. The normal rainfall at Davis, up to the year 1917, from September 1 to January 1, was 6.01 inches; to February 1, 9.71 inches; to March 1, 12.53 inches; and to April 1, 15.14 inches. Whenever the rainfall was below normal on these dates, sufficient water was applied to make up the deficiency.

Rows 1 and 9 received no irrigation.

Rows 3 and 11 were irrigated in the fore part of growing season (April or May, depending upon rainfall). They were also irrigated shortly before harvesting and about 30 days after harvesting.

Rows 5 and 13 were irrigated sufficiently to insure a high soil-moisture content at time of blossoming (February or March, if rainfall were not sufficient), at the time of rapid length growth (April or May), and shortly before harvesting.

Rows 7 and 15 were irrigated to insure ample moisture in the soil at the time of most rapid fruit growth (May or June), and about 30 days after harvesting.

The cultural treatment was the same throughout the orchard during the entire period of observation. The orchard was plowed early in the spring of each season, in order to kill all volunteer vegetation. No cover crops were planted. The plowing was followed by disking and harrowing, and additional cultivations were given only to keep down weed growth, and to prepare the soil before and after irrigation. Pruning of the different rows was kept as uniform as possible. The recorded weights of pruning from the different rows showed no appreciable differences in the amounts of wood removed from the different trees. Thinning was done as uniformly as possible. No fertilizer was added to the soil, and it is believed that the only material difference between the rows was the amount of moisture available in the soil.

The amount of water to be applied at the times specified in the above schedule was determined by sampling the soil to a depth of 6 feet. Whenever the moisture content of the soil in the rows which were to be irrigated according to the schedule previously given was found to be less than the maximum field capacity, the requisite amount of water was applied. The maximum field capacity of the soil was determined by applying an amount of water equivalent to 12 inches in depth, to 5 plots of about 100 square feet each, and taking 13 samples in each plot to a depth of 9 feet. The samples were not taken until after gravitational movement of the water downward had ceased. The plots were located so that variations in soil would be represented. The average water holding capacity of the upper 6 feet of soil was determined by this method to be 20.18 per cent.*

Sampling the soil during 1917 and 1918 was done with a post-hole type of soil auger. A hole was bored and a sample taken from each foot of soil. The subdivision of the sample was made in the field. As previously pointed out, this method of sampling is sometimes faulty, and inconsistencies in the results were observed frequently. It was found that the amount of water applied could not always be accounted for in the soil by this means of sampling after irrigation.

During the seasons of 1917 and 1918, about 6,000 samples were taken in the orchard. The results, in 1917, of sampling the soil to determine the moisture content, and the record of irrigations are given in table 6. For assistance in the interpretation of these data, the average moisture equivalents of the different depths of soil are given at the bottom of the table. Samples from the same rows were centrifuged at different times. However, the samples used for these moisture equivalent determinations were not exactly 30 grams. The values for the wilting coefficients and hygroscopic coefficients, calculated from those for the moisture equivalents, are also listed.

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* This method of determining the amount of water the soil is capable of holding is subject to some objection since Israelsen and West[34] seem to show that the amount of water held by the soil is dependent, to some extent, on the amount of water applied.

TABLE 6

SUMMARY OF IRRIGATION TREATMENTS AND SOIL-MOISTURE CONTENTS IN MUIR PEACH ORCHARD, DAVIS, 1917

Row	Dates of irrigation	Depth of water applied in acre-inches to the acre	Dates of sampling	Percentages of moisture in the soil						Average percentage of moisture in 6 feet	Equivalent depth of water in inches
				1st foot	2nd foot	3rd foot	4th foot	5th foot	6th foot		
1, 9			Mar. 15	19.0	19.0	16.4	17.0	17.4	15.8	17.4	16.3
			Aug. 7	10.1	11.0	10.4	10.4	9.2	10.3	10.2	9.6
			Oct. 1	8.5	10.8	10.2	9.8	9.5	10.1	9.8	9.2
2, 4, 6	May 4-6	2.5	Mar. 15	19.4	18.3	16.4	17.0	17.2	15.1	17.1	16.0
8, 10, 12			May 2	16.9	15.9	15.7	17.6	19.7	17.1	17.2	16.0
14, 16			May 8	20.1	19.2	17.8	18.2	18.4	15.9	18.3	17.1
			Aug. 7	10.9	11.9	11.3	11.2	12.6	10.8	11.3	10.5
			Oct. 1	9.4	10.8	10.1	9.7	9.6	9.5	9.7	9.0
3, 11	May 18-21	5.33	Mar. 15	18.1	17.7	16.8	16.2	16.5	14.5	16.6	15.5
			May 15	12.7	15.7	15.4	16.2	14.8	14.3	14.9	13.9
	Aug. 13-16	8.05	May 22	19.8	19.6	18.0	18.1	18.2	16.6	18.4	17.2
			Aug. 7	11.8	12.1	11.4	11.4	12.0	10.7	11.6	10.8
	Oct. 8-13	7.76	Aug. 21	19.5	17.6	16.2	17.1	16.6	14.6	16.9	15.8
			Oct. 1	13.7	12.0	11.9	12.0	11.9	9.3	11.9	11.1
			Oct. 18	21.1	18.7	17.1	16.7	16.0	14.0	17.1	16.0
5, 13	May 19-21	5.28	Mar. 15	18.9	18.0	16.6	17.3	19.0	16.1	17.7	16.6
			May 15	10.8	14.8	14.6	10.8	11.6	16.1	14.5	13.6
			May 22	20.8	19.4	18.0	15.7	16.8	14.6	17.6	16.4
	Aug. 13-16	8.41	Aug. 7	11.4	11.8	11.0	10.9	11.1	10.9	11.2	10.5
			Aug. 21	20.4	18.9	16.6	16.0	14.4	14.0	16.7	15.6
			Oct. 1	14.3	13.5	12.8	12.6	12.1	11.3	13.8	11.9
7, 15	July 2-3	6.17	Mar. 15	19.9	19.1	17.2	17.1	18.1	16.6	18.2	17.0
			July 2	13.0	13.1	12.5	13.8	15.1	14.0	13.6	12.7
			July 7	20.5	18.4	15.4	16.1	15.2	14.8	16.7	15.6
	Oct. 8-13	9.00	Aug. 10	15.0	14.1	12.9	12.9	11.8	12.7	13.3	12.4
			Oct. 1	11.2	10.9	10.1	10.1	9.8	11.1	10.6	9.9
			Oct. 18	22.5	18.8	17.5	18.0	14.0	14.0	17.5	16.4
Moisture equivalent				23.5 ±0.12	21.8 ±0.18	19.3 ±0.27	18.5 ±0.40	18.5 ±0.50	17.9 ±0.67		
Wilting coefficient				12.8 ±0.06	11.8 ±0.10	10.5 ±0.14	10.1 ±0.22	10.0 ±0.27	9.8 ±0.36		
Hygroscopic coefficient				8.7 ±0.04	8.1 ±0.07	7.1 ±0.10	6.8 ±0.15	6.8 ±0.18	6.6 ±0.25		

TABLE 7

SUMMARY OF YIELDS FROM MUIR PEACH ORCHARD, DAVIS, 1917

Row	Number of trees	Dates irrigated	Total fresh fruit, including culls	Culls	Number mature peaches	Weight fresh fruit	Average weight to a fruit, fresh	Weight dried fruit	Number of pounds of fresh fruit to make one pound of dried fruit
			Pounds	*Pounds*		*Pounds*	*Pounds*	*Pounds*	
1	6	No irrigation	115.4	71.0	125	44.4	0.36	5.4	8.29
9	6		370.7	197.2	510	173.5	0.34	23.2	7.47
	Average to a tree...		40.5	22.4	53 ±8.5	18.1 ±2.5	0.35 ±0.05	2.4 ±0.4	7.88
3	6	May 18–21	402.8	220.6	485	182.2	0.38	20.0	9.12
11	5	Aug. 13–16....	351.2	171.9	455	179.3	0.37	22.6	7.95
		Oct. 8–13......							
	Average to a tree...		68.5	35.6	85.5 ±13.9	32.9 ±3.5	0.38 ±0.04	3.9 ±0.4	8.54
5	5	May 19–21....	528.4	262.0	814	266.4	0.33	37.9	7.04
13	6	Aug. 13–16....	319.7	162.9	467	156.8	0.34	21.3	7.36
	Average to a tree...		77.1	38.6	116.5 ±21.4	38.5 ±6.8	0.33 ±0.06	5.4 ±1.0	7.20
7	6	July 2–3.........	512.5	265.9	660	246.6	0.38	31.7	7.78
15	6	Oct. 8–13......	306.9	150.2	411	156.7	0.38	20.5	7.65
	Average to a tree...		68.3	34.7	89.3 ±9.3	33.6 ±2.9	0.38 ±0.03	4.4 ±0.4	7.72
2	6	May 4–6.........	409.3	185.7	595	223.6	0.38	28.2	8.03
4	5		380.4	194.4	504	186.0	0.37	23.3	7.97
6	6		410.8	211.5	606	199.3	0.33	29.1	6.85
8	5		237.4	113.3	329	124.1	0.38	16.0	7.89
10	4		186.4	81.9	211	104.5	0.49	15.2	6.85
12	6		390.0	199.0	538	191.0	0.35	26.3	7.25
14	6		286.6	149.9	391	136.7	0.35	18.2	7.46
16	4		92.1	34.6	139	57.5	0.41	6.4	9.03
	Average to a tree...		55.7	27.2	78.7 ±4.6	28.5 ±1.5	0.36 ±0.02	3.8 ±0.3	7.67

All irrigation water during the season of 1917 was applied by furrow irrigation, six zigzag furrows being used for each tree row. The water applied was measured by means of hook-gage readings on a "V" notch weir.

The first blossoms appeared on the trees on March 10, and March 18 was estimated as the mid-blossoming period. The samples taken on March 17 showed the soil to be amply moist; therefore, the irrigations in rows 5 and 13, which were scheduled, were not given.

Fruit harvest on all rows started on August 27 and continued until September 10. There were no apparent differences in the dates of ripening of the fruit on the different rows. A summary of the yields for the season of 1917 is given in table 7. The yields from trees which had been replanted, or were obviously subnormal, are not included in the table.

RESULTS OBTAINED DURING THE SEASON OF 1918

The method of sampling and the general procedure was the same in 1918 as in 1917. The method of irrigation was changed from the furrow to the basin method. Levees were constructed so that each tree was inclosed in a square basin which could be supplied with water from a delivery flume. Therefore, a definite amount of water could be supplied to each tree, with more even distribution in the soil.

The rainfall, up to February 1, was only 2.15 inches. This was 7.56 inches less than normal. The even numbered plots were therefore irrigated on February 4 and 5. The dates of the irrigation, amounts of water applied, and soil moisture records are given in table 8.

Complete records for the yields of the trees were not obtained for the season of 1918, but the yields of representative trees in the different rows were secured and compared. No significant difference could be determined in weight or size of fruit from the various irrigated rows. The yields from the trees in rows 1 and 9 were smaller than those from the other trees. The soil-moisture supply in these rows was below the wilting coefficient by June 1.

The frequent irrigations given the different rows and the interference due to the penetration of the roots of the even-numbered check rows into the adjacent irrigated rows were possible reasons for lack of difference both in the appearance of the trees and the yields obtained.

TABLE 8

SUMMARY OF IRRIGATION TREATMENTS AND SOIL-MOISTURE CONTENTS IN MUIR PEACH ORCHARD, DAVIS, 1918

Row	Dates of irrigation	Depth of water applied in acre-inches per acre	Dates of sampling	Percentage of moisture in the soil						Average percentage of moisture in 6 feet	Equivalent depth of water in inches
				1st foot	2nd foot	3rd foot	4th foot	5th foot	6th foot		
1, 9	Sept. 11–12*	4.0*	Apr. 1	18.9	18.5	14.2	14.2	11.3	11.7	13.1	11.7
			June 1	18.7	11.3	10.7	10.0	9.1	9.6	9.9	9.2
			Sept. 21	18.5	13.0	10.1	8.6	7.8	8.2	11.4	10.7
3, 11	May 21	6.05	Apr. 1	18.5	17.9	15.8	16.5	15.2	14.0	16.3	15.3
	Aug. 12	10.30	May 20	12.3	13.0	13.2	14.8	14.6	14.6	13.7	12.8
	Sept. 11–12	4.0*	May 22	26.8	21.1	18.3	17.2	16.4	15.6	19.2	18.0
	Sept. 25	6.30	Aug. 7	9.3	10.0	9.1	9.2	8.3	8.4	9.1	8.5
			Aug. 14	28.2	21.6	13.9	12.4	11.9	10.4	16.4	15.4
			Sept. 21	19.1	16.7	12.6	12.1	11.1	13.4	13.4	12.6
			Sept. 26	25.7	21.4	19.9	17.1	16.0	10.6	18.4	17.4
2, 4, 6 8,10, 12 14, 16	Feb. 4–5	8.55†	Feb. 1	13.1	10.4	10.1	9.9	10.1	9.5	10.5	9.8
			Feb. 11	20.8	19.1	16.5	15.5	14.9	12.0	16.5	15.4
	Sept. 11–12	4.0*	Apr. 1	18.9	18.4	16.2	17.6	17.4	15.5	17.3	16.2
			June 1	9.9	12.7	13.0	14.6	14.1	14.1	13.1	12.2
			Sept. 21	20.5	14.8	10.4	9.8	9.3	8.2	12.2	11.4
5, 13	Apr. 4	5.95	Apr. 1	17.2	17.2	14.6	11.8	10.9	11.0	13.8	12.9
	May 21	4.5	Apr. 6	25.0	20.5	18.5	20.6	19.1	15.2	19.9	18.6
	Aug. 12	10.1	May 20	12.7	13.5	13.4	16.1	17.2	18.2	16.9	15.6
	Sept. 11–12	4.0*	Aug. 7	9.2	10.0	9.5	9.2	8.9	8.8	9.4	8.8
			Aug. 14	26.6	19.4	15.2	10.8	9.7	10.4	15.4	14.4
			Sept. 21	21.2	18.4	14.2	12.7	10.7	12.2	14.9	13.9
7, 15	July 2	9.78	Apr. 1	20.6	19.1	17.1	17.8	18.4	15.1	18.0	16.8
	Sept. 11–12	4.0*	June 1	8.4	11.3	11.7	13.4	13.9	12.4	11.8	11.0
	Sept. 25	7.38	June 28	10.6	10.3	10.0	10.2	8.6	8.7	9.8	9.1
			July 3	30.8	23.5	20.4	17.2	12.7	11.8	19.4	18.2
			Sept. 21	19.0	14.2	10.6	10.0	9.5	10.6	12.3	11.5
			Sept. 26	26.3	21.3	19.7	17.6	16.0	15.2	19.4	18.1

* Rainfall.

† Includes 0.99 inches of rain which fell during irrigation.

For moisture equivalents see table 6.

RESULTS OBTAINED DURING THE SEASON OF 1919

Investigations of the root systems of the trees during the winter of 1918–1919 showed that the roots of the trees in adjacent rows overlapped, and there was a possibility that the trees in the check rows took moisture from the adjacent irrigated rows. For this reason the trees in the even-numbered rows were removed in February, 1919, leaving rows 1, 3, 5, 7, 9, 11, 13, and 15. This numbering was retained. The trees were then 20 feet apart in the rows and the rows were 40 feet apart. It was decided to give the two rows which constituted one treatment only one irrigation, instead of two or more irrigations which were given in the two previous seasons.

The differential irrigation treatments were as follows:

Rows 1 and 9 received no irrigation.

Rows 3 and 11 were irrigated near to the time when length growth was beginning to slacken. This was usually about the first week in June.

Rows 5 and 13 were irrigated shortly before harvesting. The time of application was about the first week in August.

Rows 7 and 15 were irrigated about 30 days after harvesting to observe the possible influence on dormancy and fruit bud formation. The irrigation was given about the middle of September.

These treatments were given during the remainder of the experiment which was carried on until the end of the season of 1922. It should be noted that these treatments are not essentially different from those given the same rows during 1917 and 1918. During 1917 and 1918, rows 1 and 9 were not irrigated; the soil moisture in rows 3 and 11 was maintained at a high percentage during the fore part of the season when rapid length growth was being made. The percentages of soil moisture in rows 5 and 13 were high during the time when the fruit was maturing; and rows 7 and 15 were supplied with ample moisture after the crop was removed.

The method used in 1917 and 1918 to determine the amount of water to apply, was followed in 1919 and subsequent seasons. At each irrigation, water was applied in amounts sufficient to raise the first 6 feet of soil to the maximum amount it was capable of holding against gravity. The trees were irrigated each time in basins, to insure the evenness of application of the water. Square basins 20 feet by 20 feet were constructed around each tree. Since the rows

TABLE 9

SUMMARY OF THE IRRIGATION TREATMENTS AND SOIL-MOISTURE CONTENTS IN THE MUIR PEACH ORCHARD, DAVIS, 1919

Row	Depth of soil sample	Dates irrigated	Depth of water applied in inches	Moisture content in percentage on dry weight basis																				
				Apr. 3	Apr. 18	May 22	June 5	June 7	June 9	June 11	July 11	Aug. 1	Aug. 6	Aug. 7	Aug. 11	Aug. 22	Aug. 26	Sept. 11	Sept. 15	Sept. 17	Sept. 20	Oct. 15	Nov. 25	Dec. 23
1, 9	0–3 3–6			15.4 15.2	14.8 14.9	11.6 13.8	10.5 12.6				9.2 10.7	8.6 9.8					8.7 9.2	8.6 9.3				8.6 9.3	8.7 9.4	13.0 9.7
		Average		15.3	14.9	12.7	11.5				10.0	9.2					9.0	9.0				9.0	9.1	11.4
3, 11	0–3 3–6	June 6	8.06	16.0 16.2	14.9 15.8	12.2 14.2	11.0 12.7	23.2 19.7	20.6 18.6	18.2 16.9	12.1 12.2	10.7 10.8					9.6 9.6	9.4 9.2				9.5 9.3	9.4 9.3	14.3 9.9
		Average		16.1	15.4	13.2	11.8	21.4	19.6	17.6	12.1	10.7					9.6	9.3				9.4	9.4	12.1
5, 13	0–3 3–6	Aug. 5	9.67	16.0 15.8	15.1 15.0	12.1 13.7	10.7 12.4				9.4 9.8	9.2 10.3	23.1 18.2	21.2 18.6	19.0 16.6	15.2 14.9	13.4 13.2	12.4 12.2				11.1 11.0	10.6 10.4	14.8 10.5
		Average		15.9	15.0	12.6	11.5				9.6	9.8	20.6	19.9	17.8	15.0	13.3	12.3				11.1	10.3	12.7
7, 15	0–3 3–6	Sept. 11	10.21	16.2 18.0	15.2 17.7	11.8 13.9	11.1 12.2				9.6 10.8	9.2 10.2					8.8 9.8	8.7 9.4	22.8 21.0	20.1 20.4	18.2 18.8	17.0 17.4	16.8 16.0	18.4 16.0
		Average		17.1	16.4	12.9	11.6				10.2	9.7					9.3	9.1	21.9	20.2	18.4	17.2	16.4	17.2

were 40 feet apart, this left a dry strip 20 feet wide between the rows. The interference of adjacent trees probably was greatly lessened by this method.

Beginning with the season of 1919, all soil samples were taken with a soil tube, and the results show much greater consistency in the moisture determinations. The samples were taken to a depth of 6 feet. The soil removed from the first 3 feet and that from the second 3 feet, were placed in separate soil cans. The results, in percentages, of moisture obtained were the averages of moisture contents of these two depths of soil. The entire core of soil removed from the tube was retained for the moisture determination. A summary of the irrigations applied and the moisture contents of the soil at different times throughout the season are given in table 9.

The moisture equivalents of the soil in the rows, grouped according to irrigation treatments, are given in table 10.

TABLE 10

SUMMARY OF MOISTURE EQUIVALENT DETERMINATIONS AND CALCULATED VALUES OF THE WILTING COEFFICIENTS AND HYGROSCOPIC COEFFICIENTS OF THE SOIL IN THE MUIR PEACH ORCHARD, DAVIS

Row		Depth of soil, in feet		
		0-3	3-6	0-6
1, 9	Moisture equivalent	18.82±0.38	16.24±0.40	17.53±0.27
	Wilting coefficient	10.23±0.21	8.82±0.22	9.33±0.16
	Hygroscopic coefficient	6.95±0.14	5.99±0.15	6.33±0.11
3, 11	Moisture equivalent	18.66±0.38	16.42±0.69	17.54±0.38
	Wilting coefficient	10.11±0.21	8.92±0.35	9.53±0.21
	Hygroscopic coefficient	6.89±0.14	6.06±0.25	6.47±0.14
5, 13	Moisture equivalent	19.60±0.23	16.00±0.50	17.80±0.26
	Wilting coefficient	10.65±0.12	8.70±0.27	9.68±0.14
	Hygroscopic coefficient	7.23±0.08	5.91±0.78	6.58±0.10
7, 15	Moisture equivalent	19.82±0.21	15.88±0.42	17.85±0.23
	Wilting coefficient	10.77±0.11	8.63±0.23	9.70±0.12
	Hygroscopic coefficient	7.31±0.08	5.86±0.15	6.59±0.08

The moisture contents of the soil in the rows throughout the growing season of 1919, are graphically illustrated in figure 16. The graphs in this figure are drawn in the same manner as those which illustrate the moisture conditions in the Santa Clara Valley orchards.

However, in these graphs, the scale is changed, the time for which the moisture contents are shown is shorter, and the losses of moisture from the soil following irrigation are more clearly defined. The lines representing the loss of moisture from the upper 3 feet of soil and those representing the loss from the lower 3 feet approach much closer

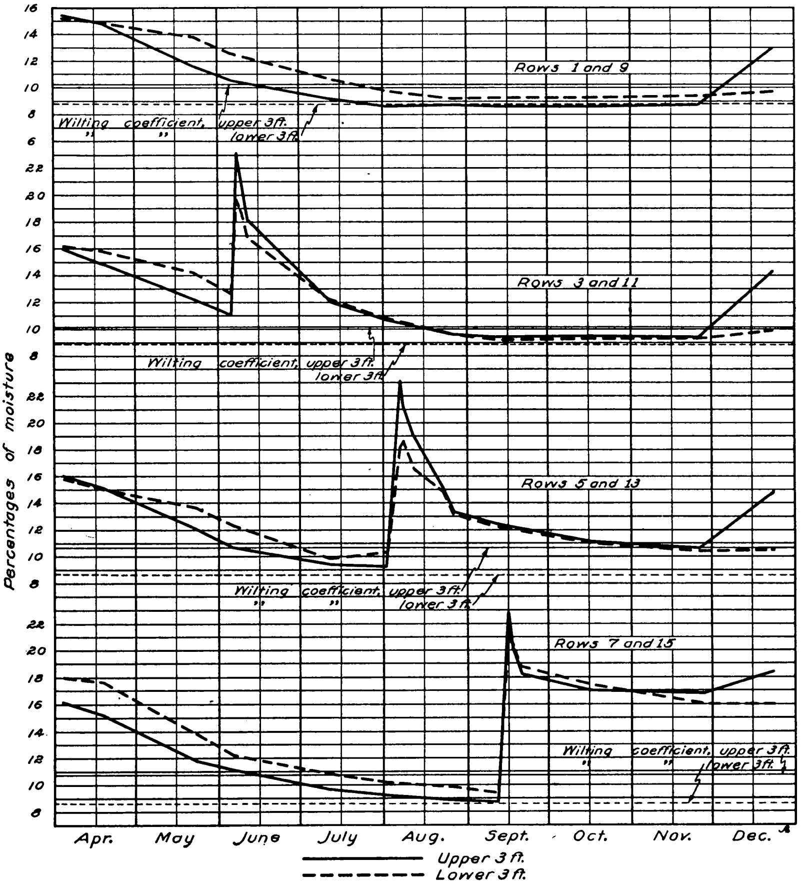

Fig. 16. Soil-moisture conditions in the Muir peach orchard at Davis during the growing season of 1919. The rows are grouped according to irrigation treatment.

to parallelism here than in the graphs of the soil moisture in the Santa Clara Valley orchards. At each irrigation in the peach orchard, sufficient water was applied to wet the soil to a full depth of 6 feet. This insured the same relative amounts of available water for growth in the two depths of soil.

The first picking was on August 13, 1919. Four pickings were made, the last one being made on August 27. There were no differences in the dates of ripening of the fruit in the different rows. A summary of the yields of fresh and dried fruit from the rows constituting the different treatments is given in table 11. These records show that there were no significant differences in the weight of fresh fruit, the weight of dried fruit, the number of fruits to the tree, the average weight of a peach; or the drying ratio.

After the peaches had been thinned, and after the chance of so-called "June drop" were lessened, measurements of circumferences of the peaches were started. Ten peaches, regularly spaced or located on each tree, were tagged and the maximum horizontal circumferences were measured with a small steel tape. The averages of these measurements are given in table 12. It is apparent from these records as well as those of the average weight of a peach given in table 11 that there were no significant differences in the sizes of peaches produced on the different trees.

TABLE 11

SUMMARY OF YIELDS FROM MUIR PEACH ORCHARD, DAVIS, 1919

Row	Number of trees	Dates irrigated	Total weight fresh fruit	Pounds culls	Number matured peaches	Weight fresh fruit	Average weight of a fruit fresh	Weight dried fruit	Number of fresh fruit to make one pound of dried fruit
1	6	No irrigation	1182.0	91.0	4249	1092.7	0.26	201.95	5.4
9	6		1308.5	97.5	5553	1211.0	0.22	235.30	5.2
	Average per tree		208.0	15.7	816 ±54.4	192.0 ±9.5	0.24 ±0.01	36.44	
3	6	June 5–6	1405.8	143.0	5105	1262.8	0.25	242.59	5.2
11	5		1093.5	143.5	3896	950.0	0.24	179.06	5.2
	Average per tree		227.0	26.1	820 ±38.1	201.0 ±6.8	0.25 ±0.01	38.33	
5	6	Aug. 4–5	1240.3	136.3	4448	1104.0	0.25	204.0	5.4
13	5		1143.0	166.5	4096	976.5	0.24	175.8	5.5
	Average per tree		216.6	27.5	775 ±56.6	187.0 ±12.8	0.24 ±0.02	34.5	
7	6	Sept. 11	1311.8	146.8	5391	1165.0	0.21	228.4	5.1
15	4		737.25	88.8	2505	648.5	0.25	131.5	4.9
	Average per tree		204.9	23.5	789 ±45.4	181.3 ±8.0	0.23 ±0.01	36.0	

Fig. 17. Wilting and partial defoliation of trees in the unirrigated row 9 caused by drought, August 18, 1920.

Fig. 18. Condition of trees in the unirrigated row 9 on August 2, 1919. Much less wilting is shown than in figure 17.

TABLE 12

AVERAGE SIZE OF PEACHES FROM MUIR PEACH ORCHARD, DAVIS, 1919. THE MAXIMUM HORIZONTAL CIRCUMFERENCE IN CENTIMETERS IS RECORDED

(Each value is the average of the measurements of 60* peaches for each row, or of 120 peaches for the average for each treatment.)

Row	June 21	July 11	July 30	Aug. 9	Aug. 15
1	12.4	14.0	16.5	18.7	19.3
9	11.7	13.0	15.4	17.6	18.2
Average	12.0 ±0.10	13.5 ±0.12	16.0 ±0.15	18.2 ±0.18	18.8 ±0.18
3	12.3	13.7	16.1	18.4	19.0
11	12.3	13.9	16.2	18.5	19.3
Average	12.3 ±0.07	13.8 ±0.09	16.2 ±0.13	18.4 ±0.13	19.2 ±0.19
5	12.2	13.6	16.1	18.5	19.2
13	11.9	13.3	15.7	18.5	19.3
Average	12.1 ±0.09	13.5 ±0.11	15.9 ±0.15	18.4 ±0.15	19.2 ±0.17
7	12.0	13.3	15.7	17.8	18.6
15	12.6	13.8	16.2	18.4	19.1
Average	12.3 ±0.09	13.6 ±0.10	16.0 ±0.10	18.1 ±0.17	18.8 ±0.16

* A few peaches dropped before the final measurements were made.

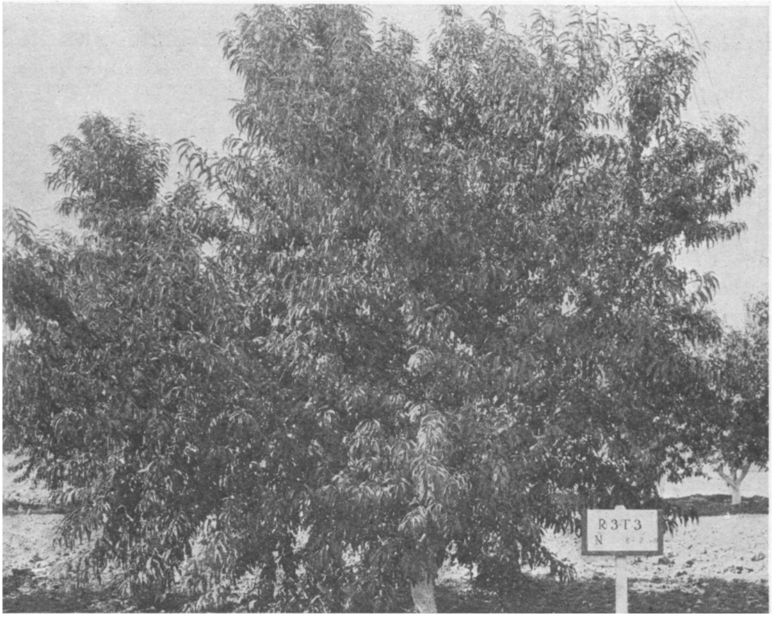

Fig. 19. Condition of trees in irrigated row 3 on August 2, 1919. The heavier foliage and absence of wilting is evident when this figure is compared with figures 17 and 18.

TABLE 13

Summary of Irrigation Treatments and Soil-Moisture Contents in Muir Peach Orchards, Davis, 1920

Row	Date of irrigation	Depth of water applied	Depth of soil in feet	Percentage of moisture								
				Apr. 5	Apr. 27, 29	June 5	June 16	July 10	Aug. 7	Aug. 10	Sept. 17	Sept. 24
1, 9	No irrigation........	....	0–3	14.7	13.5	9.8	....	9.1	8.3	....	8.3	....
			3–6	9.1	9.0	8.8	....	8.3	7.5	....	7.7	
			Average	11.9	11.3	9.3	....	8.7	7.9	....	8.0	
3, 11	June 9–10...............	9.96	0–3	14.9	15.2	9.9	17.1	12.5	10.8	....	8.4	....
			3–6	9.3	11.3	9.0	15.4	13.3	9.4	....	8.8	....
			Average	12.1	13.3	9.5	16.3	12.9	10.1	....	8.6	....
3, 13	Aug. 7.....................	11.04	0–3	15.0	13.4	10.2	10.1	9.2	8.5	22.2	10.9	....
			3–6	9.2	9.4	9.1	9.2	9.2	8.2	19 0	13.6	....
			Average	12.1	11.4	9.7	9.6	9.2	8.4	20.6	12.3	....
7, 15	Sept. 20–21–22.....	10.68	0–3	17.7	15.9	10.4	....	9.8	8.7	....	8.4	21.6
			3–6	11.7	12.4	11.4	....	10.3	9.3	....	9.1	15.6
			Average	14.7	14.2	10.9	....	10.1	9.0	....	8.8	18.6

RESULTS OBTAINED DURING THE SEASONS OF 1920, 1921, AND 1922

The procedure during the seasons of 1920, 1921, and 1922 was the same as that just described for the season of 1919. A partial summary of the soil moisture data of 1920 is given in table 13 for comparison with the soil-moisture condition in 1919, as shown in table 9. The rainfall during the winter of 1920 was only 8.35 inches, a deficiency of 6.79 inches. This was a particularly severe season for the unirrigated rows. The moisture content of the 3 to 6-foot depths of the soil in rows 1, 3, 5, 7, 9, and 11, was below the wilting coefficient on June 5. All of the trees in these rows were wilted at this time and some leaves had dropped. Row 9, the inside row which was not irrigated, clearly showed the effect of lack of water. The trees in row 1, the other unirrigated row, were not so badly wilted as those in row 9. The wilted and defoliated condition of the trees in row 9 on August 18, 1920, is illustrated by the photograph of tree 3 (fig. 17), which is typical of the trees in that row. While these trees showed some wilting in 1919 (fig. 18), they were in much better condition than in 1920. The condition of the trees in row 9 in 1919, can be further compared with the condition of those in row 3, by means of figures 18 and 19. The latter is a photograph taken of tree 3, in row 3, on August 2, 1919. The upper 3 feet of soil in row 3 had just been reduced to the wilting coefficient on August 1, but the lower 3 feet was above the wilting coefficient on this date.

Early in May a severe north wind blew for several days. This was an extremely hot and strong wind which caused much damage to the outside trees on the north and west sides of the orchard. For this reason the summary of the yields of only the inside trees in each row is given in table 14.

The first picking on all but row 9, was made on August 17, 1920, and the last picking on August 28. The fruit on row 9 did not mature until August 23. The last picking on this row was on September 3. Table 15 gives the average circumferences of peaches for the year 1920. These measurements were made in the same manner as those in 1919. The difference in size on the last date the measurements were made between the averages of rows 1 and 9, and 5 and 13, is 2.1 ± 0.55 centimeters. However, the size of the peaches in row 1 was not less than that of the peaches in row 3. The trees in row 9 were practically defoliated by the date of the last picking, September 3, and the peaches in this row were noticeably smaller than in the other rows.

TABLE 14

SUMMARY OF YIELDS OF INSIDE TREES OF MUIR PEACH ORCHARD, DAVIS, 1920

Row	Dates of irrigation	Number of trees in average	Weight of fresh fruit, pounds	Weight to a tree, pounds	Number of fresh fruit	Number to a tree	Average weight of a fruit, pounds	Weight of dried fruit	Weight of dried fruit to a tree, pounds	Pounds of fresh fruit for 1 pound of dried fruit	Weight of culls, pounds
9	No irrigation	4	238.5	59.5	1705	426	0.14	56.0	14.0	4.3	0
3, 11	June 9-10	7	797.0	114.0	3535	505	0.23	202.5	29.0	3.9	210.0
5, 13	Aug. 6	7	776.5	110.0	3572	510	0.22	176.5	25.0	4.4	86.0
7	Sept. 20–22	4	409.0	102.5	2205	551	0.19	95.0	24.0	4.3	35.0

TABLE 15

AVERAGE SIZE OF PEACHES FROM MUIR PEACH ORCHARD, DAVIS, 1920. THE MAXIMUM HORIZONTAL CIRCUMFERENCE IN CENTIMETERS IS RECORDED

(Each value is the average of the measurements of 60 peaches for each row, or of 120* peaches for the average for each treatment.)

