UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

I. IRRIGATION EXPERIMENTS WITH PEACHES IN CALIFORNIA

A. H. HENDRICKSON and F. J. VEIHMEYER

II. CANNING QUALITY OF IRRIGATED PEACHES

P. F. NICHOLS

BULLETIN 479
NOVEMBER, 1929

UNIVERSITY OF CALIFORNIA PRINTIN
BERKELEY, CALIFORNIA
1929

I. IRRIGATION EXPERIMENTS WITH PEACHES IN CALIFORNIA

A. H. HENDRICKSON[1] AND F. J. VEIHMEYER[2]

INTRODUCTION

Although irrigation has long been practiced in the growing of deciduous fruits in California, and in other places where rainfall during the growing season is scanty, there is record of comparatively little careful experimental work on the many phases of this important agricultural operation. Consequently, there have arisen many prejudices and dogmatic beliefs concerning the results obtained where irrigation is necessary for fruit growing. Many of these theories have been accepted as facts through continued repetition of the idea as first expressed. Growth, yields, winter hardiness of orchard trees, flavor and keeping qualities of fruit, desirability of nursery stock are, according to some of these beliefs, often adversely affected by irrigation.

Some of the early experimental work on the irrigation of fruit trees is unintelligible in the light of recent work at this station[(15)] [(17)] concerning soil-moisture and its use by plants. The terminology and the methods used by early workers on this problem lack uniformity. Furthermore, descriptions of methods are in many cases so brief as to make evaluation of the results practically impossible. The importance of certain soil-moisture constants and of their relation to one another is not effectively considered.

SOME PERTINENT FACTS CONCERNING SOIL MOISTURE

Certain facts concerning soil moisture which have been brought out within recent years make desirable a general discussion of them, which may lead to proper interpretation of the material presented in this paper. Furthermore, some of the terms used must be defined.

Efforts of the writers[(13)] [(18)] to maintain a soil-moisture percentage less than the field capacity, have met with failure in every case. Numerous attempts both with field plots and with soil in tanks, were made to maintain moisture contents less than the amounts of

---

[1] Associate Pomologist in the Experiment Station.

[2] Associate Irrigation Engineer in the Experiment Station.

water the soils will hold against gravity, but it was found impossible to bring about relatively low moisture contents throughout the soil mass. The idea that water applied at any point in the soil would be quickly and uniformly distributed, we believe, is the cause of serious objections to interpretations of much of the earlier work on the relation of soil moisture to plant growth.

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

Water, applied to the surface of a soil, will penetrate to a certain depth, depending upon the amount of water applied, the previous moisture content of the soil, and the other factors mentioned in the previous paragraph. The experience of the writers has been that after an irrigation, the soil throughout the area wetted will be raised to a uniform moisture content. Experiments have shown[2] however, that if a fine-textured soil overlies a coarser one, the zone immediately above the coarse soil will, for some time after rain or irrigation have a moisture content considerably higher than the same soil would hold if it were uniform throughout. In soils with unrestricted drainage and with no decided discontinuities in types or structure, downward movement of water practically ceases 24 to 48 hours after the water has disappeared from the surface. The moisture content of the soil in this condition may be called the field capacity and will be so designated in this paper. In other words, the moisture content of samples taken 24 to 48 hours after a rain or irrigation may be used to measure the field capacity of that soil.

Downward movement of moisture subsequent to the 24–48 hour period may take place at a slow rate and eventually might produce an increased moisture content at lower depths within, or even beyond, the wetted area. All tests made by the writers, however, indicated a uniform distribution of moisture throughout the wetted area of soil. 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.

The field capacity of the loam soils, but not of the fine sand, used in the present experiments agreed closely with the moisture equivalent, which accordingly, may logically be taken as an approximate measure of the field capacity or of the amount of water the soils would hold against gravity. The moisture equivalent, as determined in the laboratory, is defined as the "percentage of water retained by a soil when the moisture content is reduced by means of a constant centrifugal force (1000 times gravity) until brought into a state of capillary equilibrium with the applied force." In ascertaining the moisture equivalent, the sample of soil is prepared in a prescribed manner and subjected to a centrifugal force of 1000 times gravity for a period of 30 minutes' duration. The samples are then weighed, dried, and reweighed, and the moisture percentage on a dry weight basis is calculated. As the method is an arbitrary one, careful precautions must be taken to secure reproducible results. A description of the moisture equivalent method and of the exact procedure to follow may be found in two previous publications.[14] [18]

The moisture equivalent is used in the present studies as a relatively quick and convenient method of determining comparative moisture properties of soils. The exact procedure mentioned above yielded results that showed close agreement among successive samples in the same soil.

Soil moisture moves very slowly from areas of moist soil to areas of drier soil.[13] [16] Lack of knowledge of this fact has led to erroneous ideas concerning what constitutes "light" and "heavy" irrigations. For instance, a "light" irrigation was thought to moisten a given volume of soil to a less percentage than a heavy irrigation, the water being distributed uniformly by capillarity. As a matter of fact, a light irrigation, or the application of a small amount of water, simply wets a smaller volume of soil to its field capacity than a heavy irrigation, or application of a large amount of water. In field practice, this means a light irrigation wets the soil to a shallower depth than a heavy one.

The water in the soil is not all available to plants. A certain portion of moisture is held by the soil with sufficient force to prevent the roots of plants from absorbing it rapidly enough to prevent wilting. Although various stages or degrees of wilting of plants might be recognized, only one, "permanent wilting," represents a fairly definite condition, which has consequently received the most study. Permanent wilting is defined[6] as that stage at which the leaves first undergo a permanent reduction of their moisture content because of deficient soil-moisture supply. A permanent reduction is here taken to mean a deficiency of leaf-water content from which the leaves do not recover, in an approximately saturated atmosphere, without the addition of water to the soil.

The wilting of plants and trees which often occurs in late afternoon during the hot weather and from which they recover during the night, is different from the permanently wilted condition defined above. When these plants do not recover turgidity over night and are still in the wilted condition early in the morning, they may be considered for practical purposes to be permanently wilted. If plants do not remain in this state too long, addition of water to the soil by rain or irrigation will revive them.

It was formerly thought[6] that the percentage of moisture at which plants permanently wilted bore a constant relation to the moisture equivalent, and that this relationship was the same for all soils and all plants. Briggs and Shantz, concluded, from rather extensive experiments, that the percentage of moisure at permanent wilting, or their "wilting coefficient," could be obtained for all soils by dividing the moisture equivalent by the factor 1.84. While the writers have observed a remarkable constancy of the residual moisture content for a given soil when permanent wilting is attained, a common factor to evaluate the amount of water which remains in all soils at permanent wilting cannot be used. The amount of water available for plant growth cannot be obtained from the moisture equivalent alone.[17] It must be determined for each soil under consideration, because plants are apparently able to reduce the moisture content of different soils to different degrees of dryness (relative to the moisture equivalent) before they become permanently wilted. In this paper the term "dry soil" means soil which contains less moisture, while "moist soil" or "wet soil" contains more moisture, than the permanent wilting percentage. The moisture present in the soil at permanent wilting or the "permanent wilting percentage" calculated on the dry weight basis, is a rather narrow range of soil moisture percentages at which plants wilt and do not revive unless additional water is added.

Previous work at this station has indicated[13] [15] that the soil moisture above the permanent wilting percentage is readily available for use by plants. Of course, plants sometimes do use water below the permanent wilting percentage, but the amount of water that the plants can secure from the soil below this percentage is not sufficient to permit them to remain turgid. The fact that they can obtain water from the soil below the permanent wilting percentage, but not rapidly enough to maintain turgor, indicates that the soil moisture is not so readily available below this percentage as above it. This paper uses the term "readily available" moisture for these reasons. Apparently, with the plants and soils studied, no one moisture content could be considered as "optimum" for plant growth. The plants did not show any measurable departures from normal growth until the soil-moisture content was reduced to about the permanent wilting percentage.

EXPERIMENTS WITH MUIR PEACHES

The Muir peach orchard from which the data presented in the first part of this paper were secured, was planted in February, 1921. It is situated in the slightly rolling country four miles east of the town of Delhi, in Merced County. The planting consisted of 27 rows with 27 trees in each row, the rows being 24 feet apart and the trees 24 feet apart in the rows. The trees planted were the Muir variety budded on Salwey peach seedlings. They were, when received from the nursery, approximately three to four feet tall, uniform, free from disease, and apparently true to name.

The Muir variety was chosen because it is one of the leading kinds used for drying. The tree, although smaller than other varieties, is, furthermore, known to be a regular and prolific bearer. A peach used for drying was chosen because, it was thought, that data could be secured on the behavior of growth and ripening of fruit on the tree, and on the drying characteristics, about which there seemed to be much confusion.

The soil in which the orchard was planted was classified as Oakley fine sand. A layer of compacted subsoil or hardpan was present under most of the orchard at a depth of from four to six feet. The thickness of this compacted layer varied, but in general was great enough to interfere with the downward movement of water and the growth of peach roots. The sandy nature of the soil had permitted a wind-blown ridge to form diagonally across the area intended for the orchard. Considerable grading was necessary in this part of the orchard in order to permit of irrigation. The soil outwardly appeared uniform, but the moisture equivalents of the top three feet of soil were found to vary from 2.62 per cent to 6.16 per cent. The presence of the compacted layer in the second three feet caused the moisture equivalents in this zone to vary from 4.08 per cent to 19.09 per cent. Enough moisture equivalents in this depth were not made to assist in interpreting the experimental results.

The climate of the region is typical of a large part of the San Joaquin Valley.[3] During the summer months, the maximum temperatures of over 100° F occurred frequently during June, July, August,

[3] Complete meterological records from Delhi are available at the Branch of the College of Agriculture, Davis; or the United States Weather Bureau records for Merced may be consulted.

and September. Temperatures as high as 110° F were not infrequent. The thermometer frequently indicated 90° F or higher as early as 9 a.m., and the maximum was ordinarily reached by 3 or 4 p.m. These extreme temperatures were often ameliorated by a northwest breeze during the afternoon. The annual rainfall of approximately 12 inches

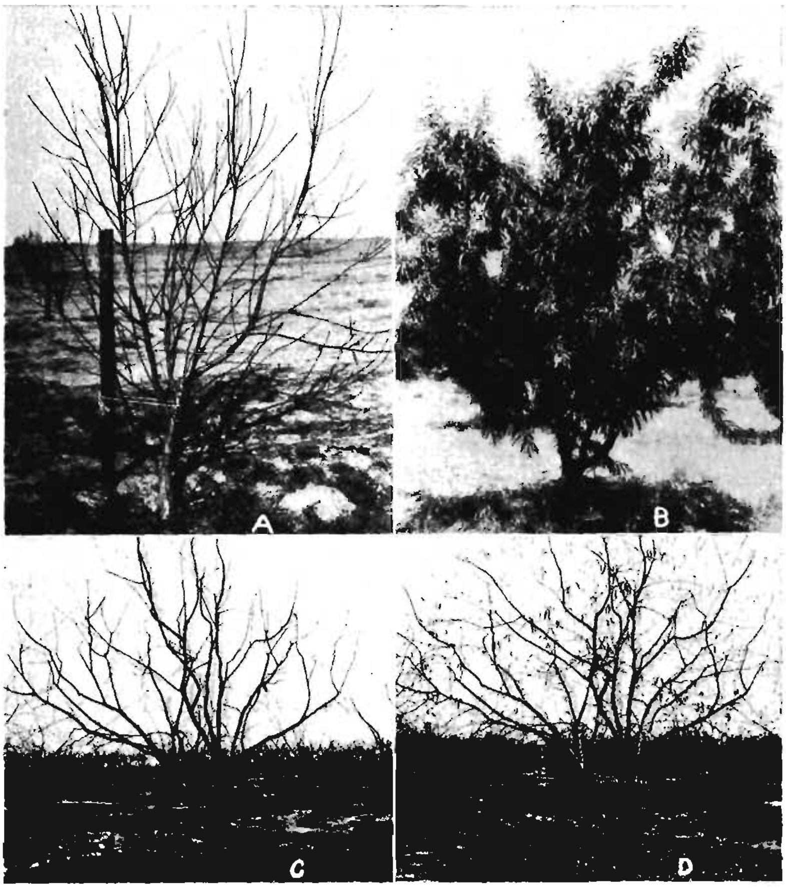

Fig. 1.—A typical Muir peach tree in the Delhi orchard; at *A*, two years of age, *B*, in the early part of its sixth year, *C*, at the end of its seventh growing season, *D*, at the end of the experiment.

occurred principally during December, January, and February Minimum temperatures during the winter months frequently reached 25° F. The trees blossomed about the middle of March, and the fruit ripened about the middle of August.

The cultural treatment given for the first two years was planned so as to make the trees grow as vigorously and uniformly as possible.

The cultivation consisted in spring plowing or discing, followed by as frequent harrowings as necessary to keep down weed growth. The trees were watered at first from tanks, and later by small irrigation furrows on each side of the row. For the first two years, all trees received the same cultural treatment. After the second year, the irrigation treatment was varied according to the plan presented later in this paper. Of necessity, the cultivation of the different plots varied somewhat, but at no time were they cultivated oftener than was necessary to keep down weeds. During the first two years, strips of rye were planted between the rows to keep the sand from blowing. For several years during the early life of the orchard, winter cover crops were used, but toward the end of the experiment this practice was discontinued.

The orchard was sprayed regularly for the control of the ordinary diseases and insects common in the district. The treatment consisted of a fall application of Bordeaux, made about December 1, and a spring application of either Bordeaux or lime-sulfur, just before the buds opened. These sprays served to hold the diseases and insects in check and were generally satisfactory except in 1925, when the lime-sulfur caused a severe injury to the buds.

The trees were pruned as uniformly as possible, to prevent errors which might be attributed to this factor. Figure 1 (a, b, c, d) shows the growth made by a typical tree and gives a general idea of the type of pruning employed. Thinning of the fruit was done under the careful supervision of the orchard foreman.

Toward the end of the experiment, several trees appeared stunted and produced very little new length growth. Investigation of the upper part of the root system showed in every case that these stunted trees were more or less seriously infected with crown gall (*Pseudomonas tumefaciens*). Such trees. if in the experimental rows, were discarded, and their records not used in the data presented in this paper.

Plan of the Experiments.—As was previously mentioned, the orchard consisted of 27 rows of 27 trees each (figure 2) with the rows 24 feet apart, and the trees 24 feet apart in the rows. Because of the topography of the land, and the necessity of placing the underground pipe lines for irrigation along the highest elevations, the orchard was divided into two irregularly shaped parts. This arrangement precluded the possibility of having all experimental plots of the same size.

The circumference of the tree trunks was measured just above the swelling at the bud union, or about 5 to 6 inches above the surface of the ground. From these measurements the areas of the cross-sections of the trunks were obtained. These data for the first two growing seasons determined the selection and grouping of the various experimental plots.

The experimental plots were laid out, insofar as possible, in blocks of 30 trees. The plots consisted of 3 rows of 10 trees each, wherever the topography of the land and the position of the pipe line made this

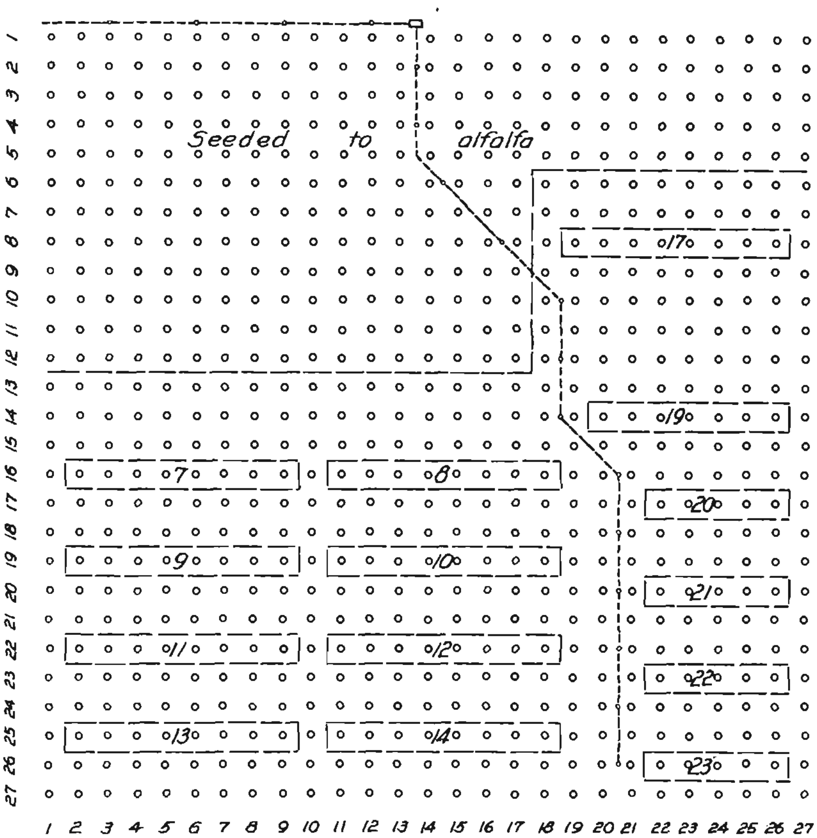

Fig. 2.—Muir peach orchard at Delhi, showing location of plots and irrigation pipe line. The trees from which measurements were taken are inclosed in the broken lines.

arrangement possible. In the southeast corner of the orchard the plots consisted of 3 rows of 7 trees each. Only the middle row was measured. The two outer rows and the two end trees of the center row were guards, but all received the same irrigation treatment as the center row. Thus each plot of 30 trees contained only 8 guarded on all four sides, from which the experimental data were secured. The smaller plots contained a smaller number of experimental trees, surrounded by guards in a similar manner.

The experiment, as originally planned, called for 23 plots. Eight irrigation treatments were proposed, allowing 3 plots to all treatments except one which included only 2 plots.

In general, the plan was laid out to follow as closely as possible the recommendations of Batchelor and Reed,[4] who made a careful study of variation in fruit trees. As yield records were not available, the circumstances of the trunks were used as a basis for the grouping of treatments. The original plan was to group plots of high, low, and medium variabilty, as measured by trunk circumference, but in a few cases, certain difficulties in applying irrigation water necessitated rearrangement of the groupings. Thus, the plots receiving the greatest amounts of water or the most frequent applications were placed closest to the pipe line to avoid inadvertently wetting other plots. The coefficients of variability, calculated for the orchard as a whole and for the individual plots, are given in table 1.

