

CIRCULAR 50

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ESSENTIALS

of

IRRIGATION
and
CULTIVATION

of
ORCHARDS

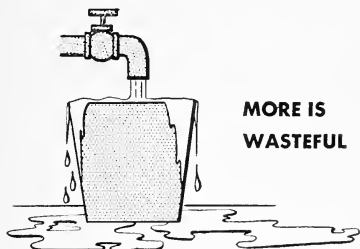
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Irrigation . . .

ENOUGH IS ENOUGH!



The purpose of irrigation is to keep the soil supplied with readily available moisture at all times.

The benefits derived from good irrigation practices are cumulative, but may be slow in appearing.

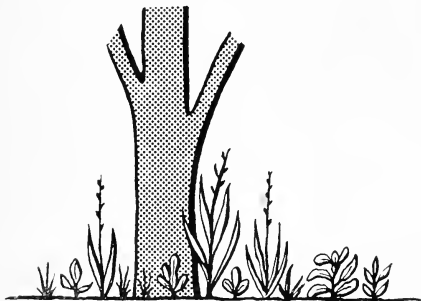
But . . .

nothing is gained by irrigating frequently enough to keep the soil moisture at a high level.

On the Other Hand . . .

if the soil is allowed to become dry and remain in that condition for a considerable period, harmful results may follow.

Cultivation . . .



The most important purpose of cultivation of orchard soils is to remove weed competition.

THE AUTHORS . . .

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THIS CIRCULAR briefly summarizes the results of experiments conducted by the writers on the irrigation and cultivation of deciduous orchards in California.

Work of others in California on the irrigation of citrus trees, cultivation, and moisture control has been taken into account.

While the discussion deals with orchards, the principles also apply to other crops. The fruit grower is interested in soil moisture from the standpoint of plant growth rather than from the physical forces involved in its presence and behavior. In this circular, therefore, soil moisture is discussed from the viewpoint of its availability to plants.

WATER IN SOILS

HOW WATER IS STORED IN THE SOIL

Soil is a porous material composed of particles of many different sizes touching each other at certain points. The space not occupied by the particles themselves constitutes a large portion of the volume of the soil. This space is called the pore space. It is in this pore space that water is stored.

THE SOIL IS A RESERVOIR FOR WATER

The soil in which most of the roots of a tree are growing may be likened to a reservoir containing various amounts of water at different times of the year. Ordinarily, in California, the soil containing these roots is filled to its field capacity at the beginning of the growing season. In mature orchards where drainage is unrestricted, without irrigation the readily available moisture in the soil occupied by roots is usually exhausted before the end of the growing season. The trees then remain wilted until fall rains renew the water supply. In other words, the trees use all the readily available water and then exist as best they can. There is no

way of remedying this situation, except by irrigation.

HOW SOILS ARE WETTED

After an irrigation, the soil throughout the portion wetted is at uniform moisture content as far as can be detected with the means of sampling now available.

The downward movement of water in soil is due more to gravity than capillarity which cannot be depended upon to distribute moisture uniformly. Hence, a light irrigation simply wets a shallower depth to its field capacity than a heavy one does. It does not bring about a moisture content less than the field capacity. In other words, soils cannot be partially wetted. They must be completely wetted or not at all. (Fig. 1.) Of course, in undrained soils the field capacity may be exceeded. In this connection, when the furrow system is used and the furrows are too far apart, portions of the soil will remain dry, since lateral movement caused by capillarity is very limited. The occurrence of a plow sole or of decided differences in soil texture or structure will increase the lateral movement.

GLOSSARY OF TERMS

A clear understanding of some of the terms used in this circular will aid in the discussions which follow.

FIELD CAPACITY

... is all the water a soil will hold after it is drained.

When water is applied to a soil the pore spaces are almost filled for a short time to the depth wetted. During this interval the soil is nearly saturated. (Fig. 2.) If drainage takes place, some of the water will move downward and, to a less extent, laterally, by gravity. The water moving downward is called gravitational or free water. Gravitational water stays in drained soils for only a short time. The amount of water held by the soil after drainage has taken place is called the field capacity of that soil. At field capacity each soil particle is completely surrounded by water, but most of it exists in the form of wedges between the soil particles at their points of contact. (Fig.