Row	May 21	June 7	July 1	July 20	Aug. 6
1	10.3	11.5	13.1	16.0	18.7
9	10.9	11.2	12.8	14.6	16.8
Average	10.6 ±0.08	11.4 ±0.12	13.0 ±0.16	15.3 ±0.30	17.8 ±0.36
3	10.2	11.1	13.0	15.4	18.4
11	11.1	11.7	13.7	16.4	19.6
Average	10.6 ±0.10	11.4 ±0.12	13.4 ±0.13	15.9 ±0.18	19.0 ±0.25
5	10.6	13.3	15.2	18.2	20.6
13	11.3	12.1	14.0	16.4	19.2
Average	11.0 ±0.09	12.7 ±0.21	14.6 ±0.25	17.3 ±0.37	19.9 ±0.42
7	11.0	11.9	12.9	15.3	17.8
15	11.4	12.4	13.8	16.4	19.4
Average	11.2 ±0.05	12.2 ±0.10	13.4 ±0.19	15.8 ±0.19	18.6 ±0.32

* **After August 6 so many peaches dropped that further measurements could not be made.**

During the seasons of 1921 and 1922, the irrigation treatments and the procedure were the same as in 1919 and 1920. The irrigations given in 1921 were as follows: Rows 3 and 11 irrigated on June 7 and 8 with 8.80 acre-inches to the acre; rows 5 and 13 on August 8 with 10.50 inches; and rows 7 and 15 on October 7 with 10.00 inches.

TABLE 16

SUMMARY OF YIELDS FROM MUIR PEACH ORCHARD, DAVIS, 1921

Row	Number of trees	Dates irrigated	Total weight fresh fruit, including culls	Culls	Weight fresh fruit	Weight dried fruit	Number of fresh fruit to make 1 pound of dried fruit
			Pounds	*Pounds*	*Pounds*	*Pounds*	
1	6	No irrigation	1666.5	222.5	1444.0	211.5	6.8
9	6		960.5	140.0	820.5	194.0	4.2
	Average to a tree		218.9	30.2	188.7 ±18.23	33.8 ±2.69	
3	6	June 7–8	1331.0	230.5	1100.5	226.0	4.8
11	5		1177.5	162.0	1015.5	215.5	4.7
	Average to a tree		228.6	35.7	192.4 ±6.53	40.1 ±1.26	
5	6	Aug. 8	1571.0	172.5	1408.5	249.0	5.7
13	6		1742.5	279.0	1463.5	249.0	5.9
	Average to a tree		276.1	37.6	239.3 ±15.44	41.5 ±2.62	
7	6	Oct. 7	1457.0	162.5	1294.5	258.0	5.0
15	6		1372.0	223.5	1148.5	221.0	5.0
	Average to a tree		235.8	32.2	203.6 ±13.03	40.0 ±2.44	

During 1922 rows 3 and 11 were irrigated on June 23 with 8.00 inches, rows 5 and 13 on August 12 with 10.00 inches, and rows 7 and 15 on September 20 with 10.50 inches. The soil-moisture conditions in the different rows during the seasons of 1921 and 1922, were substantially the same as those given for the year 1919. For this reason they are not reported.

The yields for the season of 1921 are given in table 16. The first picking was on August 23, and the last on September 2. The yields of green fruit from the different rows for the season of 1922 is given in table 17. The first picking was on August 26, and the last on September 5, 1922.

TABLE 17

SUMMARY OF YIELDS FROM MUIR PEACH ORCHARD, DAVIS, 1922

Row	Number of tree	Dates irrigated	Total weight fresh fruit	Culls	Weight fresh fruit	Average weight fresh fruit to a tree
			Pounds	*Pounds*	*Pounds*	*Pounds*
1	6	No irrigation	1561.5	348.5	1213.0	202.2
9	6		1087.0	107.0	980.0	163.3
Average			1324.2	227.8	1096.5	182.6 ±9.32
3	6	June 23	1458.8	238.5	1220.2	203.4
11	5		1349.5	160.0	1189.5	237.9
Average			1404.1	199.3	1204.9	219.1 ±9.92
5	6	Aug. 12	1681.0	342.0	1339.0	223.2
13	6		1826.0	216.0	1610.0	268.3
Average			1753.5	279.0	1474.5	245.1 ±12.59
7	6	Sept. 15	2294.0	149.5	1244.5	207.4
15	6		1613.5	306.0	1307.5	217.9
Average			1953.8	227.8	1276.0	212.7 ±6.62

ANALYSES OF PEACHES FOR SUGAR AND ACID CONTENT

Samples of fruit for analyses were taken from the different rows during the seasons of 1917, 1918, and 1919. Care was taken in selecting the samples to secure representative fruits of average ripeness and size. At each sampling, two peaches were taken from each tree, one from the south side, and one from the north side. Analyses were made of the samples from each tree. Samples were collected every other day, starting about 10 days before picking. The first samples were quite green, and the last were over-ripe. All were taken from the trees at 8:30 o'clock in the morning.

The results obtained showed no significant differences in percentage of soluble solids, most of which, presumably, would be sugars, that could be attributed to the differences in irrigation treatments. A summary of the results of the determinations of soluble solids in the pulp and juice of the peaches for the season of 1918 is given in table 18. The results of acid determinations for the season of 1919 are given in table 19. The amounts of acid found in the juice likewise showed no significant differences. The variations in the rows receiving the same treatment were in many cases as great as the differences between the rows irrigated differently.

TABLE 18

SUMMARY OF PERCENTAGES OF SOLUBLE SOLIDS IN PULP AND JUICE OF PEACHES FROM MUIR PEACH ORCHARD, DAVIS, 1918

Row	Dates of irrigation	Dates samples were collected				
		Aug. 9	Aug. 12	Aug. 16	Aug. 22	Aug. 26
1	No irrigation	3.43	4.56	3.87	4.30	3.51
9		3.83	2.97	3.37	3.20	4.37
Average		3.63	3.76	3.62	3.75	3.94
3	May 21	4.45	3.99	....	5.44	3.91
11	Aug. 12	3.33	3.00	....	3.30	3.53
	Sept. 25					
Average		3.89	3.50	....	4.37	3.72
5	Apr. 4	3.55	3.25	3.14	3.62	3.17
13	May 21	3.73	3.63	3.23	3.17	3.23
	Aug. 12					
Average		3.64	3.44	3.18	3.40	3.20
7	July 2	3.75	3.21	3.15	2.49	3.72
15	Sept. 25	3.78	3.06	3.47	3.21	2.99
Average		3.76	3.14	3.31	2.85	3.36
2		4.08	4.50	3.38	3.78	5.29
4	Feb. 4	3.78	3.73	2.88	4.21	3.33
6		3.55	3.39	2.83	2.68	2.82
8		4.07	3.02	3.19	2.84	3.82
10		3.28	4.61	3.39	3.82	2.76
12		3.66	3.61	2.77	2.93	4.49
14		3.83	2.55	2.50	4.04	3.92
Average		3.75	3.63	2.99	3.47	3.78

TABLE 19

ACID CONTENT OF THE JUICE OF PEACHES FROM MUIR PEACH ORCHARD, DAVIS, 1919, IN GRAMS TO A LITER OF JUICE

Row	Dates of irrigation	Dates samples were collected				
		Aug. 8	Aug. 11	Aug. 13	Aug. 15	Aug. 17
1	No irrigation	16.89	12.71	7.72	4.29	4.70
9		10.72	11.26	9.11	3.22	5.63
Average		13.30	11.98	8.41	3.75	5.16
3	June 5–6	11.69	8.58	7.72	4.07	6.03
11		11.79	9.38	11.39	3.75	3.75
Average		11.74	8.98	9.50	3.91	4.89
5	Aug. 4–5	8.58	10.72	7.51	4.29	5.63
13		10.72	13.71	9.87	4.51	4.02
Average		9.65	12.21	8.69	4.40	4.82
7	Sept. 11	9.65	11.53	8.26	4.07	5.63
15		11.80	11.26	8.26	5.90	4.02
Average		10.72	11.39	8.26	4.98	4.82

MEASUREMENTS OF GROWTH OF PEACH TREES UNDER DIFFERENT SOIL–MOISTURE CONDITIONS

Beginning with the season of 1919, measurements were made of the circumferences of the trunks just above the crown of the tree, and of the main branches of the trees near the point where they left the trunk. The measurements were taken each time at the same place.

The bark was carefully smoothed before each measurement by scraping away with a knife any rough edges which protruded beyond the general surfaces of the trunk or branches. Only in one or two instances were measurements recorded which seemed to be incorrect. The results obtained from the beginning of the season of 1919 to the beginning of that of 1922, calculated in square centimeters of area of cross-section of the trunks of the trees in the different rows, grouped according to the irrigation treatment they received, are given in table 20. The average areas of cross-section of the main branches of the trees for the different rows also were obtained for this same period. Since no significant differences were found in the measurements for the trees in the different rows, these data are not presented.

TABLE 20

AREAS OF CROSS-SECTION OF THE TRUNKS OF MUIR PEACH TREES, DAVIS MEASUREMENTS IN SQUARE CENTIMETERS

Row	Number of trees	Season of 1919							
		April 25	May 15	June 6	June 14	July 3	July 29	Aug. 28	Sept. 18
1	6	221.6	226.0	230.4	230.2	234.6	238.2	243.4	247.0
9	6	182.5	186.0	189.1	188.2	190.9	192.3	193.8	195.2
	Average	202.1	206.0	209.8	209.2	212.8	215.3	218.6	221.1
		±4.69	±4.83	±5.37	±5.32	±5.31	±5.69	±5.95	±6.26
3	6	200.2	203.8	206.6	207.3	211.7	215.0	219.6	223.4
11	5	182.1	185.3	187.8	188.3	191.7	199.4	201.2	204.6
	Average	191.2	194.5	197.2	197.8	201.7	207.2	210.4	214.0
		±8.63	±6.95	±7.40	±8.63	±7.40	±7.45	±7.15	±7.99
5	6	179.8	182.5	186.1	186.5	188.3	193.7	194.1	197.2
13	5	217.7	220.8	222.4	222.5	225.8	228.7	232.0	235.7
	Average	198.8	201.7	204.2	204.5	207.1	211.2	213.1	216.4
		±8.12	±6.62	±4.80	±6.02	±6.08	±6.43	±6.24	±6.20
7	6	197.6	198.0	202.9	203.4	203.8	208.1	209.9	212.8
15	5	202.8	208.2	211.0	210.6	214.2	219.3	221.3	224.3
	Average	200.2	203.1	207.0	207.0	209.0	213.7	215.5	218.5
		±5.62	±5.89	±6.19	±6.20	±6.43	±6.89	±7.18	±7.41

Row	Number of trees	Season of 1920							Season of 1921		1922
		Jan. 13	May 5	May 21	June 9	July 1	July 20	Aug. 6	Feb. 25	June 7	Jan. 26
1	6	251.6	256.8	259.1	261.4	266.2	269.7	271.5	285.2	296.9	306.5
9	6	197.2	203.0	204.1	204.7	206.5	207.6	207.5	212.3	222.2	228.9
	Average	224.4	229.9	231.6	233.1	236.3	238.6	239.5	248.8	259.7	267.7
		±6.46	±6.63	±6.84	±7.06	±7.43	±7.79	±7.94	±9.19	±9.85	±10.34
3	6	225.1	231.2	231.4	233.5	236.2	239.2	241.4	245.8	259.4	264.7
11	5	208.7	215.7	216.9	219.9	223.9	228.6	231.1	231.4	246.8	257.8
	Average	216.9	223.5	224.1	226.7	230.0	233.9	236.3	238.6	253.1	261.2
		±7.93	±8.13	±8.08	±8.09	±8.05	±8.20	±8.19	±8.37	±8.78	±9.30
5	6	199.4	205.5	206.5	207.7	210.0	213.1	216.1	220.4	232.4	239.2
13	5	238.9	247.3	249.9	251.1	254.9	258.4	259.7	271.1	285.4	289.9
	Average	219.1	226.4	228.2	229.4	232.4	235.8	237.9	245.7	258.9	264.5
		±6.17	±6.40	±6.55	±5.60	±6.89	±7.07	±7.69	±8.31	±8.48	±8.68
7	6	214.3	221.8	222.7	224.4	227.7	228.8	229.6	234.7	246.5	255.7
15	5	226.9	233.9	235.0	239.9	240.6	243.6	246.2	254.3	265.0	274.9
	Average	220.1	227.9	228.8	232.1	234.2	236.2	237.9	244.5	255.7	265.3
		±7.59	±7.84	±8.93	±7.72	±8.00	±8.26	±8.38	±8.71	±9.22	±10.29

The peach trees were too large to permit taking length growth measurements directly. Estimates were made of the seasonal growth each year. With the exception of the year 1920, during which the trees in row 9 apparently did not make as good growth as the other trees, no apparent differences could be detected. Such estimates on trees so large as those under observation, are of doubtful value. Tufts[50] found high coefficients of correlation between circumference of trunk and weight of top, and also between circumference of trunk and weight of root, on two-year-old peach trees. This author calls attention to the fact that circumference measurements made to determine growth "take into consideration only quantitative changes in the plant, and pay no regard whatever to qualitative changes. For this reason, circumference measurements lose much of their value as soon as the trees cease their purely vegetative growth and prepare for the production of blossoms and fruit."

The writer, together with Professor A. H. Hendrickson, of the Division of Pomology, made measurements of total length of new growth and circumferences of trunk, in an orchard of French prune trees adjoining the Muir peach orchard under discussion. Data were secured from 195 trees which were being studied to determine the variability before starting an irrigation experiment. The trees were nursery stock, French prunes on Myrobalan root, planted in the orchard in February, 1917.

Measurements were made at the end of the growing seasons of 1919 and 1920. The trees bloomed and bore a few prunes in 1920. The coefficient of correlation between length growth and area of cross-section of trunk in 1920 was 0.74 ± 0.026. In January, 1921, the coefficient of correlation between length growth and area of cross-section was 0.71 ± 0.025, and the coefficient of correlation between length growth and increase in area of cross-section was 0.68 ± 0.026. In each case there was strong positive correlation, indicating that a measure which gives the area of the cross-section of the trunk, gives a satisfactory indication of the amount of new growth being made by prune trees in an orchard for four seasons.

While measurements of circumferences of trunks may not be an exact measure of the growth of older producing trees, the fact that no significant differences were found in either the increase in area of cross-sections of trunks, or of main branches of the peach trees under observation, may indicate that there was no difference in growth due to different soil-moisture conditions. Figure 21 graphically illustrates the data given in table 20, and shows that no significant difference in rate of increase in the cross-sectional area of the trunks under the different treatments occurred from April, 1919, to January, 1922.

A record of the growth made by trees in the different rows was obtained by a photographic method which will be described in detail elsewhere. Comparisons made between measurements taken from photographs made at different times show there was no significant difference in the growth of the trees in the different rows with the exception of the season of 1919–1920, an unusually dry season during which trees in the unirrigated rows were wilted for a long period.

DISCUSSION OF RESULTS

These studies with peach trees lead to the same general conclusions reached in the studies with the Santa Clara Valley prune orchards. Differences could not be observed in trees growing on soil with high moisture content and those growing on soil with low moisture content until the soil-moisture supply had been reduced to a condition corresponding to the calculated wilting coefficient.

The yields from the non-irrigated trees in rows 1 and 9 in 1917, 1918, 1920, and 1922, were less than those from the irrigated trees. The soil-moisture content in each of these years was reduced to the wilting coefficient early in the season and the trees remained in a wilted condition for a long time. There appear to be no significant differences in yields from the trees in the rows under the different irrigation treatments.

The size of the peaches did not seem to be affected by irrigation near the time of picking. Likewise, the quality as measured by the amount of water in the fruit was not influenced by a high moisture content in the upper 6 feet of soil near the time of ripening. Furthermore, the results of the determinations of the amount of soluble solids, most of which were sugars, and the acid content, though based on so few samples from each tree, also indicate that the quality of the fruit was not materially influenced.

As in the case with the mature prune trees, it was noted that these peach trees always wilted when the moisture supply of the first 6 feet of soil had been reduced to the wilting coefficient even though the soil below this depth was moist. It appears, then, that the number of roots below the 6-foot depth was not sufficient to keep the trees from wilting. However, except during the season of 1920 when the trees in the unirrigated rows were badly wilted and largely defoliated toward the end of the season, some turgid leaves would be found on the wilted trees even though the upper 6 feet of soil were dry.

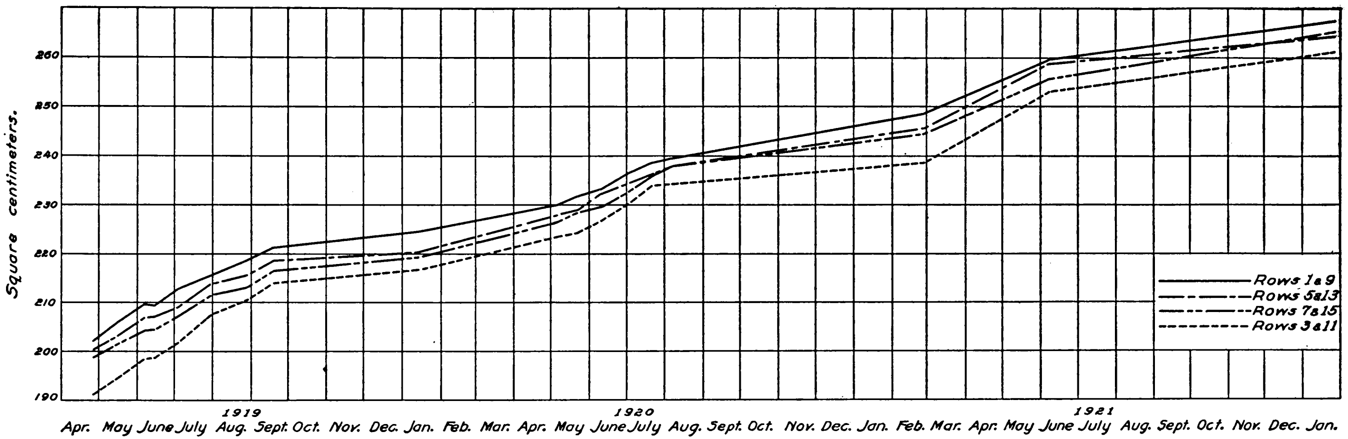

Fig. 20. Areas of cross-section of trunks of Muir peach trees, Davis.

The moisture content of the soil was not reduced to the same relative degree of dryness by these peach trees as by the mature prune trees. The lowest moisture content found in any of the plots in the Muir peach orchard was 7.5 per cent in August, 1920. The wilting coefficient of the soil in this plot is 8.8 per cent and the hygroscopic coefficient is 7.5 per cent.

The range of soil-moisture content for the soil of the plots in the Muir peach orchard between the maximum field or capillary capacity and the wilting coefficient is approximately 10 per cent. This is equivalent to about 9.5 acre-inches of water in 6 feet of soil. The fluctuations of water supply between these limits in this depth of soil did not seem to influence the growth of the trees.

The set of fruit buds did not seem to be influenced by the application in the fall of sufficient water to raise the upper 6 feet of soil to its maximum capillary capacity.

The use of water by trees and the effect of the maintenance of the soil-moisture supply between different ranges is discussed in the following section.

SECTION III

STUDIES OF TREES GROWN IN CONTAINERS UNDER CONTROLLED SOIL-MOISTURE CONDITIONS

The need for more definite information concerning the effect of different soil-moisture conditions on deciduous fruit trees and the use of water by these trees under these different conditions is apparent when an interpretation of the results obtained in the Santa Clara Valley and Muir peach orchard studies reported in the two foregoing sections is attempted. For this reason the studies* reported in this section were undertaken. Studies of plants grown in tanks or potometers have been numerous, and the number of papers dealing with this subject is large. The work of Briggs and Shantz,[13] Kisselbach,[36] and Fowler and Lipman,[27] are typical with respect to methods and equipment used. The studies reported herein are similar to these.

Trees were grown in large galvanized-iron tanks varing in size from 23.5 to 27.08 inches in diameter, and from 4 to 6 feet deep, holding from 1000 to 2000 pounds of moist soil. Each tank was protected with a tight fitting cover having a central opening for the trunk of the tree. The annular space between the trunk of the tree and the central opening in the cover was filled with absorbent cotton. The absorbent cotton extended a short distance up the trunk of the tree. A piece of oiled-cloth was tied around the absorbent cotton and trunk of the tree and sealed to the outside of the cover with an asphaltic roofing paint. The loss of water was thus confined almost entirely to that through the leaves, and rain water was entirely excluded.

Different kinds of deciduous fruit trees were grown in these tanks, but only the results obtained from the tests with French prune trees will be presented. The trees were standard nursery stock, grown on Myrobalan rootstock. They were from 3 to 4 feet high at the time of planting and were two years old.

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* Professor A. H. Hendrickson of the Division of Pomology, University of California, has collaborated to a very substantial degree in the work on which this section is based. He has also very kindly read the manuscript and offered helpful suggestions, for all of which acknowledgment is gratefully extended.

METHOD OF PACKING THE SOIL IN THE TANKS AND PLANTING THE TREES

The soil was placed in the tanks in layers corresponding to those it occupied in place in the field, and was packed so that the volume weight or apparent specific gravity was the same as the volume weight of the undisturbed soil. The volume weight of the field soil at Davis was 82 pounds to a cubic foot, while that of the soil at Mountain View was 90 pounds to a cubic foot. The tanks were coated with cement mortar, leaving a very rough surface, in order to secure a closer contact of the soil with the sides of the tanks. The mortar was brushed on the inside of the tanks so that horizontal ridges were formed when the cement set. When the soil was packed in the tanks so treated, it was possible to add water to the surface of the soil in the tanks with little downward movement around the sides of the tank. It was found that an even distribution of the water applied could be secured in this way.

All of the tanks were provided with means to drain them. In most, especially the older tanks, a pet-cock was fitted to the bottom and a screen and layer of gravel about 1 inch in thickness were placed in the bottom before packing. The newer tanks, these 27.08 inches in diameter and 72 inches deep, were constructed with a chamber at the bottom with a pet-cock to collect any drainage water. However, it is of interest to note that only in one or two instances was water found collected at the bottom of the tanks. This indicates that the water used for the irrigations was not in excess of what the soils could hold. Samples taken after irrigation showed that the soil was wet throughout the full depth of the tanks.

The first lot of trees was planted in the tanks at Davis on April 15, 1919, and were grown there until October, 1920, when they were moved to the Deciduous Fruit Station of the University of California, at Mountain View, in the Santa Clara Valley. These trees were planted in soil which is classed as Yolo loam. The tanks had been filled with this soil in 1912, and alfalfa had been grown in the tanks for five years. Before the trees were set in the tanks, the alfalfa plants and the soil to a depth of about 10 inches were removed and the roots screened out of the soil. The soil was then replaced and tamped to the same compactness in all of the tanks. The weight of the empty tanks, and the weight of the water-free soil in each tank was known. The percentage of moisture in the soil could be calculated from the weights of the tanks at any time.

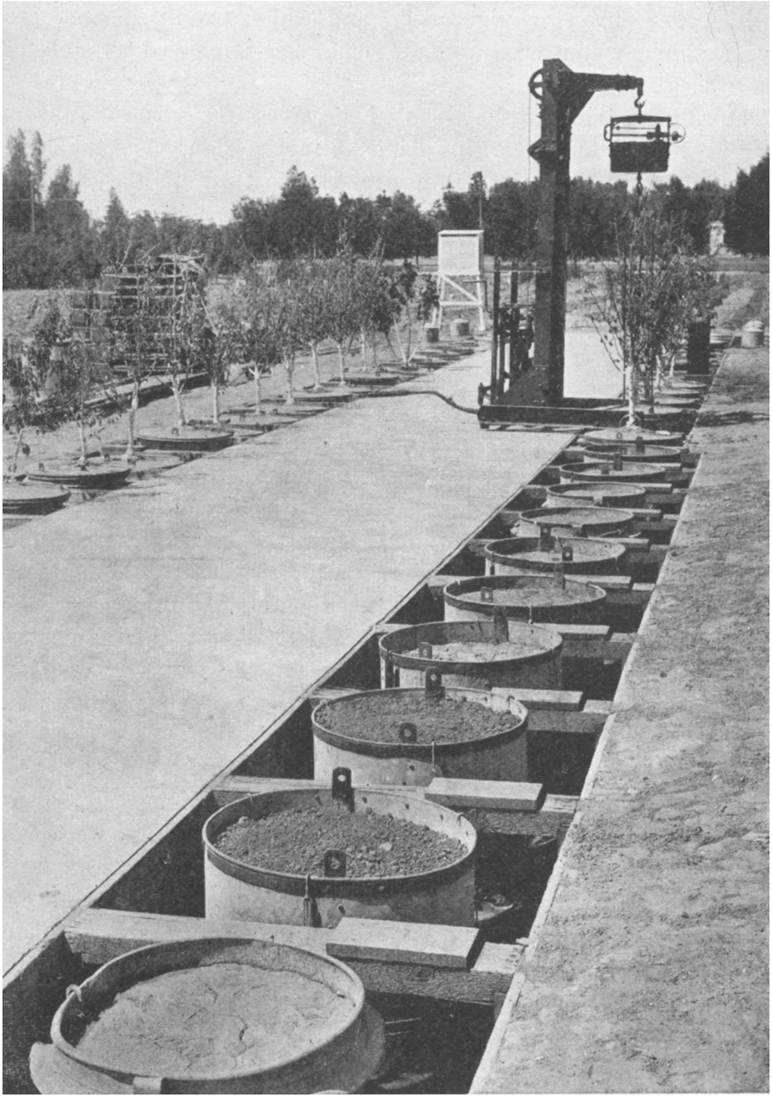

Fig. 21. Equipment for water-relation and evaporation studies installed at Davis.

The second lot of French prune trees was planted in the tanks at Mountain View on April 14, 1921. The soil used in these tanks was taken from a cherry orchard of about 25 years of age, the trees of which were growing vigorously, and which produced good crops in years when water was applied. This soil is classed as Yolo clay loam with gravel.

The soil adhering to the roots of the trees was washed away and the trees were pruned to whips about 20 inches high. The tanks were placed in trenches in order to prevent heating of the soil from exposure to the direct rays of the sun. To protect the tanks further from undue heating, the compartments of the trenches in which the tanks were placed were fitted with planks or sheathing cut to fit around the tanks. The equipment and its installation, after it had been moved to Davis in 1923, is illustrated in figure 21. The photograph was taken before the protecting sheathing was placed around all of the tanks. The trenches, which were arranged along the sides of an 8-foot concrete platform, were 3 feet wide and 4½ feet deep for the smaller tanks, and 3½ feet wide and 6½ feet deep for the larger tanks. The trenches were lined with 1-inch redwood planks nailed to framed bents or supports constructed of heavy timbers. The bents were spaced 41⅜ inches, center to center, which was the distance from one front wheel of the portable weighing derrick, to the other front wheel. Cleats were nailed to the tops of the bents, so that when the derrick was rolled onto them, the front wheels would stop at a position such that the hook on the weighing scales would be exactly over the center of the tanks.

Samples of soil in 1-foot depths were taken from each of the tanks containing the Yolo loam from Davis, and duplicate moisture equivalent determinations were made on each sample. Samples were taken at four places in each tank. The average moisture equivalent was found to be 22.0 per cent. Samples taken from the tanks containing the Yolo clay loam from Mountain View, also had an average moisture equivalent of 22.0 per cent. The Yolo clay loam samples, however, showed much greater variation in the value for the moisture equivalent than the samples of Yolo loam.

METHOD OF WEIGHING THE TANKS

The method of using the portable derrick is illustrated in figure 21. Two suspension scales were used throughout the tests, one for the smaller tanks weighing less than 1500 pounds, and one for the larger tanks weighing in excess of 2000 pounds. These scales were carefully adjusted before any weighings were made, and checked against a master weight of 386 pounds. The scales gave satisfactory weights to within one pound. Weights of one pound placed on a tank while it was being weighed would be accurately recorded on the beam of the scales.

The portable derrick could be lengthened by the addition of an extension frame to permit tanks deeper than 6 feet to be moved from one compartment of the trench to another. Different sized weighing bales accommodated the derrick to the different sized trees to be weighed. However, in weighing, it was not necessary to lift the tanks out of the trench. It was only necessary to raise the tank a few inches until it swung clear of the bottom. The portable derrick with the scales and bales weighed almost a ton. However, it could be readily moved about the platform. It was possible to weigh 50 tanks within one hour with this apparatus. The weighings could be made on days with moderate winds which would prohibit weighings if the tanks had to be lifted out of the trenches. Most of the weighings were made early in the morning.

Distribution of Soil Moisture in the Tanks and Method of Applying Water

In the many experiments which have been made to determine the effect of variation in soil-moisture content upon plant growth, water has been added to the soil in different ways. Some have applied all of the water from above, others from below. In still other attempts, the applications have been made by means of specially arranged, perforated pipes. In the containers supposed to have a relatively low moisture content throughout the entire mass of soil there is evidence that the water applied was not uniformly distributed.

It is the belief of the writer that dependence upon capillary forces to bring about a uniform distribution in the soil of the water applied at any point has caused many erroneous conclusions to be drawn from water relation studies.* Attempts made during the present

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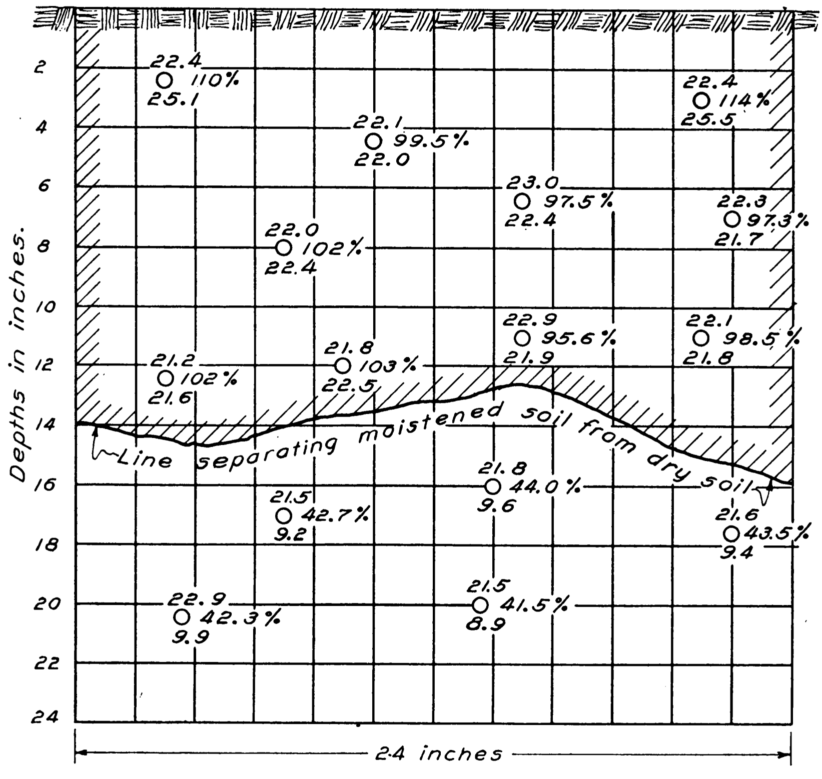
* A paper (Shantz, H. L., Soil moisture in relation to the growth of crop plants, Jour. Am. Soc. Agron., **17**: 705–711. 1925), has appeared since this manuscript was prepared, in which the author expresses the same opinion, for he states: ''Because of the peculiarities in the distribution of moisture in soils much of the work on the effect of varying water content on growth of crop plants, fungi, and bacteria, on the effect of varying water content on transpiration, water requirement, or the physical functions of the plant is entirely unreliable and will have to be repeated when conditions are known or better understood.''

investigation to maintain a soil-moisture percentage less than that which the soil would hold against the force of gravity, the maximum field or capillary capacity, have met with failure in every case. During the course of these studies numerous trials were made, both with soils in tanks and with field plots, to maintain moisture contents less than the amounts of water the soils will hold against gravity, but it was found to be impossible to bring about relatively low moisture contents in the soil.



O = Point from which soil samples were taken.

Upper numbers = Moisture equivalent determined by centrifuge method.

Lower numbers = Actual moisture content of sample from field.

Percentages are the ratios of the moisture content to the moisture equivalent.

Fig. 22. Vertical distribution of water in a loam soil 48 hours after a rainfall of 2.15 inches. The upper margin of the diagram represents the soil surface.

An appreciation of the significance of this fact is vital to the proper interpretation of the results of water-relation studies with plants grown in containers, as well as in field plots. While the distribution of moisture by capillary action will be taken up in a later section, the following discussion may be helpful at this point. A picture of what actually takes place when water is applied to dry soils is given in figure 22. A trench was cut in a field of Yolo loam soil at Davis just after a rainfall of 2.15 inches. The field was level, and had produced a crop of barley the previous summer which had reduced the moisture content of the soil to an amount between 9 and 10 per cent. A system of coördinates was marked off on the face of the trench and samples were taken at the places indicated in figure 22. The line separating the moistened soil from the dry soil was sharply defined. The moisture content of the samples was determined, and the moisture equivalent determinations were then made on soil from these samples. The close agreement between the percentages of moisture, found in the moistened area, and the moisture equivalent is clearly shown in figure 22. There was an immediate drop in the ratio of the percentage of moisture to the moisture equivalent in the samples taken below the line of demarcation of wet and dry area. In all of the studies of the distribution of moisture after irrigation, this condition invariably has been observed. An application of a certain amount of water to a soil results in the wetting of that soil to its maximum field capacity to a definite depth, which depends upon the water holding capacity of the soil, and the initial moisture content.