TABLE 1

COEFFICIENTS OF VARIABILITY OF PEACH TREES BASED ON CROSS-SECTION AREA OF TRUNKS AT DELHI, CALIFORNIA, DECEMBER, 1922, BEFORE DIFFERENTIAL IRRIGATION TREATMENT WAS STARTED

Plot	Per cent coefficient of variability	Plot	Per cent coefficient of variability
1	11.2±1.92	13	19.0±3.32
2	15.2±2 63	14	8.8±1.55
3	17.2±3.16	15	11.3±1.93
4	23.7±4.49	16	10.0±1.70
5	21.5±4 02	17	10.6±1.82
6	10.7±1.82	18	8.6±1.46
7	24.0±4.28	19	7.2±1.29
8	16.2±2.80	20	11.1±2.68
9	19.0±3.52	21	9 2±1.95
10	10.7±1.95	22	9.1±1.92
11	7.2±1.26	23	4 9±1.03
12	6.7±1.16	Entire orchard	10.8±0.196

Outline of Irrigation Treatments.—The irrigation treatments of all plots followed the general plan of wetting the entire soil mass in the root zone to a depth of 6 feet, or to the underlying compacted layer, to its field capacity at each irrigation. This method was thought to be more desirable than applying definite amounts of water at predetermined intervals, a method which might result in wetting the soil in the different plots to variable depths. The experiments were designed to obtain information on the relative effects of different soil-moisture conditions, rather than to determine the water requirements of peach trees. Soil samples were taken in three-foot increments with a soil tube at frequent intervals. The plan of irrigation treatments for the different plots is described below.

Treatment A: Plots included in this treatment were irrigated frequently, and the soil moisture, though fluctuating, did not go below the permanent wilting percentage. This treatment contained the high moisture percentage plots.

Treatment B: The plots in this treatment were irrigated in a manner similar to the general practice in the community. Water was applied at rather long intervals, the moisture of the soil above the compacted layer was reduced, often for rather prolonged periods, to the permanent wilting percentage or below.

Treatment C: This treatment served as a check for the others. The plots, irrigated at infrequent intervals, received much less water than would be considered practical commercially. The trees remained in a permanently wilted condition for long periods during the growing season. The severity of this treatment was reflected in the size of both trees and crops.

Treatment D: Plots in this treatment were irrigated each year in the manner described for Treatment *A*, until the fruit began to turn slightly yellow. The plots were thus supplied with readily available moisture during approximately the first half of the growing season. After harvest, the plots received either no more water, or one irrigation when the trees seemed in danger of permanent injury if water were withheld longer.

Treatment E: This treatment was essentially the same as treatment *C* until the crop was harvested. After picking the fruit, the intention was to keep this plot supplied with available moisture. Because of the low moisture-holding capacity of the soil, it was found, after the experiments were started, that plots *C* and *G* needed irrigation after the harvest, in order to prevent injury to the trees. Consequently, the *E* plots were treated in essentially the same way as the *C* and *G* plots.

Treatment F: This treatment was the same as *A* except that the plots were also irrigated once during the dormant season.

Treatment G: These plots were treated the same as those in *C*, with the addition of an irrigation during the dormant season.

Treatment H: Plots in this treatment usually received only one irrigation before harvest, and were allowed to deplete the soil moisture below the permanent wilting percentage several weeks before the fruit began to ripen. Water was added to the soil a few days prior to picking the fruit.

Changes in Treatment of Certain Plots.—Before the end of the 1924 growing season, it became increasingly evident that certain plots must be discarded and not included in the experiment as originally planned. Most of these plots were making a very poor growth, and showed an increasingly large amount of variability among themselves. All of the plots thus affected were situated in that section of the orchard from which the top soil had been removed during the grading operations; this fact was probably the most important reason for the inferior growth of the trees.

Experimental treatment of plots 1, 2, 3, 4, 5, 6, 15, 16, and 18 was discontinued in May, 1925. The grouping of plots from 1925 to the end of the experiment is given in table 2.

TABLE 2

ARRANGEMENT OF EXPERIMENTAL PLOTS AT DELHI, 1925 TO 1928 INCLUSIVE

Treatment	Plots	Treatment	Plots
A	14, 21	E	7, 19
B	12, 20	F	8, 13
C	10, 23	G	9
D	11, 22	H	17

Treatment of Plots not Included in the Experiment.—In February, 1926 (fig. 3) the plots excluded from the original experiment were seeded to alfalfa, which was thereafter maintained as a permanent cover crop (fig. 4). The benefits accruing from this use of alfalfa on this sandy soil appeared before the end of the first season. The foliage of the trees, previously yellowish-green in color, was changed to a dark green, and the leaves produced late in the season were much larger than those which appeared earlier. Beginning with the season of 1927 the yields from the trees in alfalfa increased. All who were familiar with the orchard conceded that the presence of alfalfa among the poorest trees had changed them from a liability to an asset.

Experimental Results.—The data presented in this bulletin were secured from annual measurements of the tree trunks; from yields, on both the fresh and the dry fruit basis; from sugar and moisture content of the fruit; from soil-moisture determinations of the various plots, before and after each irrigation; and from the measured quantities of water applied.

Table 3 gives the amounts of water applied to the different plots. The record of the amounts applied during the winter irrigation are omitted, because this additional water had no apparent effect on either the yield or growth of the trees. Furthermore, the rainfall was sufficient to wet the soil above the hardpan to its field capacity. During the 1926 season, irrigations on several plots were inadvertently omitted after the crop was picked. The average amounts of water applied during the dormant season to those plots receiving winter irrigation were between 4 and 5 acre-inches per acre in addition to the amounts given in table 3. The number of times each plot was

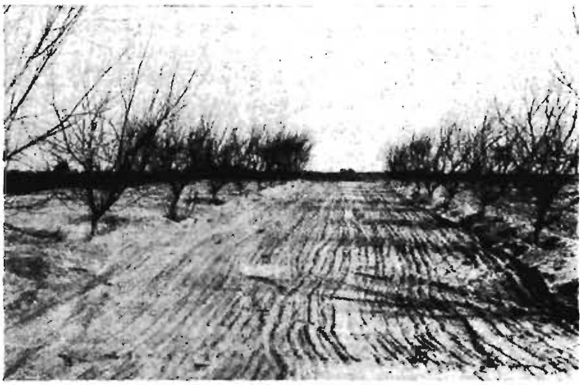

Fig. 3.—Method of preparing land in Muir peach orchard before seeding with alfalfa.

Fig. 4.—Alfalfa as a permanent cover crop in a portion of the Muir peach orchard at Delhi. Photograph taken in late fall.

irrigated is given in table 4. The average amounts of water applied to the plots in similar treatments are given in table 5.

Treatments *A* and *F* received the greatest quantities of water, an average of 25.3 acre-inches per acre during each of the last five years; treatment *D* received the next largest amount, an average annual application of 19.8 acre-inches per acre; and treatment *B* received less water than D, or 13.4 acre-inches per acre; and treatment *C, G,* and *E* received only approximately one-half the amount applied on *A* and *F*, or 11.1 acre-inches per acre each year. The reasons for grouping certain treatments together will be discussed later. The approximate dates of application of irrigation water for two typical seasons are indicated in figures 5 and 6. In treatments *A* and *F* the moisture contents of the soil were kept above the permanent wilting percentage.[4] Soil-moisture

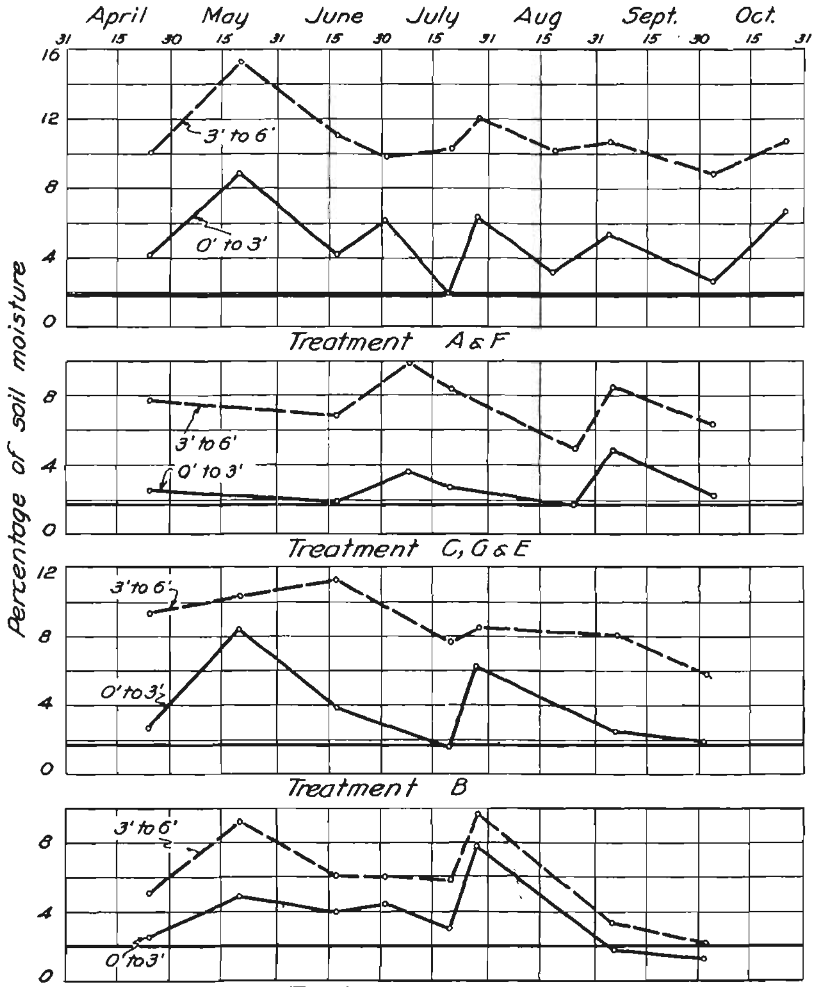

Fig. 5.—Moisture contents of soil in orchard treatments at Delhi, 1924. The permanent wilting percentage of the 0 to 3-foot depth is indicated by the heavy horizontal line.

---

[4] As previously mentioned, the presence of a compacted layer in the 3 to 6-foot depth, precluded the possibility of obtaining uniform soil in the samples. Consequently, many more moisture equivalent determinations would have been necessary, in order to interpret the soil-moisture conditions, than it was possible

conditions for 1924 and 1927, years typical of the entire experiment, are also shown in figures 5 and 6. In 1927, when the trees were older, more frequent application of irrigation water was necessary than in 1924, when they were younger and smaller. The curves in 1927 indicate that available soil moisture in the sandy soil at Delhi was generally exhausted in from two to three weeks, when another irrigation was needed.

The flatness of the curves for the infrequently irrigated treatments (*C*, *G*, and *E*) indicates that when the soil moisture was reduced to approximately the permanent wilting percentage, very little additional water was obtained by the trees. As this variety of peach usually ripens, during the early part of August, obviously the fruit as well as the trees from these plots was subjected to extremely severe conditions.

In accordance with the plan of irrigation in treatment *B*, the soil moisture was reduced to the permanent wilting percentage several times during the season. The curves for treatment *B* show that this condition was approximated. In treatment *D*, the plots were irrigated frequently until about the time the fruit began to turn color, and thereafter they received no water or only one irrigation. Consequently the trees in these plots were dry for long periods during the latter part of the growing season. The figures show this condition actually prevailed.

TABLE 3

AMOUNTS OF WATER IN ACRE-INCHES TO THE ACRE APPLIED TO PLOTS IN DELHI PEACH ORCHARD*

Plot and treatment	1923	1924	1925	1926	1927	1928†
8, F	5.2	23.6	23.8	11.3	34.2	17.8
9, G	3.2	6.5	7.4	11.9	8.4	13.1
10, C	4.0	8.9	7.5	6.9	6.0	9.7
11, D	3.0	18.7	16.8	19.9	20.3	19.8
12, B	4.6	9.6	10.7	12.1	15.9	13.0
13, F	9.9	26.1	27.8	16.5	41.3	26.6
14, A	8.9	26.2	26.4	14.7	32.3	19.4
17, H	3.4	23.1	16.8	17.5	19.9	12.5
9, E	2.6	8.4	12.3	13.4	15.6	11.1
20, B	2.6	14.7	16.5	18.6	27.9	22.7
21, A	7.0	30.7	33.2	20.1	20.1	34.3
22, D	2.6	12.4	23.2	16.9	25.3	29.1
23, C	Max.‡	15.6	17.9	12.8	10.9	17.6

* Does not include water applied during the dormant season.
† Record of irrigations for 1928 extends from beginning of season to October only.
‡ Portion of plot accidentally flooded by broken pipe line.

o secure with the available facilities. The permanent wilting percentage, therefore, in this depth was not accurately determined. However, the curves showing he moisture conditions in both the 0 to 3-foot and the 3 to 6-foot depths are practically parallel, and it is assumed that moisture when not readily available in he upper 3 feet, was also not readily available in the lower 3 feet.

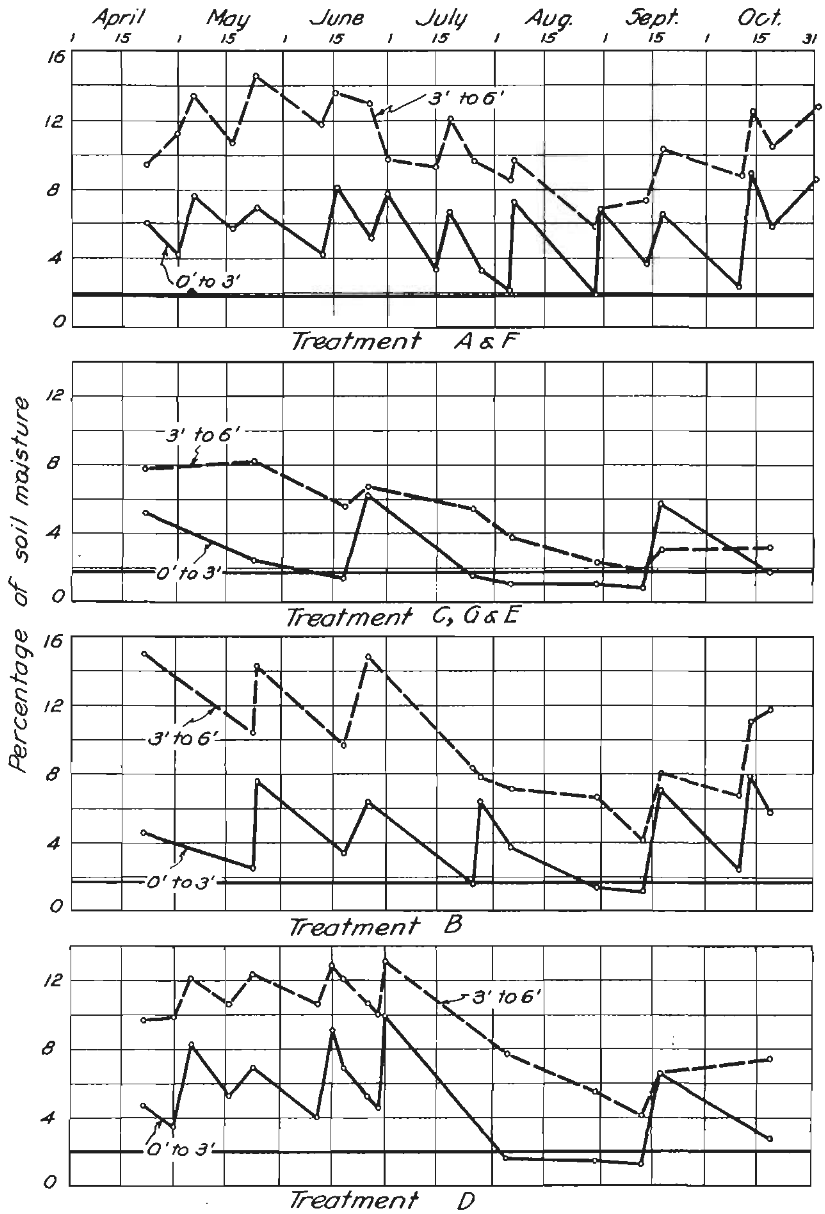

Fig. 6.—Moisture contents of soil in orchard treatments at Delhi, 1927. The permanent wilting percentage of the 0 to 3-foot depth is indicated by the heavy horizontal line.

TABLE 4

NUMBER OF IRRIGATIONS RECEIVED BY EACH PLOT OF PEACH TREES AT DELHI, DURING THE GROWING SEASON

Plot and treatment	1923	1924	1925	1926	1927	1928*
8, F	4	6	7	4	10	6
9, G	2	3	3	3	2	3
10, C	2	2	2	3	2	3
11, D	2	3	4	4	5	5
12, B	2	2	3	4	5	4
13, F	3	6	7	5	10	6
14, A	3	5	6	5	10	6
17, H	3	5	4	5	6	4
19, E	2	2	3	3	4	3
20, B	2	3	3	4	5	4
21, A	3	6	6	5	10	6
22, D	2	2	4	4	5	5
23, C	Max.†	3	3	3	2	3

* Record of irrigations for 1928 extends from beginning of season to October 1 only.
† Portion of plot accidentally flooded by broken pipe line.

TABLE 5

AVERAGE AMOUNTS OF WATER APPLIED TO DELHI PEACH ORCHARD, EXPRESSED IN ACRE-INCHES TO THE ACRE; PLOTS GROUPED ACCORDING TO SIMILAR TREATMENTS; AMOUNTS DURING GROWING SEASON

Treatments	Plots	1923	1924	1925	1926	1927	1928*
A and F	8, 13, 14, 21	7.8	26.6	27.8	15.7	31.9	24.5
B	12, 20	3.6	12.2	13.6	11.6	21.9	17.9
D	11, 22	2.8	15.6	20.0	16.3	22.8	24.5
C, G, and E	9, 10, 19, 23	3.3	9.9	11.3	11.3	10.2	12.9

* Record of irrigation for 1928 extends from beginning of season to October 1.

Effect of Winter Irrigation on Growth and Yield.—The effect of winter irrigation on growth[5] and yield of peach trees at Delhi was negligible. This result was obtained with both the frequently and the infrequently irrigated plots. The growth of the trees in treatment *A* (average of two plots), which were supplied with readily available moisture throughout the season, was parallel to the average of two plots receiving treatment *F*, which were irrigated similarly to *A*, with an additional irrigation, in January or February of each year, of approximately 4 acre-inches per acre. The results are shown graphically in figure 7, which also shows the average yields in pounds of

[5] The cross-section area of the tree trunks was used as a measure of the annual growth increment of the trees. The cross-section area, although perhaps not an exact measure of the growth of bearing trees, was the only practical measurement that could be employed with the numbers of trees used in these experiments. It may, however, reasonably be used as a relative measure of the growth of the trees in the various treatments.

fresh fruit. Clearly, the addition of a winter irrigation did not affect either the growth or the yields in these plots. In the results which follow, therefore, plots receiving treatment *A* are grouped with those under *F*.