3.) It is from these wedges that plants get most of their water. Some of the water in the soil is capable of moving by capillarity. This is sometimes called capillary moisture. As pointed out later, movement of water in soil by capillarity is very limited in the absence of a water table.

That portion of the moisture in the soil which is supposed to be unable to move by capillarity is called hygroscopic moisture. Hygroscopic moisture is present in varying amounts in soils taken from the field, even when the soils appear to be dry. There is no sharp distinction between capillary and hygroscopic moisture.

The classification of soil moisture into gravitational, capillary, and hygroscopic water is not very helpful in interpreting plant responses, because capillary water may become gravitational water and may be made to drain away from the soil under certain conditions. In some cases, plants may use some of the so-called hygro-

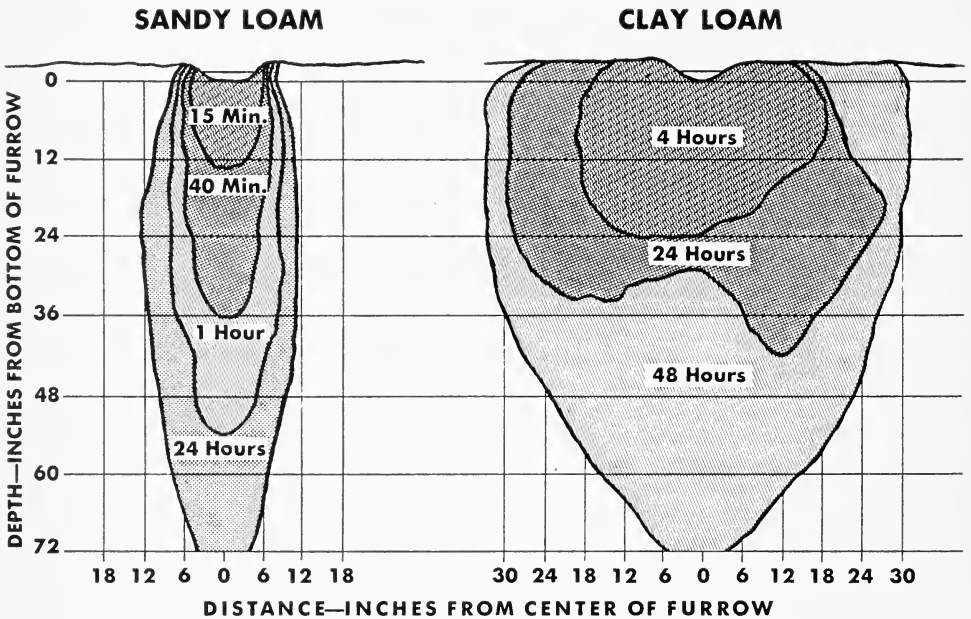


Fig. 1. A light irrigation simply wets a shallower depth to its field capacity than a heavy one does. Soils cannot be partially wetted. They must be completely wetted or not at all.

scopic moisture; in others, they cannot use all of the capillary moisture. In still others, they may even use gravitational water.

When irrigation water is applied to a soil, that soil is moistened to its field capacity to a definite depth, which depends upon the dryness of the soil and the amount of water used.

We may consider that the moistened portion of a drained soil of uniform texture and structure reaches its field capacity a short time, say 2 or 3 days, after a rain or an irrigation. Any layer of soil which hinders the movement of water will increase the time necessary for the soil to reach its field capacity.

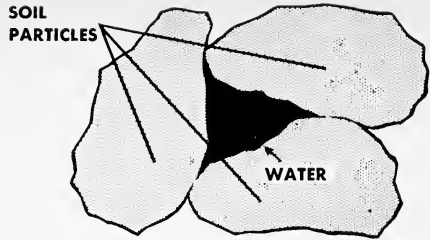
The field capacity may be considered the starting point from which trees begin to use water from the soil in their normal functions of growth and fruiting, although some water may be used while the soil is being irrigated and before the field capacity is reached.

Texture, Structure, Uniformity, and Depth of the soil will influence Field Capacity . . .

The field capacity of a soil is influenced by a number of factors, such as texture, structure, uniformity, and depth.