Relatively small amounts of water applied to the surface of the soil in a tank in which a plant is growing will affect only the soil-moisture content to the depth of soil which can be raised to its maximum field capacity by this amount of water. The rate of extraction of moisture by the plant would usually be such that the moisture supply would be depleted long before additional downward movement could take place even if further capillary movement of moisture from the moist to the drier soil were appreciable in extent as some investigators assume. Alway and McDole[3] are two of the few investigators who have studied the downward penetration of definite amounts of water in soils and have considered the relative water retentiveness of the soils. These investigators found from the study of the downward movement of one inch of water applied to soils in glass cylinders about three inches in diameter that the applied water seemed to reach equilibrium at the end of five days in the finer-textured soils, but in the coarser ones it continued to move downward for a longer time.

However, the downward movement, in all cases, was relatively slow after the first hour, and in most cases, over 50 per cent of the movement which occurred in five days took place within the first hour after the water was applied. These investigators also pointed out that the moisture content of the moistened layer showed a rather constant relation to both the hygroscopic coefficient and the moisture equivalent.

In all of the soil-moisture studies made in connection with the work reported herein, such an agreement has been found immediately after irrigation, which in the loam soils used in these experiments was between 24 and 48 hours after irrigation, between the moisture content of the soil to the depth wetted and the moisture equivalent, that it is believed the latter can be used as a measure of the field capacity of these loam soils. Results of trials with the Yolo loam and the Yolo clay loam, used in the tanks, show that water in amounts sufficient to raise a certain depth of soil to a percentage equal to the moisture equivalent, resulted in wetting the soil to the desired depth. It is possible that there may be subsequent downward movement of moisture which continues for a long time and which results in an increase in moisture with increase in depth of soil when equilibrium is reached, as Israelsen and West[34] seem to show does occur, and which Gardner[28] thinks theory demands. However, in all of the tests made during these trials with the loam soils, there seemed to be a uniform distribution of moisture throughout the depth wetted. The extraction of moisture by plants on cropped soils was always sufficiently rapid to reduce the moisture content before further downward movement could be detected.

An amount of water was applied at each irrigation which would bring the moisture content of the soil to the desired depth up to the moisture equivalent or to the field capacity. It was found that in no case, either in the tanks with growing trees or in the field plots, could there be maintained a pre-determined moisture content less than the maximum field capacity of the soil. Therefore, the variation in soil-moisture conditions in these experiments was between the moisture equivalent, or the field capacity, and a certain minimum. For instance, a series of tanks was irrigated so that the soil-moisture content was maintained between 22 per cent, the field capacity, and 16 per cent. The tanks were irrigated when the weight of the tank indicated that the moisture content of the soil had been reduced to 16 per cent; others were irrigated when the moisture supply was reduced to the wilting coefficient, and so on. Therefore, instead of attempting to maintain a definite amount of moisture in the soil, the moisture content was allowed to fluctuate through a definite range.

Fig. 23. Prune tree on soil with a water table 2½ feet from the surface. Photographed in the fall.

The graphs of the soil-moisture conditions in the Santa Clara orchards and the Muir peach orchard at Davis show this to the the actual condition in a growing orchard. The moisture supply may be kept above any desired minimum, and that is all that can be accomplished.

The surface of the soil in the tanks was kept level, and all of the water was applied on the surface. The soil was kept in close contact with the sides of the tanks so that there would be no downward movement around the sides of the tank. In this manner a uniform depth of penetration was obtained. A slide in the cover could be removed to permit the water to be applied from a hose. The tanks were irrigated with tap-water from the domestic water supply. The amount of water added was weighed on the suspension scales and recorded in pounds.

In some of the tanks containing the trees, a water table was maintained at 2½ feet below the surface of the soil. This arrangement is illustrated in figure 23. An outer tank, serving as a reservoir, was supported around the inner tank which contained the growing tree. Water was added to the reservoir through the filling tube. A gage attached to a float was placed in the tube and the position of the gage indicated the position of the water table. The inner tank was perforated with many small holes to permit entry of the water. The annular space between the reservoir and the inner tank was covered with several thicknesses of oiled-cloth, which were securely sealed to both tanks by a coat of asphaltic roofing paint. This prevented the entrance of rain, and also prevented evaporation from the surface of the water in the reservoir.

Root Systems of Trees Grown in Tanks

Apparently Myrobalan root stock is well adapted to water-logged soils, since the trees growing in the tanks with a high water table showed no ill effects, appearing to be vigorous and healthy at all times. Prune trees on Myrobalan roots growing in water-logged soil in tanks for three seasons showed no injury. The root system of tree No. 1, which had been in soil with a water table 2½ feet from the surface, during the previous growing season, is illustrated in figure 24. The soil was washed from around the roots of the tree, and the tree was carefully removed from the tank. The soil was thoroughly permeated with roots and there was a matted mass of roots below the plane where the water had been maintained. The great mass of roots which grew below the water surface is clearly shown in figue 24. At the time the tree was removed from the tank, these roots were making growth. The typical condition of the root systems of trees grown in soils in the tanks normally irrigated is shown in figure 25. This is a photograph of tree No. 22, for which data are presented in the following pages.

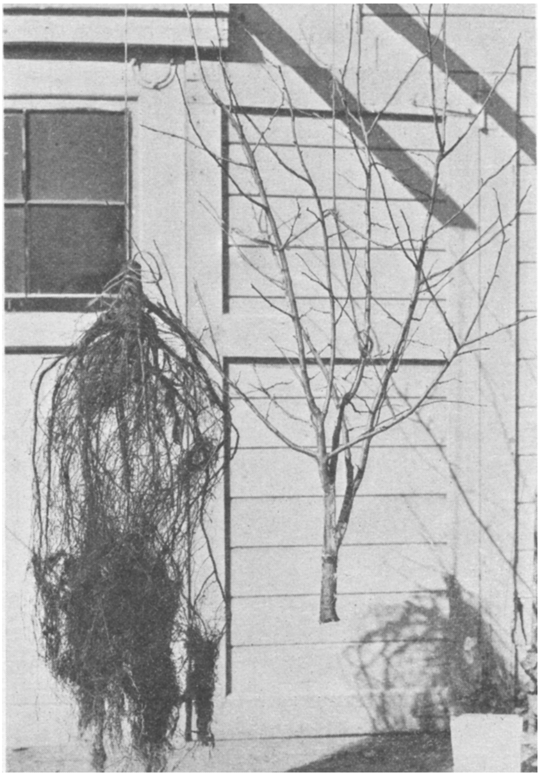


Fig. 24. Tree No. 1, French prune on Myrobalan root, grown with a water table 2½ feet from the surface. Lower matted mass of roots grew below the water surface. Trunk and branches weighed 3¾ pounds, roots 4½ pounds. Tree planted in tank April 15, 1919; photographed January 31, 1923.

The root systems of all of the trees except those in water-logged soil were found to be similar to that illustrated in figure 25. The soil was permeated with roots and the trees were pot-bound. Undoubtedly this condition influenced the growth of the trees and resulted in much less growth being made than under normal field conditions. However, since the tests were designed to indicate only the relative use of water and the response to different soil-moisture conditions, this was not a disadvantage. The calculation of moisture present in the soil at different times usually was based upon the total weight of water-free soil in the tanks. Therefore, it was essential that all of the soil be penetrated by the roots of the trees at the time the tests were made. The calculated percentage of moisture was the average moisture content of the entire soil mass, and if there had been portions of the soil unoccupied by roots, or in which there was relatively few roots, these portions would have a higher moisture content than the calculated average. The moisture percentages calculated from the known weight of dry soil in the tanks were checked at times by taking soil samples from the tanks with a soil tube and the percentages of moisture obtained in these two ways usually agreed.

As mentioned before, it has been found during these studies that the capillary movement of moisture in these loam soils is very slow, and as the soil-moisture content decreases, the movement becomes practically negligible, resulting in little readjustment of moisture in the soil. The result is that the tree may not be responding entirely to a soil-moisture content calculated to be the average, if the soil in the container be not thoroughly permeated with roots. The pot-bound condition of the trees was therefore an advantage.

Weaver, Jean, and Crist,[52] studying the developments of the roots of plants grown in containers, also find that "the movement of water by capillary plays a rather unimportant role in replenishing water at the various levels from those adjacent." Briggs and Shantz[12] recognized uneven root distribution and lack of adjustment of the soil-moisture content through capillary movement as a source of error even in the very small containers in which they grew seedlings.

CLIMATOLOGICAL MEASUREMENTS

Climatic conditions were measured by means of maximum and minimum thermometers, a hygrothermograph, and a hygrodeik exposed in a standard shelter about 4 feet above the ground surface, an anemometer set about 4 feet above the ground surface, a pyschrometer, a rain gage, and an evaporation tank. The evaporation tank was 3 feet in diameter and 3 feet deep, set in the ground 2.75 feet. The evaporation was read with a hook-gage to 0.01 inch. The evaporation tank, its construction and the manner of reading, were similar to the evaporation tanks and methods used by Sleight,[46] who showed the relative evaporation for tanks of various sizes and under different conditions. Briggs and Shantz[14] point out that although the evaporation from a deep tank showed practically no correlation with transpiration when hourly values were considered, a discrepancy which results from the storage of heat energy in the large mass of water during the day, there is a correlation between the daily evaporation from a deep tank and daily transpiration.

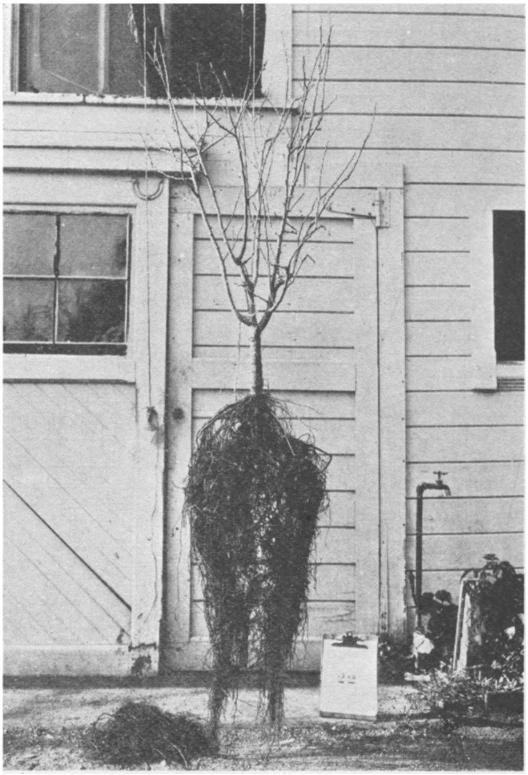


Fig. 25. Tree No. 22, French prune on Myrobalan root, normally irrigated. Trunk and branches weighed 3½ pounds, roots 4½ pounds. Tree was planted in tank on April 15, 1919; photographed January 30, 1923.

Since the greater part of the experiments were conducted during 1922, some of the measurements of the climatic conditions at Mountain View for the growing season of this year, are summarized in table 21.

TABLE 21

SUMMARY OF CLIMATOLOGICAL MEASUREMENTS AT MOUNTAIN VIEW, DURING THE GROWING SEASON, 1922

Month	Days (inclusive)	Temperatures					Precipitation total for 5-day period	Evaporation total for 5-day period	Average wind velocity per hour
		Average of			Maximum	Minimum			
		Means	Maximums	Minimums					
		° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*Inches*	*Inches*	*Miles*
March	1- 5	47	59	35	64	31	.30	.36	2.8
	6-10	49	60	38	63	32	.14	.36	2.8
	11-15	48	58	37	63	31	.43	.20	2.2
	16-20	49	62	36	72	33	.25	.39	1.6
	21-25	52	64	41	67	36	.04	.26	1.8
	26-31	54	63	44	64	37	.19	.36	2.4
April	1- 5	54	67	40	75	38	....	.55	2.4
	6-10	60	76	43	70	30	....	.70	2.8
	11-15	43	59	37	62	33	.08	.59	3.5
	16-20	52	71	33	79	31	....	.85	2.1
	21-25	53	67	39	74	36	....	.66	1.7
	26-30	54	72	35	79	34	....	.88	1.7
May	1- 5	62	83	41	89	40	....	.89	1.6
	6-10	53	65	41	73	39	.28	.69	2.3
	11-15	66	89	44	96	36	....	.89	2.3
	16-20	64	73	54	77	50	.05	.82	1.7
	21-25	56	73	40	79	38	....	1.11	2.4
	26-31	60	78	43	89	36	....	1.26	1.4
June	1- 5	59	72	46	74	41	....	.81	1.4
	6-10	63	75	51	79	43	.03	.92	2.7
	11-15	63	74	52	85	45	....	.97	2.5
	16-20	66	86	46	96	44	....	1.21	1.3
	21-25	67	87	47	97	45	....	.93	1.3
	26-30	66	76	56	89	54	....	1.38	1.6
July	1- 5	68	80	57	86	50	....	1.11	1.2
	6-10	66	77	55	80	48	....	1.16	1.3
	11-15	68	80	55	92	50	....	1.23	1.3
	16-20	66	79	52	84	50	....	1.15	1.2
	21-25	60	73	46	75	41	....	1.45	1.3
	26-31	64	80	48	85	45	....	1.30	1.0

TABLE 21—(*Continued*)

Month	Days (inclusive)	Temperatures					Precipitation total for 5-day period	Evaporation total for 5-day period	Average wind velocity per hour
		Average of			Maximum	Minimum			
		Means	Maximums	Minimums					
		° F.	*° F.*	*° F.*	*° F.*	*° F.*	*Inches*	*Inches*	*Miles*
August	1- 5	64	76	52	80	48	....	1.03	1.1
	6-10	62	79	46	90	44	....	.97	1.1
	11-15	64	81	48	83	42	....	1.13	2.4
	16-20	62	77	47	82	45	....	1.05	1.5
	21-25	62	77	46	87	43	....	1.02	1.1
	26-31	66	82	49	95	45	....	1.26	1.1
September	1- 5	64	82	47	90	46	....	.87	1.1
	6-10	70	92	49	100	51	....	.83	1.0
	11-15	72	88	56	92	51	....	.91	.7
	16-20	66	83	49	95	53	....	.72	.6
	21-25	64	81	46	85	43	....	.76	.8
	26-31	62	80	43	86	37	....	.76	.8
October	1- 5	60	72	48	74	41	.20	.33	1.1
	6-10	61	74	48	79	44	.33	.36	1.2
	11-15	58	69	46	75	42	....	.45	.7
	16-20	58	72	45	80	38	....	.38	.5
	21-25	60	81	39	88	37	....	.48	.4
	26-31	62	76	47	70	31	.43	.38	.9
November	1- 5	48	63	34	68	31	....	.37	.9
	6-10	53	59	47	60	40	1.33	....	1.2
	11-15	49	64	34	67	30	....	.30	.4
	16-20	50	60	39	65	33	....	.15	.3
	21-25	50	66	34	70	32	....	.19	.2
	26-31	46	59	33	66	28	....	.22	.6

USE OF WATER BY PRUNE TREES IN SOILS WITH VARYING RANGES OF MOISTURE CONTENT

The moisture treatment of the soil on which the trees had been growing up to the beginning of the season of 1922 had been substantially the same in all cases. In 1922, at Mountain View, the moisture content of some of the soils was allowed to fall below that of others, and the soil in some of the tanks was water-logged. A water table was constantly maintained at 2½ feet from the surface of the soil in the water-logged tanks. In addition to supplying water to the outer reservoir through the filling tube shown in figure 23, water was applied at frequent intervals during the season to the surface of the soil in these water-logged tanks.

Some of the trees were irrigated throughout the growing season when the moisture supply had been reduced to 16 per cent. Others were irrigated in this manner until the middle of August, and were then allowed to lower the soil-moisture content. In some cases, the soil-moisture content was allowed to fall to about the wilting coefficient before water was applied. Table 22 summarizes the use of water for the season of 1922 by some of the trees, grouped according to the irrigation treatment. The water transpired is assumed to be the total amount of water used by the plant. The amount of water retained in the plant and that used in its metabolism are so small in comparison with the amount of water transpired that they may be disregarded here.

The data in table 22 indicate the relative use of water by the prune trees in soils in which the range of moisture content varied. The use of water under high soil-moisture conditions can be compared with that under relatively low soil-moisture conditions. Such a comparison can best be made on the basis of use of water to a unit of leaf area. If there is a moisture condition optimum for growth or one above or below which the use of water by the trees is materially affected, it should be indicated by the use of water by trees under the different soil-moisture conditions maintained in these tanks. Obviously, a much more direct method would be to maintain definite moisture percentages in the soil rather than to allow the soil-moisture content to fluctuate. However, for the reasons previously stated this was found to be impossible.

TABLE 22

The Use of Water in Pounds During the Growing Season of 1922 by French Prune Trees Grown in Tanks at Mountain View

Dates	Trees 3, 6, 9*‖			Tree 1†‖			Trees 12, 14†¶			Trees 5, 7‡¶			Trees 15, 17, 18‡¶			Trees 16, 19, 20§¶			Trees 4, 13, 21*¶		
	Per tree	Per tree per day	Per 1000 sq. in. leaf area per day	Per tree	Per tree per day	Per 1000 sq. in. leaf area per day	Per tree	Per tree per day	Per 1000 sq. in. leaf area per day	Per tree	Per tree per day	Per 1000 sq. in. leaf area per day	Per tree	Per tree per day	Per 1000 sq. in. leaf area per day	Per tree	Per tree per day	Per 1000 sq. in. leaf area per day	Per tree	Per tree per day	Per 1000 sq. in. leaf area per day
Mar. 1–15	2.6	0.2	0.06	1.0	0.1	0.03	5.0	0.3	0.23	3.5	0.2	0.10	1.0	0.1	0.06	2.0	0.1	0.03	3.0	0.2	0.07
Mar. 16–31	2.6	0.2	0.06	1.0	0.1	0.03	3.5	0.2	0.16	1.0	0.1	0.05	2.0	0.1	0.06	3.3	0.2	0.06	4.0	0.3	0.11
Apr. 1–15	5.3	0.4	0.12	4.0	0.3	0.09	5.5	0.4	0.31	1.5	0.1	0.05	3.3	0.2	0.13	4.3	0.3	0.09	3.3	0.2	0.07
Apr. 16–30	17.0	1.1	0.34	20.0	1.3	0.39	17.0	1.1	0.86	1.5	0.1	0.05	6.3	0.4	0.03	8.7	0.6	0.18	9.3	0.4	0.14
May 1–15	50.6	3.4	1.05	53.0	3.5	1.05	8.5	0.6	0.47	14.0	0.9	0.46	14.7	1.0	0.63	26.3	1.8	0.48	23.7	1.6	0.56
May 16–31	78.6	4.9	1.51	83.0	5.2	1.56	16.5	1.0	0.78	27.0	1.7	0.87	30.7	1.9	1.19	45.3	2.8	0.83	43.3	2.7	0.95
June 1–15	96.3	6.4	1.98	91.0	6.1	1.83	23.5	1.6	1.25	35.5	2.4	1.23	38.7	2.6	1.63	64.0	4.3	1.26	52.7	3.5	1.24
June 16–30	139.0	9.2	2.94	157.0	10.0	2.99	30.5	2.0	1.56	69.0	4.6	2.36	42.3	2.8	1.75	88.0	5.9	1.73	78.3	5.2	1.84
July 1–15	112.5	7.5	2.40	136.0	9.1	2.72	39.0	2.6	2.03	69.0	4.6	2.36	61.3	4.1	2.57	91.7	6.1	1.79	82.7	5.5	3.24
July 16–31	154.5	10.0	3.20	141.0	8.8	2.63	40.5	2.5	1.95	83.0	5.2	2.67	69.7	4.4	2.75	108.0	6.8	1.99	88.3	5.5	3.24
Aug. 1–15	105.5	7.0	2.24	143.0	9.6	2.87	45.5	3.0	2.42	83.0	5.6	2.82	56.0	3.7	2.32	75.0	5.0	1.47	67.7	4.5	1.59
Aug. 16–31	65.5	4.1	1.31	145.0	9.1	2.72	42.5	2.7	2.11	61.5	3.8	1.95	48.3	3.0	1.88	101.7	6.4	1.88	74.7	4.7	1.66
Sept. 1–15	106.0	7.1	2.27	143.0	9.6	2.87	47.0	3.1	2.42	74.5	5.0	2.57	32.3	3.5	2.19	110.0	7.3	2.14	65.7	4.2	1.48
Sept. 16–30	95.5	6.0	1.92	95.0	5.9	1.77	34.5	4.4	1.72	51.5	3.2	1.64	25.7	1.6	1.01	70.3	4.4	1.29	57.3	3.6	1.27
Oct. 1–15	37.0	2.5	0.80	48.0	3.2	0.96	22.0	1.5	1.17	24.0	1.6	0.82	15.3	1.0	0.63	46.7	3.1	0.91	29.0	2.0	0.71
Oct. 16–31	25.5	1.6	0.51	32.0	2.0	0.60	24.0	1.5	1.17	16.5	1.0	0.51	7.0	0.4	0.25	42.7	2.7	0.79	27.3	1.7	0.60

* Soil-moisture content ranged between maximum field capacity and wilting coefficient.
† Soil water-logged.
‡ Soil-moisture content maintained above 16 per cent until middle of August.
§ Soil-moisture content maintained above 16 per cent entire season.
‖ Planted in the tanks containing Yolo loam April 15, 1919.
¶ Planted in tanks containing Yolo clay loam April 14, 1921.

Trees, 3, 6, and 9, which were planted on April 15, 1919, in the tanks containing Yolo loam soil from Davis, were irrigated when the soil-moisture content was reduced to about the wilting coefficient. The tanks containing these trees were 23½ inches in diameter and 48 inches in depth. The trees were allowed to wilt a few times (see plate 1, figure 1). Tree 9 was irrigated when the soil-moisture content was reduced to the wilting coefficient, but on June 16, all of the leaves on the tree were removed in order to measure the loss of water from the bare limbs. The use of water by this tree after June 16 is not included in the average of trees 3, 6, and 9.

Tree 1, which was planted on April 15, 1919, in a tank 23½ inches in diameter by 48 inches in depth, containing Yolo loam, was grown in water-logged soil during 1922. A water-table was maintained at 2½ feet from the surface of the soil, and in addition water was applied to the surface. The use of water by tree 1 is listed in table 22 separately from that of trees 12 and 14, which were treated in the same manner as tree 1, but which were younger trees. Trees 12 and 14 were planted on April 14, 1921, in tanks containing Yolo clay loam. These tanks were 26 inches in diameter and 48 inches deep.

Trees 5 and 7 were planted on April 14, 1921, in tanks 26 inches in diameter and 48 inches in depth, containing Yolo clay loam. These trees were grown in soil kept above 16 per cent moisture until about the middle of August, when the soil-moisture content was allowed to fall to about the wilting coefficient.

Trees 15, 17, and 18 were of the same age and were treated in the same manner as trees 5 and 7. However, these were grown in larger tanks, the dimensions being 27.08 inches in diameter and 72 inches in depth. Since Kiesselbach[36] has suggested that the size of the tank may influence the water requirement of plants, the data for these trees are listed separately from those for trees 5 and 7. However, it should be noted that within the range of sizes of tanks used in these experiments, no differences in the use of water to the unit of leaf area were found. Trees 15, 17, and 18 were grown in soil with a moisture content above 16 per cent until about the middle of August. These trees were allowed to wilt several times. The wilted condition of trees 15 and 17 on October 18, 1922, is illustrated in plate 2, figure 1.

Trees 16, 19, and 20 were grown in soil which was kept above 16 per cent moisture content throughout the growing season of 1922. These trees were planted on April 14, 1921, in tanks 27.08 inches in diameter, and 72 inches in depth, containing Yolo clay loam.

Trees 4 and 13 were planted on April 14, 1921, in tanks 26 inches in diameter by 48 inches in depth, containing Yolo clay loam. Tree 21 was planted in the same soil on the same date but the tank was 27.08 inches in diameter and 72 inches in depth. These trees were irrigated when the moisture content fell to about the wilting coefficient.

Information concerning the dates on which some of these trees were allowed to wilt, and the soil-moisture percentage at the time of wilting, compared to the theoretical wilting coefficient is given in table 27.

The area of the leaves on the trees was obtained from the average measurements of several hundred leaves on different trees of the same age, and which were growing in soil maintained within the same range of moisture content. The average area of a leaf on the younger trees was 5.21 square inches; the average of the leaves on the older trees was 2.07 square inches. The total leaf area for each tree was found by multiplying the total number of leaves on each tree by this average area.

The use of water per unit of leaf area given in table 22 is not strictly correct for the spring and fall months. Few leaves were formed on the trees in the early spring, and many leaves dropped in the fall. The leaf area used as a basis for comparison is that measured about the middle of June. Measurements of leaf area before and after this period showed little change from May 15 to September 1. Furthermore, some of the trees were allowed to wilt after September 1 and consequently were partially defoliated. If it is assumed that the leaf area of the different trees in the fore part of the season was proportional to the maximum area measured in June, the data in table 22 for this period may be of value.

These data indicate that the use of water by these trees was not materially affected by the percentage of moisture in the soil. However, as will be presently shown, there was a very noticeable effect when the soil-moisture supply was reduced below the wilting coefficient.

It is assumed that the growing season of 1922 extended from March 1 to November 4, for on the latter date most of the leaves on the trees had matured or had wilted and dropped. The total use of water for the season of 1922 by the trees planted April 14, 1921, is given in table 23. Since some of the leaves on certain trees had dropped after September 25, the loss of moisture from March 1 to September 25 is listed, and is used in the calculations. The ratio of loss of water to leaf area, is recorded as loss in pounds to the square inch of leaf area, and the ratio of the length growth made during the season of 1922 to the loss of water is recorded as the inches of growth for each pound of water used. The leaf area used for each tree was measured in June after length growth of the twigs had ceased.

The uniformity of the ratios of water loss to leaf area and new length growth is striking. The moisture content of the soil in which these trees were grown varied between wide ranges, yet the use of water by the trees was not materially affected. The use of water under similar atmospheric evaporating power seemed to be determined by leaf area. Tree 6, one of the older trees, showed a ratio of water loss to leaf area of 0.287 for the season of 1921, and in 1922 this ratio was 0.250, an agreement which is remarkably close.

TABLE 23

USE OF WATER BY YOUNG FRENCH PRUNE TREES GROWN IN TANKS AT MOUNTAIN VIEW. SEASON OF 1922

Number of tree	Length of growth in inches	Number of leaves	Leaf area in square inches	Water used per season, March 1 to Nov. 4, pounds to a tree	Water used from March 1 to Sept. 25, pounds to a tree	Loss of water to the square inch of leaf area	Inches of growth for each pound of water used
4*	536.0	756	3950	902	782	0.198	0.685
5†	348.0	394	2098	541	499	0.237	0.698
7†	403.5	346	1799	688	626	0.347	0.644
12†	214.0	239	1244	378	316	0.254	0.678
13†	363.25	474	2476	634	544	0.220	0.666
14†	221.0	253	1317	388	328	0.249	0.673
15‡	333.0	316	1644	464	427	0.259	0.778
16‡	365.0	510	2653	703	572	0.215	0.638
17‡	372.25	451	2347	647	587	0.250	0.634
18‡	185.0	154	803	302	261	0.325	0.709
19‡	491.0	627	3260	811	712	0.218	0.690
20‡	697.5	828	4305	1171	1020	0.237	0.683
21‡	351.0	398	2070	592	508	0.245	0.690
Average......	375.42	442	2305	632	552	0.250 ±0.007	0.682 ±0.001

* Grown in tank 23½ inches in diameter and 48 inches in depth.
† Grown in tanks 26 inches in diameter and 48 inches in depth.
‡ Grown in tanks 27.08 inches in diameter and 72 inches in depth.

Coefficients of correlation were calculated from the data given in table 23 for the relation of use of water to leaf area and for the relation of use to length growth made during the current season.

The coefficient of correlation between water loss and leaf area is 0.97 ± 0.11. The coefficient of correlation between water loss and length growth is 0.995 ± 0.002. Coefficients of correlations with such high values as these, and so much greater than their probable errors, may be considered to be decidedly significant. It may, then, be safely said that the use of water by these young prune trees grown in clay loam soil in tanks, under the conditions prevalent at Mountain View, has not been materially influenced by the differences in amounts of water available for growth, and that optimum moisture conditions for growth cover a range of soil moisture from the maximum field or capillary capacity to about the wilting coefficient. Fowler and Lipman,[27] likewise, have suggested that the range of soil-moisture percentages within which young Lisbon lemon trees will grow satisfactorily in the loam soil studied by them is, relatively speaking, a wide one. However, the lower limit set by them is much higher than that observed in these studies. The maintenance of the lower percentages of soil moisture in the tanks used by these investigators may not have been uniform throughout the soil mass. The soil in the tanks containing the lemon trees which received the lesser amounts of water may have been wet to slight depths at each application of water instead of the entire soil mass being raised to the desired percentage of moisture. In this connection, it may be mentioned that, although Kiesselbach[36] recognized that the lack of uniformity in distribution of water applied to the soil in containers constitutes a serious source of error in experiments of this nature, it is not at all certain that the lower soil-moisture percentages that he attempted to maintain in his tanks were the true percentages of moisture throughout the entire mass of soil in the tanks. The moisture content of the soil in the immediate vicinity of his spiral irrigating coils undoubtedly was raised to the maximum field capacity and probably other portions of the soil were dry. Tests made at Davis by Professor S. H. Beckett from 1912 to 1917 with alfalfa growing in tanks to determine the use of water by these plants with varying soil-moisture contents proved that this was true in many cases. Water was applied to the tanks containing the alfalfa plants by means of perforated irrigating pipes arranged in spider-web fashion in the soil and also by means of spiral pipe irrigators. Attempts were made to maintain certain percentages of soil moisture in the different tanks calculated from the known weight of dry soil. Water was added to the soil to bring them up to the calculated weights. After the conclusion of the tests, some of the tanks were emptied and it was found that the roots of the plants grown in the soils presumed to be at the lower moisture percentages were all within the soil in the immediate vicinity of the irrigating pipes. The soil in the bottom of these tanks probably was dry the greater portion of the time during the growing season. On the other hand, some of the tanks containing the soils assumed to be maintained at the higher moisture contents were found to be saturated at the bottoms.

USE OF WATER BY A YOUNG FRENCH PRUNE TREE GROWN IN A TANK AUTOMATICALLY BALANCED

The individual behavior in the use of water of several of the prune trees grown in the tanks was studied closely. Where tanks containing 1000 pounds or more of soil were used, as in this case, no adequate weighing device capable of weighing less than one pound was available. Since it was desired to weigh very small losses of water, tree 22, growing in a tank 23½ inches in diameter by 48 inches in depth, containing Yolo loam, was automatically balanced, so that very small losses of moisture through transpiration could be recorded. The arrangement of the apparatus is illustrated in figure 26. The principle of operation of the device is essentially the same as the self-registering transpiration machine described by Copeland[22] and the auxanometer described later by Corbett.[23] However, it differs from Corbett's auxanometer in that the tank is counterbalanced. The tank containing the soil and tree was suspended in an outer tank which was set into the ground and contained water. The tank containing the tree was then balanced with a frame made of channel iron, carrying a weight at the outer end, and supported on a knife edge. As the tree lost water through transpiration, and thus lessened the weight of the suspended tank and contents, the tank containing the tree rose in the outer tank and a mass of water equal to that which had been transpired by the tree was replaced. The tank containing the tree automatically came to rest at this point, and a recording device attached to the outer end of this channel-iron frame, recorded the loss of the weight of the tree tank. The tank containing the tree was uniform in diameter at the section which moved through the water surface. The accuracy of the results would, of course, depend upon the uniformity of this cross-section of the tank.

Some difficulty was encountered during the first two years the apparatus was used, because the water would cling to the walls of the inner tank as it raised. However, in 1921 the inner and outer tanks were coated with a patented varnish.* This varnish practically eliminated the adhesion of the water on the metal of the tanks.

The apparatus was run for two seasons at Davis, 1919 and 1920, and was removed to Mountain View and set up early in 1921. Measurements were taken frequently during these three seasons to determine shrinkage in the volume of water in the outer tank. The loss, for an entire season, by evaporation from the water in the outer tank was so small it could not be detected. There was very little fluctuation in the temperature of the water in the outer tank during the growing season, and consequently, it is probable that there was little change in the buoyancy of the water due to change in its density.

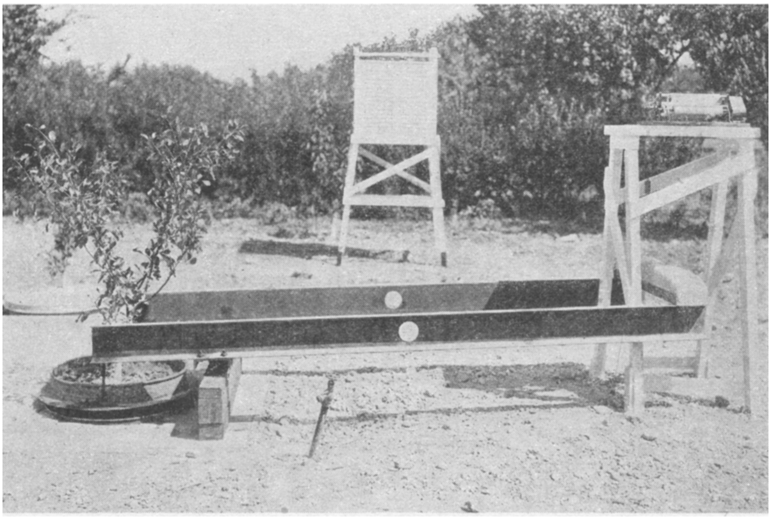


Fig. 26. Tree 22, in a tank automatically balanced so that small losses of moisture by transpiration could be measured. This photograph was taken in May, 1921, just after the apparatus had been moved from Davis to Mountain View. Later the tank was fitted with a cover and a wider rim and a low protecting wall was built around the apparatus to protect it from winds.

The movement of the outer end of the channel-iron frame was still further magnified in the recording device. The movement of the pointer on the record sheet was about 100 times the movement of the tank. The recording device was designed by Mr. E. J. Hoff, of the Division of Agricultural Engineering, Bureau of Public Roads, U. S. Department of Agriculture, and is essentially the same as the sensitive water-level recorder described by him.[32] The feature of the

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* Made by the Gumite Corporation of New York City.

recorder lay in the elimination of friction, and in bringing the recording pen into contact with the record sheet every 30 seconds. This arrangement eliminated the resistance of the pen on the record sheet and allowed the recording arm to move freely and to respond to the movement of the tank. The apparatus illustrated in figure 26 was modified somewhat before starting the experiment in 1922. The recording device shown was changed to give a daily record instead of a continuous record. The tank containing the tree was covered and a wider rim was place around it to prevent the entrance of rain. Walls about two feet high were built around the apparatus to lessen the movement caused by winds. During the season of 1921, careful observations and repeated tests showed that losses of moisture by transpiration as small as 4 ounces could be weighed with confidence. In fact, the placing of 2-ounce weights on the tanks made a measurable movement of the pen on the record sheet. The apparatus was calibrated a number of times by placing standard weights on the tank containing the tree and noting the movement of the pen of the recorder. It was found that there was a definite movement of the pen for a definite weight. One pound of water lost by transpiration equalled six divisions on the record sheet. Three typical daily record sheets are shown in figure 27. The irregular lines in the portions of the graphs between about 10 A.M. and 7 P.M. are due to the movement of the tank caused by wind. The slope of the graphs indicates the rate of loss of water through transpiration. The recording drum revolved twice in 24 hours, and the recording sheet usually had to be replaced each day.