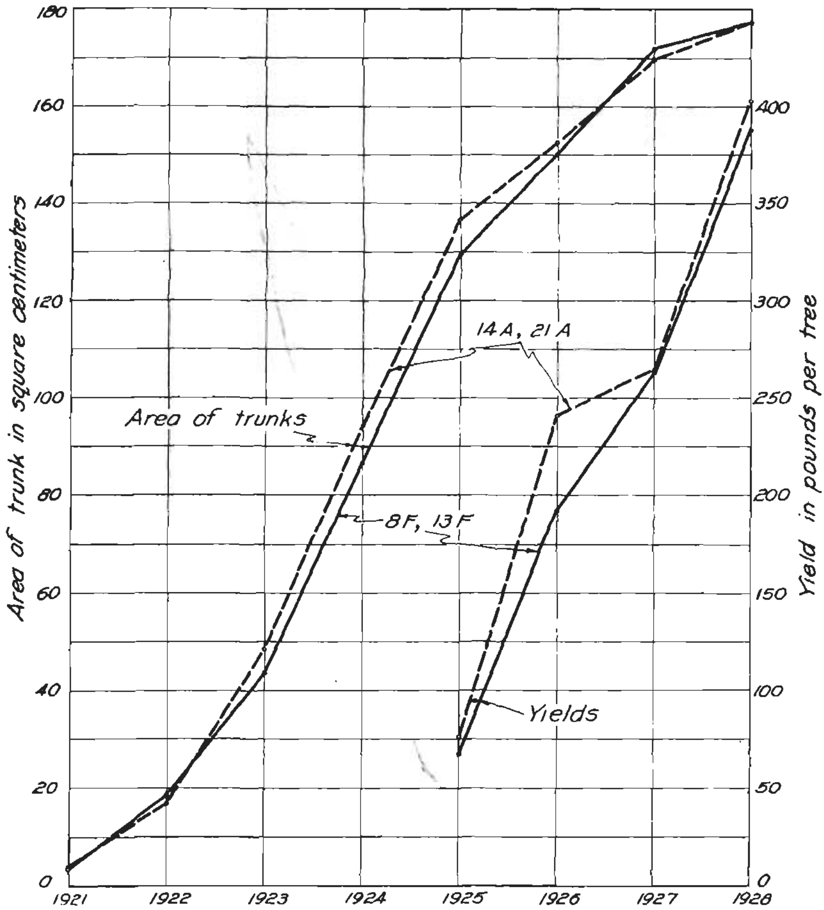

Fig. 7.—The effect of winter irrigation on growth and yield of Muir peach trees. All plots were given similar irrigation treatment during the growing season, and 8 F, and 13 F, received an additional irrigation during the dormant season.

In a similar way, the results are given for the average growth of the trees and the yields for treatments *C* and *G*, as shown in figure 8. The irrigation treatment of plot 19 *E*, as essentially similar to the treatments *C* and *G*, is grouped with the latter in the calculations that follow, except in table 6 which gives the complete record of cross-section areas of trunks of the trees in each plot.

Growth and Yield of Muir Peach Trees.—Table 6 gives the average cross-section areas of the tree trunks obtained from the circumference measurements by calculation and used as a measure of the growth of the trees. Circumferences were measured at the end of each growing

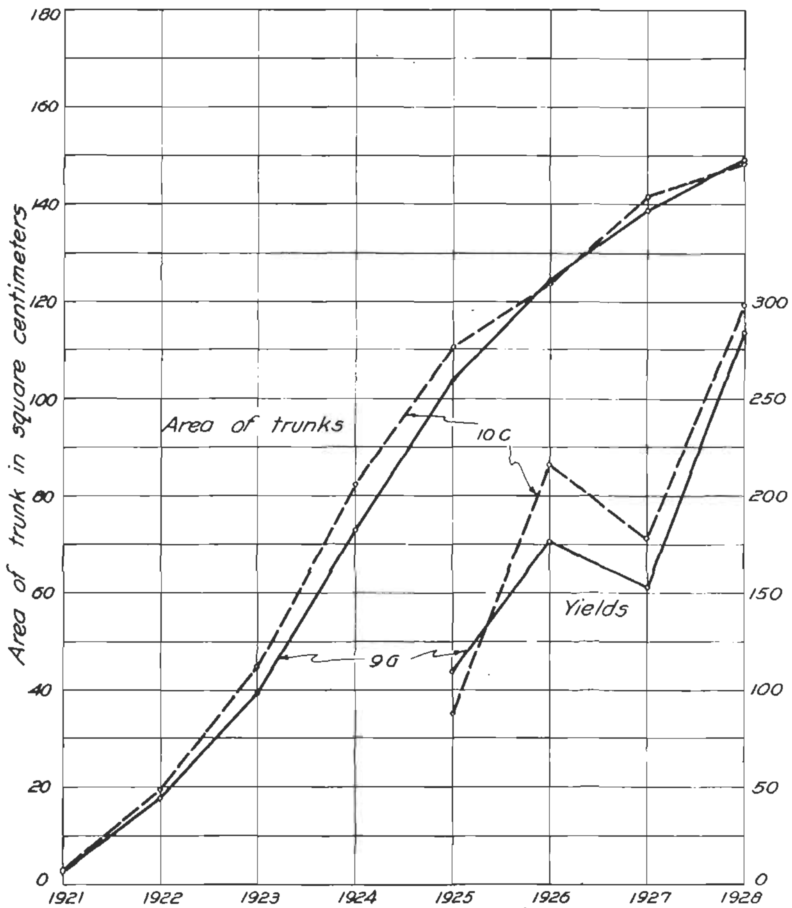

Fig. 8.—The effect of winter irrigation on growth and yield of Muir peach trees. Both plots were given similar irrigation treatment during the growing season, and plot 9 G, was given an additional irrigation during the dormant season.

season. It is clear that the trees in plots kept at a fairly high moisture content during the growing season generally made the largest and most consistent gains in size. This result is more plainly shown when the plots are combined according to similar treatments, as will be explained later. The principal exception is one of the check plots,

TABLE 6

CROSS-SECTION AREAS OF TRUNKS OF PEACH TREES IN SQUARE CENTIMETERS, DELHI

Plot and treatment	1921	1922	1923	1924	1925	1926	1927	1928	Gain, 1923 to 1928, inclusive
8, F	2.5±.16	13.6±1.15	32.4±5.96	74 8±2.70	116.5±4.08	136.1±5.06	158.2±6.47	165.7±6.41	152.1±6.51
9, G	2 9±.30	17.2±1.75	39.4±2 90	72 9±3 91	103.7±3.98	124.1±4.02	138.8±4.59	149.1±4.76	131.9±5.07
10, C	3.0±.27	19 6±1.48	45.0±1.80	82.2±2 36	110.4±3.44	123 6±3.64	141.5±4.92	148.3±5.26	128.7±5 46
11, D	4.6±.16	18.3± .59	46.3±1.08	68.1±1.55	101 1±1.08	132.5±2.33	144.6±1.15	155.5±1.55	137.2±1.66
12, B	4.3± 34	17.7± .61	43.1±1 48	74.5±1 55	105.5±1.48	123.1±2.15	138.3±2.20	149.0±2.04	131.3±2.13
13, F	4 4±.43	23.6±2.16	54.8±4.32	98 9±5.46	142.8±6.34	164 1±6.95	184.9±7.60	188.3±7.21	164.7±7.52
14, A	3.3±.30	17.4± .79	47.8±1.89	90.5±2 56	132.6±4.25	146.6±3.61	168.6±4.20	173.9±4.18	156.5±4.25
17, H	3.1± 28	14.2± .92	27 0±1 96	48 3±3 76	77.2±5.67	86.9±6.48	105.6±7 28	113.9±7.62	99.7±7.67
19, E	2.7±.19	16.1± .69	38.9±1.59	61.3±1.85	82.3±4.09	90.2±4.45	106 9±6.09	115.4±5.94	99.3±5.98
20, B	2 9±.13	12.7± .51	44.0±1.21	72.2±2.16	92.1±3.37	114 2±2.90	138.5±4.59	150.2±4.38	137.5±4.41
21, A	4 0±.46	16.6±1.23	48 9±2.97	97.6±3.98	140 7±10.59	158.3±12.61	170.5±10.59	181.3±9.44	164.7±9.52
22, D	3.3±.16	16.4± .96	41.7±1.08	74.7±2 63	99 7±3 06	121.5±5 19	146.5±6.41	159.8±8.29	143.4±8.34
23, C	5.5± 36	20 9± .71	51.0±2.04	87.2±2.09	128 1±3.51	144.7±4.32	156.1±5.19	162.9±4.92	142 0±4.97

which made a very rapid growth during 1925 because of several fortuitous applications of water from a broken irrigation pipe line.

The average yields in terms of pounds of fresh fruit are given in table 7. The lowest yields were consistently found in plots allowed to suffer for lack of available moisture during parts of the growing

TABLE 7

YIELDS OF PEACHES IN POUNDS PER TREE, DELHI*

Plot and treatment	1925	1926	1927	1928
8, F	56.5± 8.2	186.3±11.1	239.9±17.6	355.4±11.0
9, G	109.6± 9.4	175.3±12.8	152.9±11.5	283.7±13.0
10, C	88.0±55.2	215.5±10.8	177.7±21.6	297.4±12.7
11, D	55.3± 7.8	192.6±11.6	232.6± 5.4	361.2± 8.6
12, B	60.5± 8.6	191.3± 6.4	211.6±12.2	334.3± 7.6
13, F	77.6±10.1	198.0± 8.4	284.8±15.2	418.0±12.2
14, A	75.9± 8.6	246.0±12.5	284.2±10.1	396.4±13.3
17, H	50.9± 8.4	106.4±12.3	104.9± 7.6	240.2±20.9
19, E	44.6± 5.5	106.0±10.4	146.9± 4.5	285.9±13.3
20, B	115.9± 3.2	182.5±14.8	238.3±17.1	406.5±15.5
21, A	74.8±17.1	235.0±27.4	243.4±12.4	408.5± 9.8
22, D	32.7± 4.2	209.2±14.2	144.8± 8.6	382.1±20.4
23, C	78.7±15.7	252.0±21.0	194.1± 6.3	331.2± 8.8

* Trees in 1923 too young to bear full crop; in 1924 late frost caused irregular set of fruit.

TABLE 8

CROSS-SECTION AREAS, IN SQUARE CENTIMETERS, OF TRUNKS OF PEACH TREES, DELHI, GROUPED ACCORDING TO SIMILAR IRRIGATION TREATMENTS

Year	Treatments A, F, 4 plots	Treatment B, 2 plots	Treatment D, 2 plots	Treatments C, G, E, 4 plots
1921	3.56± .19	3.58± .28	3.97± .16	3.53± .23
1922	17.81± .87	15.18± .66	17.32± .53	18.46± .74
1923	45.98±1.81	43.54±1.03	44.00± .85	43.58±1.42
1924	90.45±2.27	73.37±1.23	71.40±1.48	75.90±2.04
1925	133.15±3.05	98.80±1.99	100.40±1.27	106.12±3.04
1926	151.27±4.12	118.65±1.89	127.00±2.16	120.65±3.44
1927	170.55±3.51	138.40±2.00	145.55±2.36	135.83±3.51
1928	177.30±3.30	149.30±1.90	157.10±3.11	143.93±3.50
Gain 1923 to 1928, inclusive	159.49±3.41	134.14±2.01	139.78±3.15	125.47±3.57

season. Likewise, during 1927, the declines in yield in some of the plots, may have been due to the exceptionally long period of dry soil conditions which prevailed there in 1926.

The average cross-section areas of the trunks of the trees, arranged according to similar irrigation treatments, are given in table 8.

The growth of the trees in the various treatments, as shown by the cross-section of the tree trunks throughout the experiment, is given in figure 9. The data in table 8 indicate no significant differences in growth during the first two years, or during the period before differential treatment, which was started in the spring of 1923. The first differences were noticed at the end of the 1924 growing

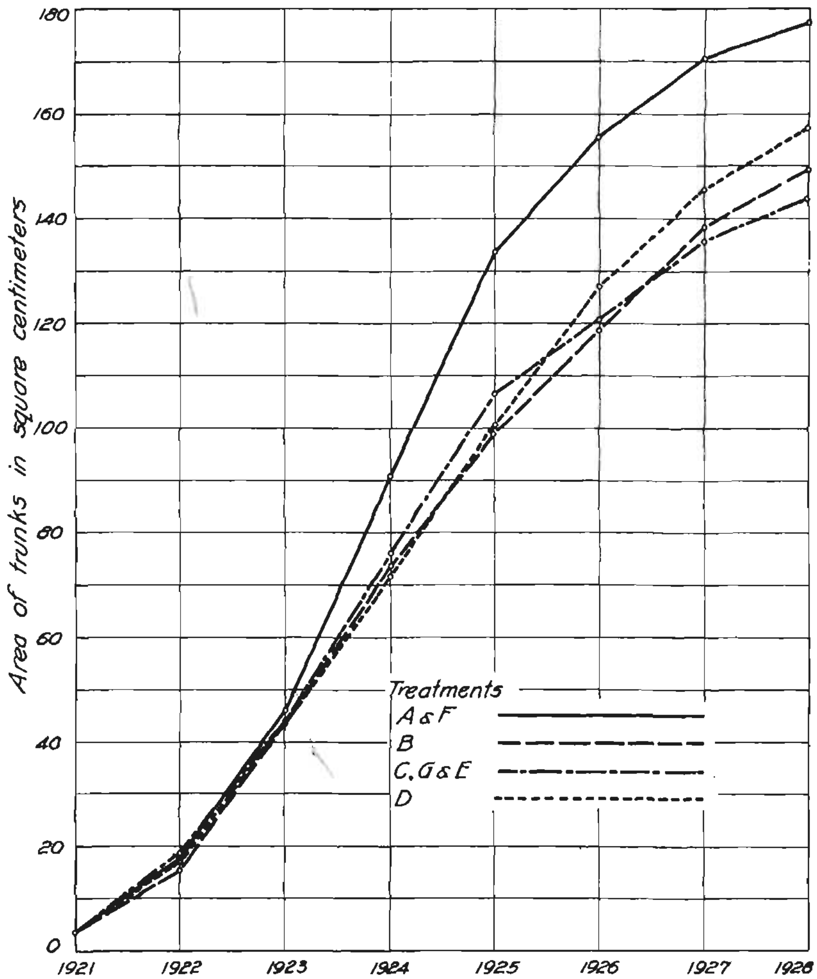

Fig. 9.—Cross-section areas of trunks of Muir peach trees in the four different irrigation treatments.

season. The trees in the plots in treatments *A* and *F* outgrew the trees in all other treatments and continued in this position of leadership throughout the experiment. The growth of trees in treatments *B* and *D* continued approximately equal until the end of the 1925 season. During the next three years treatment *D* tended to increase in size more rapidly than treatment *B*. Treated statistically, however, the difference in growth between treatments *D* and *B* was not great enough even at the end of the experiment to be considered significant, the odds being approximately only two to one.

The average size of the trees in the combined *A* and *F* plots is obviously larger than that in the other plots. The odds that *A* and *F* are larger than *B* are approximately 1350 to 1; that *A* and *F* are larger than *D*, approximately 35 to 1; that *A* and *F* are larger than *C*, *G*, and *E*, approximately 1360 to 1. The average size of trees in treatment *D* is greater than that in treatment *C*, *G*, and *E*, by odds of 9 to 2, and greater than that in treatment *B* by odds of approximately 2 to 1. The odds that *D* is larger than *B* and *C*, *G*, and *E* are thus clearly too small to indicate that the differences are significant. The odds that *B* is actually larger than *C*, *G*, and *E* are not great enough to be considered significant.

The average yields of all trees in the experimental plots are given in table 9.

TABLE 9

YIELDS OF PEACHES IN POUNDS PER TREE, DELHI, GROUPED ACCORDING TO IRRIGATION TREATMENTS

Year	Treatments A, F, 4 plots	Treatment B, 2 plots	Treatment D, 2 plots	Treatments C, G, E, 4 plots
1925	71 2±4.7	88.2±8.0	44.0±5.3	80.2± 6.2
1926	216.3±7.0	186.9±6.1	200.9±8.7	187.2±10.3
1927	263.1±5.3	224 9±9.6	194.2±9.5	167.9± 6.3
1928	394.6±6.7	370.4±9.9	371.7±9.2	299.6± 6.4

The average yields for similar treatments for the years 1925 to 1928 inclusive are graphically shown in figure 10. Because the yields in 1924 were seriously reduced by a heavy frost shortly after the young fruit had set, these data are not included. During the 1925 season, the lime-sulfur spray used for the control of peach leaf curl caused severe burning of the buds and early foliage, which resulted in a very light and irregular crop. This type of injury was common throughout the San Joaquin valley during that season. During the succeeding years Bordeaux, as a fungicide, was substituted for lime-sulfur, and no further spray injury was noted. Probably because of the light crop in 1925, all trees produced a satisfactory set in 1926. No significant differences in yield were noticeable that year. After the harvest of 1926, the entire orchard was allowed to remain dry; this procedure probably accounted for the fact that some treatments showed a decrease in yield from that of the previous season. In 1927 and in 1928, all plots were irrigated according to schedule, with the result that differences due to irrigation were apparent.