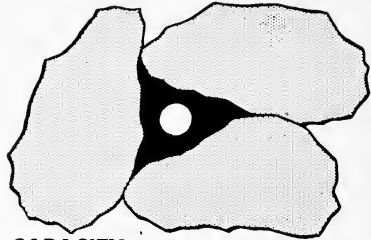
Soil texture refers to the size of the particles and indicates the coarseness or fineness of the soil. In general, the fine-textured soils, such as clays and loams, in which a majority of the particles are very small, hold more water at the field capacity than the sands. This is because the fine-textured soils have more particles in a unit volume of soil and consequently more water-holding wedges. The amount of water may be greatly influenced by the extremely small particles in the soil which are known as colloids. The field capacity can be increased only slightly by adding organic matter, and the effect is usually limited to the surface layer.

Structure is the manner, or pattern, in which the soil particles are arranged.



SATURATION

Fig. 2. When water is applied to a soil the pore spaces are filled for a short time to the depth wetted. Until drainage takes place the soil is saturated.



FIELD CAPACITY

Fig. 3. The amount of water held by the soil after drainage has taken place is called the field capacity of that soil. At field capacity each soil particle is completely surrounded by water but most of it exists in the form of wedges between the soil particles at their points of contact. It is from these wedges that plants get most of their water.

It may influence the penetration of the soil by water.

Uniformity. The field capacity is affected if the soil is not uniform in texture and structure. For example, if a fine-textured soil, such as clay, overlies a coarser soil—sand, or even gravel—the zone immediately above the coarser layer will have a higher field capacity than the clay would have if it were uniform throughout.

Depth. The depth of a soil influences the amount of water held in a soil when it is at the field capacity.

A shallow soil holds more water in a unit depth at the field capacity than a deep soil of the same kind, but this is not marked in soils deeper than about 2 feet.

The presence of a water table, also,

influences the amount of water held by a soil. The moisture content just above the water table is greater than that which this soil would have if it were drained. The distance above the water table affected this way is greater in clays than in sands. However, the amount of water held in the soil occupied by the roots is increased measurably only by shallow water tables, and not by deep ones.

MOISTURE EQUIVALENT

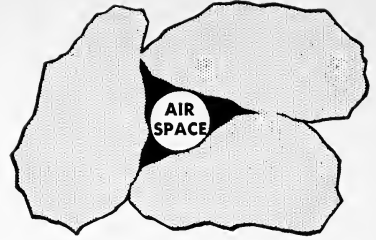
... a laboratory method of measuring a certain soil moisture characteristic or condition.

Attempts have been made to characterize soil-moisture conditions by means of laboratory tests. The method most commonly used is known as the moisture-equivalent determination.

The moisture equivalent is a useful measure because it agrees closely with the field capacity of most of the fine-textured soils, but usually is lower than that of the sands. It gives a laboratory method for making an estimate of the amount of water the soil will hold shortly after a rain or an irrigation. A direct measurement of the field capacity would be better, although it is not always practicable.

It has long been assumed that the moisture equivalent when divided by the factor 1.84 gives the "wilting coefficient," and the plants would not wilt so long as the soil-moisture content was above this percentage, but this relationship does not hold for all soils. The best method therefore, to find the amount of moisture left in the soil when plants wilt is to grow plants on each soil and determine the soil-moisture content when they wilt.

But before growers accept recommendations for the irrigation practices in their orchards based on the moisture equivalent alone, they should understand the limitations of the method used to make the determination and the fact that it cannot be used to measure the amount of water available for plants.



P. W. P.

Fig. 4. A certain amount of water is held so tightly by soil particles that the roots cannot absorb the water rapidly enough to prevent wilting. It is the soil-moisture condition at which the plants wilt and do not recover unless water is applied to the soil.

PERMANENT WILTING PERCENTAGE

... the soil-moisture condition at which trees and plants cannot obtain water readily.

The permanent wilting percentage is the moisture content below which the trees cannot readily obtain water. (Fig. 4.) It is the soil-moisture condition at which the plants wilt and do not recover unless water is applied to the soil.

Although many plants show, by a wilting or drooping of the leaves, when this soil-moisture content is reached, others do not. In the latter case the decreased rate of growth of plant or fruit, change of color of leaves, or some other sign, may indicate the lack of readily available water.