The tank was lowered and the channel-iron frame removed when the tank was irrigated. The tree tank was then raised clear of the water in the outer tank by means of the portable weighing derrick, and the desired weight of water was applied to the soil. The transpiration losses, recorded on the sheets, checked with the losses determined by weighing the tank with the suspension scales.

The data, taken from the record sheet of the automatic balance, showing the use of water by tree 22, summarized for 50 per cent of the time before each irrigation and 50 per cent of the time after each irrigation, is given in table 24. For instance, the tree was irrigated on June 3 and June 16; therefore, the average use of water is given from June 4 to June 9, and from June 10 to June 15. For the purpose of comparison, the average use of water in the forenoon and in the afternoon is given separately from the total daily use. The total number of degrees above 40° F. for each 5-hour period is also given in order to indicate the relative amount of heat during the different periods. The climatological measurements taken at Mountain View during these periods are also summarized. At each irrigation the soil in the tank was raised to its full field capacity, 22 per cent, and in the majority of cases, water was not again applied until the moisture content had been reduced to about 11.9 per cent, the wilting coefficient. Therefore, from the data in table 24, a comparison can be made between the rates of transpiration before and after each irrigation, when the soil-moisture content is high, and when it has been reduced to just above the wilting coefficient.

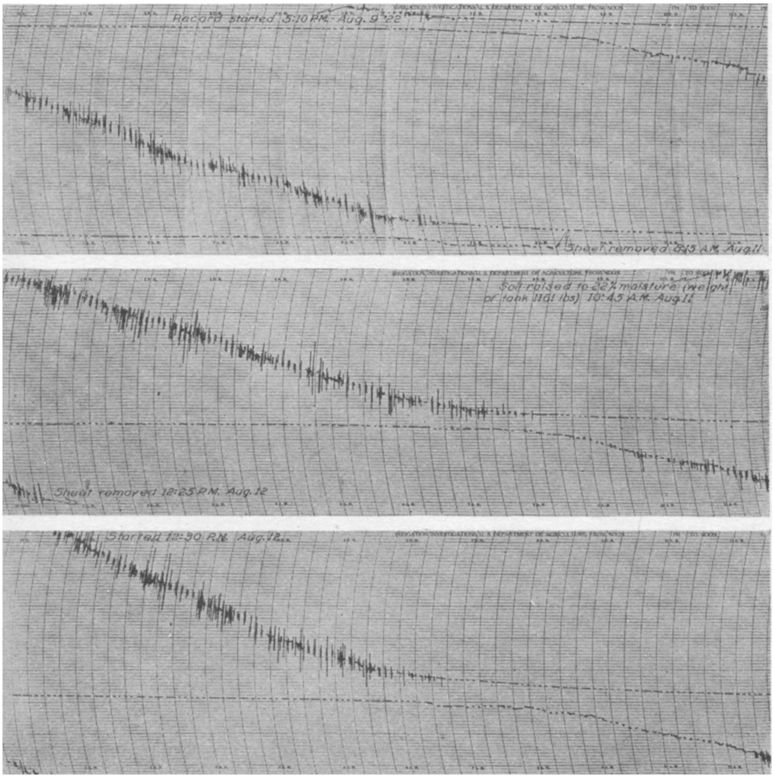

Fig. 27. Three typical daily record sheets taken from recorder used with balanced tank. The upper sheet is the record of transpiration the day before the water was applied, the middle sheet refers to that day, and the bottom sheet to the day following the application of water.

TABLE 24

USE OF WATER FOR THE SEASON OF 1922 BY YOUNG FRENCH PRUNE TREE 22 GROWING IN A TANK AT MOUNTAIN VIEW, TOGETHER WITH CLIMATOLOGICAL MEASUREMENTS

Dates between irrigations for which data is summarized	Dates irrigated‡	Average use of water in pounds			Average evaporation per day	Average maximum temperature	Average minimum temperature	Average vapor pressure deficits, mm. Hg.†	Average wind velocity, miles per hour	Average total number of degrees of temperature above 40° F.*		
		8 a.m. to 1 p.m.	1 p.m. to 6 p.m.	Per day of 24 hours						8 a.m. to 1 p.m.	1 p.m. to 6 p.m.	8 a.m. to 6 p.m.
					Inches	° *F.*	° *F.*					
Apr. 25 to May 3	May 4	.99	.34	1.68	.17	75	38	8.94	1.6	145	159	304
May 5 to May 12		1.16	.57	2.22	.15	71	41	7.44	2.4	125	135	260
May 13 to May 19	May 20	2.15	1.65	4.94	.18	81	52	7.36	1.6	166	175	341
May 21 to May 26		2.68	2.41	6.28	.22	74	40	12.31	2.4	142	159	301
May 27 to June 2	June 3	2.37	2.26	5.78	.18	75	45	7.36	1.4	141	162	303
June 4 to June 9		2.35	3.24	6.49	.19	75	52	7.03	1.8	154	158	312
June 10 to June 15	June 16	2.23	2.86	6.84	.18	74	51	4.82	2.3	133	158	291
June 17 to June 19		3.00	3.94	8.47	.24	87	47	10.70	1.4	187	212	399
June 20 to June 23	June 24	5.10	4.36	11.27	.25	82	46	12.37	1.8	188	197	385
June 29 to July 3	June 28	4.35	4.70	10.45	.22	78	55	8.74	1.3	174	198	372
July 4 to July 7	July 8	4.08	4.26	9.27	.23	75	59	7.56	1.3	169	183	352
July 9 to July 12		4.31	4.67	10.50	.24	76	53	8.86	1.4	160	182	342
July 13 to July 16	July 17	4.60	4.12	10.15	.24	84	51	9.50	1.2	191	204	395
July 18 to July 21		4.54	3.84	10.15	.25	76	53	6.31	1.2	168	168	336
July 22 to July 24	July 25	4.72	3.98	10.06	.24	74	44	8.81	3.1	158	159	317
July 26 to July 28		3.83	4.74	9.99	.23	82	46	9.07	1.0	171	175	346
July 29 to Aug. 1	Aug. 2	3.56	4.08	8.93	.21	79	51	6.70	1.1	160	176	336
Aug. 3 to Aug. 6		3.72	3.66	8.79	.22	78	50	7.35	1.2	153	176	329
Aug. 7 to Aug. 10	Aug. 11	4.54	4.23	10.33	.19	76	46	8.44	1.1	153	176	329
Aug. 12 to Aug. 15		4.67	5.54	11.06	.25	82	46	14.12	2.4	166	194	360
Aug. 16 to Aug. 20	Aug. 21	4.10	4.70	9.83	.21	77	47	7.89	1.5	155	170	325
Aug. 22 to Aug. 25		4.14	5.18	10.58	.20	80	45	9.34	1.0	158	193	351
Aug. 26 to Aug. 29	Aug. 30	4.97	5.00	10.60	.20	81	51	9.62	1.1	172	188	360
Aug. 31 to Sept. 3		5.08	5.81	12.12	.20	88	46	9.41	.9	194	208	402
Sept. 4 to Sept. 7	Sept. 8	5.02	5.00	11.20	.18	82	46	13.39	1.3	165	196	361
Sept. 9 to Sept. 12		3.77	4.31	8.39	.16	92	55	10.50	.8	193	227	420
Sept. 13 to Sept. 17	Sept. 18	4.20	4.43	9.63	.18	88	52	10.71	.7	182	211	393
Sept. 19 to Sept. 23		2.80	3.03	6.87	.15	79	47	6.78	.6	142	170	312
Sept. 24 to Sept. 28	Sept. 29	3.73	3.53	6.70	.15	80	47	7.39	1.0	157	171	328
Sept. 30 to Oct. 7		2.40	2.35	5.78	.13	75	47	5.66	1.1	137	148	285
Oct. 8 to Oct. 15	Oct. 16	1.88	1.76	3.94	.09	70	48	3.49	1.0	107	127	234
Oct. 17 to Oct. 29		2.02	1.75	4.35	.08	73	41	5.84	.7	112	140	252
Oct. 30 to Nov. 12	Nov. 13	.95	.76	2.54	.07	62	39	3.03	1.0	81	79	160

* The number of degrees above 40° F for each hour was taken from the thermograph sheets and the total recorded for the 5 hours in the forenoon and the afternoon.

† Vapor pressure deficits measurements made at 5 p.m.

‡ At each irrigation the soil-moisture in the tank was raised to 22 per cent.

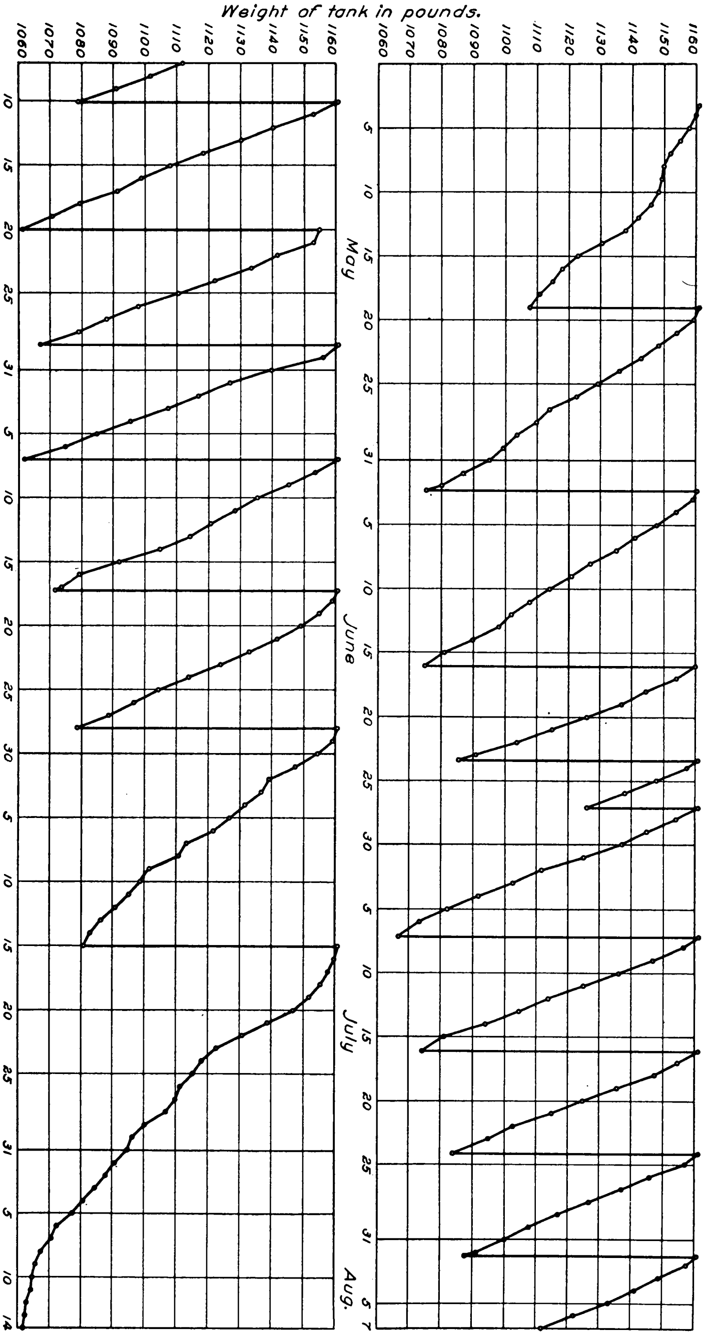

Fig. 28. Use of water by prune tree 22 during the season of 1922, at Mountain View. The weight of the tank with soil containing 22 per cent of moisture is 1161 pounds and the weight when the soil is at the wilting coefficient (11.9 per cent) is 1074 pounds.

The root system of tree 22, illustrated in figure 25, indicates that the soil in the tank was permeated with roots, therefore, the average moisture content of the soil, determined by weighing the tank and computing the moisture from the known weight of dry soil, probably gives a true value for the amount of water in contact with the roots of the tree. The data given in table 24 indicate that the use of water by this prune tree was no greater just after irrigation when the soil-moisture content was high, than it was when the moisture content was lower. The use of water both in the forenoon and in the afternoon before irrigation is about the same as that after irrigation. In some instances it is greater with low soil-moisture content than with high soil-moisture content and in others less. However, these differences are small and probably can be attributed to differences in the evaporating power of the air for the different periods. The agreement between the use with high and low soil-moisture content seems to hold throughout the entire growing season.

TABLE 25

SUMMARY OF THE MONTHLY USE OF WATER DURING THE SEASON OF 1922, BY YOUNG FRENCH PRUNE TREE 22

Month	Number of days for which record was obtained	Average use of water in pounds to the hour			
		8 a.m. to 1 p.m.	1 p.m. to 6 p.m.	For daylight hours	For 24-hour day
April	6	0.18	0.03	0.10	0.05
May	30	0.39	0.32	0.36	0.19
June	29	0.70	0.71	0.70	0.35
July	31	0.83	0.89	0.86	0.43
August	29	0.84	0.93	0.88	0.42
September	28	0.78	0.83	0.80	0.38
October	29	0.38	0.35	0.37	0.22
November	15	0.16	0.11	0.14	0.09

These facts are strikingly illustrated in figure 28, in which is plotted the daily use of water by tree 22. The weights of the tank, taken from the automatic record sheets on successive days, are plotted. The rate of use of water, which is indicated by the slope of the line representing the loss of moisture from the tank, is no greater immediately after irrigation when the soil-moisture content was 22 per cent than it is just before irrigation when the soil-moisture content is about 11.9 per cent. When the climatological data, given in tables 21 and 24, are compared with the slope of the graphs in figure 34, it is apparent that conditions which made for high evaporation from a free water surface, likewise cause the tree to use greater amounts of water. Apparently, atmospheric evaporating power rather than stage of growth of the trees determines the use of water. Of course, the amount of evaporating surfaces exposed by the plant influences the use of water. Since there was practically no increase in leaf area after the middle of May, the increased use of water after this time can not be attributed to this cause. The records of the use of water by tree 22 are summarized for each month in table 25. The increased use in the warmer months is clearly indicated in this table.

Hourly weighings, by means of the portable device and scales, of other trees growing in tanks were made before and after irrigation several times during the season of 1922. In no case did there seem to be any difference in the amounts of water transpired before and after irrigation which could be attributed to the differences in soil-moisture content. The results from one of the trees which was irrigated on May 3 and on May 19, and weighed in this manner is given in table 26. These records were obtained from tree 6, which was planted on April 15, 1919, in a tank 23½ inches in diameter and 48 inches in depth, containing Yolo loam. Only the record of the weighings at 8 o'clock in the morning, at noon, and at 5 o'clock in the afternoon are recorded. Some of the climatological data are also recorded for comparison. There was no change in leaf area between May 3 and May 30. The low rate of transpiration from May 3 to May 9, which averaged only 2.6 pounds a day, compared to 5.3 pounds a day for the period May 10 to May 18, probably was due to differences in climatic conditions. The fact that the rate of transpiration between May 19 and May 30 was very uniform indicates that the transpiration was not measurably affected by the variation in amount of moisture above the wilting coefficient present in the soil.

It is interesting to note that this result was obtained in all of the trials made. The observations made after the removal of the equipment to Davis in 1923 also indicate that the use of water by the trees in these tanks was not influenced by the amount of soil moisture present, provided the moisture content was not reduced below the wilting coefficient.

TABLE 26

USE OF WATER AT MOUNTAIN VIEW BY PRUNE TREE 6

(Tree irrigated May 3 and May 19.)

1922	Weight of tank in pounds			Percentage of moisture in soil at 5 p.m. Calculated from weight of tank	Total loss of water through transpiration in 24 hours. *Pounds*	Evaporation from free-water surface in 24 hours. *Inches*	Wind velocity in miles to the hour	Total number of degrees temperature above 40° F.*
	8 a.m.	12 noon	5 p.m.					
May								
3	1050	1050	1120	21.7	....	0.19	1.6	442
4	1119	1118	1116	21.3	4	0.20	1.7	314
5	1116	1115	1112	20.8	4	0.15	1.5	339
6	1112	1111	1109	20.5	3	0.18	1.3	277
7	1109	1108	1106	20.1	3	0.25	4.2	200
8	1105	1104	1103	19.7	3	0.19	2.5	186
9	1103	1103	1102	19.6	1	0.03	2.0	141
10	1101	1100	1098	19.2	4	0.04	0.8	228
11	1098	1096	1094	18.7	4	0.18	3.5	309
12	1093	1091	1089	18.1	5	0.19	3.6	401
13	1088	1085	1082	17.3	7	0.20	1.4	454
14	1080	1078	1073	16.2	9	0.12	1.4	502
15	1072	1069	1066	15.4	7	0.20	1.4	377
16	1064	1063	1060	14.7	6	0.19	1.2	313
17	1061	1061	1058	14.4	2	0.19	1.5	266
18	1056	1055	1054	14.0	4	0.20	1.8	225
19	1052	1050	1120	21.7	....	0.17	2.7	248
20	1119	1118	1115	21.2	5	0.07	1.5	232
21	1113	1110	1107	20.6	8	0.24	2.4	293
22	1106	1104	1100	19.7	7	0.18	1.9	347
23	1099	1097	1094	18.7	6	0.23	1.9	285
24	1093	1091	1088	18.0	6	0.23	2.4	281
25	1087	1085	1081	17.1	7	0.26	3.3	232
26	1079	1076	1073	16.2	8	0.24	2.4	361
27	1071	1069	1066	15.4	7	0.21	0.8	442
28	1066	1065	1061	14.8	5	0.25	2.0	302
29	1061	1059	1055	14.1	6	0.18	1.0	341
30	1054	1053	1050	13.5	5	0.20	1.5	274

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* The number of degrees above 40° F. for each hour taken from the thermograph sheets and the total is recorded.

THE PERCENTAGE OF MOISTURE IN THE SOIL AT THE TIME OF WILTING OF PRUNE TREES IN TANKS

Throughout the several years of observation of the trees growing in the tanks, there were numerous opportunities to determine the moisture content of the soil when the trees wilted and would not revive until water was added to the soil. The dates on which the prune trees growing in tanks were allowed to wilt and the corresponding moisture content of the soil in which the trees were growing are listed in table 27. The trees were judged to be wilted when the leaves had lost turgidity and were not revived early in the morning, or until water was added to the soil. The nights at Mountain View were cool and generally the relative humidity was high, reaching 100 per cent at night many time during the growing season. Fogs frequently drifted in from the north from San Francisco Bay at night. At Davis, the nights were cool during the summer, but fogs were uncommon.

Briggs and Shantz[12] defined permanent wilting to be the condition at the time when the leaves of the plant first undergo a permanent reduction in their moisture content. By permanent reduction is meant a condition from which the leaves can not recover in an approximately saturated atmosphere without the addition of water to the soil.

Livingston and Koketsu[38] have further defined permanent wilting as that stage of progressive wilting from which recovery fails to occur within a period of 24 hours, if the wilted plants are exposed to a practically water-saturated atmosphere (in darkness) during that period. The large trees and containers used in these experiments made it impossible to place them in a moist chamber. Therefore, it is not known how far the condition of wilting (without recovery until water was added to the soil), adopted in these experiments, departs from the condition of permanent wilting as above defined.

The data presented in table 27 show close agreement between the percentage of moisture in the soil when these prune trees wilted without recovery until water was added to the soil and the calculated wilting coefficients for these loam soils. The wilting coefficients given are the averages of calculated values from duplicate moisture equivalent determinations made on two samples from each tank. All of the values have been averaged and recorded in the table. Weighed samples of 30 grams each were used in making the moisture equivalent determinations. When the weight of the tank at the time the

TABLE 27

MOISTURE CONTENT OF THE SOIL AT THE TIME OF WILTING OF PRUNE TREES IN TANKS, AND MINIMUM EXTRACTION OF MOISTURE BY THE TREES

The equipment was moved to Davis in February, 1923. Observations and samples taken previous to this date were at Mountain View, and after at Davis.

Tree number‡	Date wilted	Weight of tank at wilting, pounds	Calculated weight of tank at wilting coefficient based on weight of dry soil in tank, pounds	Percentage of moisture in soil at wilting based on weight of dry soil in tank	Determined by centrifuge method*		Days after wilting before water was applied	Minimum weight of tank reached, pounds	Time in days to reach minimum	Percentage of moisture in soil calculated from dry weight of soil	Minimum moisture percentage reached, determined by sampling	Condition of tree
					Wilting coefficient	Hygroscopic coefficient						
3	May 3, 1922	1004	1000	11.6	11.1	7.5	4	998	4	10.9	....	Tree revived.
3	Aug. 14, 1922	995	1000	10.5	11.1	7.5	8	982	6	8.9	8.1	Tree revived.
3	Sept. 28, 1922	1001	1000	11.2	11.1	7.5	33	980	24	8.0	8.0	Leaves yellow, finally defoliated.
4	Aug. 23, 1922	1032	1032	11.1	11.1	7.5	4	1011	4	8.6	8.5	Some yellowing, but tree revived.
5	Aug. 25, 1922	1356	1353	13.0	12.7	8.6	1	....	....	....	....	Tree revived.
5	Oct. 7, 1922	1353	1353	12.7	12.7	8.6	10	1343	3	11.8	11.3	Leaves yellow, finally defoliated.
5	May 3, 1923	1349	1353	12.3	12.7	8.6	3	....	....	....	....	Tree revived.
6	Aug. 21, 1922	1034	1037	11.6	11.9	8.1	1	....	....	....	....	Tree revived.
6	Sept. 2, 1922	1035	1037	11.7	11.9	8.1	1	....	....	....	....	Tree revived.
6	Apr. 29, 1922	1032	1037	11.3	11.9	8.1	4	1027	4	10.8	....	Some yellowing but tree revived.
7	Aug. 22, 1922	1343	1355	11.0	12.1	8.2	1	....	....	....	....	Tree revived.
7	Oct. 7, 1922	1349	1355	11.5	12.1	8.2	10	1328	7	9.6	10.6	Completely defoliated.
9	Oct. 13, 1922	1074	1077	11.6	11.9	8.1	1	....	....	....	....	Tree revived.
10	July 7, 1924	1442	1437	11.9	11.6	7.9	1	....	....	....	....	Tree revived.
11	July 26, 1923	1318	1317	11.3	11.2	7.6	1	....	....	....	....	Tree revived.
11	Aug. 28, 1923	1320	1317	11.5	11.2	7.6	4	1309	4	10.0	....	Some leaves yellowed and dropped.
13	June 12, 1923	1409	1411	12.1	12.3	8.3	1	....	....	....	....	Tree revived.
15	Sept. 14, 1922	1830	1837	11.0	11.5	7.8	61	1809	23	9.5	9.7	Leaves yellow, finally defoliated.
15	June 13, 1924	1912	1924†	11.0	11.8	8.0	1	....	....	....	....	Tree revived.
17	Aug. 28, 1922	1824	1830	11.8	12.2	8.3	1	....	....	....	....	Tree revived.
17	Oct. 7, 1922	1832	1830	12.3	12.2	8.3	38	1814	8	11.1	10.7	Leaves yellow, finally defoliated.
17	May 30, 1924	1900	1893†	12.3	11.9	8.1	3	1885	3	11.3	....	Tree revived.
18	Aug. 12, 1922	1862	1865	10.6	10.9	7.5	7	1850	7	9.8	9.9	Some yellowing and defoliation.
18	Nov. 2, 1922	1863	1865	10.7	10.9	7.5	25	1862	2	10.6	10.5	Tree defoliated.
18	July 7, 1924	1896	1891†	11.5	11.2	7.6	1	....	....	....	....	Tree revived.
19	June 13, 1924	1941	1942	11.1	11.2	7.6	1	....	....	....	....	Tree revived.
20	June 13, 1924	1923	1929	11.0	11.4	7.8	1	....	....	....	....	Tree revived.

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* Wilting coefficients calculated from moisture-equivalent determinations made on 30-gm. samples; 2 samples were taken from each tank and duplicate determinations made.

† Extra equipment and additional soil added to tanks in 1924.

‡ Trees 3, 6, and 9 were planted in Yolo loam, April 15, 1919, in tanks 23¼ inches in diameter by 48 inches deep. Trees 15, 17, 18, 19 and 20 were planted April 14, 1921, in Yolo clay loam in tanks 27.08 inches in diameter by 72 inches deep. Trees 5, 7, 10, 11 and 13 were planted April 14, 1921, in Yolo clay loam in tanks 26 inches in diameter and 48 inches deep.

trees wilted and its weight at the theoretical wilting coefficient, calculated from the weight of dry soil in the tanks, are compared, the agreement is seen to be extremely close.

The equipment was moved to Davis in February, 1923. Therefore, observations and samples taken after this date were made at Davis and previous to this date at Mountain View. The climatic conditions which affect the rate of transpiration are markedly different in these two localities. Furthermore, the observations were made at different times during the growing seasons, so there were differences in atmospheric evaporating power, and yet the calculated wilting coefficient apparently is a measure of the moisture condition of these loam soils when the prune trees wilted and did not recover until water was added to the soil.

The results obtained by Briggs and Shantz[12] lead them to conclude that atmospheric environmental conditions have little or no effect upon the residual water content of the soil at the time of permanent wilting and that the wilting coefficient for any given soil is approximately constant for all species of plants grown on it and for all stages of their development. Caldwell[18] and Shive and Livingston,[47] who also studied the wilting of seedlings grown in small containers, found that the amount of residual moisture in the soil at the time of permanent wilting is dependent upon the intensity of atmospheric evaporating power for the period during which permanent wilting is attained. Caldwell's[18] work seems to indicate that, while wilting under high atmospheric evaporating power always exhibited soil-moisture residue somewhat higher than the calculated wilting coefficient, this lack of agreement was less marked with the higher moisture holding capacity soils used by him. Mechanical analyses of the loam soils used for these prune trees show a silt and clay content of over 60 per cent, very fine sand about 20 per cent, and the remainder fine and medium sand. The soil used by Caldwell, which had the highest water-holding capacity, had a calculated moisture equivalent of 20.09 per cent, while the loam soils used in the present investigation had a moisture equivalent of about 22 per cent. Shive and Livingston[47] also show that the difference between the actual soil-moisture residue at permanent wilting and the calculated value become very small with the heavier soil of high water-holding power used by them.

The concurrence of the calculated wilting coefficient and the percentage of moisture in the soil at the time of wilting without recovery until water was added to the soil, has also been observed in the case of apricots and Calimyrna fig trees grown in tanks containing Yolo clay loam soil when studied in the same manner described in the case of prune trees. However, fig trees have been more difficult to study under these conditions, since they drop their leaves more readily than the prunes or apricots when water is withheld. It is interesting to note that these three varieties of fruit trees apparently wilt when the moisture content of the loam soil on which they were growing was reduced to the same percentage at any time during the growing season.

THE MINIMUM REDUCTION OF SOIL MOISTURE BY TREES IN TANKS

Some of the prune trees were allowed to remain for various periods of time in a wilted condition. These periods were generally toward the end of the growing season after other required data had been obtained from the trees earlier in the season. The minimum amounts of water found in the soil at the end of the time the trees were allowed to remain wilted are given in table 27. It should be noted that in no case was the water supply in the soil reduced to an amount equal to the calculated hygroscopic coefficient. Apparently, the trees in these tanks were only able to use about half of the water in the soil between the wilting coefficient and the hygroscopic coefficient. This is substantially the same result observed in the Muir peach orchard at Davis and in the Santa Clara Valley prune orchards, except in orchard No. 6 and orchard No. 2, where the soil-moisture supply was reduced to the hygroscopic coefficient.

The condition of trees 3, 4, and 5 on October 18, 1922, is shown in plate 1, figure 1. Tree 3 wilted on September 28, 1922, and tree 5 wilted on October 7, 1922. The soil-moisture content in the soil on which tree 4 was growing was kept above the wilting coefficient. The leaves on tree 3 were mostly dead and had completely collapsed, taking on a dark brown color before October 18. Tree 5 was decidedly wilted and the leaves were yellow and limp. Most of the leaves on tree 4 had turned yellow but all were turgid. This tree was maturing its leaves normally. The photograph, plate 1, figure 2, of the trees on October 28, shows the condition of trees 3 and 5 when the effects of drought had progressed still further. All of the leaves on tree 3 were black, and tree 5 was almost completely defoliated, while the leaves on tree 4 were dropping normally. A further example of the effects of withholding water for long periods of time is illustrated in plate 2, figure 1, by the condition of tree 15, which wilted on September 14, 1922. Tree 17 wilted on October 7, 1922; the soil in which tree 16 was growing was kept above the wilting coefficient. The photograph was taken on October 18, 1922.

The minimum reduction of the soil moisture by vetch grown in tanks was studied in the same manner as were the trees. The following may be cited as examples of these observations. On November 4, 1921, vetch seed was planted in a tank holding about 1000 pounds of soil. This tank was 23½ inches in diameter and 48 inches in depth. The vetch matured seed pods on June 1 and became permanently wilted. The weight of the tank on this date was 1121 pounds and apparently all loss of moisture from the tank had ceased by June 20, when the tank weighed 1116 pounds. The plants were removed and samples taken in foot depths to a depth of 3 feet. The moisture contents of these samples were determined and moisture equivalent determinations were then made. The following results were obtained:

Depth of soil sampled, feet	Percentage of moisture found in samples	Wilting coefficient	Hygroscopic coefficient
0 to 1	8.6	12.4	8.4
1 to 2	11.1	12.7	8.6
2 to 3	10.5	11.8	8.0

A tank, 26 inches in diameter by 48 inches deep, holding 1200 pounds of soil, was planted with vetch on the same date (November 4, 1921). More plants were allowed to grow in this than in the other. After the plants had matured and wilted and no further loss of moisture took place, samples were taken and the following results obtained:

Depth of soil sampled, feet	Percentages of moisture found in sample	Wilting coefficient	Hygroscopic coefficient
0 to 1	9.3	11.9	8.1
1 to 2	10.4	12.9	8.8
2 to 3	8.7	10.4	7.1

These records show that vetch plants and prune trees in these tanks used a considerable portion of the moisture in the soil below the wilting coefficient. Obviously the wilting coefficient is not the lowest limit of available water, although when the moisture content of these loam soils was reduced to a moisture content corresponding to the calculated wilting coefficient, the plants wilted and did not recover until water was added to the soil. These results agree with observations made in the Santa Clara Valley prune orchards and in the mature Muir peach orchard at Davis. Therefore, it seems that the calculated wilting coefficient of the soils used in these experiments represents a critical soil-moisture condition. This soil-moisture constant is a better basis for comparing moisture conditions of soils than the hygroscopic coefficient, which probably represents the extreme lower limit of available moisture. Furthermore, the difficulty of directly determining the hygroscopic coefficient, as Puri[43] has shown, which also makes the value calculated from the moisture equivalent doubtful, mitigates against its use.

EFFECT OF SOIL-MOISTURE CONTENT ON CONDITION OF PRUNE TREES IN TANKS IN THE FALL

In connection with the study just described, observations were made of the condition of the prune trees in tanks in the fall under different soil-moisture contents. Trees 19 and 20 were irrigated so that the soil-moisture content was maintained between a range of maximum field capacity and 16 per cent throughout the entire season. The soil on which tree 18 was growing was kept above 16 per cent until about the end of the first week in August and then allowed to wilt and remain in this condition until August 12, 1922. Thereafter it was irrigated whenever the soil-moisture content had been reduced to about the wilting coefficient. The maximum field capacity of the soil in those tanks varied from 20 to 22 per cent. The wilting coefficient of the soil on which tree 18 was growing was 10.9 per cent; tree 19 was growing on soil with a wilting coefficient of 11.2 per cent, and tree 20 on soil with a wilting coefficient of 11.4 per cent. The condition of these three trees on October 18, 1922, is illustrated in plate 2, figure 2. More of the leaves on tree 19 had turned yellow than of those on trees 18 and 20, but the condition of these trees and leaves was substantially the same as that of trees with higher or lower soil-moisture content, provided those with lower soil moisture were not below the wilting coefficient. Trees which had grown on water-logged soil colored their leaves in the usual manner as early as did trees 18, 19, and 20. The condition of two of the trees, 13 and 14, which were on water-logged soil, is illustrated in plate 3, figure 1. The photograph was taken on October 18, 1922. Tree 13, the center tree in this figure, was on soil, the moisture content of which was just above the wilting coefficient. It was noted that many of the leaves of other trees on water-logged soil were yellow on October 18. The soil-moisture content for tree 13 had been maintained between the maximum field capacity and the wilting coefficient. Further illustration of the fall condition of trees on soils with different moisture contents is shown in plate 1, figure 1. Tree 3 was decidedly wilted, while tree 5 had been wilted for a short time before the photograph was taken. Tree 4, which was on soil with a moisture content just above the wilting coefficient, was holding its leaves normally, although many had turned yellow. Plate 1, figure 2, illustrates the condition of these trees 10 days later. The wilting of trees 3 and 5 had progressed further, while the leaves of tree 4 were normally dropping.

Defoliation caused by wilting could be induced by withholding water until the soil-moisture content was reduced below the wilting coefficient, but no differences in condition of the leaves or in the time the leaves dropped in the usual manner could be noted when trees on soil with high moisture content were compared with trees on soil with lower moisture content but not below the wilting coefficient.

This suggests that the time of beginning of coloring of the leaves in the fall and probably of dormancy or of maturity of the plant tissues is not affected by variations of soil-moisture content within a wide range. Furthermore, no injury from low temperatures during the dormant season could be detected in the trees in the Santa Clara Valley prune orchards and in the Muir peach orchard at Davis, which had been irrigated late in the season but before the leaves had dropped.