The average yield of the combined treatments *C, G,* and *E* was significantly smaller than *A* and *F*, by very great odds, and smaller than *B* and *D* by odds of 230 to 1 and 528 to 1 respectively. The odds that

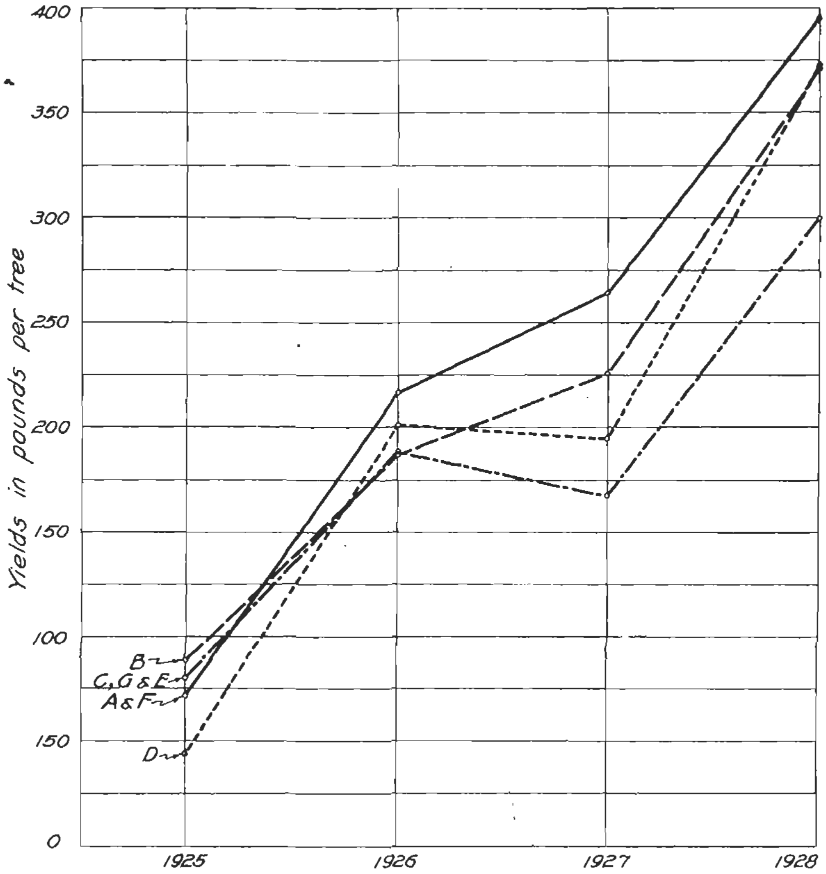

Fig. 10.—Yields of Muir peach trees in the four different irrigation treatments.

the yields of *B* and of *D* treatments are smaller than the average yield of *A* and *F*, are not great enough to indicate significance.

Rate of Growth of Muir Peaches in Relation to Soil Moisture.—Measurements of fruit were made at weekly intervals on 10 peaches on each of 6 trees in each plot measured, beginning with the first week in May and continuing until the fruit was picked (fig. 11). The greatest horizontal circumference of each of the fruits was measured, and the volume obtained by calculation. The curves thus obtained show several interesting features. Each year, during the time the pit was hardening, the rate of growth was fairly slow. More rapid growth during the period of final enlargement usually began sometime between the middle of June and the first week in July, depending on the season and to some extent, as will be shown later, upon the presence or absence of readily available soil moisture. In general the shapes of the curves are substantially the same as those reported for other stone fruits.

As previously mentioned, the permanent wilting percentage is not an exact point, but rather a narrow range of soil moisture within which plants wilt permanently. The resumption of rapid growth after hardening of the pit seems to be independent of soil moisture, provided water is readily available in the soil. When the soil moisture is reduced to the condition corresponding to about the permanent wilting percentage, resumption of rapid growth of the fruit is seriously delayed. This fact was observed with Muir peaches at Delhi. A typical case is presented in figure 11, which shows the growth for peaches during the season of 1928 under three different irrigation treatments. Rapid growth of the fruit in the frequently irrigated plot had evidently been resumed on June 20, as shown by the heavy solid line. Fruit in plots 9 and 10 of the *C, G,* and *E* treatment, as indicated by the dashed line, did not resume rapid growth until July 4, following an irrigation on June 29. The fruit in the plot represented by the dots, which was subjected to a more prolonged drought than plots 9 and 10 in treatment *C, G,* and *E,* did not resume rapid growth until later, and never did equal the rate of growth of the fruits in the other two plots.

The soil-moisture curves show that the soil-moisture content of plots 13 and 14 in treatment *A* and *F* was above the permanent wilting percentage at all times. The soil in plots 9 and 10 of treatment *C, G,* and *E* was depleted to approximately the permanent wilting percentage about June 23. These plots were irrigated on June 29, and the effect of this supply of readily available water was measurable by July 4 in terms of increase in the size of the fruit. The soil moisture in plot 17 *H,* represented by the dotted line, was depleted to the permanent wilting percentge for several weeks prior to ripening of the fruit. This plot was then irrigated about a week before the fruit was harvested. In spite of the preceding dry period, no marked increase in size appeared to result from this watering. The time of picking is stated in the legend.

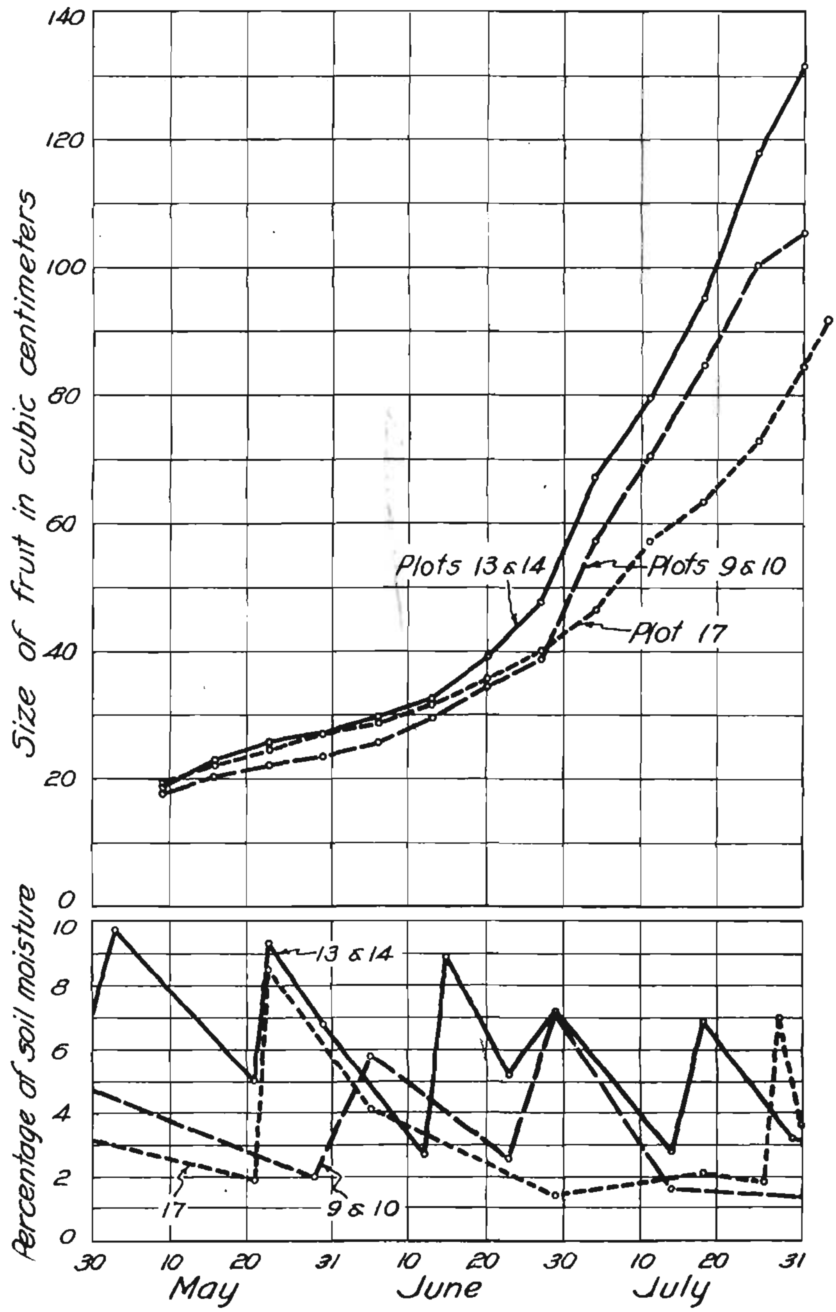

Fig. 11.—Growth of Muir peaches in relation to soil moisture, Delhi, 1928. The upper curves indicate the rate of growth of the fruit, and the lower, the percentage of soil moisture. Plots 13 and 14 received *A* and *F* treatment; 9 and 10 received *C* and *G* treatment; and 17 received *H* treatment. The permanent wilting percentage for 13 and 14 was 2.1; for 9 and 10, 1.6; and for 17, 1.3. Crop picked July 31 and August 3.

Sugar and Moisture Determinations of Muir Peaches.—At harvest time during three years of the experiment, the total sugar content of peaches from several plots was determined, from a composite sample of ten peaches from each tree in the experiment. The results, as given in table 10, are on a fresh weight basis. At the same time, moisture determinations were made on the ripe fruit. Fully mature representative peaches were placed in tared cans in the orchard, and dried in a ventilated oven at 70°–75° C for a period of six days. The pits were not removed, and are included in the dry weight of the fruit. While this factor no doubt affects the results, the pits of this freestone variety were purposely included, because the same procedure had to be followed in similar determinations made with clingstone varieties, as reported in this paper, and it was thought desirable to use comparable methods with both kinds.

TABLE 10

SUGAR AND MOISTURE CONTENTS OF MUIR PEACHES, DELHI

Treatment	Plots	Percentage of total sugars on fresh weight basis			Percentage of moisture on fresh weight basis		
		1926	1927	1928	1926	1927	1928
A, F	8, 13, 14	8.53±.08	9.98±.20	8.86±.10	86.5±.24	83.0± .14	79.8±.69
B	12	8.84±.10	10.4 ±.30	9.13±.14	85.4±.27	82.1± .34	80.6±.69
C, G	9, 10	....	10.6 ±.20	9.69±.11	....	79.6±1.01	78.9±.69
H	17	....	9.52±.01	9.91±.16	....	82.0± .23	79.2±.19

Table 10 shows that the fruit from plots *A* and *F* contained a slightly, probably significantly, higher moisture content than the fruit from both, *C*, *G*, and *E* and the *H* plots in 1927. All other differences between the frequently irrigated plots, *A* and *F*, and the infrequently irrigated and the dry plots were not significant. Furthermore, the fruit in the *H* treatment, which was irrigated a few days before picking, did not show a significantly higher moisture content than did that from the dry plots. The fruit from the *A* and *F* treatment in 1928 contained a significantly lower sugar content on the fresh weight basis than did that from either the *C*, *G*, and *E*, or the *H* treatments. In the other sugar determinations there were no significant differences.

Drying Ratios of Muir Peaches.—The drying ratios, or the relative weight of fresh fruit to dried fruit, are given in table 11. The data show great variability for similar treatments within a given year and also from one year to another; they were obtained by handling the fruit by the usual commercial method. The question of when the fruit was sufficiently dried to keep well in storage depended entirely upon the judgment of the man in charge of the drying operations. The drying ratios for all of the plots for each of the four years showed how one operator's judgment may vary from year to year. The figures show, furthermore, that plots with a high drying ratio for one season often gave a very low ratio the following year. The average drying ratio for 1927 was 4.92 for all plots, while in 1928 it was 6.30. The

TABLE 11

DRYING RATIOS OF MUIR PEACHES, DELHI

Plot and treatment	1925	1926	1927	1928	Average for 4 years
8, F	6 20	5.80	5.07	6 52	5.89
9, G	7.20	6 10	4.38	5 89	5.89
10, C	6.00	6.50	4.20	6.44	5.78
11, D	5.90	5.20	4.97	6 24	5.58
12, B	5.40	4 90	5.17	5.61	5.27
13, F	7.80	5 40	5.25	6 32	6.19
14, A	5.50	6 00	5.42	6.36	5.82
19, E	4.70	5.70	4 76	6.26	5 36
20, B	5.80	5.90	5.36	6.93	6.00
21, A	5.80	5.60	4.92	7.11	5 86
22, D	6.10	5.70	4 84	6.42	5.77
23, C	6.40	5.20	4.77	5 60	5 49
Average	**6.06**	**5.66**	**4.92**	**6.30**	5 74
Average of treatments A and F					5.94
Average of treatment B					5.64
Average of treatment D					5.68
Average of treatments C, G, and E					5.63

records showed that the irrigation treatments for these two years had been as nearly identical as possible. The great difference between the two years must be attributed to difference in judgment on the part of the man in charge of the drying operations, and also on the part of the receiving clerk. Evidently, when the plots are grouped according to irrigation treatments, as shown at the bottom of the table, no significant differences in the drying ratio, as determined commercially, exist.

Influence of Irrigation Late in Growing Season.—The effect of various irrigation treatments, particularly those late in the growing season, on the subsequent behavior of the trees was observed. Contrary to a rather widespread belief, lack of maturity and hardiness to freezing temperatures were not associated with late watering. Under the comparatively mild winter conditions prevailing in California, no injury resulting from lack of maturity was observed in this orchard.

Peach trees could not apparently, be kept growing late enough in the season to be injured by cold weather. In one year, a plot of peach trees was inadvertently irrigated because of a broken pipe line until late in October. No injury was apparent the following spring, and the trees blossomed normally. None of the plots showed any decisive differences in blossoming time that could be attributed to the irrigation treatment during the previous growing season.

EXPERIMENTS WITH IRRIGATION OF CANNING PEACHES

Experiments on the effect of irrigation on the growth and quality of canning peaches were conducted in 1926, 1927, and 1928, in typical canning peach sections in Sutter and in Stanislaus counties the climate of which is typical of the Sacramento and San Joaquin Valleys.[6] The Tuscan and Phillips varieties were used in Stanislaus County, the Phillips in Sutter County. Both of these varieties are standard commercial sorts, the former being the earliest canning variety to ripen, and the latter, one of the latest.

The two plots used consisted of 12 uniform mature trees which showed the typical characteristic habits of growth of each variety. The trees from which records were taken were surrounded on all sides by trees which received the same irrigation treatment as those in the experiments and which served as guards. Briefly stated, cultural treatment for each set of plots was identical, except for the amount of water applied and the dates of application. The pruning, spraying, cultivating, thinning, and picking were done by the owner. The irrigation treatment of the plots was varied in such a way that the trees in certain plots, hereafter called "dry" plots, were subjected to a more or less prolonged period of drought, and the soil moisture was reduced to about the permanent wilting percentage before the peaches were harvested.

In other words, the last one to three irrigations, before picking the fruit, were omitted in the case of the dry plots. Without these last irrigations, the readily available soil moisture was depleted, and the trees were subjected to a period of drought. These conditions are described more fully later in this paper. The "wet" plots were those in which the soil-moisture contents were usually above the permanent wilting percentage throughout the growing season.

The soil in the Stanislaus County orchard was classified as a Fresno sandy loam, having an impervious layer at a depth of four to

[6] Meteorological data may be obtained from the annual summaries issued by the United States Weather Bureau for Marysville, Modesto, and Oakdale.

five feet from the surface. The soil in the Sutter County orchard was a Madera and Gridley loam and also had an impervious layer found at about the same depth as in the Stanislaus County orchard. The moisture equivalents of the soils used are given in table 12.

TABLE 12

MOISTURE EQUIVALENTS OF SOILS IN PLOTS USED FOR IRRIGATION EXPERIMENTS WITH CANNING PEACHES

Depth	Sutter county		Stanislaus county*			
	Phillips variety		Tuscan variety		Phillips variety	
	Wet plot	Dry plot	Wet plot	Dry plot	Wet plot	Dry plot
First foot	23.10±0.19	24.99±0.08	8.26±0.16	6.12±0.07	9.76±0.05	8.31±0.06
Second foot	21.78±0.25	24.37±0.09	7.81±0.17	5.18±0.05	9.16±0.06	7.11±0.05
Third foot	21.13±0.25	23.70±0.10	8.01±0.16	5.14±0.03	9.31±0.06	7.18±0.06
Fourth foot	21.24±0.25	23.38±0.09	8.36±0.19	5.12±0.03	10.35±0.10	7.15±0.06

* Differences between wet and dry plots in Stanislaus county are due to texture of the soil and not to irrigation treatment. Moisture equivalents of soils from these plots taken two years after the differential irrigation treatment ceased showed similar differences.

Outline of the Experiments.—The general procedure during the experiments was to have the owner carry on all cultural operations according to the custom of the district. The only departure from this schedule was the omission of the last one to three irrigations from the dry plots, on which applications of water were stopped at a time decided after the stage of maturity, the soil-moisture conditions, and the probable date of picking had been considered.

The soil was sampled at weekly intervals. During the first year (1926) samples were taken in 3-foot increments, i.e., from 0 to 3 feet in one sample, and from 3 to 6 feet in the second. During the second and third years (1927–1928) they were taken to a depth of 5 feet in 1-foot increments.

Ten peaches on each of the experimental trees were measured on the same day that the soil samples were taken. The greatest horizontal circumference was ascertained with a steel tape, and this measurement was converted into volume, all peaches being assumed to be approximately spherical. These measurements were started immediately after thinning, usually during the first week in May, and continued up to picking time. The curves obtained show the growth of the fruit during the period of pit hardening and the period of final enlargement.

At harvest time, adequate samples of fruit were picked for the determination of several qualities. Ten peaches from each tree, carefully chosen for uniformity in ripeness, were used for determination of the sugar and the acid content. The moisture content of the fruit was determined on lots from each tree which were placed in sealed containers immediately after picking. Several boxes from each plot were used in storage tests, and, in 1926 and 1928, representative lots were canned by the Division of Fruit Products of the University of California. In 1927, 500 pounds of fruit from each plot were canned in a commercial cannery.

Growth of Canning Peaches in Relation to Soil Moisture.—Data are presented to show the growth of peaches and the soil-moisture conditions in 1927 and in 1928. The results obtained in 1926 are essentially similar to those of 1927 and 1928. In 1926 the soil-moisture samples were taken in 3-foot increments, but the presence of hardpan in the 3 to 6-foot depth increased the difficulty of interpretation of the soil-moisture determinations. For this reason, the data on growth of fruit and on soil moisture are not included. The sugar, acid, and moisture contents for all three years are, however, given later. Figure 12 shows the soil-moisture conditions in the Phillips plots in the Sutter County orchard in 1927. Both the wet and the dry plot received the same irrigation treatment during the early part of the season. The sharp rises in the curves indicate the addition of water by irrigation. Neither plot was allowed to wilt during the early part of the season. Each application of water usually resulted in wetting the soil to a depth of about 3 to 4 feet. Most of the roots were probably in this volume of soil because of the impervious layer occurring 4 to 5 feet below the surface.

The dry plot received the last irrigation on July 13. Thereafter, the soil-moisture content fell to about 10 per cent, which approximates the permanent wilting percentage. The soil-moisture curve for the dry plot was, it will be noticed, practically horizontal for about three weeks before picking—an indication that the trees extracted little or no more water from the soil. During this period the trees in the dry plot showed evidence of drought by a wilted condition of the leaves and a partial loss of the foliage. Those in the wet plot were, on the other hand, amply supplied with readily available water at all times before the ripening period. In addition to the irrigations given to both plots, the wet plot was watered three times, viz., July 20, August 4, and August 16. The soil-moisture curve for the wet plot does not show a rise after the irrigation of August 4, because soil samples could not be secured on the regular sampling date, August 5.