Because of the difficulty in obtaining precise results in soil sampling and in determining exactly when a tree is wilted, the permanent wilting percentage, as used in this circular, represents a narrow range of soil-moisture contents within which wilting takes place.

When the soil moisture is reduced close to the permanent wilting percentage, a drooping of the leaves occurs, usually during the late afternoon. It has been found for a wide range of soils that if this wilted condition is noticeable when transpiration begins the following morning, the

permanent wilting percentage has been reached in that part of the soil filled by the major portion of the root system. This limits the normal activities of the tree.

The term "permanent wilting percentage" is commonly referred to as the "PWP." This abbreviation, therefore, is used throughout the pages which follow.

READILY AVAILABLE MOISTURE

... is the moisture above the PWP.

Soil moisture is not so readily available below the PWP as above it.

All of the water in a soil cannot be used by plants. A certain amount is held so tightly by soil particles that the roots cannot absorb it rapidly enough to prevent wilting.

Our experiments show that water may be used by plants with equal ease throughout the entire range of moisture contents of the soil in contact with the roots between the field capacity and the PWP. In this circular therefore, the moisture ABOVE the PWP is called readily available moisture.

There is no simpler way, so far as we know, of determining the amount of readily available moisture in a soil at known field capacity than by growing a plant on it and finding the PWP.

While the field capacity of clay soils is greater than that of sandy soils, we have found some sandy soils that actually contained MORE readily available moisture than some clays. Tests with soils showed that the readily available water varied from about one-quarter to three-quarters of the moisture equivalent. These differences did not depend upon the textural grade, that is, whether it was a clay, a loam, or a sand.

The amount of readily available water in a soil may be likened to the amount of water which may be drawn from a faucet on the side of a barrel filled with water. (Fig. 5.) The field capacity is the amount of water the barrel will hold after drainage. The water above the faucet may be

drawn off and represents the readily available moisture. If the faucet is placed low on the side of the barrel, a large amount of water may be taken from the barrel while only a small amount may be taken from a high faucet. Some soils are like barrels with low faucets and others like those with high faucets.

OPTIMUM MOISTURE

... a false idea.

There is no "optimum," or best, soil moisture content for plant growth. Generally, "optimum moisture," is supposed to be a moisture percentage less than the field capacity.

Our experiments have shown that there is no one percentage of the readily available moisture at which plants grow better than at another and which, therefore, could be considered an optimum for plant growth. Furthermore, even if there were a theoretical soil-moisture content for best plant growth, as many have supposed when using the term "optimum," this moisture content could not be maintained in the soil, and consequently, is of no practical importance. Attempts to maintain any soil-moisture content lower than the field capacity have been failures because, as explained later in more detail, the movement of moisture by capillarity is too slow to bring about a uniform distribution in the soil of the water applied at any point. In other words, it is not possible to bring about any desired moisture content, such as 10, 15, or 20 per cent in a soil on which plants are growing, if these percentages are lower than the field capacity.

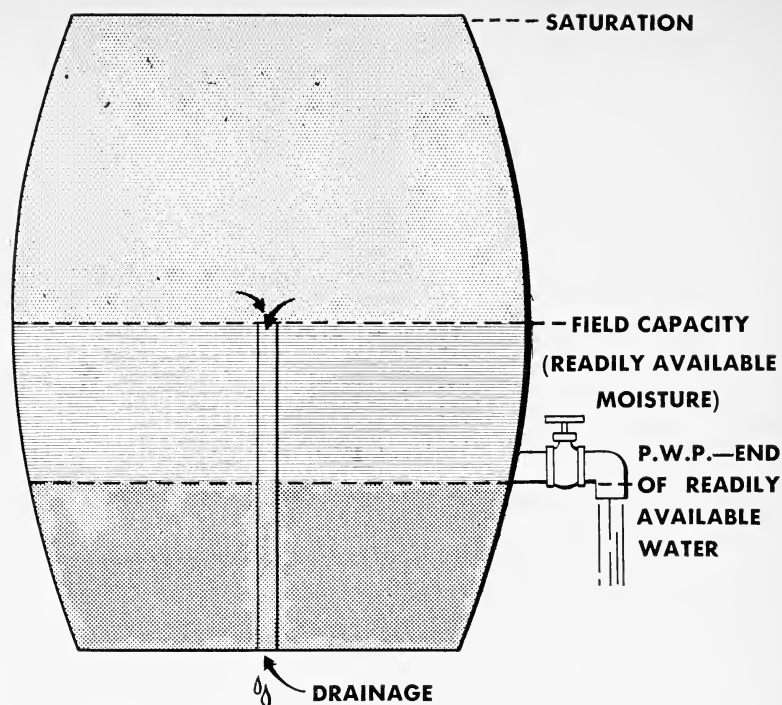
WET AND DRY SOIL

... as determined by the growing behavior of plants.