USE OF WATER DURING THE DORMANT SEASON BY PRUNE TREES IN TANKS

During the growing season, the pieces of oiled-cloth which had been tied around the trunks were loosened to allow them to expand. However, at the beginning of the dormant season, the pieces of oiled-cloth were sealed tightly around the trunks of the trees. Therefore, there was an opportunity to measure the losses of moisture, within the limits of accuracy of the weighing device, from the bare twigs and branches of the trees during the dormant season. The condition during the dormant season of three trees which had been growing in the tanks for three seasons is shown in plate 3, figure 2.

The results of the observations during the winter of 1922 at Mountain View are given in table 28. The losses are given for the period November 25, 1921, when all of the trees were completely defoliated, to March 1, 1922, the date on which the trees began to show activity again. For comparison, the losses also are given for the period, November 25, 1921, to April 1, 1922, at which time some leaves were formed on the trees.

TABLE 28

LOSSES OF MOISTURE BY EVAPORATION FROM THE BARE TWIGS AND BRANCHES OF PRUNE TREES GROWN IN TANKS DURING THE DORMANT SEASON OF 1922, AT MOUNTAIN VIEW

Number of of tree	Size of tank in which tree was growing	Date tree was planted	Loss of water Nov. 25, 1921 to March 1, 1922	Loss of water Nov. 25, 1921 to April 1, 1922
	Inches		*Pounds*	*Pounds*
1	23½ by 48	Apr. 15, 1919	1	2
3	23½ by 48	Apr. 15, 1919	3	8
4	23½ by 48	Apr. 14, 1921	3	7
5	26 by 48	Apr. 14, 1921	4	9
6	23½ by 48	Apr. 15, 1919	0	2
7	26 by 48	Apr. 14, 1921	2	6
9	23½ by 48	Apr. 15, 1919	4	11
10	26 by 48	Apr. 14, 1921	6	12
11	26 by 48	Apr. 14, 1921	8	5
12	26 by 48	Apr. 14, 1921	4	7
13	26 by 48	Apr. 14, 1921	8	15
14	26 by 48	Apr. 14, 1921	8	13
15	27.08 by 72	Apr. 14, 1921	5	9
16	27.08 by 72	Apr. 14, 1921	7	11
19	27.08 by 72	Apr. 14, 1921	2	8
20	27.08 by 72	Apr. 14, 1921	6	9
21	27.08 by 72	Apr. 14, 1921	5	....
22	23½ by 48	Apr. 15, 1919	3	....
Average			4.4 ±0.39	8.4 ±0.61

The soil in all of the tanks was fully wet on November 25, 1921, so that there was ample moisture available. While the covers fitted the tops of the tanks closely, they were not absolutely tight and, of course, some losses occurred by evaporation from the surfaces of the wet soil. No check tanks were available, consequently no estimate can be made of these losses. In this connection, it should be noted from the data in table 28 that apparently there is no agreement between size of the tree and the resulting loss. For instance, the large trees, such as trees 1, 3, and 6 shown in plate 3, figure 2, lost less than the smaller trees, such as trees 10, 11, 13, 14, and 15. A further example, tree 21, the tree shown in the left in plate 3, figure 2, lost five pounds, which was greater than the loss from any of the larger and older trees as the data in table 28 show.

A further example of the relatively slight losses of moisture through the young prune trees under observation when the leaves have been removed, is given in the results of the losses of moisture from tree 9, which was completely defoliated on June 16, 1922. This tree transpired 15 pounds of water during the 24 hours preceding the defoliation. From June 16 to July 1, the date on which the leaves began to open again, only 12 pounds of water were lost from the tank. On July 5, it was estimated that the tree was almost 3 per cent leafed out. Three pounds of water were lost between July 1 and July 5. On July 10 the tree was 20 per cent leafed out and had used 8 pounds of water between this date and July 5. During the week following July 10, the tank lost 40 pounds of water. The soil in the tank was wet to its maximum field capacity on the day the tree was defoliated. There were about 50 prunes on the tree, most of which stayed on until after the leaves were again formed.

The loss of water through these prune trees during the dormant season is relatively slight. Probably only in years of exceptionally light rainfall would prune trees in localities such as the Santa Clara Valley need irrigation during the dormant season so far as the current needs of the trees are concerned. However, as Batchelor and Reed[5, 6] have shown to be essential for walnuts, available water must be present during the dormant season.

DISCUSSION OF RESULTS

During the course of the experiments described in this section, it was found impossible to bring about a uniform moisture content in the soil less than maximum field capacity. Applications of water to the surface of soils in containers or in field plots resulted in wetting the soil to a definite depth, depending upon the maximum field or capillary capacity and upon the initial moisture content. The water applied to the loam soils used in these containers raised the moisture content to the maximum field capacity in each tank, and this moisture content was established throughout the entire depth of soil penetrated by the water. The percentage to which the soil was raised seemed to be independent of the amount of moisture in the soil previous to the application of water. There seemed to be little subsequent movement of moisture and clearly there was no adjustment of moisture which would cause a uniform moisture condition to be established between the wet and drier soils.

It was found that the soil-moisture supply could be kept above a certain minimum. The soil could be raised to a maximum content and this condition reestablished when the plants had reduced the soil moisture supply to a certain minimum. All attempts to apply water, whether to the surface or from below, or by means of specially arranged, perforated irrigating pipes, in order to establish a uniform relatively low moisture content throughout the soil mass, met with failure. Experiments to determine the effect of varying moisture conditions upon the use of water by plants must be planned with these facts clearly in mind. Serious objections may be raised to previous water relation studies, wherein dependence has been placed upon capillary forces to bring about a uniform distribution in the soil of water applied at any point.

The data presented in this section show that the use of water by these prune trees grown in tanks was not affected by the total amount of water in the soil until the soil moisture supply was reduced to about the wilting coefficient. High coefficients of correlation were found between use of water and leaf area and the use of water and length of growth, even though the trees were grown on soils with varying ranges of moisture contents. These young prune trees, grown on clay loam soil in tanks under the conditions prevalent at Mountain View, were not influenced by the differences in amounts of water available for growth above the wilting coefficient. Optimum moisture conditions for growth cover a range of soil moisture from the maximum field capacity to about the wilting coefficient. In the loam soils used in these experiments there was a rather wide range of moisture content within which the trees seemed to thrive and develop equally well; it was equivalent on the average to a depth of 1.6 inches of water to a foot of soil. The moisture content corresponding to the wilting coefficient was a perceptibly dry condition, and one at which most orchardists would unhesitatingly judge the soil to be in need of water.

A number of investigators have shown that even though the moisture in the soil may fluctuate within a considerable range the plant will develop normally. However, the belief is prevalent that there is for each soil a particular water content, the optimum water content for growth at which plants grow best.

There appears to be no reason, either from physical considerations of the forces involved between the moisture and the soil particles or from physiological requirements of the plant, why optimum moisture conditions for growth should not vary from the maximum field capacity to about the wilting coefficient.

Shull[48] has shown that at the wilting coefficient, the soil withholds water from the plant with a force almost equal to four atmospheres, while the usual osmotic concentration of the sap of root cells of land plants is equal to seven or eight atmospheres. Under normal field conditions, therefore, the pressure gradient in favor of the plants should run from four to eight atmospheres, as the water holding power varies from zero to four atmospheres. Shull thinks that wilting at the wilting coefficient can not be due to lack of water, nor can it be due to equalization of forces between root hair and soil water. Therefore, he attributes the wilting of plants at the wilting coefficient to be due to the failure of water movement from soil particle to soil particle and from these to the root hairs, rather than from lack of moisture or of pressure gradient. However, Bouyoucos,[9] from the results of freezing point and dilatometer methods, believes that moisture near the wilting coefficient is held by the soil with such force that the plants can not extract it, and that the concentration of the soil solution is comparatively high, a factor which would tend to influence the intake of water by the roots. Bouyoucos holds that plants wilt, not because the soil moisture moves at an insufficiently rapid rate, but because it does not move at all. He points out that the dilatometer method results show that the percentage of moisture which fails to freeze at the supercooling of —1.5° C. is very nearly the same as that at which plants begin to wilt, a fact which indicates that the wilting coefficient of soils is at the point where the free moisture ends and the capillary adsorbed moisture begins. According to Bouyoucos' physiological classification of soil moisture, it is only the free water or the water which freezes at the supercooling of —1.5° C. that the plants can take up very readily, because very little force is needed to utilize it, since it exists in a free condition and is not held very rigidly by any outside force. The free or ''the readily available'' or ''very available'' water of Bouyoucos' classification corresponds to the moisture from the wilting coefficient to the field capacity. However, Bouyoucos[8] believes that the free water in the soil, the water between the wilting coefficient and the field capacity, would evaporate almost at the same rate as free water in mass, which indicates that he thinks the free water in the soil is held very loosely and very little if any force need be exerted to utilize all of it.

The rate of evaporation, vapor pressure, freezing point depression, wilting coefficient, hygroscopic coefficient, water holding capacity, and the unfree water content are all measures of the force with which water is held by the soil at different moisture contents. Parker[42] has discussed the different methods of determining the attractive force the soil has for water and he shows that when the force with which water is held by the soil at different moisture contents is graphically represented the curves obtained by the rate of evaporation, vapor pressure measurements, freezing point depressions, and the method of Shull are all very similar. However, the curves differ in that the point of greatest curvature comes at different moisture contents. All of the curves show that for a wide range of moisture content there is only a slight increase in the force with which the water is held by the soil but the force increases very rapidly below a certain moisture content. Parker[42] points out that the freezing-point method and the method of Shull are more sensitive than the evaporation or vapor-pressure methods and that the point at which the force holding the water in the soil begins to increase rapidly will be at higher moisture content when measured by the freezing-point and probably by the method of Shull than the corresponding points obtained by the rate of evaporation and vapor pressure methods. However, all of the methods show that at low moisture contents, the water is held with much greater force than the additional water at the high moisture contents. Shull[48] shows a very slight increase in the force holding the water in the soil until the moisture content is reduced to the wilting coefficient, but below this the force increases very rapidly. The silt loam soil used by him had a wilting coefficient of 19.1 per cent. The increase in surface force from saturation to 18.87 per cent moisture was from 0 to 3.8 atmospheres; at 17.93 per cent the surface force was 11.4; at 10.06 per cent, 22.4; and at 13.16 per cent, about the hygroscopic coefficient, the surface force increased to 72 atmospheres. Thomas[49] measured the aqueous vapor-pressure lowerings of several soils at different moisture contents. One of the loam soils used by him had a moisture equivalent of 23.3 per cent. By growing beans, Thomas found the plants wilted in this soil at 9.3 per cent. This gives a ratio of the moisture equivalent to the moisture content when the beans wilted of 2.5, which is much higher than the ratio of 1.84 given by Briggs and Shantz.[12] The calculated wilting coefficient for this soil, using the ratio of 1.84, is 12.7 per cent. Thomas[49] reports a vapor pressure depression of 0.30 mm. at a moisture content of 9.5 per cent for this soil, which in a solution at 25° means an osmotic pressure of about 17 atmospheres. The vapor pressure depression at 12.7 per cent calculated from Thomas' formula would be 0.14 mm., which means an osmotic pressure of about eight atmospheres, which is about twice that found by Shull. Thomas' data indicates that above the calculated wilting coefficient the vapor pressure changes are very slight for large variations in moisture content but that the vapor pressure begins to fall rapidly with lower moisture contents.

It has been shown by a number of investigators that plants do not absorb solutes in the same proportion in which they exist in the soil solution. It also appears that the amount of solutes absorbed bears no direct relation to the amount of water absorbed, and that increasing transpiration does not accelerate the entrances of solutes. Hoagland[33] has recently pointed out that plants can make equally good growth in a very great variety of culture solutions and that there is no evidence that plants thrive only in solutions with certain specific ratios between various elements. Solutes and solvent may move into the plant independently and the movement of water within the plant may be independent of the movement of solutes, as Curtis[24] seems to show, and since there is a wide range of soil solutions in which plants develop normally, there seems to be no physiological reason why the environmental soil conditions necessary for good growth should not be met within a range of moisture content from the maximum field, or capillary capacity, to about the wilting coefficient. Furthermore, the fact that the best evidence seems to show that the force with which water is held by the soil does not increase rapidly until the moisture content is reduced below the wilting coefficient indicates that optimum moisture conditions extend from the field capacity to about the wilting coefficient.

There was close agreement between the wilting of these prune trees without recovery until water was added to the soil and the calculated wilting coefficient of the loam soils used in these experiments. Inasmuch as these observations were made at Mountain View and Davis throughout several seasons and at different times during each season there were differences in atmospheric evaporation power, and yet the wilting coefficient of these loam soils calculated from the moisture equivalent seemed to be a measure of a moisture condition at which the prune trees wilted and did not recover until water was added to the soil.

The moisture content of the loam soils in the tanks was reduced much below the calculated wilting coefficient by the prune trees but in no case was the water supply reduced to the calculated hygroscopic coefficient. The trees were able to use only about half of the water in the soil between the wilting coefficient and the hygroscopic coefficient. Substantially the same results were obtained in the Santa Clara Valley prune and the Muir peach orchard irrigation studies. However, the soil-moisture supply was reduced to the hygroscopic coefficient in a few cases by these mature trees.

Vetch plants grown in tanks were allowed to reduce the moisture content of the soil. When no further loss of moisture could be detected by the means at hand for weighing the tanks, samples taken indicated that approximately half of the moisture between the wilting coefficient and the hygroscopic coefficient had been used. Although the wilting coefficient is not the lower limit of available water, it probably is a better basis for comparing moisture conditions of soils than the hygroscopic coefficient which probably represents the extreme lower limit of available moisture but which, according to Puri,[43] can not be satisfactorily determined.

The different amounts of water available in the soil apparently had no noticeable effect on the condition, in the fall, of the prune trees grown in tanks. Defoliation caused by wilting could be brought about by withholding water until the soil-moisture content was reduced to the wilting coefficient, but no differences could be noted in the time the leaves normally dropped when trees on soil with high moisture content were compared with those on soils with lower amounts of available water, but in which the soil-moisture content was not reduced below the wilting coefficient. The fact that the time of beginning of the coloring of the leaves in the fall, and probably of the beginning of dormancy or maturity of the plant tissues, was not affected by variation in amounts of available soil moisture within a wide range, should be expected from the results reported in the first part of this section, wherein it is shown that the use of water and the growth of these young prune trees were not affected by variations in amounts of available water during the growing season.

While it must be remembered that the results of the studies under controlled conditions were obtained with young prune trees in containers, and that they are applicable only under the conditions of these experiments, they do suggest that many of the current views regarding the soil-moisture relations of other plants may also be questioned.

SECTION IV

THE LOSSES OF MOISTURE BY EVAPORATION DIRECTLY FROM THE SURFACE OF THE SOIL AND THE MOVEMENT OF MOISTURE IN THE SOIL

Early in the course of the studies described in the preceding sections, it was noted that the amount of water transpired by growing plants was tremendously greater than that evaporated directly from the surface of the soil. These results are based not only on comparisons of the losses of water through trees growing in tanks with losses of water from uncropped tanks, but also on the results of sampling the soil for moisture determinations in fallow and cropped areas in the field. Therefore, if it is established that the great majority of water is taken from the soil by plant transpiration, the results of sampling the soil in orchards, if such sampling be representative, might indicate the presence or absence of roots, which in turn would indicate the depth of soil necessary to be wetted at each irrigation. For this reason, as well as for the direct bearing the results of such studies have on orchard practices, and the importance of information concerning the movement of moisture in soils, the studies reported in this section were undertaken. Furthermore, the absence of rains during the summer months in California makes the conditions unusually favorable for such studies and affords an opportunity not generally met with in other sections.

The conclusion that losses of moisture are occasioned by the upward movement of moisture from the lower moist layers of soil to the surface and dissipated into the air is based upon the familiar teaching that moisture is capable of moving in the soil in all directions through capillary forces. It is reasoned that moisture exists in the form of films around the soil particles and in wedge-shaped masses of water between the soil particles at the points of contact with each other, being held partly by the attraction of the non-water particles for the water, and partly by the molecular attraction of the liquid itself. Adjoining particles with different thicknesses of moisture films surrounding them hold different amounts of water in the adjacent capillary spaces.

The amount of this capillary or imbibitional water in the soil is determined by a number of conditions. The most important of these is the number of soil particles, the soil texture, and the arrangement of the particles, or the structure of the soil. The depth of the soil to the level of standing water also is an important factor in determining the amount of water held in the soil. Other conditions, which exert much less influence, are the temperature and the kind and quantity of material dissolved in the water.

Briggs[11] points out that the moisture surface around the particles containing less amounts of water than adjacent particles will have greater curvature and consequently greater pressure outward. Moisture will move through the connecting film from the greater to the lesser mass until the pressure becomes the same, a process which takes place when the capillary spaces contain equal amounts of water. This movement can extend to any number of capillary spaces through any number of films. A decrease in the amount of water in the capillary spaces in the upper layers of soil would then be expected to result in water being drawn to that point.

However, Buckingham[17] pointed out many years ago that when a soil is very wet, the water in the capillary spaces is continuous and the wedge-shaped masses merge into one another at their edges. A current of water could flow through the soil without having to flow through the films. As the water content of the soil is reduced, the capillary masses or drops cease to be continuous and communicate with one another only through the film water. Then the resistance of these thin films to the flow of water is much greater than the resistance in the parts of the path which lie in the capillary water, and it is reasonable to assume that the movement is materially retarded.

The commonly accepted idea of the part that cultivation plays in preventing the upward rise and consequent loss of moisture into the atmosphere is based upon the theory that by loosening the surface, rapid drying takes place and the soil particles are removed from close contact with each other. The first condition results in a decrease in evaporation, since the dry soil is assumed to act as a blanket; the second, reducing the points of contact, lessens the capillary pulling power.

The movement of moisture in soils contained in glass or metal cylinders and columns of soil in tanks or metal lined flumes, when the lower ends are in contact with free water, has received much study. The movement of moisture from moist soils to soils containing lesser amounts of moisture, the field condition more frequently met with in California, has received less study. The work of Harris and Turpin,[30] Alway and McDole,[3] Willard and Humbert,[54] and McLaughlin,[40] is typical of many of the experiments dealing with moisture movement under controlled conditions in soils where a water table is not present. It might be mentioned in passing that the results obtained by these investigators all indicate, although some of them did not come to this conclusion, that the movement of moisture, especially in an upward direction, from moist soils to drier soils is slight in amount and extent, when the source of the moisture supply is not saturated soil in contact with a free water surface.

Numerous observations of moisture conditions in the field by soil sampling have been reported and, in many cases, the upward movement of moisture by capillary action, and consequent large losses by evaporation have been held to be extremely important. Widtsoe[53] states that there is, soon after each irrigation, a steady upward movement of water causing a general drying out of the soil to great depths. Cameron[20] maintained that the larger part of the water from rains in humid areas returns to the surface through distances of many feet. Hall[29] holds that in some soils the capillary rise of water might be as much as 200 feet.

King,[37] in many of the reports of the Wisconsin Agricultural Experiment Station and in his several text books, laid stress upon the losses of moisture through evaporation from the soil surface by upward capillary movement. Hilgard and Loughridge,[31] in the reports of the California Agricultural Experiment Station, held the same opinion. In the reports for 1897–1898 of this station, cultivation to conserve soil moisture under semi-arid and arid conditions and the need for deeper cultivation under these conditions are strongly recommended. Fortier and Beckett[26] studied the losses of moisture from irrigated soils contained in large tanks and state that soil mulches are effective in lessening these losses.

On the other hand, Alway[2] concludes that but comparatively little water which has once passed below the first foot is lost by evaporation, and again the same investigator[1] concludes that the loss of moisture from the subsoil of dry lands under crop seems to take place almost entirely through transpiration. From field studies extending over seven years, Burr[16] reached the conclusion that in order to obtain water the roots of plants must extend themselves into the soil where available water is present, rather than depend upon the water being brought to them by capillarity, since there seemed to be little upward movement of subsoil water in the absence of a water table.

Loughridge,[39] in reporting observations of moisture movement in citrus groves, lays stress on the loss of moisture by evaporation and upon the value of cultivation, but shows that there is relatively little lateral movement of moisture from irrigation furrows when the downward movement is not obstructed. Moreover, his data indicate that no loss of moisture by either upward or downward movement occurred below four feet in a citrus grove through the period of one month. He states, "It is extremely doubtful that water at a depth of more than five feet below the root systems will be of any benefit to the trees in times when needed, for the capillary rise is extremely slow." Briggs, Jensen and McLane[15] found that available moisture below the third foot did not prevent orange trees from wilting when the moisture content of the upper soil which contained the roots of the trees had been exhausted below the wilting coefficient.

In studying the root systems of corn and sorghum in Kansas, Miller[41] found that there was little depletion of soil moisture below the depth to which the roots penetrated. Baker[4] reports that the loss of moisture by direct evaporation from the surface of the soil is very small after the water has become distributed. It is reported by Young[55] that the loss of moisture is largely by transpiration through plants. He also concludes that the soil mulch is not more effective than an unmulched soil in retarding evaporation. Call and Sewell[19] conclude that cultivation is not effective in preventing evaporation.

Rotmistrov[44] makes the following statement after a number of years' observation, "As regards the circulation (of moisture) in an upward direction, there exists a wrong impression, which our literature has almost made a household word. It is maintained that water can rise to the surface from the deep layers by capillary action. I shall not name the authors who maintain this theory—they are too numerous—but I do not know of a single author who could prove this proposition," and again "that water percolating beyond a depth of 40 to 50 centimeters does not return to the surface except by way of roots."

Sewell[45] reviewed much of the literature dealing with tillage, and since tillage is supposed to affect soil moisture, his conclusion, that cultivation may be necessary only to kill weeds and to keep the soil in a receptive condition to absorb rainfall, may be of interest in this connection. Furthermore, Chilcott and Cole,[21] after an extensive investigation in the Great Plains, conclude, "The quite general popular belief in the efficiency of deep tillage as a means of overcoming drought, or of increasing yields, has little foundation of fact, but is based on misconceptions and lack of knowledge of the form and extent of the root systems of plants, and of the behavior and movement of water in the soil."

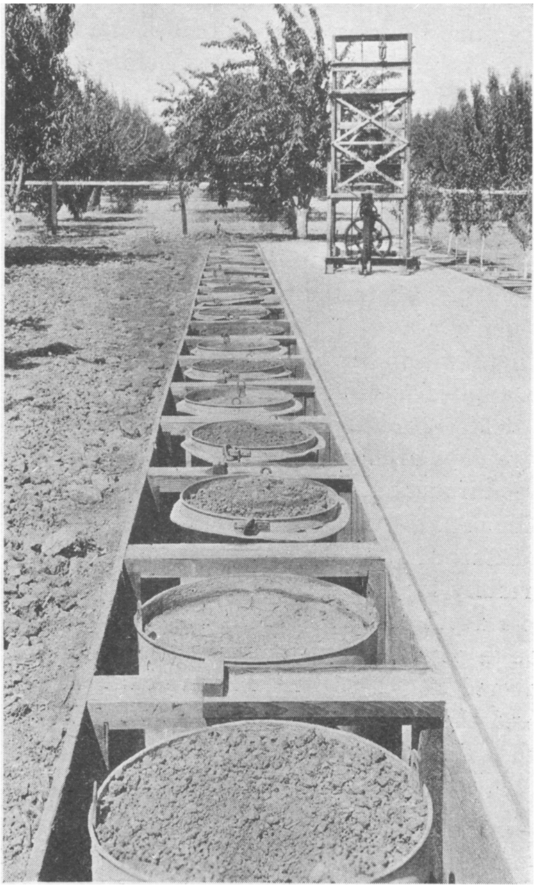

Fig. 29. Soil tanks at Mountain View used to determine the losses of moisture by evaporation directly from the surface of the soil. Later the tanks were further protected from temperature changes by pieces of board sheathings cut to fit around the tanks.

Losses of Moisture by Evaporation Directly from the Surface of Bare Soils in Tanks

Tanks similar to those in which the trees were planted were used during the summer of 1921 at Mountain View, in tests to determine the loss of water from bare soil by evaporation directly from the surface. These tanks were of two sizes: the smaller tanks with an exposed surface of 3.01 square feet held about 1000 pounds of soil; the larger tanks with an exposed surface of 3.69 square feet held about 1400 pounds of soil. The tanks, all of which were 48 inches deep, were packed with a Yolo clay loam soil, and the packing was such that it had the same volume weight as that of the field soil. The tanks were allowed to stand for six months before the tests were begun. The weight of water-free soil in each tank was known.

On August 17, 1921, sufficient water was applied to all of the tanks except Nos. 23, 24, and 26, to equal a calculated average percentage of moisture in the soil of 20 per cent. It was thought undesirable to disturb the soil in the tanks; therefore, no samples were taken immediately after the water was applied. As a consequence, the distribution of water in the soil in the tanks at this time is not known. However, the amount of water applied should have been sufficient to wet all of the soil to within six inches of the bottom. More than enough water was applied to tanks Nos. 23, 24, and 26 to fill the soil to the maximum field capacity. The excess water was drained off during the first five days after the water was applied. These tanks, therefore, were wet throughout the entire depth of soil.

The soils in nine of these tanks, Nos. 23, 25, 27, 29, 31, 33, 36, 38, and 41, were not disturbed after the water was applied to the surface, except to pull carefully any weeds which started to grow. The soils were cultivated to a depth of six inches in the tanks numbered 24, 26, 30, and 39, as soon as possible after the water was applied. The soils in the tanks numbered 28, 32, 35, and 42 were cultivated to a depth of eight inches, and the soils in the tanks numbered 34, 37, and 40 were cultivated to a depth of ten inches. The soils were cultivated every week until the end of the test by means of a small five-pronged garden fork, which was thrust into the soil the desired depth, thus loosening and stirring it. This was followed by further cultivation with a small pointed hoe shaped somewhat like the blade on a shovel cultivator. This hoe was drawn backwards and forwards through the soil, thoroughly stirring it. The tanks were weighed at frequent intervals during the course of the test, which ran from August 17, 1921, to November 4, 1921. The weighings were made with the portable derrick and suspension scales previously described. The arrangement of the tanks in the trench and the condition of the surface of the soil in some of the tanks is illustrated in figure 29, the photograph for which was taken on August 24, 1921, seven days after the water was applied. Later, the tanks were further protected from undue temperature changes by pieces of board sheathings cut to fit around the tanks.

The accumulated loss from the beginning of the tests, August 17, 1921, until November 4, 1921, at different times as determined by weighing with the portable derrick and suspension scales is given in table 29. Since the tanks differed in size, the loss is calculated as pounds to the square foot of surface exposed to evaporation. One pound of water to a square foot is equivalent to a depth of 0.19 inches, or about 3/16 inches, of water. The data in table 29 are shown graphically in figure 30.

It will be noted that in every case the loss which occurred within the first week after the water was applied was approximately 50 per cent of the total loss which occurred within 80 days. The relatively rapid loss immediately after the application of water to the soils in the tanks is shown by the results obtained from observations made in 1922 on tanks Nos. 26 and 27, containing Yolo clay loam, with an area exposed to evaporation of 3.01 square feet. These tanks were irrigated on May 14, 1922, with sufficient water to saturate the bottom six inches of soil in the tanks. The soil in tank No. 26 was found to contain an average moisture content of 23.9 per cent, and the soil in tank No. 27 contained 24.0 per cent moisture when samples were taken on October 25, 1922, 164 days after the water was applied. Tank No. 26 lost 14 pounds, and tank No. 27 lost 13 pounds during the week following irrigation. The accumulated loss at the end of the first month from tank No. 26 was 20 pounds, and from tank No. 27, 19 pounds. The total loss for the entire 164 days, or from May 14 to October 26, 1922, from tank No. 26 was 35 pounds and from tank No. 27, 32 pounds. The surface of the bare soil in these tanks were undisturbed except to pull weeds which started to grow.

These rapid losses by evaporation from the soil surface, which immediately followed irrigation and which constituted about one-half of the total loss from this cause within a period of about three months, occurred before the surface of the soil was in condition to be properly cultivated. It will be seen, then, that the supposed efficiency of cultivation in controlling these losses is doubtful in any event, since so large a portion of the total loss occurs before the surface of the soil is dry enough to be properly cultivated.

TABLE 29

LOSSES OF MOISTURE IN POUNDS TO THE SQUARE FOOT* BY EVAPORATION DIRECTLY FROM THE SURFACE OF BARE SOILS IN TANKS CONTAINING YOLO CLAY LOAM AT MOUNTAIN VIEW. WATER WAS APPLIED TO THE SOIL ON AUGUST 17, 1921. THE TOTAL LOSSES UP TO EACH DATE ARE GIVEN

Tank	Treatment of soil	Area of soil in tank exposed to evaporation, sq. ft.	August			September					Oct.	November	
			25	27	29	2	10	16	24	30	8	1	4
23	Undisturbed except to pull weeds	3.69	4.0	4.9	5.4	6.2	7.3	8.4	8.4	9.2	9.2	10.3	10.3
25		3.01	4.0	4.6	4.6	5.6	6.0	6.6	7.0	7.6	7.3	8.0	8.3
27		3.01	4.6	4.6	5.3	6.0	6.6	7.0	7.3	8.1	7.6	8.6	8.6
29		3.69	4.9	5.2	5.9	6.2	7.3	8.1	8.1	9.0	9.2	10.0	10.0
31		3.01	5.6	6.0	6.3	7.0	7.6	8.0	9.0	9.3	9.0	10.0	10.0
33		3.01	5.3	6.0	6.3	7.3	7.6	8.0	8.6	9.0	9.0	9.6	9.6
36		3.01	3.6	4.0	4.3	5.0	6.0	6.3	7.3	7.3	8.0	8.3	8.6
38		3.01	4.3	5.0	5.0	6.0	6.6	7.3	7.6	8.0	8.3	10.0	9.6
41		3.69	4.6	4.6	5.4	5.7	6.5	6.8	7.0	8.4	8.4	9.2	9.2
	Average		4.6 ±0.15	5.0 ±0.15	5.4 ±0.15	6.1 ±0.13	6.8 ±0.15	7.4 ±0.2	7.8 ±0.16	8.4 ±0.16	8.4 ±0.13	9.3 ±0.19	9.4 ±0.17
24	Cultivated weekly to depth of 6 inches	3.69	4.3	4.8	6.0	6.2	7.6	7.8	8.2	9.0	8.6	10.0	10.8
26		3.01	5.0	5.6	5.6	6.4	7.6	7.6	8.6	9.4	9.4	10.3	10.3
30		3.69	4.1	4.0	4.8	5.4	6.8	6.8	7.0	7.6	7.6	8.9	9.2
39		3.01	4.6	5.0	5.0	5.4	6.4	6.6	7.0	8.0	8.0	8.2	9.0
	Average		4.5 ±0.13	5.0 ±0.22	5.4 ±0.2	5.8 ±0.18	7.0 ±0.22	7.2 ±0.2	7.8 ±0.28	8.4 ±0.19	8.4 ±0.24	9.4 ±0.31	9.8 ±0.29
28	Cultivated weekly to depth of 8 inches	3.01	5.3	5.4	6.0	6.4	7.0	7.6	8.0	8.4	8.4	9.6	10.0
32		3.01	5.0	5.6	5.6	6.6	7.0	7.4	8.0	8.0	8.4	9.6	10.0
35		3.69	3.8	4.0	4.4	4.8	6.0	6.6	7.0	7.0	7.0	8.4	8.4
42		3.69	5.2	5.4	5.7	6.0	6.8	7.4	7.6	8.2	8.6	9.5	9.5
	Average		4.8 ±0.23	5.0 ±0.24	5.4 ±0.25	6.0 ±0.15	6.6 ±0.16	7.2 ±0.17	7.6 ±0.15	7.8 ±0.19	8.0 ±0.24	9.3 ±0.20	9.5 ±0.25
34	Cultivated weekly to depth of 10 inches	3.01	4.3	5.0	5.1	5.3	6.0	6.6	6.6	7.0	7.3	8.1	8.7
37		3.01	4.0	5.0	5.0	5.3	6.4	6.6	7.0	7.4	7.4	8.6	8.6
40		3.01	4.6	4.6	5.0	5.2	6.0	6.7	7.4	7.4	7.3	8.6	8.7
	Average		4.3 ±0.11	4.9 ±0.08	5.0 ±0.03	5.4 ±0.03	6.0 ±0.05	6.6 ±0.03	7.0 ±0.16	7.3 ±0.09	7.3 ±0.03	8.4 ±0.10	8.7 ±0.03

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* One pound of water to a square foot is equivalent to 0.19 inches of water.

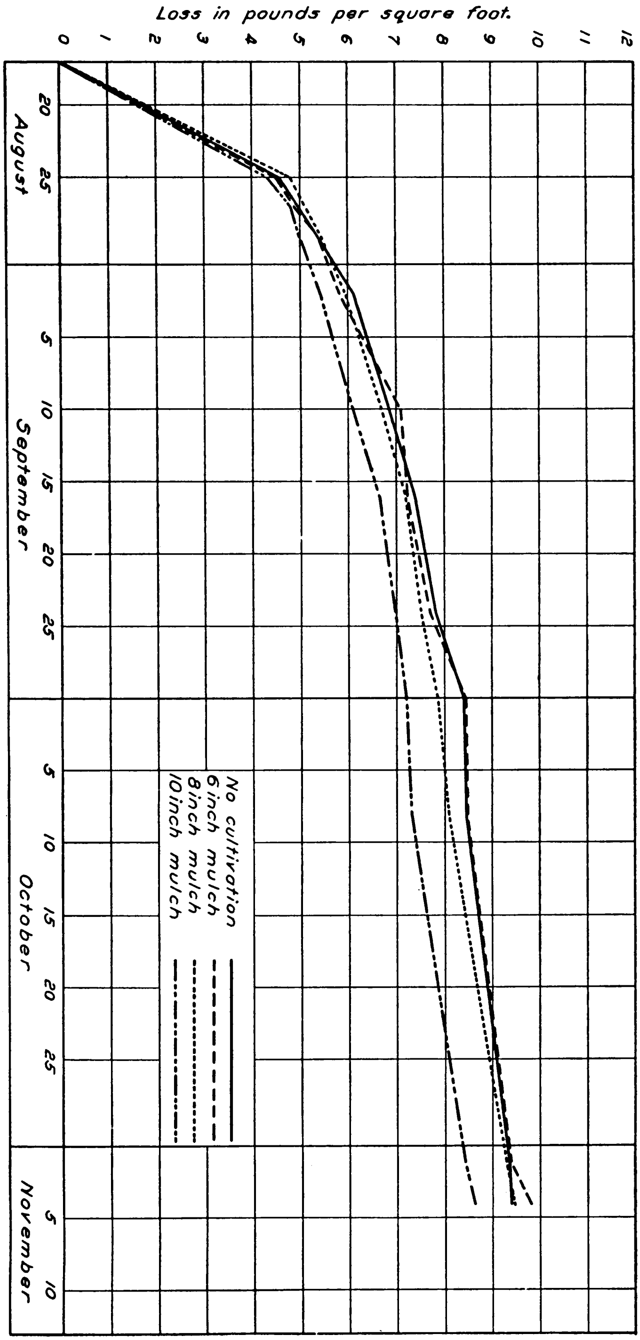

Fig. 30. Loss of water by evaporation directly from the surfaces of bare soils in tanks at Mountain View, 1921.