The curves in figure 13, showing the increase in size of fruit, indicate how the growth was affected when the moisture supply was reduced to about the permanent wilting percentage. The fruit in both plots grew slowly and uniformly during the season when the pit was hardening. The final period of enlargement ordinarily showed a rapid increase in the size of the fruit. Rapid growth, in the dry plot was resumed during the final period of enlargement in

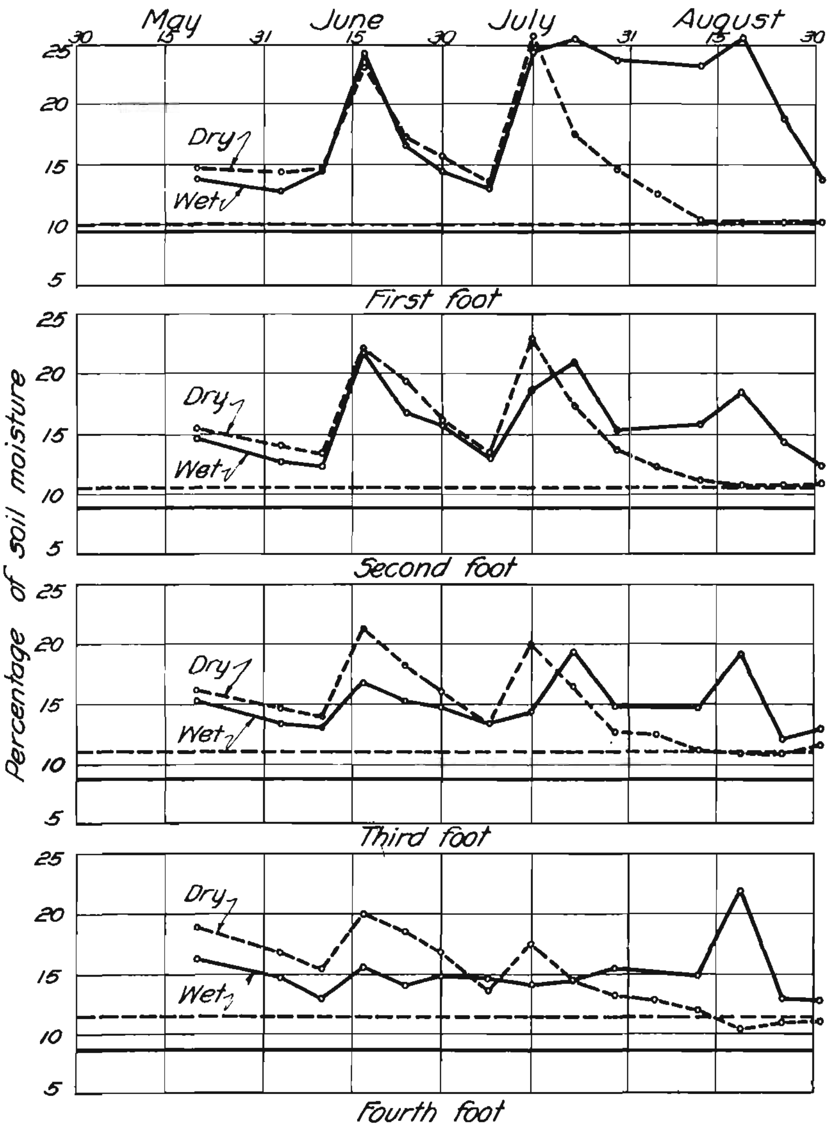

Fig. 12.—Soil-moisture conditions in Phillips peach orchard in Sutter County in 1927. The percentage of residual moisture at permanent wilting is shown by the heavy horizontal lines.

the week ending July 22. By the first of August, however, the rate of growth in the dry plot was much slower than that in the wet. Figure 12 shows that the soil-moisture content in the dry plot at this time was nearing the permanent wilting percentage. By the time the peaches

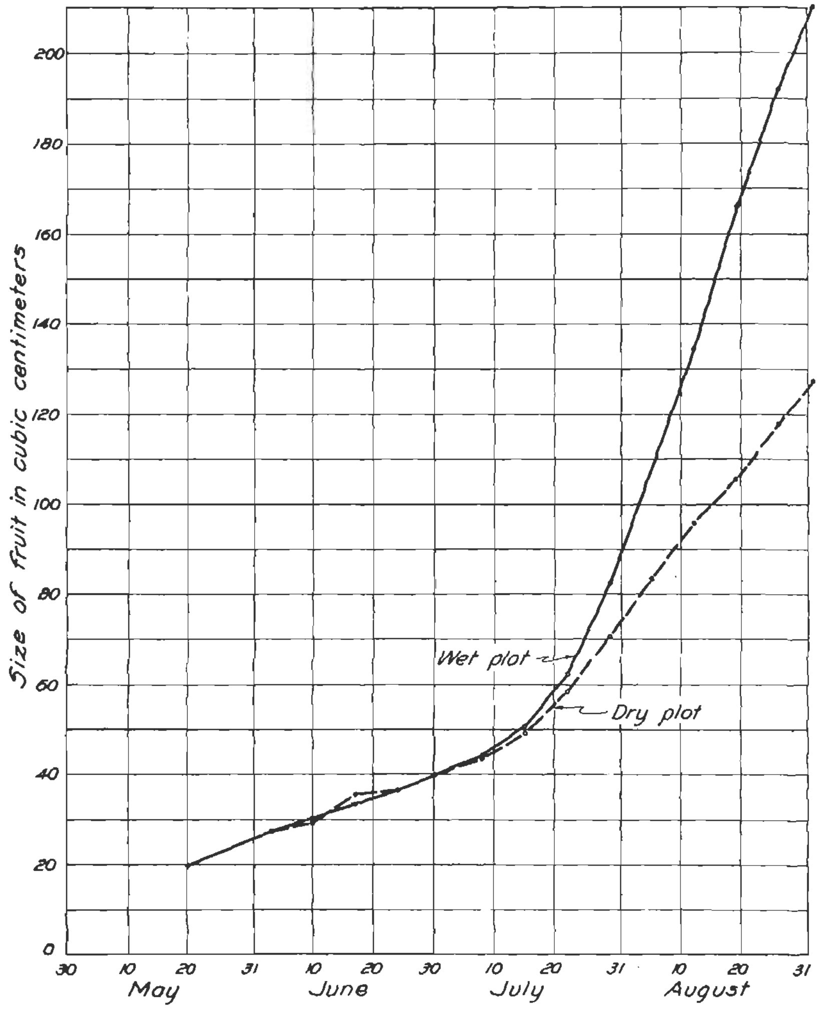

Fig. 13.—Growth of Phillips peaches in a Sutter County orchard in 1927.

were picked on September 5, many of those in the dry plot were unmarketable because of their small size. At the end of the experiment, the average size of the measured fruit in the wet plot was 210.6 cubic centimeters, and that in the dry plot, 127.3 cubic centimeters.

The results of soil-moisture determinations and of the growth measurements obtained in the Phillips peach plots in Stanislaus County in 1927 are shown in figures 14 and 15. After July 6, when the dry plot was given its last irrigation, the wet plot received three

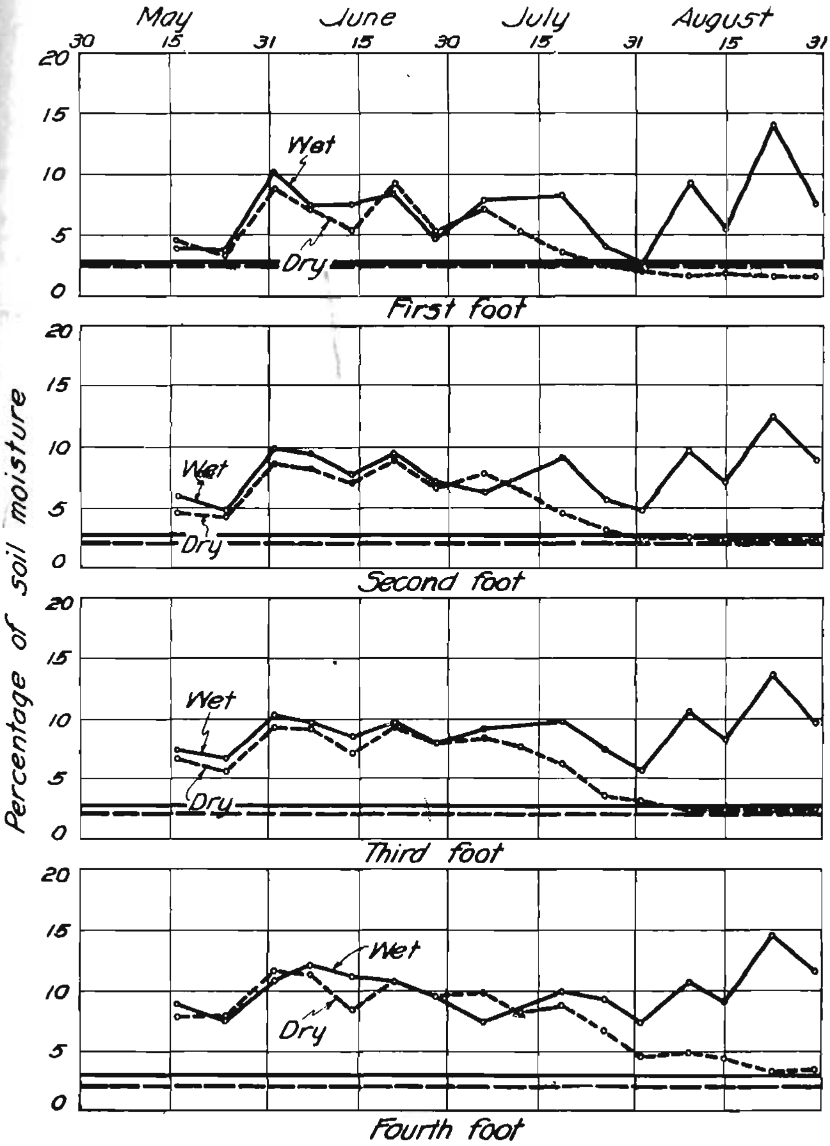

Fig. 14.—Soil-moisture conditions in Phillips peach orchard in Stanislaus County in 1927. The percentage of residual moisture at permanent wilting is shown by the heavy horizontal lines.

more. The soil samples taken on August 22 showed that the moisture content was much higher than the moisture equivalents (table 12). Standing water remained, in fact, on portions of the plot for more than a week preceding harvest. Again the curves in general show

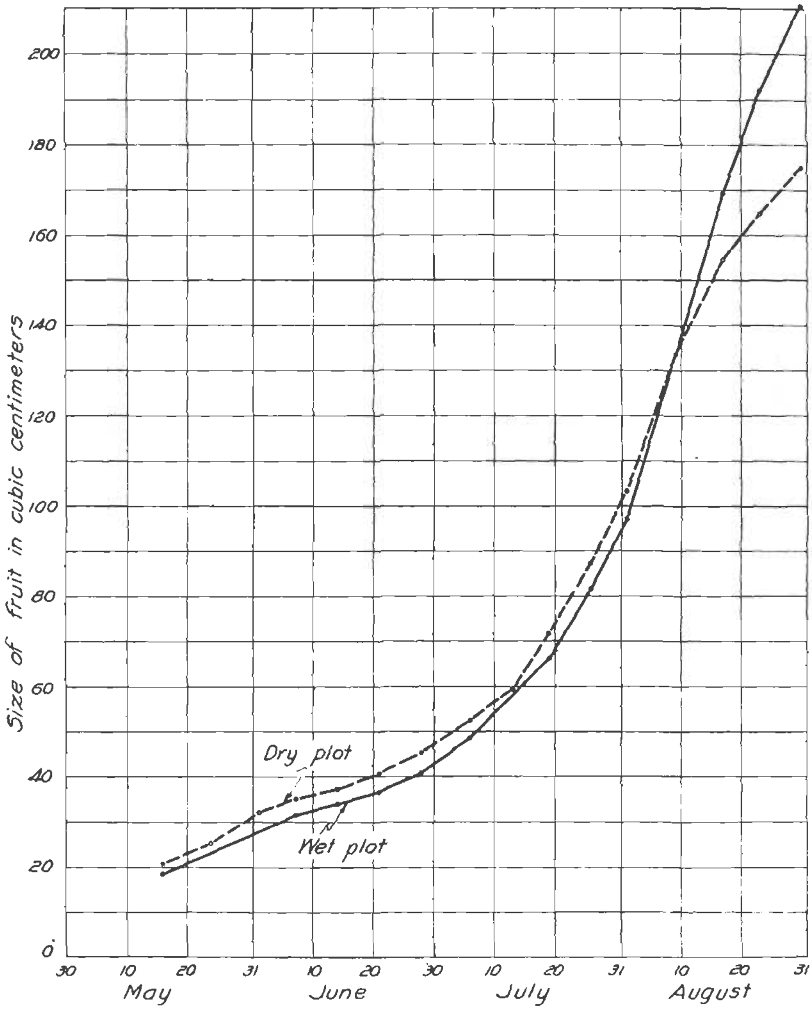

Fig. 15.—Growth of Phillips peaches in Stanislaus County orchard in 1927.

that after the permanent wilting percentage is reached, practically no further moisture is removed by the trees. The growth curves of the fruit indicate that the peaches in the dry plot were slightly larger than those in the wet plot at the beginning of the experiment.

They maintained this relative position until the soil-moisture content in the dry plot was reduced to about the permanent wilting percentage; thereafter they grew more slowly than the fruit in the wet plot. The

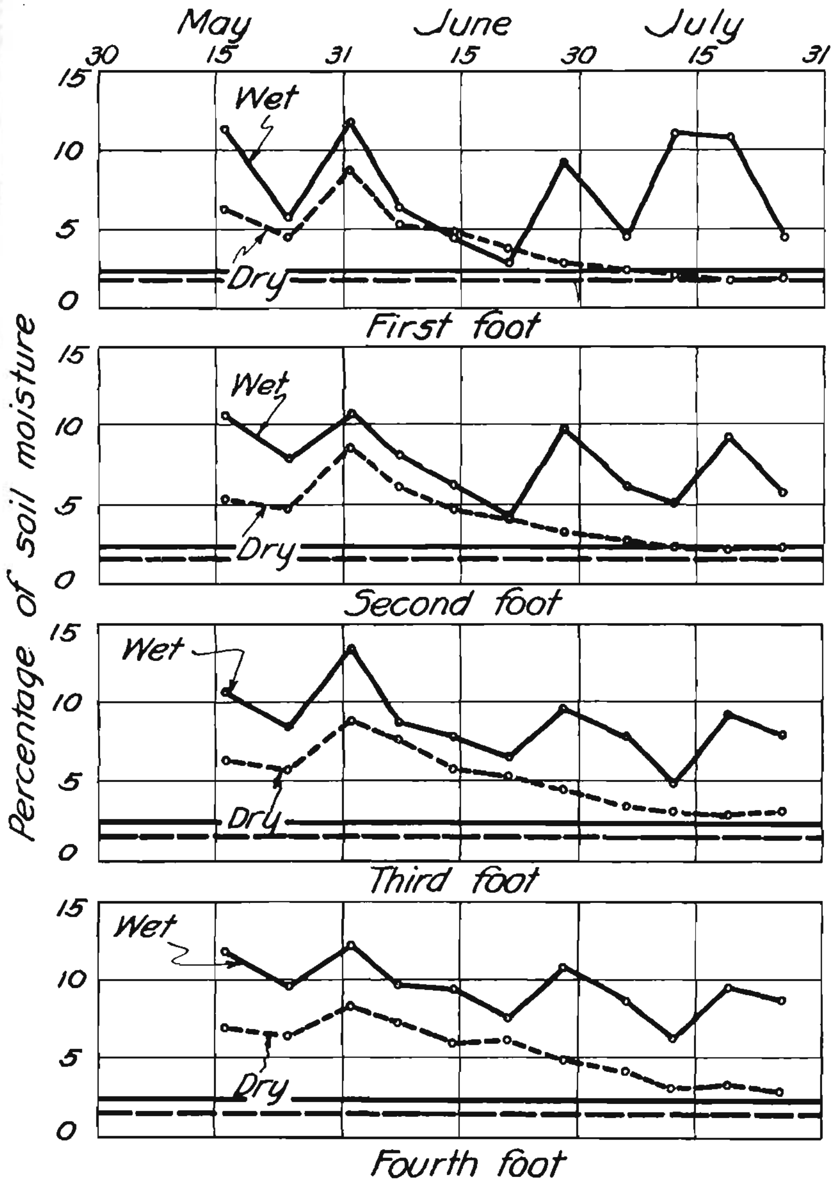

Fig. 16.—Soil-moisture conditions in Tuscan peach orchard in Stanislaus County in 1927. The percentage of residual moisture at permanent wilting is shown by the heavy horizontal lines.

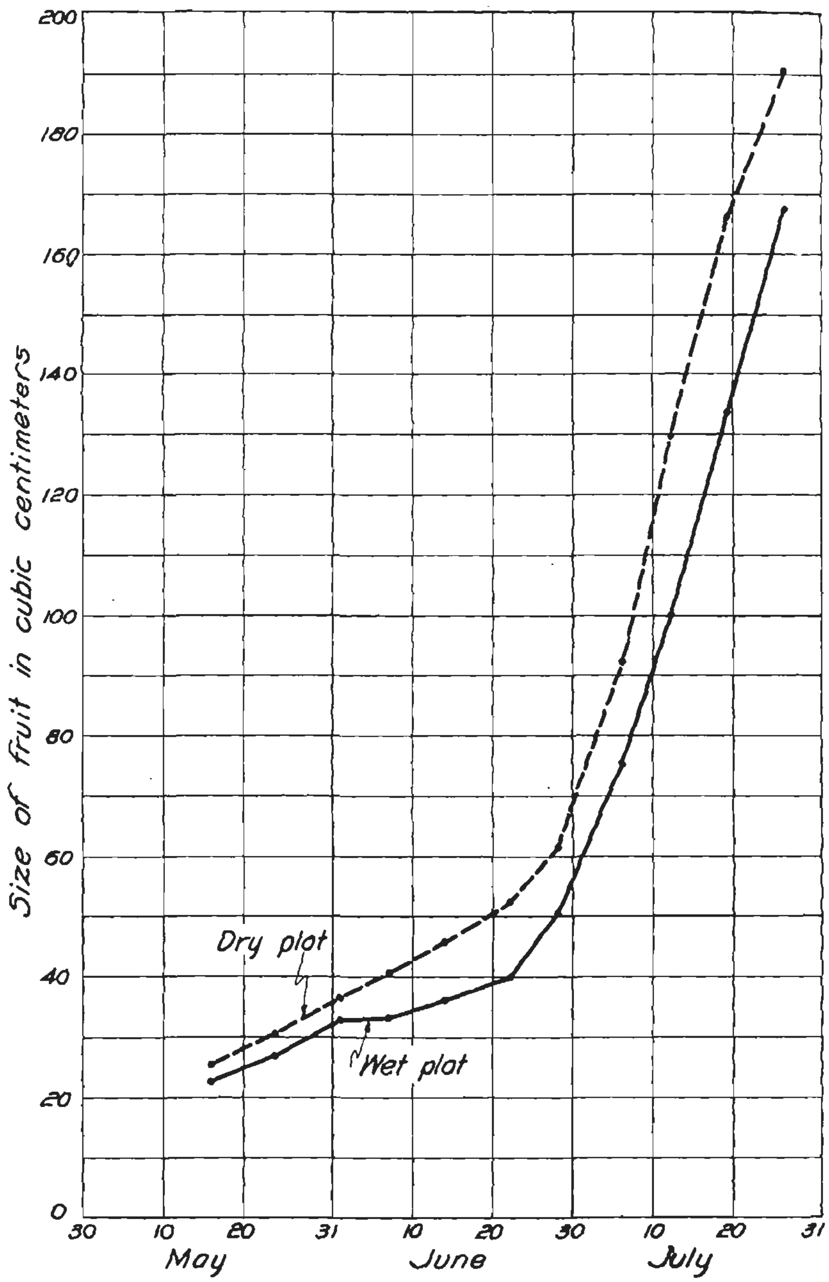

Fig. 17.—Growth of Tuscan peaches in Stanislaus County orchard in 1927.

beginning of the slow growth period during the last four weeks of the season coincides very closely with the time when the soil-moisture content was reduced to about the permanent wilting percentage.