Several of the tanks were kept under observation for long periods of time. One of these, tank No. 25, which may serve to illustrate the extremely slow rate of loss of moisture after the first few weeks, had an area exposed to evaporation of 3.01 square feet. This tank was irrigated on August 17, 1921, and the bare surface of the soil was undisturbed except to pull the weeds which started to grow. The tank was covered during rains to prevent the addition of water to the soil in the tank after the initial irrigation. The losses from this tank for the period of August, 1921, to November, 1922, are graphically shown in figure 34. The total accumulated loss of moisture by evaporation at the end of different periods of time is given in table 31. On November 2, 1925, the total loss was 57 pounds, which is 18.9 pounds to the square foot of surface exposed to evaporation, and is equivalent to a depth of about 3⅜ inches of water in a period of over four years. The data (see table 31) when compared with those presented in Sections I and II show that amounts of water equivalent in depth to this were used very rapidly by mature prune and peach trees. This tank was at Mountain View up to February, 1923, and was then moved to Davis.

When the average losses of moisture by evaporation from the uncultivated soil and the cultivated soils are compared, and the probable errors of the mean values are considered, it will be seen that there are no significant differences in the results obtained. Furthermore, the average loss of water by evaporatsion directly from the surface of the bare uncultivated tanks in 80 days was 9.4 ± 0.17 and the average loss from the eleven cultivated tanks was also 9.4 ± 0.16. It is apparent, then, that cultivation seems to have little influence in controlling the amount of water evaporated from the bare surface of the soil in the tanks.

Other comparisons between the losses of moisture from cultivated and uncultivated soils were made at Davis. Some of the tanks used in this way at Davis are shown in figure 21. The results have been the same as those obtained at Mountain View, in that apparently there are no real differences between the losses from the cultivated and uncultivated soils. During 1923 and 1924, a soil much lighter in texture than the soil previously used either at Davis or at Mountain View was tried. A sandy loam, with a moisture equivalent of 15.7 per cent was packed in the tanks. The losses of moisture by evaporation from the surface of bare soils were determined for a period of 11 months. The average loss of moisture by evaporation during this time was 51 pounds to a tank, or 13.8 pounds to the square foot of area exposed to evaporation. This total loss is greater than the loss from finer textured soils, such as the Yolo clay loam or the Yolo loam. The evaporation losses observed from field plots were also greater on the sandy soil.

TABLE 30

PERCENTAGE OF MOISTURE IN SOIL IN TANKS AT MOUNTAIN VIEW. SAMPLES TAKEN NOVEMBER 4, 1921. TANKS IRRIGATED AUGUST 17, 1921

Tank	Treatment of soil surface	Depth of soil samples (inches)					Depth of soil samples (inches)			Totals
		0-4	4-8	8-12	12-16	16-20	0-12	12-24	24-26	0-36
23	Undisturbed except to pull weeds	9.8	16.1	18.4	20.4	22.5	13.4	20.6	24.0	19.2
25		11.3	15.9	17.8	17.3	18.9	13.2	18.4	19.7	16.9
27		10.5	14.9	17.0	18.9	20.0	18.4	18.7	17.6	17.9
29		9.7	16.0	18.0	19.7	17.7	16.2	18.6	18.6	17.8
31		8.8	15.5	16.9	18.5	18.5	13.7	19.4	18.1	17.1
33		8.2	15.5	16.5	18.8	18.6	13.3	18.7	18.1	16.7
36		8.7	17.2	18.1	19.4	18.4	13.0	17.4	17.1	16.0
38		9.3	13.1	18.3	18.3	17.0	11.3	17.7	18.4	15.5
41		8.3	13.3	18.2	20.2	19.1	12.2	19.4	17.0	15.6
	Average............	9.4 ±0.25	15.3 ±0.30	17.7 ±0.18	19.2 ±0.24	19.0 ±0.32	13.9 ±0.46	18.8 ±0.21	18.7 ±0.41	17.0 ±0.28
24	Cultivated weekly to depth of 6 inches	10.0	19.3	18.6	20.0	20.2	15.7	19.0	22.6	19.2
26		10.7	18.9	20.3	21.3	21.7	14.8	20.5	24.0	19.5
30		10.0	21.9	19.0	18.7	19.9	15.6	21.6	17.0	17.8
39		8.0	15.5	17.7	15.9	20.7	15.3	....	16.6	....
	Average............	9.7 ±0.40	18.9 ±0.83	18.9 ±0.37	19.0 ±0.82	20.6 ±0.28	15.3 ±0.15	20.4 ±0.54	20.0 ±1.59	18.8 ±0.46
28	Cultivated weekly to depth of 8 inches	10.4	12.5	18.9	11.7	20.0	14.6	20.2	18.0	17.8
32		8.6	16.7	18.7	19.3	19.5	14.0	18.0	16.2	16.2
35		7.0	16.6	17.2	19.4	19.3	11.0	19.1	18.8	16.7
42		6.7	14.9	18.1	18.4	20.4	12.6	20.2	15.5	16.5
	Average............	8.9 ±0.72	15.2 ±0.72	18.2 ±0.28	17.2 ±1.34	19.8 ±0.20	13.0 ±0.61	19.4 ±0.40	17.1 ±0.61	16.8 ±0.24
34	Cultivated weekly to depth of 10 inches	8.8	16.0	18.2	20.0	20.1	12.9	19.0	19.5	17.7
37		7.0	14.2	17.4	16.6	17.1	12.7	15.4	17.6	15.3
40		6.7	14.1	15.1	17.6	15.1	13.4	17.9	17.1	16.4
	Average............	7.5 ±0.52	14.8 ±0.50	16.9 ±0.72	18.1 ±0.78	17.4 ±1.06	13.0 ±0.16	17.4 ±0.82	18.1 ±0.57	16.5 ±0.50

DISTRIBUTION AND TOTAL AMOUNT OF MOISTURE IN SOIL FOLLOWING EXPOSURE TO EVAPORATION

Samples to determine the amount and distribution of moisture in the soil were taken on November 4, 1921, 80 days after the water was applied, in all of the tanks for which data are reported in table 29. Samples of the soil in 4-inch layers to a depth of 20 inches were taken with a special large soil tube and samples in foot depths to 3 feet were also taken. The results of these moisture determinations are given in table 30.

Apparently there is little difference in distribution of moisture in the soil in the cultivated and uncultivated tanks. The greater amount of loss of moisture seemed to be confined largely to the upper 4 inches of soil. It will be noted that below 8 inches there were very uniform percentages of moisture, even 80 days after the water was applied.

TABLE 31

DISTRIBUTION OF MOISTURE IN THE BARE UNCULTIVATED SOIL IN TANK NO. 25. WATER WAS APPLIED TO THE SOIL ON AUGUST 17, 1921*

Depth of soil samples, inches	Moisture equivalent	Dates samples were taken					
		Nov. 4, 1921	Apr. 11, 1922	June 20, 1922	Dec. 15, 1922	Aug. 8, 1924	Nov. 2, 1925
0 to 4	21.5	11.3	7.6		6.8	5.3	4.3
4 to 8	22.6	15.9	13.8		11.5	5.7	6.2
8 to 12	22.3	17.8	15.4		13.4	10.2	9.8
12 to 16	23.1	17.3	16.6		14.9	11.1	11.4
16 to 20	22.5	18.9	17.3		16.3	13.0	11.8
Average	22.4	16.3	14.2		12.6	9.2	8.7
0 to 12	22.0	13.2	12.0	10.8	9.8	6.3	6.1
12 to 24	21.9	18.4	17.7	18.0	15.6	10.6	11.6
24 to 36	22.7	19.7	19.6	17.0	18.0	15.5	15.6
36 to 42	22.3				19.0	16.0	16.0
Average	22.2	17.1	16.4	15.3	15.5	12.1	12.3
Pounds lost since water was applied on Aug. 17, 1921		25	35	35	37	51	57

* The average moisture content calculated from the weight of dry soil in the tank was 20 per cent on August 17, 1921. However, the soil was not wet to full depth. The tank was covered during rains and no water was added after the application on August 17, 1921.

Tank No. 25, from which the evaporation losses have been measured for a long period of time, was sampled several times during the three years of these observations. The results of these moisture determinations are given in table 31. There was a gradual loss at an extremely slow rate throughout the entire depth of soil. This result was also noted in other tanks observed for long periods; however, it is remarkable that even after four years' exposure to evaporation, the average moisture content of all of the soil in the tank was not reduced below the wilting coefficient. Whether the losses of moisture from the lower depths of soil were due to upward capillary movement, or to the gradual drying effect of the movement of air through the soil mass is not known. This point is discussed further in subsequent pages.

The presence of relatively large amounts of water in the soil in these tanks, even after long exposure to evaporation was demonstrated in a rather striking way. Sixteen of the 20 tanks used in the evaporation experiment during the summer of 1921 were planted to vetch and barley after having been exposed to evaporation for 80 days, namely, on November 4, 1921. Since, as indicated in table 30, the first 4 inches of soil were too dry to germinate the seed, from 3 to 4 pounds of water (less than one-half gallon) were added to the tanks after planting. Owing to a dry hot wind which followed the planting and dried out the soil before the seeds germinated, a few of the tanks received a subsequent application of a like amount of water. After the plants were up, they were thinned to a definite number to a tank. The number selected gave a stand comparable to that usual with cover crops in orchards. It was possible to mature satisfactory cover crops in these tanks. The loss of moisture by evaporation during the previous 80 days, which is longer than the usual time between irrigations, had not been sufficient to prohibit the growth of cover crops. The tanks were covered during rains by means of a canvas drawn over a frame. The tanks containing the vetch and barley plants are shown in figure 31, as they were on March 10, 1922. This figure should be compared with figure 29, in which the same tanks are shown.

Both the vetch and barley made the same growth in all of the tanks, and no difference could be distinguished between the growth made by the plants in the tanks which had been cultivated and those which had not been disturbed during the 80 days preceding the planting of the seeds. Apparently, cultivation had not affected the amount of water available for growth or its distribution in the soil.

The growth made by the vetch in tank No. 36 is shown in figure 32. The soil in tank No. 36 was undisturbed for 80 days after the irrigation on August 17, 1921, and was in the condition shown in tank No. 35, figure 33. The growth made by the vetch plants in tank No. 30 is shown in figure 33. The soil in tank No. 30 was cultivated during the 80-day period and was in the condition shown in tank No. 29, figure 33. Tank No. 30 was larger than tank No. 36 and contained more plants, otherwise the growth and vigor of the plants was the same. The photographs were taken on May 6, 1922.

The Yolo clay loam in these tanks had a relatively high moisture-holding capacity and the plants were grown for the greater part of the time when the transpiration losses were low. It is, of course, obvious that such an experiment could not be carried on with a sandy soil, or one with a low moisture-holding capacity, or during a time of the year when the atmospheric evaporating power was high. However, it does clearly show that there was a relatively large quantity of water left in the soil after a long period of exposure to evaporation and that there were no differences in available moisture in the soils which had been cultivated and those which had not been cultivated during this period.

The loss of water from four typical tanks used in these experiments is graphically illustrated in figure 34. The results obtained from tanks Nos. 30 and 36, which have just been described, are also shown in this figure. The increased loss after the vetch was planted in these tanks on November 4, 1921, is clearly shown. The total loss from tank No. 30, from August 17, 1921, to June 1, 1922, when the vetch was matured was 148 pounds. The loss from August 17, 1921, to June 30, 1922, from tank No. 36, which contained a fewer number of plants, was 110 pounds. The loss from August 17, 1921, to June 20, 1922, from tank No. 25, the bare uncultivated tank, was only 35 pounds. The loss was 39 pounds from tank No. 32, the bare cultivated tank during this time.

After the crop of vetch was removed from tank 36, on June 20, 1922, it was irrigated and vetch was again planted. On September 11, 1922, this crop matured. During this time 295 pounds of water were used. The vetch was irrigated several times. The loss from the bare uncultivated tank No. 27, at this time of the year, is shown for comparison in figure 34. The loss from tank No. 36 after the crop was removed on September 11, 1922, and after it was again irrigated, is also shown.

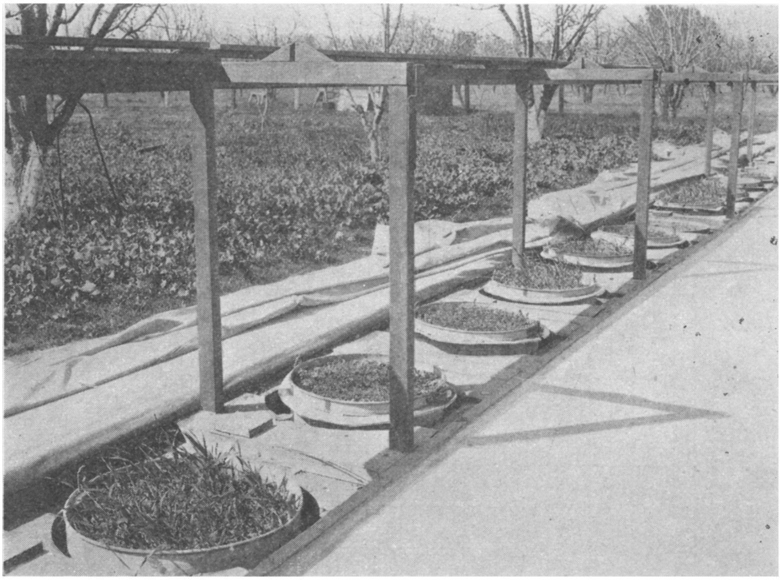

Fig. 31. Barley and vetch plants growing in tanks irrigated 80 days before the seeds were planted. Rain was prevented from wetting the tanks by means of the wooden frame and a canvas cover. Photographed March 10, 1922.

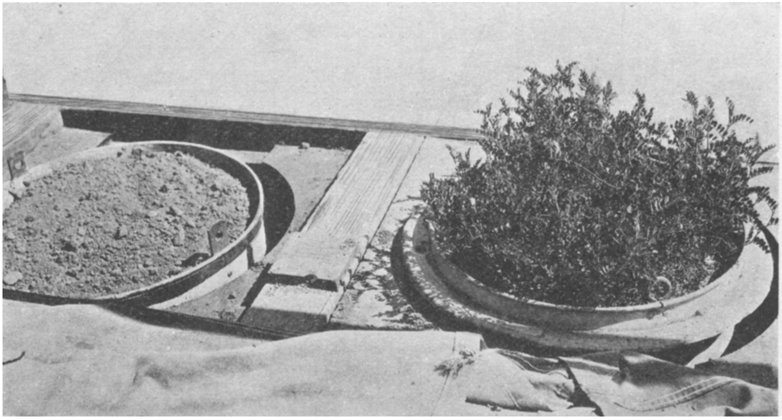

Fig. 32. Vetch plants growing in tank No. 36 on soil which had been exposed to evaporation for a period of 80 days after irrigation and before the seeds were planted. The soil in this tank was uncultivated during this period, being in the same condition as that in tank No. 29, shown on the left in figure 33. Photographed May 6, 1922.

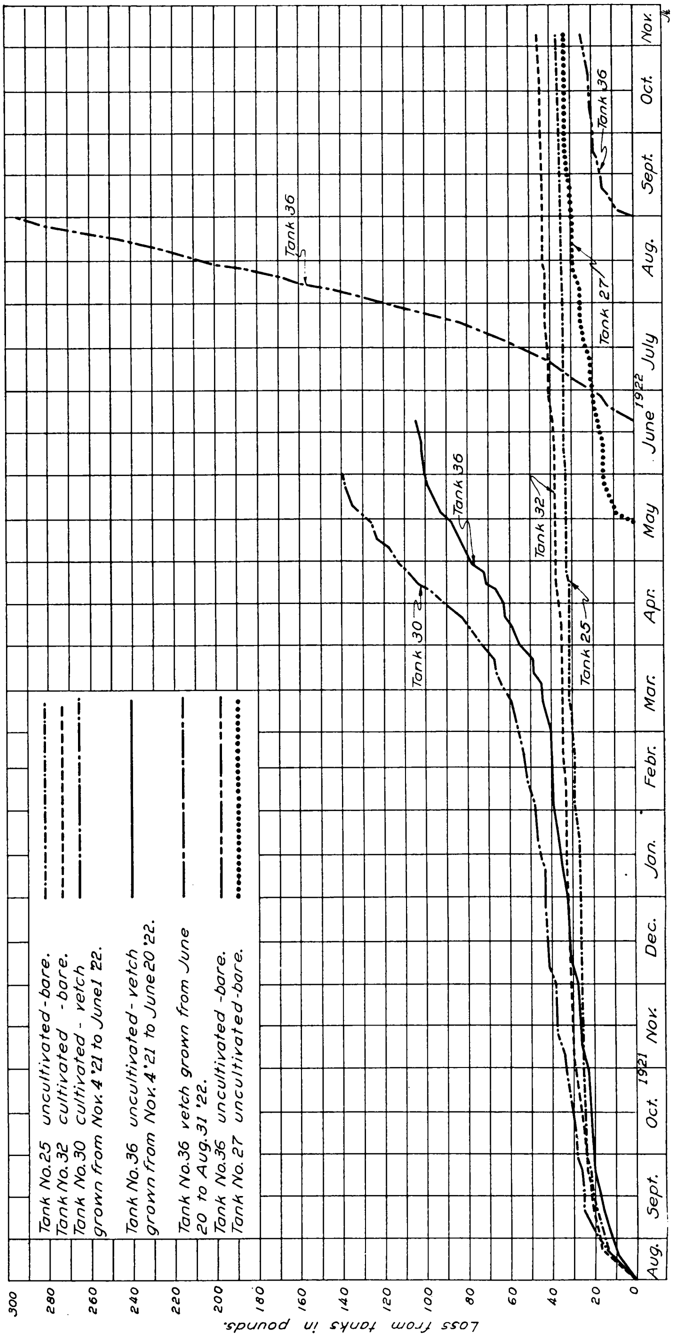

Fig. 34. Loss of water from bare soils compared to the loss through plants.

Several tanks, among which was tank No. 27, for which the evaporation loss is shown in figure 34, were irrigated on May 13, 1922, and the surface soil was undisturbed until October 26, 1922. During this time tank No. 27 lost 32 pounds through evaporation. On this date the soil to a depth of one foot in these several tanks was removed and thoroughly mixed on a piece of canvas and replaced in the tanks. Vetch seedlings, which had been grown in flats, were planted in the tanks. No water was applied to the soil and the tanks were protected from the rains. The vetch plants matured, making a growth comparable to that of similar plants in the orchards even though the uncultivated soils had been exposed to evaporation from May 13, 1922, to October 26, 1922, a period of 167 days.

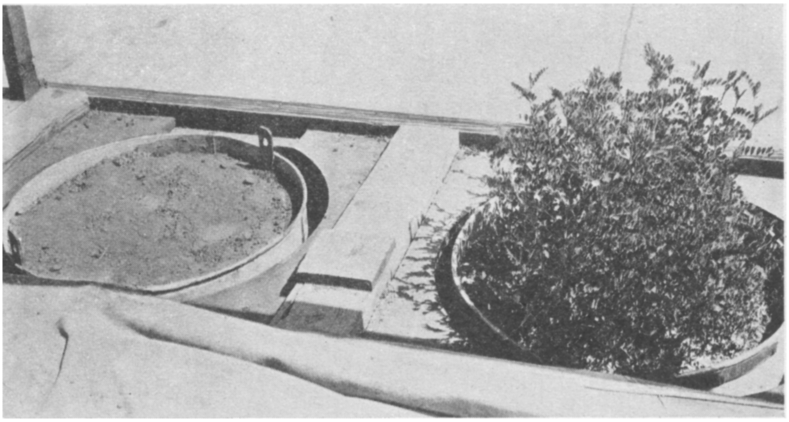

Fig. 33. Vetch plants growing in tank No. 30 on soil which had been exposed to evaporation for a period of 80 days after irrigation and before the seeds were planted. The soil in tank No. 30 was cultivated during this period and was in the same condition as that in tank No. 35, shown on the left in figure 32. Photographed May 6, 1922.

LOSSES OF WATER FROM BARE SOILS COMPARED TO LOSSES THROUGH PLANT TRANSPIRATION

The data graphically illustrated in figure 34, details concerning which have been described, and the instances mentioned above, show that the losses by evaporation directly from the surface of the soil are a small portion of the total losses which occur from irrigated soils on which plants are growing during the summer.

The records obtained from the tanks in which trees were growing also afford an opportunity to compare the losses by evaporation directly from the soil surface and those through transpiration. While it can not be assumed that such comparisons are strictly quantitative they do serve to show that the losses by evaporation from the soil are extremely small when compared to the amount of water transpired by the trees. In 1921, a three-year-old prune tree in a tank used 585 pounds of water between May 21 and November 21, a period of six months, while a similar tank containing the same kind of soil with a high moisture content but uncropped, lost only 28 pounds of water within the same time, an amount no greater than this small tree used in one instance within three days. This same tree, from March 1, 1922, to November 4, 1922, used 1250 pounds of water, while the uncropped tank, which was irrigated February 11 with 23 pounds of water, again lost only 28 pounds of water between this date and November 4, 1922. Tank No. 2, the bare uncultivated tank just mentioned, contained Yolo loam, which had been packed in the tank in 1912, and had not been disturbed since that time.

A further illustration of the demand made upon the soil-moisture supply by growing plants is shown in the record of the use of water by morning glory (*Convolvulus arvensis*) plants grown in a tank. This tank was 23½ inches in diameter and 48 inches in depth, and was packed with Yolo clay loam at Mountain View, in February, 1921. It was one of the series used to determine the losses of moisture by evaporation directly from the surface of the soil in which the soil was cultivated to a depth of six inches following the application of water on August 17, 1921. The loss of water by evaporation from this tank for the first 80 days after irrigation, given in table 29, was 31 pounds, or 10.3 pounds to a square foot. The total loss of moisture by evaporation from August 17, 1921, to May 13, 1922, the date on which water was again added to the soil, was only 41 pounds or 13.6 pounds to a square foot. The tank was irrigated again on May 13, 1922, but the surface soil was undisturbed until October 26, 1922. Between May 13 and October 26, 1922, only 35 pounds of water were lost by evaporation. Vetch plants were set on October 26, 1922, and grew to maturity without additional water being applied in this tank as they did in tank No. 27, which has been described. The vetch was taken out of the tank in June, 1923, and the soil was undisturbed throughout the summer.

Three pieces of morning glory (*Convolvulus arvensis*) roots were planted in the tank on October 11, 1923, and the soil was thoroughly irrigated. Early in the spring of 1924, the roots began to grow, and by March 28, 1924, leaves had begun to appear. The soil was irrigated 10 times up to August 19, 1924. Between March 28, 1924, and August 19, 1924, a period of 144 days, the tank lost 704 pounds of water. The appearance of the plants on August 19, 1924, is shown in figure 35. It will be seen that the surface of the soil was well shaded by the plants; there was probably little loss of water by direct evaporation from the soil surface. The record of the loss of water from the young plants in this tank, for a period of 23 days, from May 7 to May 30, 1924, of 120 pounds is surprising when it is considered that tank No. 25, which contained the same kind of soil, but which was bare and uncultivated, lost only 57 pounds of water in a period of over four years. The loss from the plants in 23 days was more than twice as much as from the bare soil in four years.

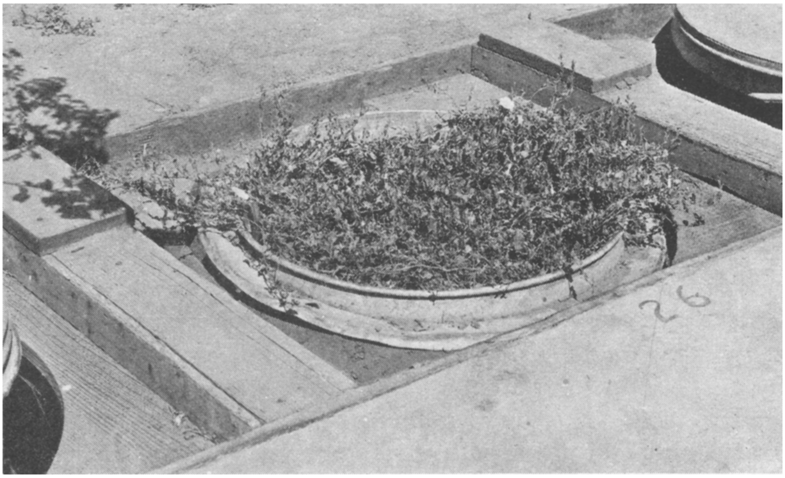

Fig. 35. Tank 26, containing morning glory (*Convolvulus arvensis*) plants. Photographed August 19, 1924.

A number of such data might be cited, all of which would show that the amount of water lost by direct evaporation from the surface of the soil under conditions prevalent in California is extremely small when compared to that transpired by plants.

That the loss of moisture by evaporation from the surface of the soil is a very small portion of the total losses from the soil may be true only under conditions governing these experiments. The losses of moisture by evaporation may become a large portion of the total amount of water applied to the soil, whether by rainfall or by irrigation, if these applications are in small amounts and are made on light soils in the warmer part of the year when evaporation is high.

Small amounts of water applied will wet the soil to shallow depths only and evaporation will cause much of the moisture retained in these depths to be lost. However, in California the rains usually come when the atmospheric evaporation power is low, and the usual practice is to apply water in irrigation in amounts sufficient to wet the soil to considerable depths. Therefore, the amount lost from the upper few inches of soil is a small portion of the total amount applied.

THE LOSS OF MOISTURE BY EVAPORATION FROM BARE SOILS IN FIELD PLOTS

Trials with field plots also were made to determine the loss of moisture by direct evaporation from the soil. The effect of cultivation was studied in these trials as it was in the tanks. The plots were located at Davis, on Yolo loam soil; at Mountain View, on Yolo clay loam soil; at Delhi, in the San Joaquin Valley, on Oakley fine sand; and at Whittier on a Yolo clay. These locations represent a wide range in climatic conditions and in soils. At each place four plots were laid out and prepared for irrigation. Each of the plots was 20 feet wide by 90 feet long, an area large enough to be cultivated by farm machinery, and yet not too large to be adequately sampled for moisture determinations. In all but one of these trials, that at Whittier, the plots were arranged side by side. The arrangement of the plots is shown in figure 36. The plots were separated from each other by a dry strip 10 feet wide. The places where samples were taken are indicated by the circles and numbers. The plots at Whittier were arranged in pairs, one uncultivated plot being opposite one cultivated plot.

Fairly level pieces of ground were selected, far enough removed from trees to prevent the extraction of moisture through their roots. Levees were constructed to enclose the four plots, and several cross-levees were thrown up across them to enable a more even application of the water. The water applied to each plot through the delivery ditch to the ditches along the high sides of each plot was measured over a weir with a hook-gage. It was possible to apply a definite depth of water to each plot by this means. Samples were taken before irrigation and the water necessary to wet the soil to a depth of five feet was calculated and applied.

Two of the plots at each location were cultivated to a depth of six inches as soon after irrigation as was possible. The cultivations were repeated at weekly intervals until the end of the experiment.

The other two plots were untouched, except to remove weeds by careful hoeing, as they appeared. Different types of tools were used in the different locations to cultivate the plots. Usually a disk was used first and then a spring-tooth harrow. In fact, the cultivations given each week were done as thoroughly as possible, and were more thorough than those given by the average orchardist.

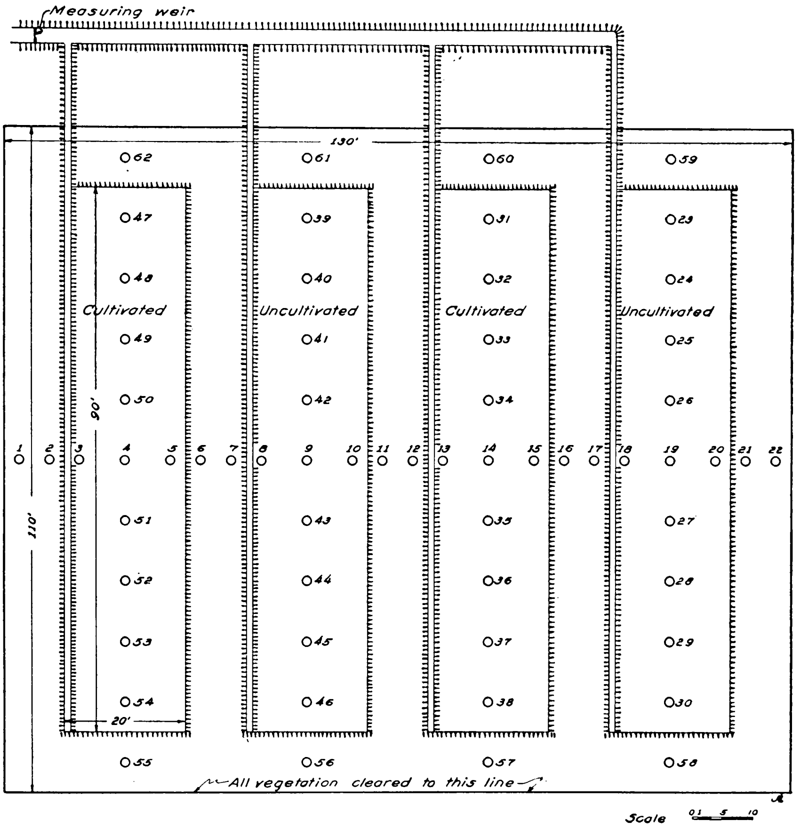

Fig. 36. The arrangement of the field plots used to determine the loss of moisture from bare cultivated and bare uncultivated soils. The places where samples were taken are indicated by circles and numbers.

The condition of the soil two months after irrigation in the cultivated plots at Whittier is shown in figure 37, and the condition of the uncultivated plots is shown in figure 38. These conditions were typical of those at the other locations. The cultivated plots were cultivated immediately after taking the weekly set of samples for moisture determinations. In the uncultivated plots there was some

Fig. 37. Condition of the Yolo clay soil in the cultivated plots at Whittier, two months after irrigation.

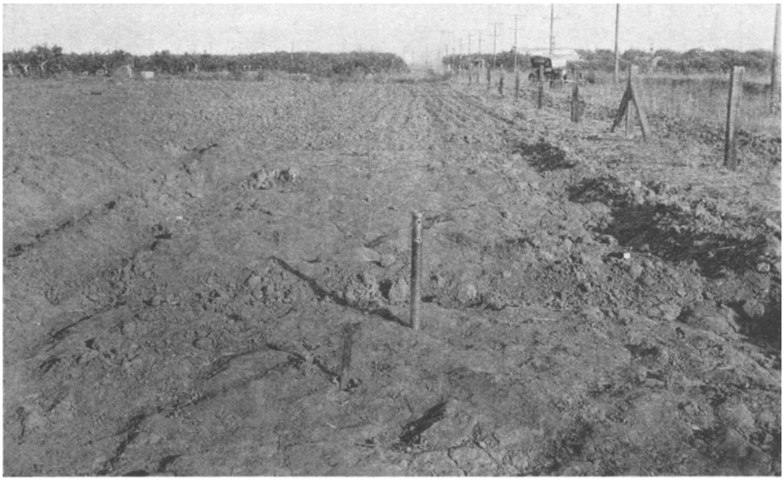

Fig. 38. Condition of the uncultivated Yolo clay soil in the uncultivated plots at Whittier, two months after irrigation. The place of sampling is indicated by the stake in the foregound and the special tube used to take samples in 4-inch depths is shown.

disturbance of the soil at the places where samples were taken, but it may be seen from figure 38 that this was slight and certainly not equivalent to cultivation.

METHOD OF SAMPLING THE PLOTS

Samples were taken with a soil tube, and all of the soil removed from the hole was retained in making moisture determinations. The soil from the upper 3 feet was placed in a soil can, and the soil from the second 3 feet, or from 3 to 6 feet, was kept separately and moisture contents were determined for these two depths of soil. Samples were also taken in depths of 4 inches to a total depth of 20 inches in all of the plots, and in some cases the soil-moisture content in foot depths was determined. The special large soil tube shown in figures 37 and 38 was used to take these 4-inch samples.

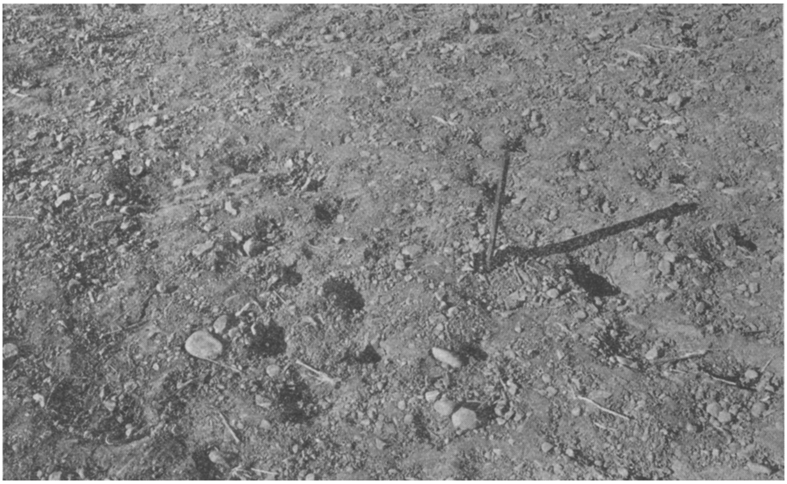

Fig. 39. The manner of spacing the holes around the stake indicating the place of sampling for moisture determinations in the field plots used in the evaporation trials. Photograph taken in one of the uncultivated plots at Mountain View two months after irrigation.

Eleven samples were taken in each plot as indicated in figure 36. These were spaced 10 feet apart, and the outer holes, such as 47, 54, 39, and 46, were 5 feet from the edge of the plots. Samples, which were only 2½ feet from the wetted areas, were taken in the strips between the plots as indicated by holes numbered 1, 2, 6, 7, 11, 12, etc. Samples, indicated by holes 55 to 62 in figure 36, were also taken around the outer edges of the plots.

The manner of sampling at each place is shown in figure 39, which indicates the condition in one of the uncultivated plots in the Santa Clara Valley at Mountain View, two months after irrigation. The first sample was taken at a definite distance from the stake which had been placed before irrigation. The hole made at the next sampling was a measured distance from the last hole. This method was followed until a circle was completed around the stake. Then the place of sampling was moved out 6 inches further from the stake and a new circle of holes was started. The holes made in sampling in the uncultivated plots were not refilled, since it was thought that this addition of soil might be considered to constitute a mulching. Of course, in the cultivated plots the stakes were removed before cultivating. These were replaced before the next set of samples were taken by surveying from fixed points outside the plots, so that the places of sampling were fixed. In this way the possibility of obtaining the same type of soil at each sampling is thought to have been greater than if even a much greater number of samples were taken at random in the plots.

Attention again is called to the difficulty in obtaining representative samples even in such small areas as the plots used in the present study. Considerable variation was found in the amount of moisture contained in different samples taken simultaneously from the same localities in the plots. Of course, this is due in part to differences in the water retentiveness of the soil in the samples and it is not improbable that errors were caused by inequalities in drying the samples. Drying usually extended over long periods and was never less than three days with the larger samples, but even then constant weights were not always obtained.

It must be kept in mind that the interpretation of soil-moisture data is extremely difficult, and wide differences must be obtained to be significant. However, the probable errors are listed in each case, since they do serve to indicate the range of variation of the individual values used in calculating the means. It is thought that the number of samples taken was sufficiently great to calculate the significance of the results by the standard method; that is, the difference must be 3.2 times the probable error of the difference before it begins to be significant.

The means of moisture equivalent determinations of the soils in the different plots are given in table 32. At least 250 samples from each group of plots at each of the five locations were centrifuged.

These moisture equivalent determinations were made on 30-gm. weighed samples and they may be used to indicate the relative moisture retentiveness of the different soils.

RESULTS OF SAMPLING THE PLOTS

The data obtained from the plots at Davis are summarized in table 33. The moisture content of the plots was quite high before irrigation. The plots were irrigated with amounts of water estimated to raise the moisture content of the soil to 22 per cent to a depth of 6 feet. The water was applied on August 2, 1921, and the tests were run until September 23, 1921, after which rains caused them to be discontinued. In addition to the fact that no real difference exists between the moisture contents in the cultivated and uncultivated plots, the record of the moisture conditions in the soil from 3 to 6 feet in depth is especially interesting since the data indicate that there was no change in the moisture content below the third foot. The samples taken on August 3 were from 12 to 20 hours after irrigation. Those on August 5 were taken approximately 72 hours after irrigation. Probably there was a downward movement of moisture between the samplings on August 3 and August 5, but from August 5 to September 23 there was practically no loss from the lower 3 feet of soil.

TABLE 32

MEAN VALUES FOR THE MOISTURE EQUIVALENTS OF THE SOIL IN THE PLOTS USED TO DETERMINE LOSSES BY EVAPORATION

Location of plot	Soil	Samples of soil from 0–3 feet in depth	Samples of soil from 3–6 feet in depth	Average for 0–6 feet in depth
Delhi	Oakley fine sand	5.77±0.77	11.09±0.24	8.43±0.12
Davis	Yolo loam	23.82±0.14	20.77±0.19	22.29±0.12
Santa Clara	Yolo clay loam with gravel	15.02±0.14	20.13±0.27	17.57±0.15
Whittier	Yolo clay	24.18±0.07	26.65±0.10	25.41±0.06

The relatively slight losses of moisture from the soil below the first foot after the moisture had become distributed, a condition which was observed in all of these tests, are indicated in table 34. The moisture content of the soil in foot depths to a depth of 6 feet is given in this table, and it will be noted from these data that the losses of moisture from the soil seem to be confined almost entirely to the first foot.

In order to convey some idea of the relative quantities of water present in the soil at different times during the test, the moisture contents given in table 34 are given in table 35 in amounts of water in acre-inches to the acre.

The plots at Mountain View, in the Santa Clara Valley, were irrigated on June 26, 1921. The results of sampling the soil for the determination of the moisture contents are given in tables 36 and 37. The results of sampling in the cultivated and uncultivated plots are very close. As in the plots at Davis, it was found that the moisture content of the lower 3 feet of soil remained practically constant. The samples taken on June 27 were made from 12 to 24 hours after the water was applied; and some downward movement may have taken place between this time and that of the sampling on June 28, which was about 48 hours after irrigation.

TABLE 33

Summary of Soil-Moisture Contents in Three-Foot Depths in Percentages on a Dry-Weight Basis in the Bare Cultivated and Uncultivated Plots at Davis. Irrigated August 2, 1921

Depth of soil sampled, feet		Aug. 3	Aug. 5	Aug. 8	Aug. 15	Aug. 26	Sept. 23
0.3	Cultivated	23.7	21.0	20.3	18.8	18.3	18.1
		±0.86	±0.32	±0.25	±0.26	±0.26	±0.19
	Uncultivated	25.5	22.3	21.1	19.7	19.5	18.0
		±0.57	±0.18	±0.22	±0.16	±0.17	±0.14
3–6	Cultivated	19.1	17.9	20.0	18.2	19.2	18.2
		±0.29	±0.52	±0.42	±0.32	±0.27	±0.31
	Uncultivated	20.5	19.4	18.9	18.5	19.3	18.6
		±0.65	±0.37	±0.25	±0.24	±0.25	±0.27
0–6	Cultivated	21.4	19.4	20.2	18.5	18.8	18.2
		±0.45	±0.30	±0.24	±0.21	±0.19	±0.18
	Uncultivated	23.0	20.8	20.0	19.1	19.4	18.3
		±0.43	±0.21	±0.17	±0.14	±0.15	±0.15

Barley had been planted on the areas where the plots subsequently were laid out at Mountain View and at Davis. The crops were removed just before the tests were started. The amounts of water transpired by the plants had not reduced the moisture contents of the soils from the depth of 3 to 6 feet below that to which they had been raised by the winter rains. The amounts of water applied to the plots at the beginning of the tests were estimated to be sufficient to raise the moisture content of the soil to its field capacity to a depth of 6 feet, and in so far as could be judged by appearance and by feeling, the soil below the top 4 to 8 inches in the plots at both locations remained in this condition throughout the period of observation.

TABLE 34

SUMMARY OF SOIL-MOISTURE CONTENTS IN FOOT DEPTHS IN PERCENTAGES ON A DRY-WEIGHT BASIS IN THE BARE CULTIVATED AND UNCULTIVATED PLOTS AT DAVIS. IRRIGATED AUGUST 2, 1921

Depth of soil sampled, feet		Aug. 3	Aug. 5	Aug. 8	Aug. 15	Aug. 26	Sept. 23
0–1	Cultivated	25.9 ±0.79	22.2 ±0.37	20.2 ±0.65	16.3 ±0.63	15.3 ±0.53	16.2 ±0.52
	Uncultivated	27.4 ±0.52	23.4 ±0.28	20.0 ±0.22	17.4 ±0.20	17.9 ±0.28	15.2 ±0.26
1–2	Cultivated	22.6 ±0.86	21.1 ±1.01	21.0 ±0.69	20.6 ±0.36	19.8 ±0.32	19.9 ±0.32
	Uncultivated	25.9 ±0.35	23.6 ±0.25	21.3 ±0.21	21.3 ±0.37	21.1 ±0.31	20.0 ±0.23
2–3	Cultivated	21.7 ±1.04	20.4 ±0.94	19.9 ±0.74	20.6 ±0.54	20.0 ±0.35	21.6 ±0.84
	Uncultivated	23.3 ±1.14	21.9 ±0.34	21.9 ±0.25	20.8 ±0.33	21.7 ±0.38	19.5 ±0.45
3–4	Cultivated	18.4 ±0.61	16.9 ±0.64	18.5 ±0.86	17.0 ±0.45	17.7 ±0.32	17.1 ±0.26
	Uncultivated	20.5 ±0.70	19.4 ±0.74	17.8 ±0.57	17.9 ±0.54	18.1 ±0.36	18.2 ±0.36
4–5	Cultivated	18.7 ±0.53	17.2 ±0.97	19.2 ±1.29	17.7 ±0.82	18.6 ±0.59	17.9 ±0.51
	Uncultivated	19.3 ±0.87	20.1 ±0.59	19.6 ±0.44	18.2 ±0.69	19.4 ±0.84	19.3 ±0.59
5–6	Cultivated	20.7 ±0.44	20.7 ±0.99	20.3 ±1.11	18.0 ±1.31	21.0 ±0.88	20.6 ±0.55
	Uncultivated	22.2 ±0.87	21.3 ±0.65	21.9 ±0.58	21.8 ±0.63	22.8 ±1.06	22.4 ±0.83

TABLE 35

SUMMARY OF SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN ACRE-INCHES TO THE ACRE IN BARE CULTIVATED AND UNCULTIVATED PLOTS AT DAVIS. IRRIGATED AUGUST 2, 1921

Depth of soil sampled, feet		Aug. 3	Aug. 5	Aug. 8	Aug. 15	Aug. 26	Sept. 23
0–3	Cultivated	11.09	9.83	9.50	8.80	8.56	8.46
		±0.40	±0.15	±0.17	±0.12	±0.12	±0.09
	Uncultivated	11.94	10.44	9.88	9.22	9.13	8.42
		±0.27	±0.08	±0.10	±0.07	±0.08	±0.07
3–6	Cultivated	8.94	8.38	9.36	8.52	8.99	8.52
		±0.14	±0.24	±0.20	±0.15	±0.13	±0.15
	Uncultivated	9.59	9.08	8.85	8.66	9.03	8.70
		±0.30	±0.17	±0.12	±0.16	±0.12	±0.13
0–6	Cultivated	20.03	18.21	18.86	17.32	17.55	16.98
		±0.42	±0.28	±0.22	±0.20	±0.18	±0.17
	Uncultivated	21.53	19.52	18.73	17.88	18.16	17.12
		±0.40	±0.20	±0.16	±0.13	±0.14	±0.14

TABLE 36

SUMMARY OF SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN PERCENTAGES ON A DRY-WEIGHT BASIS IN THE BARE CULTIVATED AND UNCULTIVATED PLOTS AT MOUNTAIN VIEW, IN THE SANTA CLARA VALLEY IRRIGATED JUNE 26, 1921

Depth of soil sampled, feet		June 27	June 28	June 30	July 7	July 14	July 21	July 28	Aug. 4
0–3	Cultivated	12.7	11.3	10.4	9.8	9.4	9.5	9.3	8.1
		±0.51	±0.37	±0.36	±0.36	±0.29	±0.32	±0.26	±0.27
	Uncultivated	11.3	10.6	11.3	10.6	10.4	9.6	9.9	8.9
		±0.53	±0.44	±0.38	±0.34	±0.44	±0.29	±0.31	±0.29
3–6	Cultivated	16.2	14.3	13.9	15.3	15.9	15.9	15.5	14.9
		±0.54	±0.44	±0.43	±0.38	±0.41	±0.42	±0.40	±0.33
	Uncultivated	15.1	15.3	14.8	15.4	15.5	15.0	14.9	15.0
		±0.38	±0.42	±0.34	±0.26	±0.29	±0.26	±0.28	±0.29
0–6	Cultivated	14.5	12.8	12.2	12.1	12.7	12.7	12.4	11.5
		±0.37	±0.29	±0.28	±0.26	±0.25	±0.26	±0.24	±0.21
	Uncultivated	13.2	13.0	13.1	13.0	13.0	12.3	12.4	12.0
		±0.33	±0.30	±0.26	±0.21	±0.26	±0.19	±0.21	±0.20

The moisture equivalents for the soil in these Santa Clara Valley plots do not agree with the moisture content in the soil after irrigation. The soil was quite gravelly, as figure 39 shows. The field samples, of course, include much of the gravel which holds very little water, and the moisture content is calculated on the basis of the total dry weight of the soil in the samples. Therefore, as might be expected, the field moisture content determinations are lower than the moisture equivalents which are made only on soil particles less than 2 mm. in diameter.

TABLE 37

SUMMARY OF THE SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN ACRE INCHES TO THE ACRE IN THE CULTIVATED AND UNCULTIVATED PLOTS AT MOUNTAIN VIEW, IN THE SANTA CLARA VALLEY

IRRIGATED JUNE 26, 1921

Depth of soil sampled, feet		June 27	June 28	June 30	July 7	July 14	July 21	July 28	Aug. 4
0-3	Cultivated..........	6.43	5.73	5.27	4.97	4.76	4.81	4.71	4.10
		±0.26	±0.19	±0.18	±0.18	±0.15	±0.16	±0.13	±0.14
	Uncultivated.....	5.73	5.37	5.73	5.37	5.27	4.86	5.02	4.51
		±0.27	±0.22	±0.19	±0.17	±0.22	±0.15	±0.16	±0.15
3-6	Cultivated..........	8.21	7.25	7.04	7.75	8.06	8.06	7.85	7.55
		±0.27	±0.22	±0.22	±0.19	±0.21	±0.21	±0.20	±0.17
	Uncultivated.....	7.65	7.75	7.50	7.80	7.85	7.60	7.55	7.60
		±0.19	±0.21	±0.17	±0.13	±0.15	±0.13	±0.14	±0.15
0-6	Cultivated..........	14.64	12.98	12.31	12.72	12.82	12.87	12.56	11.65
		±0.37	±0.29	±0.28	±0.26	±0.25	±0.26	±0.24	±0.21
	Uncultivated.....	13.38	13.12	13.23	13.17	13.12	12.46	12.57	12.11
		±0.33	±0.30	±0.26	±0.21	±0.26	±0.19	±0.21	±0.20

The summary of the moisture determinations in the cultivated and uncultivated plots at Delhi are given in tables 38 and 39. Table 38 gives the moisture contents in percentages and table 39 gives the same data calculated as acre inches to the acre. These plots were irrigated on July 7, 1921, and the soil was wet to a depth of 5½ feet. The determinations of moisture content were carried on until December 3, 1921, after which heavy rains caused the sampling to be discontinued. The rainfall from September 9 to December 3 was 0.76 inches. This came in light showers; most of it evaporated soon after the surface of the soil was wetted. The soil was wetted by these rains only to a depth of about 4 inches.

The test at Delhi was repeated during 1922, the same plots being used as in 1921. The results of sampling the plots during 1922 are given in table 40. The plots were not irrigated in 1922 but were wet by rains which did not cease until early in May. No further rain fell until after the last date of sampling, September 8. A rainfall of 0.48 inches occurred just before the first set of samples was taken on May 9, 1922, and the soil was found to be wet to the full depth of 6 feet on this date.

TABLE 38

SUMMARY OF SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN PERCENTAGES ON A DRY-WEIGHT BASIS IN THE BARE CULTIVATED AND UNCULTIVATED PLOTS AT DELHI, 1921. IRRIGATED JULY 7, 1921

Depth fo soil sampled, feet		July 8	July 9	July 11	July 16	July 23	July 30	Aug. 6	Aug. 20	Sept. 9	Dec. 3
0–3	Cultivated	7.6 ±0.19	6.6 ±0.24	6.1 ±0.17	5.7 ±0.12	5.4 ±0.09	4.8 ±0.11	4.6 ±0.07	4.2 ±0.07	3.7 ±0.05	4.6 ±0.07
	Uncultivated	8.1 ±0.32	6.8 ±0.21	6.1 ±0.16	5.2 ±0.10	4.8 ±0.07	4.4 ±0.08	4.0 ±0.05	3.5 ±0.05	3.3 ±0.06	4.3 ±0.03
3–6	Cultivated	6.5 ±0.32	6.2 ±0.24	6.2 ±0.32	7.2 ±0.34	7.5 ±0.28	7.4 ±0.42	7.6 ±0.32	7.1 ±0.29	7.7 ±0.27	7.1 ±0.20
	Uncultivated	6.3 ±0.29	5.9 ±0.22	7.4 ±0.26	6.3 ±0.32	7.1 ±0.29	7.4 ±0.26	7.0 ±0.28	7.3 ±0.24	6.4 ±0.30	7.7 ±0.24
0–6	Cultivated	7.1 ±0.18	6.4 ±0.17	6.2 ±0.17	6.5 ±0.18	6.5 ±0.15	6.1 ±0.22	6.1 ±0.16	5.6 ±0.15	5.7 ±0.14	5.9 ±0.11
	Uncultivated	7.2 ±0.21	6.4 ±0.15	6.8 ±0.15	5.8 ±0.20	6.0 ±0.15	5.9 ±0.14	5.5 ±0.14	5.4 ±0.12	4.9 ±0.16	6.0 ±0.12

The cultivated plots were given the same treatment in 1922 as in 1921, and an attempt was made to keep the uncultivated plots free from weeds. At Delhi, as well as at the other localities, this was found to be very difficult during the first week or two after the wetting of the soil. The weeds could not be removed or scraped off with a hoe without disturbing the surface of the soil until they were several inches high and their presence could be detected. The loss of moisture through transpiration even from such small plants may have been appreciable under the hot interior valley conditions in California, and the apparent difference in soil-moisture content of about ½ of 1 per cent between the cultivated and uncultivated plots at Delhi from July 16 to the last date of sampling in 1921 may be due, at least in part, to this cause.

The rapidity with which water was taken from the sandy soil at Delhi by the rather sparse grasses is illustrated by the following experiment: A series of samples was taken on April 15 from an area immediately adjoining the plots on which some grasses had been allowed to grow during the spring of 1922. The soil-moisture content in the upper 3 feet was 6 per cent and 11 per cent in the lower 3 feet. Samples taken May 9, showed that the moisture content of the upper 3 feet of soil was 2.7 per cent and that of the depth from 3 to 6 feet was 5.0 per cent. On June 30 the average moisture content of the upper 3 feet of soil was only 0.8 per cent, and samples could not be taken below the 3-foot depth since the dry sand would fall into the hole made by the soil tube.

TABLE 39

SUMMARY OF SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN ACRE INCHES TO THE ACRE IN THE CULTIVATED AND UNCULTIVATED PLOTS AT DELHI, 1921. IRRIGATED JULY 7, 1921

Depth of soil sampled, feet		July 8	July 9	July 11	July 16	July 23	July 30	Aug. 6	Aug. 20	Sept. 9	Dec. 3
0–3	Cultivated........	3.94	3.42	3.17	2.96	2.80	2.48	2.39	2.18	1.92	2.39
		±0.10	±0.12	±0.09	±0.06	±0.05	±0.06	±0.04	±0.04	±0.03	±0.04
	Uncultivated....	4.20	3.53	3.16	2.70	2.49	2.28	2.07	1.82	1.71	2.23
		±0.16	±0.12	±0.08	±0.05	±0.04	±0.04	±0.03	±0.03	±0.03	±0.02
3–6	Cultivated........	3.37	3.21	3.22	3.74	3.89	3.84	3.94	3.68	3.99	3.68
		±0.17	±0.12	±0.17	±0.18	±0.14	±0.22	±0.17	±0.15	±0.46	±0.10
	Uncultivated....	3.26	3.06	3.84	3.27	3.68	3.84	3.63	3.78	3.32	3.99
		±0.15	±0.11	±0.14	±0.17	±0.15	±0.14	±0.14	±0.12	±0.15	±0.12
0–6	Cultivated........	7.31	6.63	6.39	6.70	6.69	6.32	6.33	5.82	5.91	6.07
		±0.19	±0.18	±0.18	±0.18	±0.16	±0.23	±0.17	±0.16	±0.10	±0.11
	Uncultivated....	7.46	6.59	7.00	5.97	6.17	6.12	5.70	5.60	5.03	6.22
		±0.22	±0.16	±0.16	±0.21	±0.16	±0.15	±0.15	±0.12	±0.17	±0.12

The soil below 3 feet at Delhi is very fine, compacted and cemented, but the water slowly penetrates into this layer. The larger probable errors in the averages of moisture contents of samples taken from 3 to 6 feet in these plots indicates the variability of this soil. On the other hand, the smaller probable errors in the means of the results of sampling from 0 to 3 feet indicate that this layer is fairly uniform. The average moisture equivalent of the soil in the cultivated plots in the upper 3 feet was found to be 5.98 per cent and that of the second 3 feet was 11.78 per cent, while the moisture equivalents of the two depths of soil in the uncultivated plots were 5.49 per cent and 10.40 per cent, respectively. This indicates that the soil in the uncultivated plots had a smaller water-holding capacity than that in the cultivated plots. This also is suggested by the results of the sampling on May 9, 1922, reported in table 40.

The total losses of moisture by evaporation seem to be greater from the sandy soil than from the finer textured soils. However, these losses seem to be confined almost entirely to the upper layers of soil. The data in tables 38, 39, and 40 indicate that no losses occurred from the 3 to 6 foot depth.

TABLE 40

SUMMARY OF SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN PERCENTAGES ON A DRY-WEIGHT BASIS IN THE CULTIVATED AND UNCULTIVATED PLOTS AT DELHI, 1922

Depth of soil sampled, feet		May 9	June 30	July 24	Sept. 8
0–3	Cultivated	6.3±0.03	4.0±0.04	3.5±0.04	2.9±0.04
	Uncultivated	5.5±0.06	3.3±0.06	2.9±0.05	2.5±0.04
3–6	Cultivated	12.0±0.29	10.8±0.37	10.6±0.31	10.6±0.31
	Uncultivated	10.8±0.43	9.4±0.27	9.3±0.36	9.8±0.40
0–6	Cultivated	9.1±0.15	7.4±0.19	7.0±0.16	6.7±0.16
	Uncultivated	8.1±0.21	6.4±0.14	6.1±0.18	6.2±0.20

The plots at Whittier on the clay soil were irrigated July 15, 1921. A depth of water equivalent to 4 inches was applied to all of the plots. Although a crop of barley had been raised during the previous winter and spring, the soil seemed still to be moist on July 14, 1921, when samples were taken before applying the water. On this date, the average moisture content of the soil from 0 to 3 feet was 11.8 per cent and from 3 to 6 feet it was 12.6 per cent. After the water was applied, the surface of the soil remained so wet that the first set of samples following irrigation could not be taken until July 21.

The results of the sampling in the plots at Whittier, given in table 41, seem low when compared with the moisture equivalents for these plots given in table 32, but the soil seemed to be amply moist. This high moisture content was apparent when the samples taken in the areas where the water had been applied were compared with those taken in the strip between the plots. This lack of agreement between the maximum field capacity and the moisture equivelant, in this case, may be due to the difficulty in making moisture equivalent determinations on heavy soils when 30-gram samples are used as had been pointed out by Joseph and Martin[35] and Veihmeyer, Israelsen and Conrad.[51]

The percentages of moisture given in table 41 have been calculated as equivalent amounts of water in acre-inches to the acre and are reported in table 42. Here, again, it will be seen that the differences between the moisture contents of the soil in the cultivated and uncultivated plots are not significant and that the losses of moisture are confined to the upper 3 feet of soil, since the data show no change in moisture content in the lower 3 feet of soil throughout the period of observation.

TABLE 41

SUMMARY OF THE SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN PERCENTAGE ON A DRY-WEIGHT BASIS IN THE CULTIVATED AND UNCULTIVATED PLOTS AT WHITTIER. IRRIGATED JULY 15, 1921

Depth of soil sampled, feet		July 21	July 28	Aug. 4	Aug. 11	Aug. 18	Sept. 3	Sept. 20
0–3	Cultivated	17.3 ±0.25	16.0 ±0.20	16.2 ±0.26	16.2 ±0.21	15.6 ±0.18	16.4 ±0.22	15.9 ±0.18
	Uncultivated	18.0 ±0.24	17.1 ±0.18	16.4 ±0.15	16.5 ±0.13	15.7 ±0.18	16.4 ±0.15	15.5 ±0.15
3–6	Cultivated	15.3 ±0.21	15.1 ±0.22	15.3 ±0.26	15.5 ±0.28	14.8 ±0.22	15.1 ±0.21	15.0 ±0.24
	Uncultivated	14.3 ±0.27	14.4 ±0.32	14.3 ±0.32	14.5 ±0.31	14.2 ±0.30	14.4 ±0.29	14.5 ±0.31
0–6	Cultivated	16.3 ±0.16	15.6 ±0.15	15.8 ±0.18	15.9 ±0.17	15.2 ±0.14	15.7 ±0.15	15.5 ±0.15
	Uncultivated	16.2 ±0.18	15.8 ±0.15	15.4 ±0.18	15.5 ±0.17	15.0 ±0.18	15.4 ±0.17	15.0 ±0.19

That the losses of moisture by evaporation directly from the surface of the clay soil were so small is surprising. It was thought that this soil would crack badly and thus the moisture content of the soil in the uncultivated plots would be lower than that in the cultivated plots. Apparently the uncultivated soil did not crack enough to influence the results. The amount of cracking in the uncultivated plots can be noted in figure 38.

It is a surprising fact that in the field trials, as well as in the studies of evaporation from bare soils in tanks, the uncultivated soils did not crack to an appreciable extent. However, the Yolo clay, the Yolo clay loam, and the Yolo loam cracked badly when they were dried by the extraction of moisture by plants growing on them. The absence of cracking as well as the data reported in the tables indicate that the loss of moisture from the bare soils was slight. However, in this connection, it must be remembered that soils of certain types of high colloidal content crack badly even though plants are not allowed to grow on them, and even though they do not dry out appreciably.

Approximately two months after the water was applied samples were taken in all of the plots to determine the distribution of moisture in the upper layers of soil. The moisture contents of the soil in 4-inch layers to a total depth of 20 inches were obtained from samples taken with a soil tube of large diameter (fig. 38), and the results are reported in table 43.

TABLE 42

SUMMARY OF THE SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN ACRE INCHES TO THE ACRE IN THE CULTIVATED AND UNCULTIVATED PLOTS AT WHITTIER. IRRIGATED JULY 15, 1921

Depth of soil sampled, feet		July 21	July 28	Aug. 4	Aug. 11	Aug. 18	Sept. 3	Sept. 20
0–3	Cultivated	9.59 ±0.14	8.87 ±0.11	8.98 ±0.14	8.98 ±0.12	8.55 ±0.10	9.09 ±0.12	8.82 ±0.10
	Uncultivated	9.98 ±0.13	9.54 ±0.10	9.09 ±0.08	9.15 ±0.07	8.71 ±0.10	9.09 ±0.13	8.60 ±0.11
3–6	Cultivated	8.49 ±0.12	8.38 ±0.12	8.54 ±0.14	8.60 ±0.15	8.21 ±0.12	8.38 ±0.12	8.32 ±0.13
	Uncultivated	7.93 ±0.15	7.99 ±0.18	7.93 ±0.18	8.05 ±0.17	7.88 ±0.17	7.99 ±0.16	8.05 ±0.17
0–6	Cultivated	18.04 ±0.18	17.25 ±0.17	17.52 ±0.20	17.58 ±0.19	16.76 ±0.16	17.47 ±0.17	17.14 ±0.17
	Uncultivated	17.91 ±0.20	17.53 ±0.17	17.12 ±0.20	17.20 ±0.19	16.59 ±0.20	17.08 ±0.19	16.65 ±0.20

These data show clearly that the losses of moisture by evaporation were confined largely to the upper 8 inches of soil, and that the greater portion of the loss from this depth of soil occurred in the first 4 inches. When the moisture contents given in table 43 are compared with those for the upper 3 feet of soil given in tables 33 to 42, it seems that there were slight losses at least to a depth of 20 inches. The results obtained in the study of the losses by evaporation from bare soils in tanks also show that water was lost throughout the entire depth of the soil (table 31). However, the loss below the surface layer was at an extremely slow rate and would be negligible in amount for even longer periods than the usual ones between irrigations or between rains. It can not be assumed that those losses below the surface layers are due entirely either to upward movement of moisture by capillarity or to loss by water vapor movement. Amounts of water lost from the soil by water vapor are generally held to be very small, the work of Buckingham[17] and Bouyoucos[7] frequently being cited to show that this is true. However Bouyoucos and McCool[10] have recently pointed out that considerable aeration of soils takes place because of atmospheric pressure changes, and the slight losses of moisture from the deeper layers of soils in the plots and in the tanks may have been due to movement of air and water vapor through them. Of course, the ease of air movement between the soil mass and the sides of the tanks was greater than that for movement through the soil in the field plots, and it should be expected that moisture would be lost throughout a greater depth of soil in the tanks.

TABLE 43

SUMMARY OF MOISTURE CONTENTS IN FOUR-INCH DEPTHS OF SOIL IN PERCENTAGES ON A DRY-WEIGHT BASIS IN CULTIVATED AND UNCULTIVATED PLOTS IN 1921. SAMPLES TAKEN APPROXIMATELY TWO MONTHS AFTER IRRIGATION

Location of plots	Treatment	Depths of soil samples in inches				
		0 to 4	4 to 8	8 to 12	12 to 16	16 to 20
Davis	Cultivated	6.6 ±0.37	15.7 ±0.51	20.1 ±0.47	19.1 ±0.28	18.6 ±0.23
	Uncultivated	8.6 ±0.39	15.5 ±0.23	19.0 ±0.41	19.0 ±0.21	19.4 ±0.21
Mountain View	Cultivated	4.0 ±0.20	9.5 ±0.41	10.2 ±0.34	10.3 ±0.37	10.7 ±0.41
	Uncultivated	3.9 ±0.15	9.1 ±0.28	10.4 ±0.36	11.0 ±0.67	10.9 ±0.79
Delhi	Cultivated	1.3 ±0.06	3.9 ±0.12	4.1 ±0.12	4.1 ±0.10	4.2 ±0.15
	Uncultivated	1.5 ±0.05	3.1 ±0.06	3.3 ±0.06	3.7 ±0.09	4.1 ±0.25
Whittier	Cultivated	4.1 ±0.22	11.5 ±0.33	15.1 ±0.54	16.2 ±0.31	15.9 ±0.23
	Uncultivated	4.1 ±0.21	11.0 ±0.28	16.2 ±0.43	17.3 ±0.39	16.5 ±0.47

It should be noted from the data in table 43 that the only significant differences in moisture content of the soil in 4-inch depths in the cultivated and uncultivated plots appears to be in the 4 to 8 and 8 to 12 inch depths in the plots at Delhi. The difference in moisture content in favor of the cultivated plots is 0.8 ± 0.13 per cent in each instance. This is equivalent in amount to a depth of water of only 0.09 inches in the 8 inches of this sandy soil. In every other case, the differences were insignificant, and it is apparent that thorough cultivation at weekly intervals for a period of approximately two months failed to result in a saving of moisture or to influence its movement by capillarity. In fact, the results reported in tables 33 to 43, as well as those secured in the studies of the loss of moisture from bare soils in tanks indicate that the movement of water by capillarity from moist soils to drier soils is extremely slow and is effective only through very short distances.

TABLE 44

SUMMARY OF SOIL-MOISTURE CONTENTS IN THREE-FOOT DEPTHS IN PERCENTAGES ON A DRY-WEIGHT BASIS IN SAMPLES TAKEN FROM THE UNWETTED AREAS BETWEEN AND AROUND THE CULTIVATED AND UNCULTIVATED PLOTS AT THE BEGINNING AND AT THE END OF THE TESTS

Location of plots	Depth of soil samples	Moisture content at beginning of tests	Moisture content at end of tests
Davis	0–3	14.6±0.55	14.9±0.40
	3–6	17.2±0.46	17.3±0.29
Mountain View	0–3	6.7±0.23	6.0±0.22
	3–6	13.1±0.28	13.2±0.27
Delhi	0–3	1.7±0.14	1.3±0.09
	3–6	6.0±0.93	6.2±0.57
Whittier	0–3	12.3±0.25	12.0±0.22
	3–6	15.1±0.43	14.6±0.45

This is further substantiated by the records of the moisture contents of the samples taken in the strips between the plots and those taken outside the wetted areas around the plots (see figure 36) which are reported in table 44. There are no significant differences in the moisture contents of the samples taken at the beginning and of those taken at the end of the tests. Some of these samples were taken 5 feet from the wetted areas but the majority were taken only 2½ feet away. The latter samples, taken at frequent intervals, showed no increase in moisture content throughout the duration of the experiments. This indicates that there probably was no movement of moisture from one plot to another and also that there was little if any loss of moisture from the plots by lateral movement. Certainly the lateral movement to a distance of only 2½ feet was not enough to change the moisture content at this point. The results of further studies on the movement of moisture from moist soils to drier soils are given in the following pages.

THE MOVEMENT OF MOISTURE FROM MOIST SOILS TO DRIER SOILS IN COLUMNS

Since the data from the studies of the losses of moisture from bare soils in tanks and in field plots indicate that the movement of moisture from moist soils to drier soils, when the source of water is not a free water surface, is slight in amount and extent, an effort was made to secure more direct evidence concerning such movement by studying the behavior of moisture in columns of soils. The columns used in this study are the same as those described by McLaughlin.[40][*]

The columns were made of redwood planks 2 inches thick and 8 inches wide, nailed together and lined with galvanized iron, and were therefore 6 inches by 6 inches inside and 6 feet long.

All of the columns were packed with Yolo clay loam taken from the surface of the orchard at the Deciduous Fruit Station of the University of California at Mountain View. The gravel was screened and the soil was thoroughly mixed. Midway from end to end the columns were packed with air-dry soil, this being held in place by tight-fitting boards at both ends of the soil section. In filling this central section the soil was added in uneven thin layers, then compackted evenly. The weight of water-free soil was known and the column was frequently weighed during the process of packing so that a definite volume weight of soil corresponding to that of the soil in place in the field was obtained. Weighed quantities of water were then added to raise the soil to its field capacity. The soil was then covered and allowed to stand for 48 hours, after which samples were taken and the moisture content determined. If the water seemed to be uniformly distributed throughout the soil mass, the holes made in sampling were refilled with soil properly moistened, and this soil

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[*] The writer is indebted to Mr. W. W. McLaughlin of the Division of Agricultural Engineering of the Bureau of Public Roads, United States Department of Agriculture, for the use of this equipment.

was tamped into place. The supports for the pieces of boards holding the central section of wetted soil in place were removed and the end sections packed with the drier soils. The packing was done in the same manner as that for the central section, and the same volume weight was obtained. The end boards which retained the central section now were removed and the spaces occupied by them were thoroughly packed with the drier soil. Strips of asphaltic roofing paper were laid along the edges of the planks and a plate glass cover was securely clamped into place and the columns placed upright.