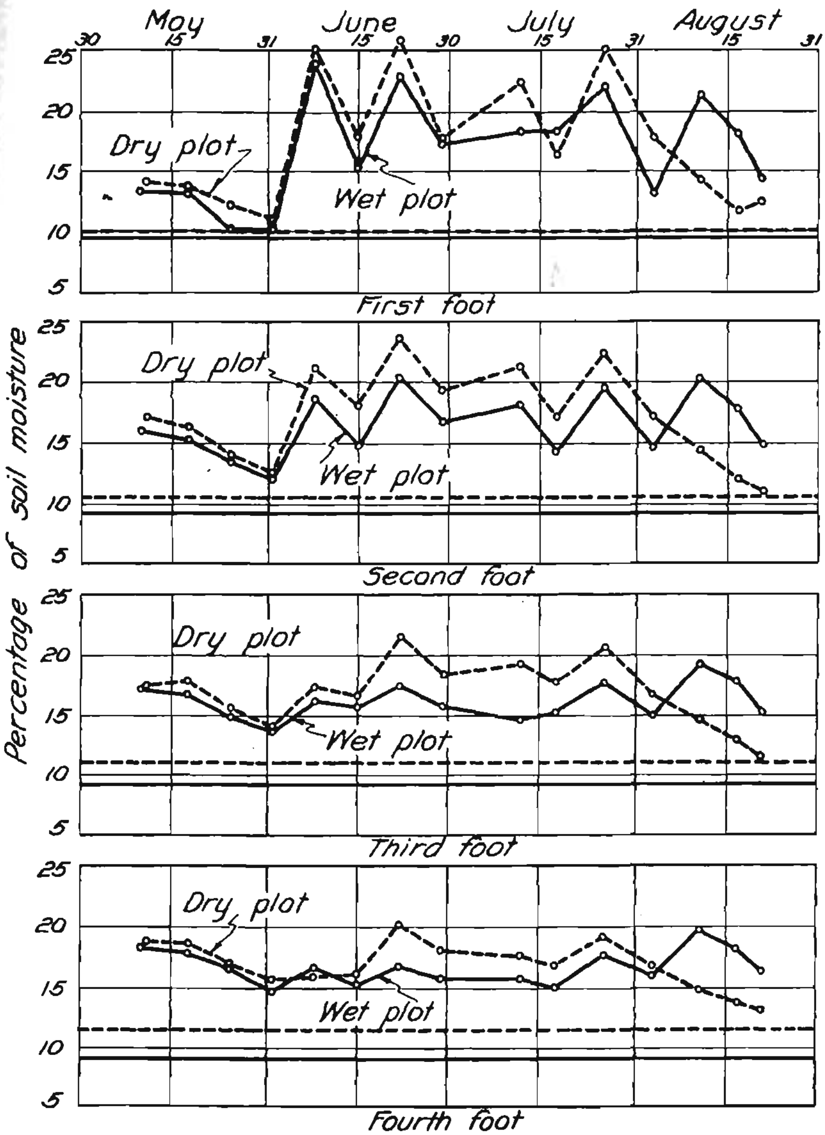

Fig. 18.—Soil-moisture conditions in Phillips peach orchard in Sutter County in 1928. The percentage of residual moisture at permanent wilting is shown by the heavy horizontal lines.

The soil-moisture conditions in the Tuscan peach plots in Stanislaus County are shown in figure 16. The dry plot received the last irrigation on May 29, while the wet plot had three additional waterings before the fruit was picked. As the curves show, the permanent wilting percentage on the dry plot was reached in the first 2 feet of soil between two and three weeks before harvest. In the third and fourth foot, however, the soil-moisture content did not actually reach the wilting percentage. The fruit in the dry plot, as shown in figure 17, was larger than that in the wet plot at the beginning of the experiment, and remained so until picked. This fact did not affect the results as the experiment was concerned only with the rate of growth. The slope of the curve of the fruit in the dry plot gives a slight indication that the rate of growth had begun to diminish during the week preceding harvest. The difference in soil-moisture content in the two plots makes it surprising that more marked difference in the rate of growth of fruit was not obtained.

The soil-moisture curve (fig. 18) for the Sutter County orchard in 1928 show that both the wet and the dry plots were maintained above the permanent wilting percentage, except for a brief period late in May, until late in the season, when soil moisture in the dry plot was reduced to about this percentage, except in the fourth foot. Growth of the fruit in the dry plot, as shown in figure 19, became slower, as the soil-moisture content was reduced almost to the permanent wilting percentage. Apparently, the rate of growth of fruit was influenced principally by the moisture content of the upper three feet. The deficiency of readily available soil moisture in the dry plot was evidenced by the decreased yield. The average yield of the wet plot was approximately 16 tons per acre, while that of the dry plot was about 9.6.

Acid, Sugar, and Moisture Determinations of Canning Peaches.—The acid, sugar, and moisture contents of well-matured fruit were determined each year. These analyses were made on the fresh weight basis and are presented in table 13.

The results given in table 13 are similar to those obtained with the Muir peaches. In general they indicate that, on a fresh weight basis, the acid content of the fruit showed no consistent differences between plots, but that the sugar content of the peaches was significantly higher for the dry plots than for the wet. At the same time, the fruit from the dry plots showed considerably less moisture than that from the wet when calculated on the fresh weight basis. Obviously, sugar analyses made on two lots of peaches calculated on a fresh weight basis cannot be directly compared, because of the differences in initial moisture content of the samples. On a dry weight basis, therefore, the difference in sugar content between the two lots would be decreased or even reversed.

The average dry weights of peaches from both the wet and the dry plots were obtained in 1928, but not in 1926 or in 1927. On this basis, the fruit from the dry plot in 1928 contained 57.8 per cent total

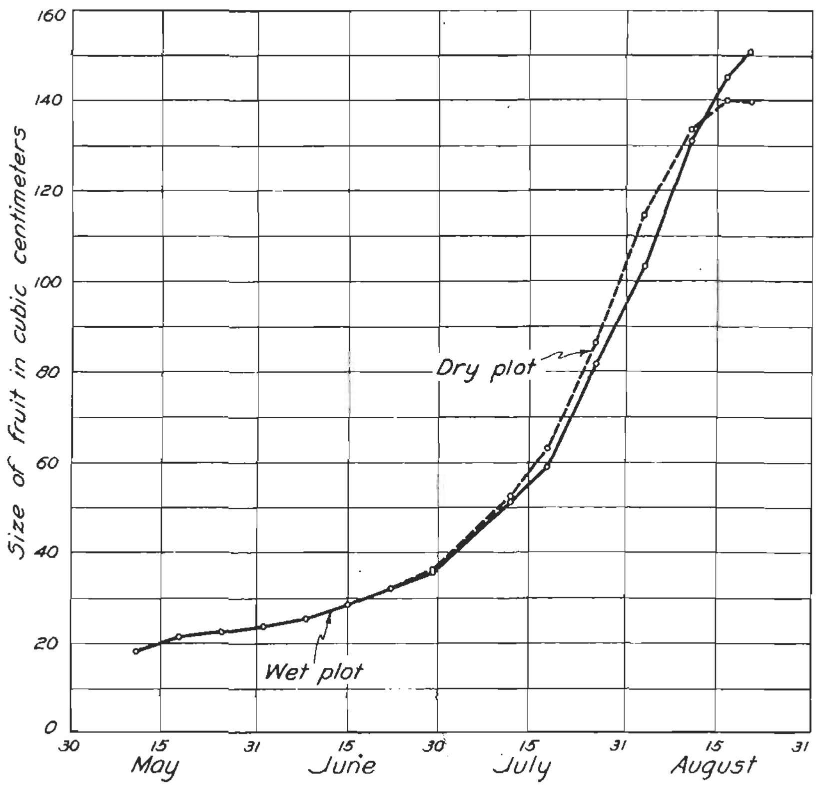

Fig. 19.—Growth of Phillips peaches in Sutter County orchard in 1928.

sugar, and the fruit from the wet plot, 64.3 per cent. Thus, a small difference in total sugar content in favor of the peaches from the dry plot was found when the determinations were based on the fresh weight of fruit; but the total sugar content of the fruit from the wet plot was higher than that from the dry plot, when calculated on the dry weight basis. Similar differences between experimental lots most likely prevailed in both 1926 and 1927.

Storage of Canning Peaches.—Each year several boxes of peaches from each of the experimental plots were taken to Davis and held in

TABLE 13

ACID, TOTAL SUGAR, AND MOISTURE CONTENT OF CANNING PEACHES 1926, 1927, 1928

Variety	Location of orchard	Plot	Per cent acid as H_2SO_4 on fresh weight of juice			Per cent total sugar on fresh weight basis			Per cent moisture on fresh weight basis		
			1926	1927	1928	1926	1927	1928	1926	1927	1928
Tuscan	Stanislaus county	Dry	0.50±.06	0.40±.004		9.24±.12	10.10±.12		85.8±.20	81.5±.28	
		Wet	0.51±.08	0.50±.008		8.55±.05	8.06±.07		86.0±.21	84.5±.30	
Phillips	Stanislaus county	Dry	0.33±.008	0.43±.007		9.60±.15	10.90±.006		83.9±.33	80.3±.33	
		Wet	0.34±.003	0.42±.009		8.00±.12	9.60±.09		86.5±.26	83.7±.41	
Phillips	Sutter county	Dry		0.42±.016	0.39±.008		11.99±.01	8.94±.14		77.7±.43	80.9±.30
		Wet		0.35±.010	0.42±.007		10.25±.25	8.13±.12		84.0±.36	84.2±.38

storage to determine the effect of the irrigation treatment on the keeping quality of the fruit. The fruit was brought from the orchard to Davis by automobile truck. The distance from one orchard to Davis was approximately 45 miles, from the other about 100 miles. In consequence of these distances, the fruit was subjected to considerable jolting, and showed, upon arrival, considerable injury from bruising, which seemed worse on the fruit from the wet plots. The fruit from the dry plots, was probably better able to withstand this jolting which was even more severe than when fruit is handled in carload lots. Part of the fruit from each plot was held at room temperature (70° F), and part at 36° F for a week or ten days, and then at room temperature for the remainder of the test. The results obtained in 1927 and 1928 are given in table 14.

DISCUSSION

Under conditions prevailing at Delhi, the annual winter rainfall sufficed to moisten the soil to its field capacity at least to the depth of the hardpan. The addition of irrigation water during the dormant season produced no increase in either growth of trees or in yield of fruit. Probably the only benefit derived from winter irrigation on soils with unrestricted drainage, would be to wet to its field capacity a greater depth of soil than would normally be moistened by winter rainfall. The hardpan in the Delhi orchard precluded the possibility of uniformly wetting the soil to a greater depth than that at which it occurred. While the extra moisture applied by irrigation during the winter probably accumulated above the hardpan, no deleterious results, as far as the vigor of the trees was concerned, were observed at any time during the experiments. Most of this additional water probably seeped through cracks or moved along the upper surface of the hardpan. The additional water applied during the winter season to certain plots did not prevent the soil-moisture content of these plots from being reduced to the permanent wilting percentage as soon as that of plots not winter irrigated. Previous studies with walnuts (5) and with prunes (13) gave the same general results.

The above general considerations may apply only in districts where the winter rainfall is sufficient to wet the soil in which most of the roots are located to its field capacity. During years of deficient rainfall, it may be desirable to apply water during the dormant season, in order that the trees may enter the growing season with available water in the root zone.

In the plots in the Muir peach orchard at Delhi, where the soil moisture was kept above the permanent wilting percentage throughout the growing season, the trees in treatments *A* and *F*, made a growth in cross-section area of trunks significantly greater than did the trees in treatments *C*, *G*, and *E*, in which the soil moisture was reduced to the permanent wilting percentage for long periods during the growing season, or in treatments *B* and *D*, in which the soil moisture was reduced to the same condition for comparatively short periods each season. In other words, a continuous supply of readily available soil moisture during the growing season produced larger trees than an intermittent supply. The same story is not true for yields. In the latter case, the yields from the trees in the treatments *A* and *F*, in which the soil moisture was kept above the permanent wilting percentage, were significantly greater than those from the treatments in which the soil moisture was reduced below the permanent wilting percentage for long periods during the growing season; but the yields were not significantly greater than those from the trees in the treatments *B* and *D*, in which the soil moisture was below this percentage for comparatively brief periods. Strangely enough, trees in treatments *B* and *D* were not significantly larger, but yielded greater crops, than those in the treatments *C*, *G*, and *E*, in which the soil moisture

TABLE 14

STORAGE TESTS OF PEACHES; PER CENT OF FRUIT DECAYED

Variety	Location of orchard	Storage temperature	Irrigation treatment of plots	Date of picking	2 days after picking	3 days after picking	4 days after picking	6 days after picking	7 days after picking	8 days after picking	9 days after picking	10 days after picking
Tuscan	Stanislaus county	36° F	Wet	7/26/27	....	....	3.2	16.7	18.9	23.0*	....	27.9
Tuscan	Stanislaus county	36° F	Dry	7/26/27	....	....	3.8	19.0	21.8	25.6*	....	30.8
Tuscan	Stanislaus county	70° F	Wet	7/26/27	....	....	16.4	45.4	62.8	71.5	....	80.7
Tuscan	Stanislaus county	70° F	Dry	7/26/27	....	....	14.1	29.6	43.2	55.3	....	69.9
Phillips	Stanislaus county	53° F	Wet	8/30/27	....	0	....	....	....	....	....	0
Phillips	Stanislaus county	53° F	Dry	8/30/27	....	0	....	....	....	....	....	0
Phillips	Stanislaus county	70° F	Wet	8/30/27	....	10.0	....	....	....	....	....	80.0
Phillips	Stanislaus county	70° F	Dry	8/30/27	....	0	....	....	....	....	....	31.2
Phillips	Sutter county	53° F	Wet	9/5/27	....	....	0	0	....	11.5	....	....
Phillips	Sutter county	53° F	Dry	9/5/27	....	....	0	0	....	0	....	....
Phillips	Sutter county	70° F	Wet	9/5/27	....	....	30.0	68.4	....	86.7	....	....
Phillips	Sutter county	70° F	Dry	9/5/27	....	....	1.0	4.1	....	4.1	....	....
Phillips	Sutter county	36° F	Wet	8/21/28	0	....	0	0	....	....	0*	....
Phillips	Sutter county	36° F	Dry	8/21/28	0	....	0	0	....	....	0*	....
Phillips	Sutter county	70° F	Wet	8/21/28	25.0	....	45.0	76.3	....	....	80.0	....
Phillips	Sutter county	70° F	Dry	8/21/28	27.0	....	28.3	30.8	....	....	32.1	....

* Changed to room temperature.

† Remaining fruit showed no evidence of decay, but was shriveled and unpalatable.

was below the permanent wilting percentage for long periods each season.

The figures showing the rate of growth of peaches, in connection with those showing the soil-moisture conditions, clearly indicate that the relative amount of moisture in the soil had little effect on the growth of the fruit, so long as some water was readily available. As the moisture content of the soil was reduced to about the permanent wilting percentage, however, water became less readily available to the tree, and this condition was reflected in the rate of growth of the fruit.

TABLE 14—(*Continued*)

STORAGE TESTS OF PEACHES; PER CENT OF FRUIT DECAYED

11 days after picking	12 days after picking	13 days after picking	14 days after picking	15 days after picking	16 days after picking	17 days after picking	18 days after picking	19 days after picking	20 days after picking	21 days after picking	22 days after picking	23 days after picking	24 days after picking	25 days after picking	28 days after picking
50.0	......	84.2†	......	......	......	......	......	......	......	......	......	......	......	......	......
53.6	......	83.5†	......	......	......	......	......	......	......	......	......	......	......	......	......
87.9	......	94.2†	......	......	......	......	......	......	......	......	......	......	......	......	......
80.6	......	*89.3†*	......	......	......	......	......	......	......	......	......	......	......	......	......
......	2.6	......	18.5	......	......	......	29.0	......	......	......	47.4	......	65.9	81.7	100.0
......	0	......	0	......	......	......	0	......	......	......	5.5	......	12.1	19.8	58.3†
......	100.0	......	......	......	......	......	......	......	......	......	......	......	......	......	......
......	46.2	......	58.1	......	......	......	78.5	......	......	......	100.0	......	......	......	......
......	59.1	......	......	......	80.4	......	90.2	......	......	......	......	100.0	......	......	......
......	1.7	......	......	......	7.5	......	13.3	......	17.5	......	......	28.3†	......	......	......
......	*100.0*	......	......	......	......	......	......	......	......	......	......	......	......	......	......
......	4.1	......	......	......	32.0	......	46.4	......	99.0	......	......	100.0†	......	......	......
0	......	10.4	......	44.2	......	61.1	66.3	......	......	78.0	......	88.4†	......	......	......
0	......	8.5	......	36.6	......	61.0	63.5	......	......	69.5	......	80.5†	......	......	......
90.0	......	91.3	......	95.0	......	100.0	......	......	......	......	......	......	......	......	......
33.4	......	48.8	......	55.2	......	57.7	57.7	......	......	62.9†	......	......	......	......	......

Thus, in every case when the soil moisture was reduced to the condition at which permanent wilting occurred, the growth curves showed that the fruit was not growing so fast as formerly. On the other hand, addition of water by irrigation shortly before picking the fruit, did not increase the rate of growth of the peaches. This fact was clearly substantiated by results obtained at Delhi with Muir peaches in treatment *H*, which was planned to secure information on this particular point. During the experiment the soil moisture in this plot was reduced to the permanent wilting percentage or below each year for several weeks before harvesting. Irrigation water was then applied 3 to 6 days before picking (fig. 11). In no case could an appreciable increase in the rate of growth be detected. An increased rate of growth of peaches was not obtained by applying water to a dry soil shortly before harvest, and, furthermore, it was not obtained by watering a soil in which some moisture was readily available at the time the additional water was applied. This fact is decisively illustrated in figures 15, 17, and 19. There was no departure from what might be termed the normal growth curve of peaches until the soil-moisture content is reduced to about the permanent wilting percentage.

The results on the rate of growth of peaches obtained in these experiments vary somewhat from those obtained by other workers, and from opinions expressed in textbooks. Data presented in early publications[3] [11] [12] seem to show certain decisive results of irrigation. Most of these data, however, can not be satisfactorily interpreted in the light of recent work on this problem.[15] [17] Some of these publications gave only fragmentary soil-moisture records, and no information that might enable the reader to interpret the water-holding properties of the soils used. The importance of the wilting coefficient as defined by Briggs and Shantz[6] was evidently not recognized. Furthermore, the recognition of the importance of this factor would not have been helpful in every case, because we have shown[17] that the relative amounts of readily available moisture vary with different soils. Thus, the permanent wilting percentage must be determined individually for each soil used.

Where decisive results by irrigation in deciduous orchards are reported,[3] [11] [12] it is reasonable to assume that the soil-moisture content of some of the plots was reduced to about the permanent wilting percentage for longer or shorter periods during the growing season. Thus we find a comparison between trees actually suffering from a lack of water and those supplied with ample soil moisture. When considered in this light, the differences obtained between the "lightly" irrigated and the "heavily" irrigated, or between "high," "medium," and "low" moisture plots, lose much of their significance.

The tables giving the data on the acid, sugar, and moisture contents of peaches from the experimental plots show that differences in moisture content prevailed, but that the differences in acid and sugar content were relatively slight, even when calculated on a fresh weight basis. Interpretation of the results of the sugar and acid determinations, on a dry weight basis, showed that the differences, as determined on the fresh weight basis, were more apparent than real. Unfortunately, complete data for making this comparison are lacking except for the 1928 season, which showed that the fruit from the wet plot contained considerably more sugar than the fruit from the dry plot, when compared on a dry weight basis. The fact that greater differences were not obtained is surprising, inasmuch as the trees in the dry plots were subjected to extreme conditions of drought, particularly the dry plots in the Muir peach orchard at Delhi, and the Phillips plots in both Stanislaus and Sutter counties in 1927. On the other hand, the wet Phillips plots in Stanislaus County in 1927 had standing water around the trees for more than a week just preceding harvest. Jones and Colver[10] have made extensive chemical analyses of irrigated and unirrigated fruit. While no information is given on the actual soil-moisture conditions at the time the fruit was picked, the soil moisture, in the sections from which the unirrigated samples were collected, was probably reduced to the permanent wilting percentage. This is particularly likely in the case of fruits that ripened late in the season. These results are in substantial agreement with ours, in that Jones and Colver found no differences in sugar and in acid content between irrigated and unirrigated fruit, when compared on a dry weight basis, unless the trees had been subjected to prolonged periods of drought.

The moisture contents of the peaches from the dry plots at harvest time were somewhat lower than the moisture contents of the fruit from the wet. This condition may have resulted from the fact that the leaves withdrew some water from nearby fruits, leaving the latter in a wilted condition. The fruit from the trees in treatments *C*, *G*, and *E* at Delhi was also invariably smaller than that from *A* and *F*, the treatments receiving an abundance of water.

In spite of this difference in moisture content, the drying ratios of the Muir peaches, obtained in drying the fruit according to commercial practice, were not always in agreement with the moisture determinations made in the laboratory. The wide variability in drying ratios from year to year throws doubt on these figures as a criterion of the response of peaches to irrigation treatment. A safer criterion would have been the ratio of the fresh fruit to sun-dried fruit on a dry weight rather than a fresh weight basis. The idea held by many growers that irrigated fruit has a higher drying ratio than unirrigated fruit is not substantiated by our commercial drying results.

The storage tests with the Tuscan and Phillips varieties indicate no differences in rate of decay between the fruit from the wet and the fruit from the dry plots in the interval comparable to that between picking and canning. When the fruit was placed in cold storage there was, in general, no difference in keeping quality. The fruit from the wet plots decayed more rapidly when stored at room temperature (70° F) than did the fruit from the dry plots. These facts are in keeping with what might be expected. The fruit from the wet plots was turgid, that from the dry, somewhat wilted. During transportation from the orchard to the storage rooms by automobile truck, the fruit was subjected to considerable jolting. The peaches from the wet plots showed, in consequence, more bruising than those from the dry plots, allowing ready entrance of various decay organisms. Decay took place more rapidly at room temperatures than at lower temperatures, probably because of more favorable conditions for fungus growth.

One of the widespread beliefs among growers is that certain forms of injury to fruit trees are associated with any cultural practice, such as late fall irrigation, which may tend to keep the trees actively growing until late in the season. Emerson[8] reported that in Nebraska, winter injury to peaches was found to be more severe on trees growing on moist soils. Theoretically, peach trees growing under these conditions do not mature their fruiting wood, which is easily injured by prevailing winter temperatures. Chandler,[7] however, pointed out that under certain conditions peach trees may continue growth comparatively late in the season and still develop resistance rapidly enough to survive winter temperatures without injury. In our experiments with Muir peaches, no apparent evidence of winter injury ever followed soil-moisture conditions that kept the trees actively growing until late in the fall. In one extreme case a number of Muir peach trees were kept continuously moist until late in October, because a nearby break in the irrigation pipe line resulted in saturation of the soil. Studies on the maturity of the trees in the Delhi orchard[9] showed that the fruiting wood on the trees in soil kept continuously moist reached maturity at the same time as that on the trees in dry soil. These trees survived a normal California winter without injury, and blossomed normally the following spring. Evidently peach trees are able to mature their fruiting wood in time to escape injury by temperatures ordinarily prevalent in the interior valleys of California during the winter season. Furthermore, plots of Muir peaches which were allowed to become dry during the summer and then watered during the fall showed no evidence of winter injury. The same responses were observed with other deciduous fruit trees in California.[13] An abundant supply of soil moisture late in the growing season cannot alone account for the immaturity of the current growth of the tree and for the winter injury believed to follow such immaturity. Abell, after a survey of peach orchards in Utah,[1] suggested that winter injury was associated with summer drought followed by warm fall rains, which resulted in an immature growth. Inasmuch as this investigator recommends maintaining an adequate soil-moisture supply in the summer, and since precipitation in Utah is usually ample during the fall, he evidently believes that a high soil-moisture content in the fall does not of itself constitute a winter injury hazard.

One of the most critical water-requirement periods for peaches during the growing season is near the end of the pit hardening period. Lack of readily available soil moisture at this time was shown by the tardiness of the fruit in entering the final period of rapid growth, and by its small size at harvest time. This fact is evidenced by the data shown in figure 11, plot 17. Addition of irrigation water late in the fruit maturing period did not compensate for lack of readily available moisture when the pit was hardening. Furthermore, the size of the peaches cannot, apparently, be markedly increased by irrigating shortly before picking. Muir peaches watered late in the season did not show a higher moisture content than those kept above the permanent wilting percentage throughout the growing period.

One interesting result of the experiment with the Muir peaches at Delhi was that the trees in the plots *C*, *G*, and *E*, which were at or below the permanent wilting percentage for long periods, were able to withstand extremely severe drought conditions without apparent effect on the trees other than reduced size of trees and yield. The trees were small but blossomed profusely and set abundant crops. Because of their size, they yielded less than the trees receiving more water. It must be kept in mind that in the sandy soil at Delhi, soil-moisture conditions fluctuated rapidly, and conditions of drought prevailed very soon after each irrigation. Exhaustion of the supply of readily available moisture, during the growing season, is reflected in the size of tree and yields, and in wilting and dropping of the leaves, but, peculiarly enough, the trees themselves did not seem permanently injured, even after a period of drought continuing for as long as five or six weeks. These conditions were observed with both the Muirs and the two canning varieties studied. The Phillips variety, in particular, showed marked evidence of drought in the dry plots but were, to all appearances, not adversely affected the following season.

The importance of the permanent wilting percentage as a critical soil-moisture content is clearly evident from the data presented in this paper, in which the permanent wilting percentage is used in the sense of that soil-moisture content at which plants wilt permanently and do not recover without the addition of water to the soil. When the trees wilted, the writers referred to the soil-moisture condition as being "about" at the permanent wilting percentage, because this percentage cannot be determined precisely.

The permanent wilting percentage was determined directly for the surface soil in all of the orchards, and for the sub-soils in Stanislaus and Sutter County orchards. Sunflower plants were grown in tared tin cans carefully sealed to prevent loss of moisture by evaporation from the soil. The plant, when to all appearances permanently wilted, was placed in a dark moist chamber for 12 to 24 hours to revive if possible. If it did revive, it was again exposed to the evaporating conditions under which it was grown. If it did not revive, it was considered permanently wilted.

When the plant first shows signs of drooping, which in all of our trials, was at a soil-moisture condition close to the permanent wilting percentage, it quickly revives when placed in the moist chamber, and is, therefore, not permanently wilted. Sometimes a plant reaches a permanently wilted condition and remains there for several hours before being placed in the moist chamber. During this time, it loses more moisture, and consequently the observed permanent wilting percentage is lower than if the plant had been placed in the moist chamber immediately after permanently wilting. This method is somewhat arbitrary, and results vary slightly with the judgment of different workers. Remarkably close results were, however, obtained with all of the soils used. In 151 trials with the surface soil from the Sutter County orchard the permanent wilting percentage was 10.47 ± 0.025, and in 226 trials with the surface soil from the Stanislaus County orchard it was 3.08 ± 0.007. The permanent wilting percentage can be determined closely for the soil in any one place in a given plot, but it must be remembered that soil within a plot often shows considerable variation.

The soil-moisture records in general show that when irrigation was delayed, the slope of the curves changed perceptibly and became approximately horizontal. This change in direction indicated a material decrease in the rate at which the trees extracted soil moisture. The breaks in the curves correspond closely to the permanent wilting percentage as determined in the laboratory with sunflower plants. As would be expected, the horizontal parts of the curves do not always agree exactly with the permanent wilting percentage, as ascertained in the laboratory. In describing this condition we have of necessity used the term "about the permanent wilting percentage." Therefore, the permanent wilting percentage must be a narrow range of moisture contents within which the plants wilt. In other words, the peach trees we studied may have wilted a little above or below the percentage of soil moisture stated.

The slopes of the soil-moisture curves show that the trees extract moisture at a rate substantially uniform until the soil-moisture content is reduced close to the permanent wilting percentage. These results substantiate previous results by the writers,[13] [15] which show that the use of water was not influenced by variations in moisture content between the moisture equivalent and about the "wilting coefficient." While the soil-moisture curves indicate that the rate of extraction by peach trees was approximately uniform until the permanent wilting percentage was reached, this uniformity of rates may not hold rigorously when the moisture content is reduced close to the permanent wilting percentage. If drooping indicates lessened transpiration, the rate of extraction evidently decreased before the plants were permanently wilted. In order to obtain the exact slope of the curve in this region, much closer soil sampling would be necessary than could be taken in the present studies.

The soil-moisture curves give some indication of the length of time that soil moisture is readily available, after each irrigation, in the various soils studied. During the hottest part of the summer, the mature peach trees at Delhi depleted the readily available soil moisture in this sandy soil in from two to three weeks. The interval between irrigations under Delhi conditions should therefore not greatly exceed three weeks, particularly near the end of the pit hardening period and as the fruit approaches maturity. As the picking season may sometimes continue from two to three weeks, the interval between the irrigation just prior to picking and the beginning of the harvest should probably be shortened in order that the trees may not suffer during the harvesting period.

The peach trees in the plots on the sandy loam soils in Stanislaus County exhausted the readily available soil moisture in the top 4 feet in three to four weeks. This length of time may therefore be considered a safe interval between irrigations under these soil and climatic conditions. On the heavier soil in the peach orchard in Sutter County, the readily available soil moisture in the top 4 feet was usually exhausted in from five to six weeks. The irrigations should correspond to this interval.

The moisture equivalent closely approximates the field capacity in both the Sutter and the Stanislaus county Phillips orchards, but not in the Tuscan plot nor in the Delhi orchard. In the latter cases the field capacities are higher than the moisture equivalents. These facts are clearly indicated by table 12 and by the various soil-moisture records.

The soils in both the Sutter and the Stanislaus county orchards showed a relatively high proportion of the total water-holding capacity to be readily available for plant growth. In the Sutter County orchard approximately 40 per cent of the field capacity of the soil is not readily available for normal growth and fruiting of trees, while in the Stanislaus County orchards only approximately 29 per cent cannot readily serve this purpose. These facts are of interest and of great importance, particularly in the case of the Stanislaus County orchard, because they show that in this soil with a rather limited water-holding capacity, a large portion of the moisture is readily available for plant growth. In contrast, it may be pointed out that with some soils, more than 50 per cent of the field capacity is not readily available. In the Delhi orchard about 43 per cent of the moisture equivalent is not readily available. As the moisture equivalent is evidently not a true measure of the field capacity of the Oakley fine sand, it cannot be used as a basis for computing the amount of readily available moisture in this type of soil. On the basis of the field capacity, therefore, only about 30 per cent is not readily available.

The readily available soil moisture in each foot of the top 4 feet of soil in the Sutter and Stanislaus county orchards was depleted at approximately the same time. The figures show that the soil-moisture content in the third and fourth feet reached this percentage slightly later than in the first and second feet, but practically the time may be considered the same. Sufficient water should, accordingly, be applied at each irrigation to wet the soil to at least 4 feet under conditions similar to those in these orchards. When the soil-moisture content is reduced to about the permanent wilting percentage in the Sutter County orchard, water about 1 inch in depth is needed to wet 5 inches of soil to its moisture equivalent or field capacity. The Fresno sandy loam soil in the Stanislaus County orchard varied considerably in water-holding capacity, as shown by the difference in moisture equivalents in table 12. It is difficult to state exactly how far 1 inch of water would penetrate under these conditions, but most likely, on an average for all the plots, an application of 1 inch of water would wet about 8 inches of soil.

The Oakley fine sand in the top 3 feet of the Delhi orchard takes 1 inch of water to wet about 16 inches of soil. These amounts of water must actually be absorbed by the soil, and any loss in applying the water, such as evaporation, run-off, or deep percolation, should be allowed for in addition to the amounts given. If the orchard is irrigated before the moisture has been reduced to the permanent wilting percentage, less amounts will, of course, be required to wet the soil.

As the determination of the permanent wilting percentage involves much more labor, care, and apparatus than the usual orchardist can afford to devote to such work, any practical way of recognizing when this soil-moisture condition is reached is important. One of the most practical methods of determining when the soil-moisture content is reduced close to the permanent wilting percentage is observation of the condition of the trees. Deciduous fruit trees ordinarily show evidence of this fact by the wilting of the leaves during the afternoon. When the same condition is apparent early in the morning, the permanent wilting percentage has almost certainly been reached. The soil at this time will show, under examination, its condition of dryness, and the grower may become familiar enough with it to recognize readily when the moisture content is close to the permanent wilting percentage, and may, at other times, anticipate when this condition will be reached.

All the soils examined by the wrters appeared to be dry at the permanent wilting percentage. Recently, however, Professor H. A. Wadsworth of the University of Hawaii has called our attention to a soil which had a relatively high permanent wilting percentage. This soil at the permanent wilting percentage would, if examined in the field, probably appear moist. The apparent dryness of a soil may not, accordingly, always be a safe criterion of the lack of readily available moisture.

The data in this paper lead to the conclusion that no differences in the yield, growth of trees, time and relative amount of blossoming, or quality of fruit were brought about so long as the soil-moisture content was above the permanent wilting percentage. The differences which were obtained depended upon the length of time during which the soil in one of the plots remained at about the permanent wilting percentage.

The term "over-irrigation" is frequently used in connection with irrigation of deciduous orchards. In view of the data presented in this paper, this term has little meaning. The maintenance of a high moisture content in the plots of certain of our experiments did not affect adversely either the trees or fruit. In fact, the presence of standing water on the soil in some of our plots just before harvest time resulted in no injury to the crop. This condition of soil moisture was certainly "over-irrigation" in the commonly accepted sense of the term, and if continued through a long period might have caused injury to the trees. Over-irrigation should not be confused with frequent irrigation. In our opinion over-irrigation is the practice of applying water in sufficient quantities to water-log the soil, to bring about unfavorable oxygen relations, and possibily, to cause leaching or excessive losses due to deep percolation.

SUMMARY

The addition of irrigation water during the dormant season to Muir peach trees at Delhi produced no increase, either in growth of trees or in yield of fruit.

Winter irrigation of Muir peach trees at Delhi did not postpone the date when the first spring irrigation was necessary.

Maintenance of soil moisture continuously above the permanent wilting percentage at Delhi resulted in production of the largest trees.

Deficiency of readily available moisture for comparatively brief periods resulted in a decrease in growth of the trees at Delhi, but not a significant decrease in yield.

Deficiency of readily available moisture for long periods during the growing season markedly reduced the yields of Muir peaches.

The rates of growth of peaches were not affected until the soil moisture was reduced to about the permanent wilting percentage.

Application of water to the soil just prior to picking did not result in rapid increase in size of the fruit.

The peaches from plots deficient in readily available moisture in general, contained a slightly higher percentage of sugar and a lower percentage of water than the fruit from the continuously moist plots, when calculated on a fresh weight basis. Results in 1928 indicated that if sugar determinations were calculated on a dry weight basis, these results would be reversed.

Irrigation just before picking did not increase the water content of the fruit above that not irrigated in this way.

A deficiency of readily available soil moisture during the pit-hardening period seriously affects the subsequent size of the fruit.

Extreme differences in soil-moisture content did not affect the drying ratio of Muir peaches when dried commercially.

No differences in the keeping quality between the peaches from the wet plots and those from the dry plots were observed during the usual interval between picking and canning.

No evidence of winter injury to peach trees following fall irrigation was obtained.

Under conditions similar to those existing in the various experimental plots reported in this paper, a safe interval between irriga-

tions during the hottest part of the summer would be three weeks at Delhi, three to four weeks in Stanislaus County, and five to six weeks in Sutter County.