Since it was recognized there were mechanical difficulties in securing good capillary contact of the moist with the drier soil, and since poor contact might inhibit movement from the moist to the drier soil, great care was taken to avoid, as much as possible, error due to this cause. At the termination of the period of observation with each column and after the final samples were taken, the column was cut lengthwise and the place where the moist and drier soils were originally joined was carefully noted. There was no evidence of discontinuity of the soil masses in any case and the original line of demarcation between moist and drier soil could not be detected.

It was very difficult to raise the moisture content of the rather large quantities of drier soils required for the end sections to the percentages required. Although there were some departures from the moisture contents it was desired to bring about in the end sections of the columns a fairly satisfactory method was finally used. The dry soil was placed in a large metal can and water in sufficient quantity to raise it to the necessary percentage was added by spraying it on the soil in a fine mist, meanwhile rotating the can so that the soil was constantly mixed.

The amounts of water contained in the central and end sections of the columns at the beginning of the tests are not so accurately known as is the distribution of moisture at the end. Samples were taken from the ends and near the middle of each section before the columns were placed upright but only a few samples could be taken at the beginning of the test without too much disturbance of the soil. Variations of 0.7 per cent in the samples from the drier soil were obtained, while the samples from the moist soil showed a variation of about 1 per cent. The moisture contents of the soil when packed are probably accurate to within 1 per cent. The moisture equivalents made on the samples taken from the packed columns varied from 21 to 24 per cent and averaged about 22 per cent, an average which may be taken as being fairly close to the field capacity for this soil.

Several types of small soil augers were tried in taking the samples both at the beginning and at the end of the tests, but a small soil tube seemed to give the best results; at least the moisture percentages obtained with this device were higher than those with the augers, and the results secured seemed to be consistent.

The moisture contents given in the following figures were obtained from the columns at the end of the tests. The columns were taken down and the glass plates removed. The samples were taken along the center line of the column but were staggered so that one sample would not interfere with another. In taking the sample, the soil tube was pushed the full depth of the column. The moisture contents recorded, then, are the average amounts of moisture contained in the depth of the column. No attempt was made to determine the distribution of moisture in this depth. It should be noted that the movement of moisture in both an upward and downward direction determined by noting the change in color of the drier soil in every case was always less than the movement indicated by the results of sampling the soil. This might be accounted for if there were a greater movement of moisture down the back of the columns than down the front, which was covered with plate glass, and this may account for the discrepancy in the two methods of indicating the movement of moisture.

In this connection it must be mentioned that the soil columns were subject to fluctuations in temperature. Temperature variations may have caused a greater movement in one portion of the soil mass than in another. Furthermore, condensation of moisture on the sides of the container due to temperature changes and subsequent downward movement of this condensed water may account for some of the downward movement in the wet section of the columns.

The determination of the extent and rate of movement by noting the change in color of the drier soil was extremely difficult and practically impossible in the columns in which the end sections were packed with soils having the higher moisture contents. It is believed that the distribution of moisture as indicated by sampling the soil is a much more reliable and accurate measure of the extent of moisture movement than by noting the change in color of the drier soil, especially in the clay loam soils used in the present studies.

The columns selected, the data from which are presented here, are typical of all of the columns studied and represent the range in moisture contents used. Figure 40 graphically illustrates the distribution of moisture in one of the 6-foot columns, the central 2-foot section of which was packed with a soil containing 22 per cent of moisture. The upper section was packed with a soil of 3 per cent moisture content, and the bottom section with soil containing 3.5 per cent of moisture. This column was started on August 26, 1922, and the samples were taken on January 17, 1923. The results of the sampling indicate the extent and distribution of moisture after the soils had been in contact for 144 days.

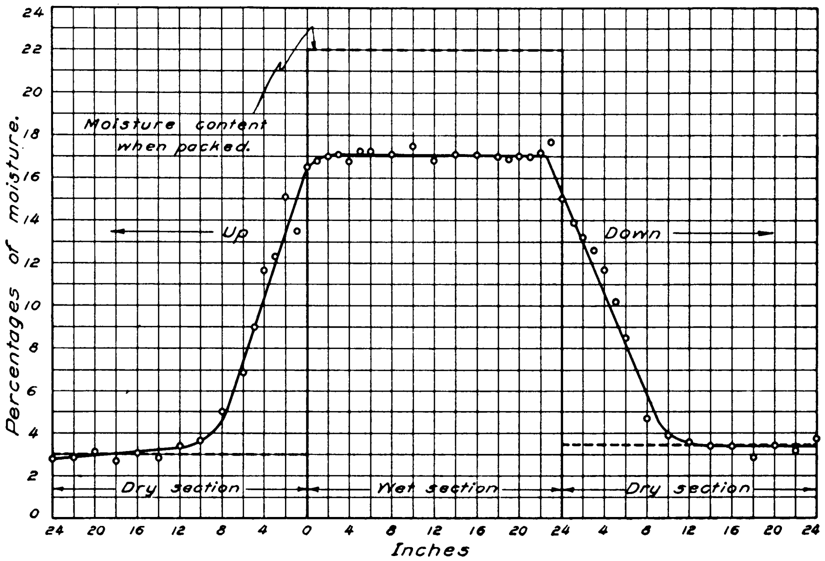

Fig. 40. The movement of moisture upward and downward (left and right in diagram) from soil mass initially containing 22 per cent of moisture to soil containing 3 per cent and 3.5 per cent of moisture. Column was started August 26, 1922, and samples were taken January 17, 1923. The place of sampling in the column and the amount of moisture found are indicated by the circles. Depth is shown by numerals along the base of diagram.

The upward movement of moisture from the moist into the dry soil in this column, as measured by the change in color of the dry soil, was 3.0 inches and the downward movement was 5.75 inches. It is evident that both of these distances are less than the movement indicated by the results of sampling, which also showed no difference in extent of moisture movement upward and downward. The results obtained by sampling in all of the columns showed this to be the case in every instance. However, McLaughlin,[40] using the same equipment, reports a greater downward movement in each of his tests. Attempts were made to determine the rate of movement of moisture from the moist soil into the drier soil by noting the advance of the moist layer. These were not entirely successful owing to inability to determine clearly the line of demarcation between moist and drier soil. However, it was clear that the greater portion of the movement took place within the first few days after the soils were placed in contact. McLaughlin[40] concludes from his studies "that the greater part of capillary distribution of the water occurs while water is being applied and in the next two or three days thereafter."

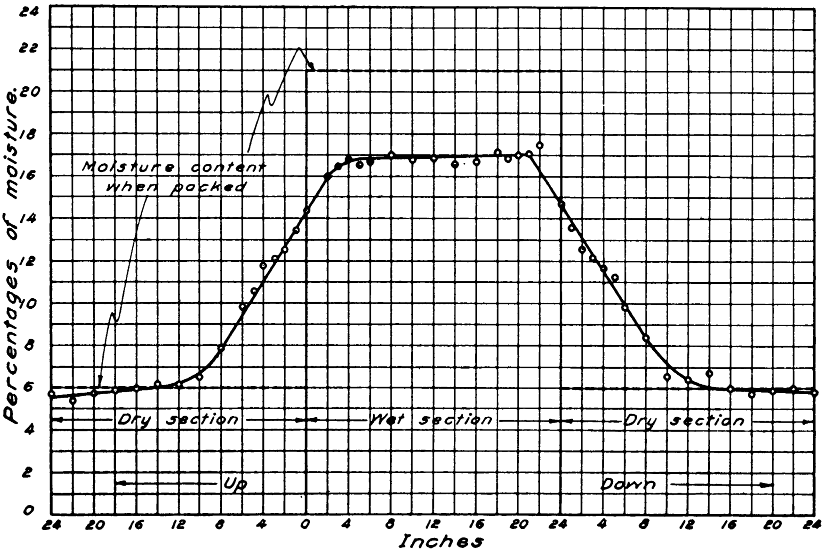

Fig. 41. The movement of moisture upward and downward (left and right in diagram) from soil mass initially containing 21 per cent of moisture to soils containing 6 per cent of moisture. Column was started August 29, 1922, and samples were taken January 17, 1923. The place of sampling in the column and the amount of moisture found are indicated by the circles. Depth is shown by numerals along the base of diagram.

The distribution of moisture and the extent of upward and downward movement from a soil with an initial moisture content of 21 per cent, occupying the central section of one of the columns, into soils with an initial moisture content of 6 per cent, in the end sections are shown in figure 41. The test with this column was started on August 29, 1922, and the samples were taken on January 17, 1923, after a period of 141 days. The upward movement of moisture from the moist soil into the drier soil was 5.4 inches, and the movement downward was 5.1 inches, as indicated by the change in color of the drier soil.

Figure 42 illustrates the distribution of moisture and the extent of movement in a column the central section of which was packed with soil which was wet to a water content of 23 per cent. The upper end section was packed with soil at 7.8 per cent and the lower end section with soil having an initial moisture content of 8 per cent. The test was continued for 141 days, from August 29, 1922, to January 17, 1923. The measurement of the line of demarcation between moist and drier soil at the end of the test, made by noting the change of color, indicated that the upward movement was 3.25 inches and the downward movement was 6.7 inches. The results presented in figure 42 indicate the distribution and extent of moisture movement from soil initially wet to about its field capacity into soil approximately at the hygroscopic coefficient.

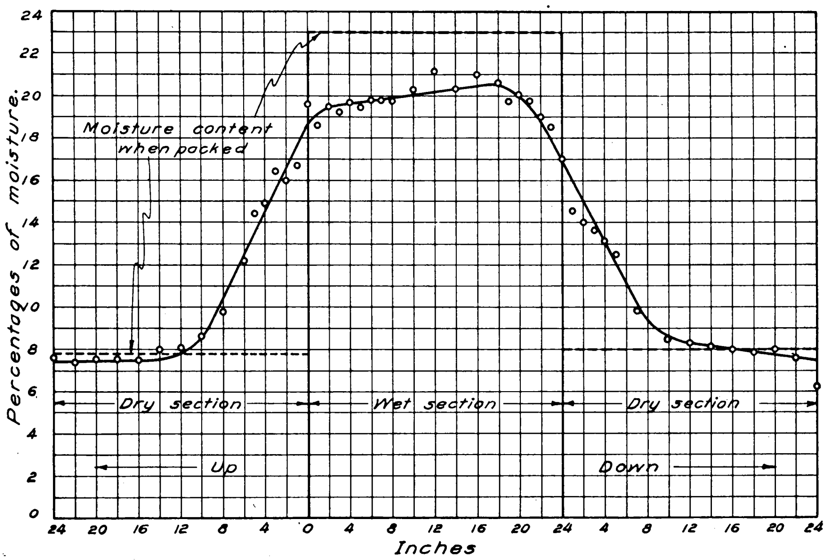

Fig. 42. The movement of moisture upward and downward (left and right in diagram) from soil mass initially containing 23 per cent of moisture to soils containing 7.8 and 8 per cent of moisture. The column was started August 29, 1922, and samples were taken January 17, 1923. The place of sampling in the column and the amount of moisture found are indicated by circles. Depth is shown by numerals along the base of diagram.

The results of sampling a column of soil the central section of which was packed with soil and wetted so that the moisture content at the start was 21.5 per cent, and the end sections were packed with soil containing 12.5 per cent of moisture, are illustrated in figure 43. The soils were in contact for 140 days. Thus the end sections initially had a moisture content approximately equal to the calculated wilting coefficient for this soil, and the movement of moisture indicated is from a soil at about the field capacity into one at the wilting coefficient. It was very difficult, because of the relatively high moisture content, to distinguish any change in the color of the drier soil used in this column as the moisture moved. The best estimate which could be made by this method was a movement upward of 3.25 inches and downward of 3.3 inches.

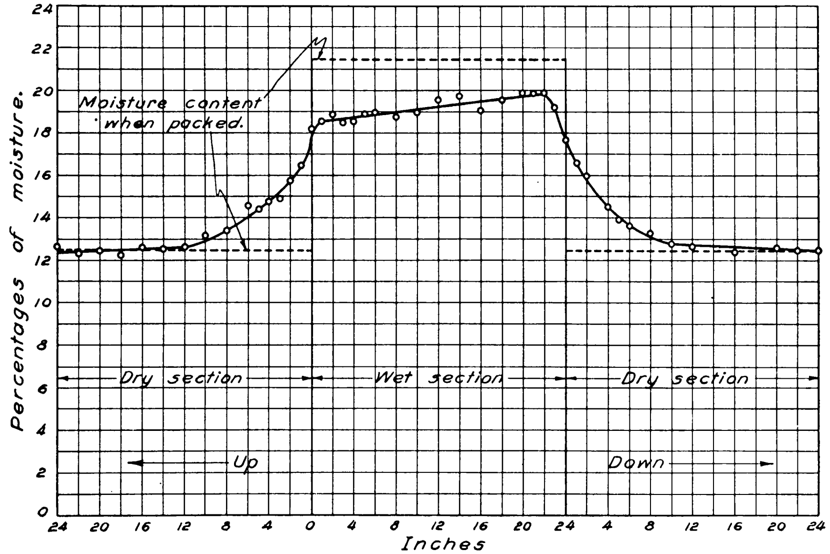

Fig. 43. Movement of moisture upward and downward (left and right in diagram) from soil mass initially containing 21.5 per cent of moisture to soil containing 12.5 per cent of moisture. Column was started September 1, 1922, and samples were taken January 18, 1923. The place of sampling in the column and the amount of moisture found are indicated by the circles. Depth is shown by numerals along the base of diagram.

The distribution and extent of moisture movement from a soil wetted to 22 per cent into soil with an initial moisture content of 14.5 per cent is shown in figure 44. The initial moisture content of the soil in the end sections of this column was as high as could be used in these experiments and yet be materially less than the field capacity. It was necessary to stir the soil constantly while applying the water, in order to bring it to an intermediate moisture content. Puddling would occur in soils at moisture contents higher than 14.5 per cent. These soils were in contact for 139 days—from September 2, 1922, to January 18, 1923. The movement upward as indicated by the color change in the drier soil was 3.2 inches and the downward movement was 3.9 inches, but these measurements were very indefinite.

The data selected for presentation here were taken from columns covering a range of moisture contents in the drier soils from an air-dried condition to a moisture content above the wilting coefficient, and they indicate the extent of moisture movement into these drier soils from a clay loam soil wet to its field capacity.

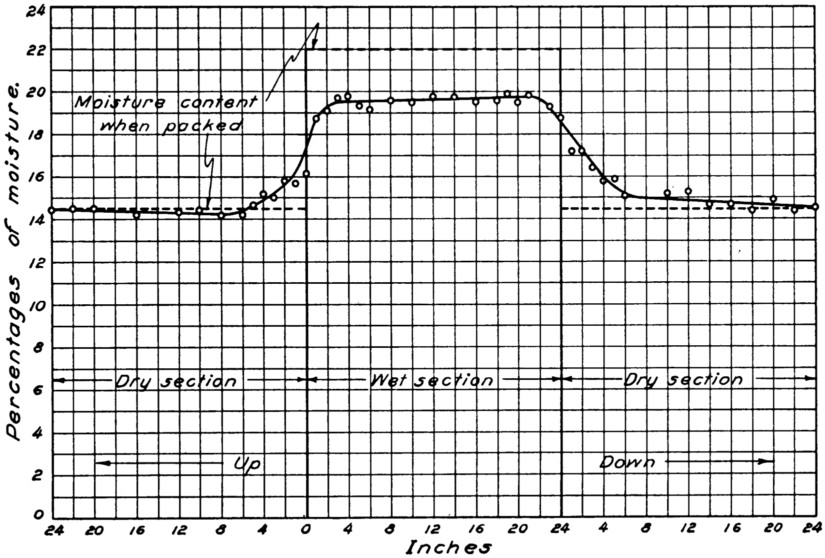

Fig. 44. Movement of moisture upward and downward (left to right in diagram) from soil mass initially containing 22 per cent of moisture to soil containing 14.5 per cent of moisture. Column started September 2, 1922, and samples taken January 18, 1923. The place of sampling in the column and the amount of moisture found are indicated by the circles. Depth is shown by numerals along the base of diagram.

McLaughlin[40] has suggested that the rate and extent of movement of moisture varies with the initial percentage of moisture in the wet pack. Therefore, it is probable that the extent of moisture movement shown in these figures is greater than that under field conditions wherein the moisture content of the wet mass of soil is rapidly being depleted by plants growing on it. Apparently the moisture content of the drier soil had little effect upon the extent of movement of moisture from the moist to drier soil.

It is evident that in the clay loam soil used in these columns the movement of moisture from the moist to the drier soil in either direction, even during long periods of time, was limited. The results of these, as well as the other studies herein reported, indicate that the capillary movement of moisture from a moist soil to a drier soil, when the soil is not in contact with a free water-surface, is too limited in extent and probably in rate to be effective for use by plants.

In view of the data presented herein concerning the capillary movement of moisture, the prevalent belief as to the results of light and heavy irrigations is plainly incorrect. The belief that the moisture content of all of the soil occupied by the roots of the trees will be raised to a certain percentage by the application of small amounts of water, because of the downward capillary movement of the water with a consequent equalization of the moisture content of all of the soil, is not in accord with results obtained in these experiments. A light irrigation, in fact, results in wetting the soil to a less depth than the application of a larger amount.

SUMMARY

The records of moisture conditions in mature prune orchards in the Santa Clara Valley of California show that the soil-moisture supply is constantly changing during the growing season. The maintenance of a uniform soil-moisture content, a condition often specified as essential for the best fruit production, probably is impossible. An approximation of a uniform soil-moisture content possibly might be brought about by very frequent applications of water. However, this practice would be objectionable not only for reasons of labor and expense involved and the interference with other orchard practices, but also because of the probable injurious effects on the soil.

The amount of water that may be stored in the soil at one application is limited. The records of soil-moisture conditions taken from the upper 6 feet of soil indicate that the moisture supply usually is exhausted within four or five weeks in a loam soil in a mature orchard during the growing season.

Irrigation during the dormant season for the purpose of storing water for use by the trees during the growing season usually is ineffective in years of normal rainfall in such localities as the Santa Clara Valley. In a year of normal rainfall, the upper 6 feet of soil in the Santa Clara Valley are usually filled with water to the maximum field or capillary capacity at the beginning of the growing season.

While a considerable amount of water was taken by the roots of the trees from the soil below 6 feet, it was much less than that taken from the upper 6 feet of soil. Also, the rate of extraction of moisture was much lower from the lower depths of soil than from

the upper 6 feet. Wilting was always noted when the moisture content of the upper 6 feet of soil had been reduced to the wilting coefficient. Therefore, the moisture content of the upper 6 feet of soil probably exerts a much greater influence on such trees than that of the soil below 6 feet. However, the moisture in these lower depths of soil probably does maintain trees during long periods after the moisture supply of the upper 6 feet has been exhausted.

The parallelism of the graphs representing the rate of loss of moisture from the upper 3 feet of soil and that from the next lower 3 feet of soil indicates that the roots of the prune trees, under the conditions of these observations, are uniformly distributed in the upper 6 feet of soil. The parallelism of these graphs also indicates that probably no movement of moisture takes place between the top 3 feet and the next 3 feet of a soil during the growing season in the absence of free water.

The moisture content of the upper 6 feet of soil in these prune orchards was reduced to, or below, the wilting coefficient toward the end of the growing season. This condition usually persisted for two or more months before the moisture supply was replenished. In every case the inability of the roots of the trees to obtain water from soil below 6 feet at a sufficiently rapid rate was evidenced by wilting and shedding of leaves.

The soil-moisture records presented here indicate that the use of water by the mature prune trees does not seem to be influenced by the amount of water present in the soil, provided the soil-moisture content has not been reduced below the wilting coefficient. The slope of the graphs representing the moisture conditions apparently are substantially the same, whether the soil-moisture supply be high or low. The intensity of atmospheric evaporating power and leaf area seemed to determine the use of water by the trees; the amount of available water present in the soil, and the condition or state of growth of the trees, except in so far as this affected leaf area, seemed to be of secondary importance.

The yields, drying ratios, size, and quality of prunes produced did not seem to be related to the frequency or amounts of water applied to the soil. The yields, drying ratios, size and quality of Muir peaches were not influenced by the amounts or times of irrigation, except in years of unusually low rainfall or when the soil-moisture content had previously been reduced below the wilting coefficient. Mature prune and peach trees did not seem to be affected by changes in soil-moisture content unless the moisture content of the upper 6 feet of soil had been reduced to about the wilting coefficient.

The results obtained in the studies of the Muir peaches were in general the same as those obtained with the mature prune trees. It was possible to make more detailed measurements of the growth of the peach trees. These indicated that, with the exception of the season of 1920, during which the soil moisture in the unirrigated rows was depleted early in the season, there was no difference in growth made which could be related to differences in soil-moisture conditions in the different rows.

Studies of young prune trees grown in tanks under controlled conditions indicate that the use of water by these young trees was not influenced by the amount of water in the soil above the wilting coefficient. Under comparable atmospheric conditions the rate of extraction of moisture by the roots of the trees was the same whether the moisture content of the soil above the wilting coefficient was high or low. Apparently the roots of these trees were able to obtain water as readily when the soil moisture content had been reduced almost to the wilting coefficient as when the soil was filled with water to its maximum field capacity.

Because of the comparatively slow capillary movement of moisture, serious objections may be raised to previous water relation studies wherein dependence has been placed upon capillary movement to cause a uniform distribution in the soil of water applied at any point. A predetermined soil-moisture content, less than the full field capacity, could not be brought about in the large masses of soils used in these experiments. It is also very probable from the results obtained that even if a relatively low moisture content could be established uniformly throughout the soil mass, a condition which probably is impossible of attainment, the moisture content would very quickly be reduced by the growing plant and the relatively low moisture content could not be maintained under natural field conditions or even in controlled experiments.

The results obtained from the controlled studies made with prune trees in tanks indicate that not only the use of water but the trees themselves were not affected by variations in amounts of soil moisture above the wilting coefficient. While these results apply only to these young prune trees, it appears that many of the current views regarding soil-moisture relations of other plants may also be questioned.

When the atmospheric evaporating power was judged, by means of the measurements and apparatus employed, to be the same in the spring as in the fall, the use of water to a unit of leaf area apparently was the same. This suggests that the use of water to a unit of leaf area by these young prune trees was not influenced by the state of growth. Within the limits of weighings made in these experiments, it was not possible to detect differences in the use of water to a unit of leaf area during the fore part of the growing season, when the trees were making rapid length growth, and the use of water in the latter part of the season, when length growth had ceased and the leaves were more mature. The intensity of the atmospheric evaporating power and leaf-area seemed to govern the use of water.

When the moisture content of the loam soils on which these young prune trees were grown was reduced below a rather definite amount, the trees wilted and did not recover until water was added to the soil. The wilting coefficient, which was calculated from the moisture equivalent, was very close to the actual moisture content found in the soil at the beginning of permanent wilting. This agreement between the theoretical wilting coefficient and the residual moisture found in the soil at the time when the trees permanently wilted persisted throughout several seasons and at different times during each season the observations were made. This indicates that, within the range of conditions under which these experiments were made, atmospheric conditions had little influence upon the amount of residual moisture in the loam soils at the beginning of permanent wilting.

While the wilting coefficient of the soils under observation in these experiments was a percentage of soil moisture at which the young trees grown in tanks, as well as the mature prune trees, began to wilt permanently, the soil moisture was reduced much below this percentage. However, the soil-moisture supply was reduced to the hygroscopic coefficient in only a few cases and only by mature prune trees. Usually about one-half of the soil-moisture between the wilting coefficient and the hygroscopic coefficient was taken by the trees. Vetch plants grown in tanks were able to reduce the moisture content of the soil only to a like amount. Although the wilting coefficient, which is a critical soil-moisture content, is not the lower limit of available moisture, it probably is a better basis for comparing moisture properties of soils than the hygroscopic coefficient.

The time of fall coloration and abscission of leaves of the young prune trees grown in tanks was the same when the soil-moisture content was high as when the soil-moisture content was low but not below the wilting coefficient. However, defoliation caused by wilting could be induced by withholding water until the soil-moisture content was reduced below the wilting coefficient.

It is probable that the beginning of dormancy or of maturity of the plant tissues is not affected by variations of soil-moisture content within a rather wide range. No injury from irrigation late in the season, shortly before the leaves dropped, could be detected in the Santa Clara Valley prune orchards or the Muir peach orchard at Davis. This suggests that the hardiness of the wood of these mature trees and probably of the young prune trees in containers had not been affected by a high soil-moisture content late in the season.

Under conditions at Mountain View, in the Santa Clara Valley of California, where these observations were made, young prune trees grown in tanks lost a very slight amount of water by evaporation from the bare twigs and branches. The use of water by these young trees during the winter was so small that the need for the application of water to meet the current demands of the trees during this season is probably negligible, except in years of unusually light rainfall.

The losses of moisture by direct evaporation from the surfaces of soils in containers were measured by repeated weighings. Losses of moisture by direct evaporation from the soil surfaces of field plots were measured by sampling the soil and ascertaining the soil-moisture contents. A rather wide range of soils and climatic conditions was obtained in the field trials. These losses were found to be relatively slight in amount. A comparison of the evaporation losses from the surfaces of bare soils with the amount of water taken from the soil by plants showed that evaporation losses were extremely small portions of the total amounts of water lost from the soil.

The loss of moisture by direct evaporation from the soil was confined very largely to shallow depths of soil. Moisture below the upper eight inches of soil was lost at an extremely slow rate. The losses of moisture from the surfaces of soils exposed to evaporation for much longer periods of time than are usual between irrigations, were insufficient to prohibit the growth to maturity of barley and vetch plants. After exposure to evaporation for the entire summer, there was sufficient moisture in the soil in tanks below the upper eight inches to grow vetch plants to maturity without applying additional water.

Cultivation did not influence the losses of moisture by evaporation from the bare surfaces of the soils in the tanks and in the field plots under observation in these experiments. Cultivation did not materially influence the distribution of moisture in these soils. There were no significant differences in the moisture contents in 4-inch depths in the cultivated and uncultivated soils with the exception of the 4 to 8 and 8 to 12-inch depths at Delhi. The differences in these depths of this sandy soil were very small but were probably significant.

The loss of moisture by evaporation from the surfaces of soils immediately following the application of water were found to be a large portion of the total evaporation loss for a long period of time. About half of the loss in 80 days occurred in the first week after irrigation, and the greater amount of this was lost before the soil was in condition to be properly cultivated.

After the water applied to the soil had become distributed, the movement of moisture by capillarity was found to be extremely slow. There was neither upward nor downward movement in the soil from the 3-foot depth to the 6-foot depth during the time the observations were made in these experiments. The movement of moisture laterally in 2½ months was not sufficient to affect the moisture content of the soil 2½ feet from the wetted area.

The movement of moisture from moist soils to dry soils packed in columns and remaining in contact with each other for 4½ months was slight in amount and in extent in both an upward and downward direction. The results of these studies indicate that the capillary movement of moisture from moist soil to drier soil, when the soil is not in contact with a free water surface, is too limited in extent and probably in rate to be effective for the use by plants.

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PLATES 1-3

PLATE 1

Fig. 1. The effect of differences in soil moisture on the condition of prune trees. Photographed October 18, 1922. Tree 3 on the left, and tree 5 on the right on soil below the wilting coefficient. Tree 4 in the center on soil with moisture content near the wilting coefficient.

Fig. 2. The same trees shown in fig. 1, ten days later.

Fig. 1

Fig. 2

PLATE 2

Fig. 1. The effect of soil moisture on the condition of prune trees in the fall. Photographed October 7, 1922. Tree 15, on the left, and tree 17, on the right, on soil with moisture content below the wilting coefficient. Tree 16, in the center, on soil with moisture content near the wilting coefficient.

Fig. 2. Tree 19, in the center, and tree 20, on the right, on soil kept continuously above 16 per cent moisture content. Tree 18, on the left, on soil kept above 16 per cent moisture content until the last week in August when it was allowed to wilt but was revived, and the soil-moisture content thereafter allowed to fluctuate between the maximum field capacity and the wilting coefficient. At the time this photograph was taken, October 18, 1922, tree 18 was on soil near the wilting coefficient.

Fig. 1

Fig. 2

PLATE 3

Fig. 1. Fall condition of prune trees on water-logged soil, compared to that of a tree on soil near the wilting coefficient. The soil on which tree 12, on the left, and tree 14, on the right, were growing was water-logged throughout the growing season. Tree 13, in the center, was irrigated only when the soil-moisture content was reduced nearly to the wilting coefficient. At the time this photograph was taken, October 18, 1922, the moisture content of the soil on which tree 13 was growing was near the wilting coefficient.

Fig. 2. Prune trees in tanks used to determine the loss of moisture by evaporation from bare twigs and branches during the dormant season. Tree 1 is on the right, tree 3 is in the center, and tree 6 is on the left.

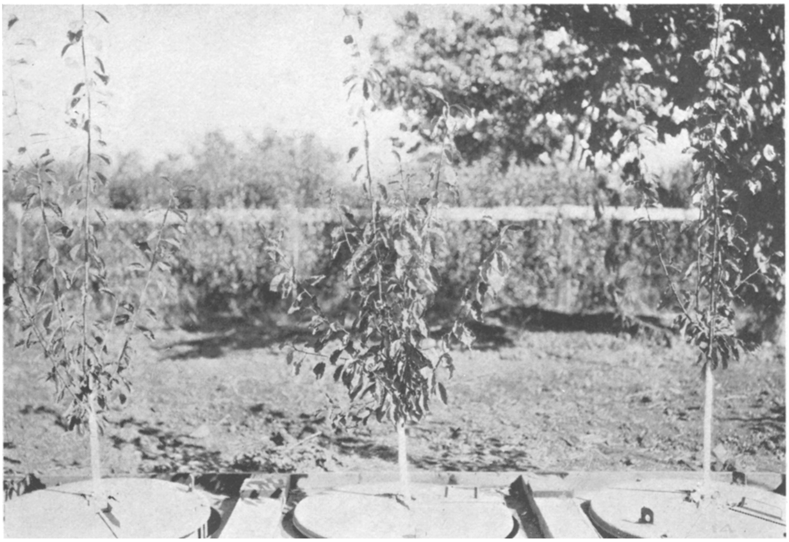

Fig. 1

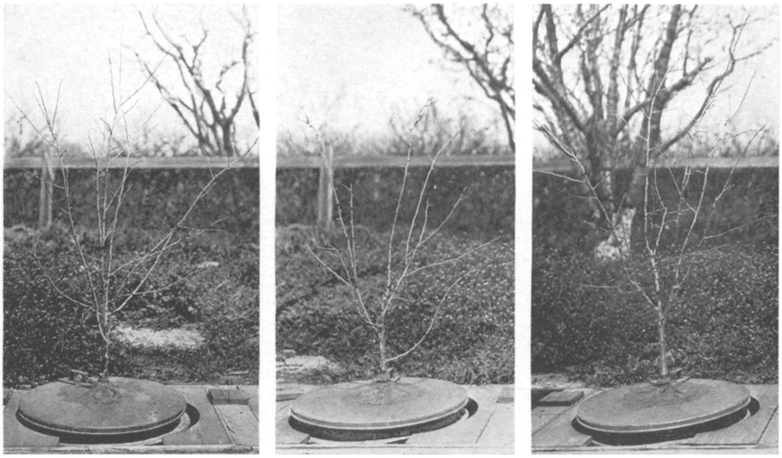

Fig. 2

The titles of the Technical Papers of the California Agricultural Experiment Station, Nos. 1 to 20, which HILGARDIA replaces, and copies of which may be had on application to the Publication Secretary, Agricultural Experiment Station, Berkeley, are as follows:

1. The Removal of Sodium Carbonate from Soils, by Walter P. Kelley and Edward E. Thomas. January, 1923.
3. The Formation of Sodium Carbonate in Soils, by Arthur B. Cummins and Walter P. Kelley. March, 1923.
4. Effect of Sodium Chlorid and Calcium Chlorid upon the Growth and Composition of Young Orange Trees, by H. S. Reed and A. R. C. Haas. April, 1923.
5. Citrus Blast and Black Pit, by H. S. Fawcett, W. T. Horne, and A. F. Camp. May, 1923.
6. A Study of Deciduous Fruit Tree Rootstocks with Special Reference to Their Identification, by Myer J. Heppner. June, 1923.
7. A Study of the Darkening of Apple Tissue, by E. L. Overholser and W. V. Cruess. June, 1923.
8. Effect of Salts on the Intake of Inorganic Elements and on the Buffer System of the Plant, by D. R. Hoagland and J. C. Martin. July, 1923.
9. Experiments on the Reclamation of Alkali Soils by Leaching with Water and Gypsum, by P. L. Hibbard. August, 1923.
10. The Seasonal Variation of the Soil Moisture in a Walnut Grove in Relation to Hygroscopic Coefficient, by L. D. Batchelor and H. S. Reed. September, 1923.
11. Studies on the Effects of Sodium, Potassium, and Calcium on Young Orange Trees, by H. S. Reed and A. R. C. Haas. October, 1923.
12. The Effect of the Plant on the Reaction of the Culture Solution, by D. R. Hoagland. November, 1923.
13. Some Mutual Effects on Soil and Plant Induced by Added Solutes, by John S. Burd and J. C. Martin. December, 1923.
14. The Respiration of Potato Tubers in Relation to the Occurrence of Blackheart, by J. P. Bennett and E. T. Bartholomew. January, 1924.
15. Replaceable Bases in Soils, by Walter P. Kelley and S. Melvin Brown. February, 1924.
16. The Moisture Equivalent as Influenced by the Amount of Soil Used in its Determination, by F. J. Veihmeyer, O. W. Israelsen and J. P. Conrad. September, 1924.
17. Nutrient and Toxic Effects of Certain Ions on Citrus and Walnut Trees with Especial Reference to the Concentration and Ph of the Medium, by H. S. Reed and A. R. C. Haas. October, 1924.
18. Factors Influencing the Rate of Germination of Seed of Asparagus officinalis, by H. A. Borthwick. March, 1925.
19. The Relation of the Subcutaneous Administration of Living Bacterium abortum to the Immunity and Carrier Problem of Bovine Infectious Abortion, by George H. Hart and Jacob Traum. April, 1925.
20. A Study of the Conductive Tissues in Shoots of the Bartlett Pear and the Relationship of Food Movement to Dominance of the Apical Buds, by Frank E. Gardner. April, 1925.