The data presented in this paper show that the permanent wilting percentage is a critical soil-moisture content, and lead to the conclusion that trees either *have* readily available moisture or *have not.*

LITERATURE CITED

[1] ABELL, T. H.
1927. Some observations on winter injury in Utah peach orchards, December, 1924. Utah Agr. Exp. Sta. Bul. 202:1–28.

[2] ALWAY, F. J., and G. R. MCDOLE.
1917. Relation of the water-retaining capacity of a soil to its hygroscopic coefficient. Jour. Agr. Res. 9:27–71.

[3] BATCHELOR, L. D.
1916. Irrigation of peaches. Utah Agr. Exp. Sta. Bul. 142:1–24.

[4] BATCHELOR, L. D., and H. S. REED.
1918. Relation of the variability of yields of fruit trees to the accuracy of field trials. Jour Agr. Res. 12:245–283.

[5] BATCHELOR, L. D., and H. S. REED.
1923. The seasonal variation of the soil moisture in a walnut grove in relation to the hygroscopic coefficient. California Agr. Exp. Sta. Tech. Paper. 10:1–31.

[6] BRIGGS, L. J., and H. L. SHANTZ
1912. The wilting coefficient for different plants and its indirect determination U. S. Dept. Agr., Bur. Pl. Ind. Bul. 230:1–83.

[7] CHANDLER, W. H.
1925. Fruit growing. Houghton Mifflin Company. p. 1–777.

[8] EMERSON, R. A.
1903. Experiments in orchard culture. Nebraska Agr. Exp. Sta. Bul. 79:1–33.

[9] HENDRICKSON, A. H.
1926. Certain water relations of the genus Prunus. Hilgardia 1:479–524.

[10] JONES, J. S., and C. W. COLVER.
1912. The composition of irrigated and non-irrigated fruits. Idaho Agr. Exp. Sta. Bul. 75:1–53.

[11] LEWIS, C. I., E. J. KRAUS, and R. W. REES.
1912. Orchard irrigation studies in the Rogue River valley. Oregon Agr. Exp. Sta. Bul. 113:1–47.

[12] TAYLOR, E. P., and G. J. DOWNING.
1917. Experiments in the irrigation of apple orchards. Idaho Agr. Exp, Sta. Bul. 99:1–48.

[13] VEIHMEYER, F. J.
1927. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia 2:125–284.

[14] VEIHMEYER, F. J., O. W. ISRAELSEN, and J. P. CONRAD.
1924. The moisture equivalent as influenced by the amount of soil used in its determination. California Agr. Exp. Sta. Tech. Paper 16:1–62.

[15] VEIHMEYER, F. J., and A. H. HENDRICKSON.
1927. Soil-moisture conditions in relation to plant growth. Plant Physiology, 2:71–82.

[16] VEIHMEYER, F. J., and A. H. HENDRICKSON.
1928. The relation of soil moisture to cultivation and plant growth. Proc. and Papers First Internat. Congress Soil Sci. Washington, D. C. 3:498–513. 1927.

[17] VEIHMEYER, F. J., and A. H. HENDRICKSON.
1928. Soil moisture at permanent wilting of plants. Plant Physiology 3:355–357.

[18] VEIHMEYER, F. J., J. OSERKOWSKY, and K. B. TESTER.
1928. Some factors affecting the moisture equivalent of soils. Proc. and Papers First Internat. Congress Soil Sci. Washington, D. C. 1:512–534. 1927.

II. CANNING QUALITY OF IRRIGATED PEACHES[1]

P. F. NICHOLS[2]

It is a common belief that irrigating peaches within two weeks immediately preceding harvest injures their canning quality. During the years 1926 to 1928, inclusive, experiments were conducted by the Division of Viticulture and Fruit Products in order to show the effect of irrigation upon the quality of clingstone peaches for canning. The fruit canned was from the wet and dry plots described in Part I of this paper.

EXPERIMENTS IN 1926

The canning procedure followed was different each year. In the preliminary work of 1926 one or two boxes of fruit from each wet and each dry plot in the Stanislaus and Sutter county orchards were shipped by express to Berkeley. On the day of arrival the fruit was cut, pitted, peeled, and canned, without grading, by members of the Fruit Products Laboratory staff. Syrup of the same degree Balling was used in the canning of all lots. The cans in each pair of lots were cooked simultaneously and for the same length of time in a vat at 212° F.

No outstanding differences in the condition of the fruit on arrival were noticed. Members of the Fruit Products staff and a few commercial canners who compared the lots were unable to find any consistent differences in the quality of the canned fruit, due to irrigation.

EXPERIMENTS IN 1927

During the season of 1927 peaches from the wet and the dry plots in the Stanislaus and Sutter county orchards were shipped with regular carloads of fruit to commercial canneries at Los Gatos and San Jose for storage and canning under commercial conditions. Each lot consisted of ten boxes totaling about 500 pounds.

[1] Grateful acknowledgment is made to F. D. Calhoon, P. H. Richert, E. M. Mrak, and H. M. Reed for assistance rendered; also to F. A. Dixon of the Canners League of California, to the Hunt Brothers Packing Corporation, and to the Pacific Coast Canneries for cooperation in providing canning facilities.

[2] Associate in Fruit Products.

Inspection of Peaches on Arrival.—When received at the canneries the peaches were weighed and superficially inspected. Two or more boxes from each lot were carefully sorted. Fruit showing any bruising, no matter how slight, or from whatever cause, was segregated from the rest. The proportion by weight of such fruit was found.

Storage Before Canning.—After approximately 36 hours in common storage, eight of the ten boxes in each lot, including those first sorted, were cut, pitted, peeled, graded and canned in accordance with the regular commercial practice. The two remaining boxes in each lot were left in storage for observation in subsequent weeks.

Observations During Common Storage.—The two boxes of each lot left in common storage were sorted periodically, usually twice a week. All fruit showing mold or rot was discarded and the sound fruit was weighed.

Observations on the Canned Fruit.—The fruit canned in the commercial manner was removed to Berkeley, where, after several months of storage it was impartially judged under code numbers by expert judges of canned peaches. Two cans from each of the six lots were displayed in pairs each representing dry and wet lots of the same grade and size. The judges were asked to designate the can of the better quality in each pair and also to designate those which appeared to have been heavily irrigated.

TABLE 1

CONDITION OF PEACHES ON ARRIVAL AT CANNERY

Location of orchard	Variety	Irrigation treatment	Fruit bruised, per cent
Stanislaus	Tuscan	Wet	40.0
		Dry	35.0
Stanislaus	Phillips	Wet	44.0
		Dry	7.2
Sutter	Phillips	Wet	24.9
		Dry	21.4

Data Obtained.—Superficial inspection of the lots on arrival indicated that all were of satisfactory canning quality. As shown in table 1, the percentage of fruit showing bruises on arrival was consistently higher in the wet plots, although the difference was of doubtful significance in the Tuscans from Stanislaus County and the Phillips from Sutter County. Moreover it is thought that the difference between fruit from the Phillips plots in Stanislaus County was somewhat exaggerated by the fact that the fruit from the wet plot was larger than that from the dry plot and the fruit segregated as bruised was chiefly stem bruised. As this is more likely to occur in large than in small fruit, it is doubtful whether this distinction really represents the correct relationship between the two plots with respect to shipping qualities.

The total and graded yields from the fruit in each plot is shown in table 2.

TABLE 2

CANNERY GRADES AND YIELDS WITH IRRIGATED PEACHES, 1927

Grade	Tuscans from Stanislaus county		Phillips from Stanislaus county		Phillips from Sutter county	
	Wet plot	Dry plot	Wet plot	Dry plot	Wet plot	Dry plot
	Cases per ton	*Cases per ton*	*Cases per ton*	*Cases per ton*	*Cases per ton*	*Cases per ton*
Fancy	3.6	2.3	19.8	6.0	6.8	11.8
Choice	8.4	14.9	23.4	31.8	20.3	25.1
Standard	10.0	4.2	2.4	3.8	....	....
Second	4.1	4.0	2.9	....	....	....
Water	2.0	1.5	....	....	....	....
Throw-out	8.7	19.2	3.3	5.3	18.3	15.7
Fancy and choice	12.0	17.2	43.2	37.8	27.1	36.9
Standard, and lower	24.8	28.9	8.6	9.1	18.3	15.7
Total, all grades	**36.8**	**46.1**	**51.8**	**46.9**	**45.4**	**52.6**
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Fancy and choice	32.7	37.3	83.4	80.7	59.7	70.2
Standard, and lower	67.3	62.7	16.6	19.3	40.3	29.8

The wet Tuscan plot and the wet Phillips plot in Sutter County yielded a smaller number of cases per ton and a smaller proportion of high grades (Fancy and Choice) than did the dry plots from these orchards. The opposite, however, was true of the Phillips plots in the Stanislaus County orchard. It should be noted that 36 hours of common storage after arrival at the cannery and before canning is unusually severe treatment, as it is customary to can all peaches on the day of arrival. Nevertheless the yield in cases per ton and the proportion of high grades was satisfactory in all cases.

The proportion of loss by rotting in the two-box portions of the lots set aside for prolonged common storage is shown in figures 1, 2, and 3. Loss was relatively most rapid in the fruit from the dry Tuscan plot and the wet Phillips plots. The periods for which the fruit was observed in common storage are, of course, far longer than any practicable storage periods for commercial use. After two weeks even the sound fruit was badly shriveled, but the keeping quality of all lots was remarkably good, especially that of the Phillips.

In judging the canned fruit, considering each judge's opinion of each pair of samples as a separate instance, the irrigation practice was correctly designated in 27 of the 42 instances, or 64.3 per cent; it was incorrectly designated in 35.7 per cent of the instances. The chief basis for judgment was the assumption that the fruit from the wet plots would be of lighter color. All the samples were considered to be of satisfactory commercial quality. While not all the judges expressed a preference as to quality, the fruit from the wet plots was

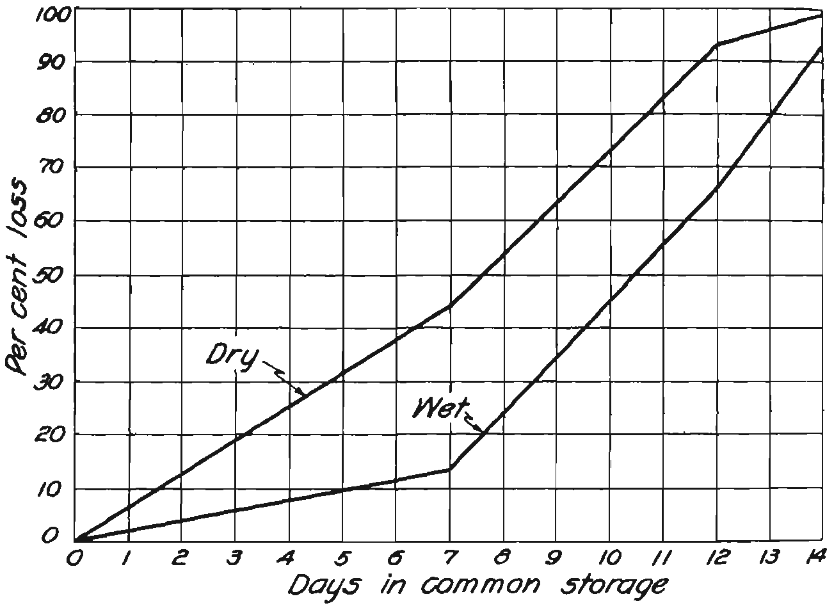

Fig. 1.—Loss from spoilage in common storage; Tuscan peaches from Stanislaus County orchard.

the more commonly chosen. One fact is particularly noteworthy. The dry Phillips plot in Stanislaus County suffered more for lack of water than did either of the other dry plots, and the wet Phillips plot in Stanislaus County received a greater excess of water than did either of the other wet plots. In fact, because of a broken ditch this plot had water standing on it for two or three weeks prior to and including the time of harvesting. Nevertheless, the canned fruit from the wet and the dry Phillips plots in Stanislaus County displayed less difference than did either of the other pairs.

Discussion.—While slight differences in bruising could be found upon arrival at the cannery, none of it was sufficiently severe to interfere with the canning quality of the fruit. All lots of the fruit kept satisfactorily for 36 hours before canning. During prolonged common storage, two of the wet lots molded more rapidly than the corresponding dry lots, but in the third pair, the reverse was true. After canning, fruit from the wet plots was distinguished from that from the dry plots in less than two-thirds of the instances. All lots were of satisfactory canning quality, even including one lot taken from a plot on which water stood for several weeks just before picking.

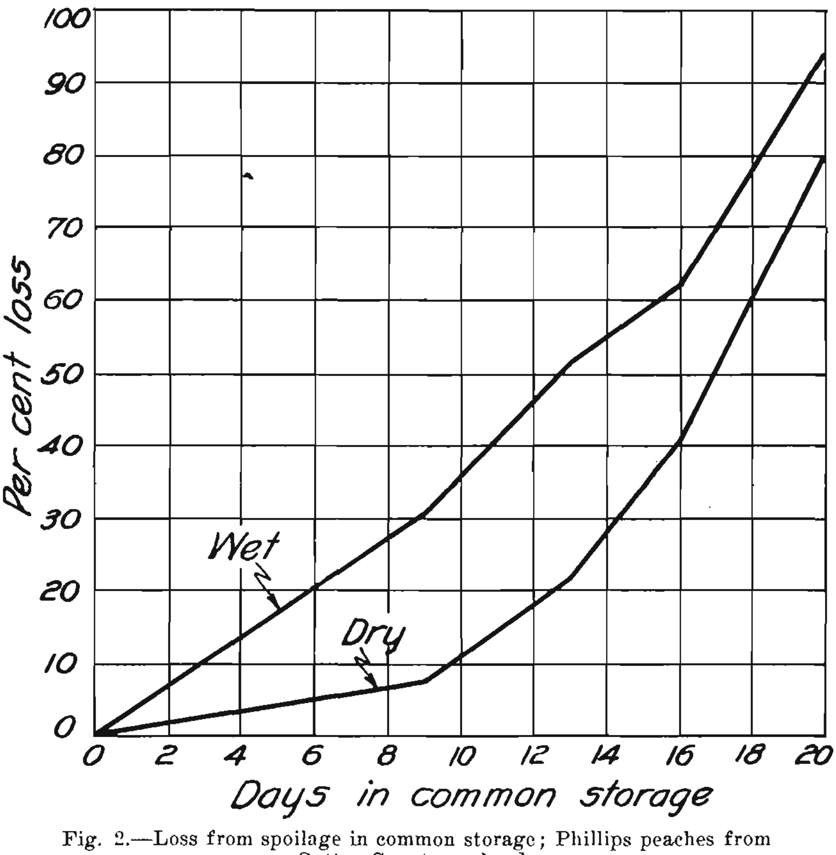

Fig. 2.—Loss from spoilage in common storage; Phillips peaches from Sutter County orchard.

EXPERIMENTS IN 1928

In 1928 another method of canning the fruit was used. Two boxes of fruit from the wet and two from the dry plot in the Sutter County orchard were wrapped and shipped to Berkeley by express. On arrival, the fruit was taken to a commercial cannery at Oakland. Here it was prepared in the regular manner by members of the cannery crew. After removal of "second" or poorer quality pieces, the fruit was placed without further grading in No. 10 cans with a syrup of 40° balling. It was then exhausted, sealed, and cooked in an agitating cooker for 26 minutes.

On arrival at the cannery the fruit was in excellent condition. Both lots were described by the cannery manager and crew as of excellent canning quality, though in one lot on cutting and pitting the fruit was described by the cannery workers as slightly more tough and woody at the center than the other lot. From this the cannery

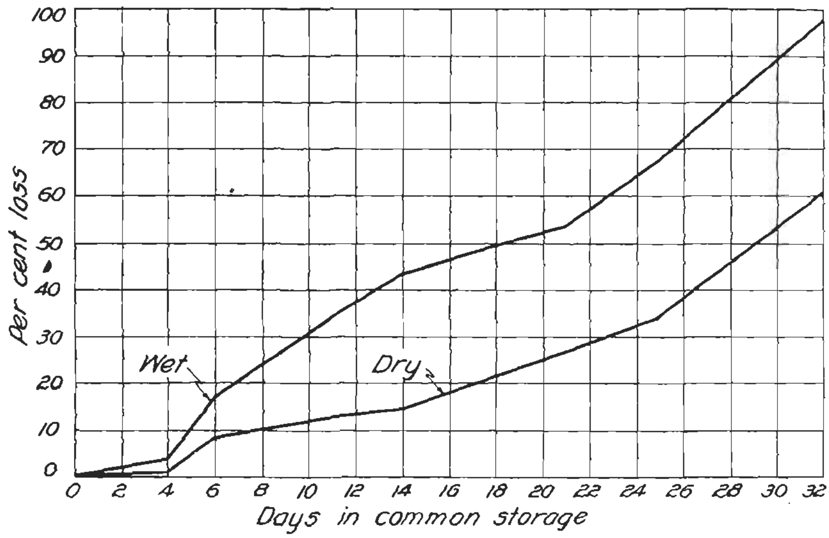

Fig. 3.—Loss from spoilage in common storage; Phillips peaches from Stanislaus County orchard.

manager, who did not know the identity of the fruit, correctly surmised that the tough lot was from the dry plot, and stated that he believed the other lot would prove to be somewhat superior in canning quality.

Eight months later several cans from each lot were opened and the fruit examined and classified, piece by piece, by W. H. Tuggle, Chief Inspector under the "Seconds Act," of the California State Department of Agriculture. Of 80 pieces from the "wet" plot examined 30 per cent were classified as choice or fancy, 68 per cent as standard, and 2 per cent as second. Of 135 pieces from the dry plot, 43 per cent were classified as choice or fancy, 48 per cent as standard, and 9 per cent as seconds. Both lots were described as of very good quality, tender and excellently cooked, and with no noticeable superiority of one lot over the other.

SUMMARY

In these experiments attempts have been made to distinguish between clingstone peaches from wet and dry plots with respect to their condition after shipment, their ability to stand up under common storage, and their canning quality. No consistent differences of significance were found even though the irrigation practices differed greatly and the storage tests were unnecessarily severe. The greatest differences in irrigation practice have been accompanied by some of the smallest differences in quality. All the experimental lots were of satisfactory canning quality. Maintenance of a high soil-moisture content up to and including the date of picking did not result in any discernible injury to the quality of the fruit.

CONCLUSIONS

From the experiments here reported it is concluded:

1. The variations in irrigation practice reported in this publication were not found to produce consistent effects on the shipping and canning quality of clingstone peaches.

2. Irrigation of clingstone peaches which resulted in the maintenance of large amounts of readily available soil moisture up to and including the time of harvesting did not injure either shipping or canning quality.