The apparent moisture condition of a soil is not always a safe way to judge the readily available moisture in that soil.

Compressing the soil in the hand, and judging if it contains sufficient water for plant growth by the way in which the

Fig. 5. Some Soils Are Like Barrels . . .



. . . with low faucets and others like those with high faucets. The amount of readily available water in a soil may be likened to the amount of water which may be drawn from a faucet on the side of a barrel filled with water. The field capacity is the amount of water the barrel will hold after drainage. The water above the faucet may be drawn off and represents the readily available moisture. If the faucet is placed low on the side of the barrel, a large amount of water may be taken from the barrel while only a small amount may be drawn from a high faucet.

SATURATION—When water is applied to a soil the pore spaces are filled for a short time to the depth wetted. During this interval the soil is saturated.

FIELD CAPACITY—The amount of water held by a soil after drainage has taken place is called the field capacity of that soil. Water may be used by plants with equal ease throughout the range of moisture contents of the soil in contact with the roots between the field capacity and almost to the permanent wilting percentage. This is the readily available moisture.

READILY AVAILABLE MOISTURE—This is the moisture content above the permanent wilting percentage. Soil moisture is not so readily available below the permanent wilting percentage as above it. All of the water in a soil cannot be used by plants. A certain amount is held so tightly by soil particles that the roots cannot absorb it rapidly enough to prevent wilting.

PERMANENT WILTING PERCENTAGE—This is the moisture content below which trees and plants cannot readily obtain water. It is the soil moisture condition at which plants wilt and do not recover unless water is applied to the soil.

particles stick together, is not always dependable. The term "wet soil" means one which contains readily available moisture, while "dry soil" does not.

It may be possible to have a soil which appears moist but from which a plant cannot get enough moisture to prevent wilting. In this sense, the soil will be dry.

USE OF WATER BY TREES

Water taken from the soil by trees is almost entirely given off as water vapor through the leaves. This is called transpiration and is like evaporation from a piece of wet paper. Transpiration may be controlled by internal conditions within the plant.

The important external factors influencing transpiration, other than soil moisture, are sunlight, temperature, humidity, and wind. (Fig. 6.) The amount and quality of the sunlight probably exerts more influence than the other factors. High temperatures are usually accompanied by low humidities. This tends to increase transpiration. Transpiration may be less on a calm day than on a windy one, but it does not increase in direct proportion to wind velocity. The effect sometimes noticed on leaves after a period of strong winds is probably due to the combination of low relative humidity, high temperatures, intense sunlight, and mechanical injury.

Large trees with great leaf areas transpire more water than small trees of the same kind. Since the transpiration takes place almost entirely through the leaves, the amount of water used by the tree is not materially influenced by the presence or absence of fruit.

Transpiration by deciduous trees is confined almost entirely to that part of the year when leaves are present, although some water is used during the leafless period. Our experiments with prunes, peaches, and apricots indicate that the use of water depends largely upon the size of the trees and not upon the particular kind. However, this may not apply to trees differing as widely as the olive

and orange. Evergreen trees use water throughout the year, but the amounts used in the winter usually are much less than in the summer.

The extraction of water from the soil by trees is not affected by soil moisture until it is reduced to the PWP in the soil in contact with the roots. The use of water is influenced by the factors already discussed, but the effect of these is much more marked when the moisture is above the PWP than when it is below.

At the PWP or below, trees use water very slowly in spite of climatic conditions favorable to transpiration. The rate of use varies with the surrounding conditions, and may not be the same during each hour of the day, although experiments in deciduous orchards under fairly uniform climatic conditions show that the rate of moisture use is substantially constant day by day until the soil moisture is reduced to about the PWP. Of course, changes in evaporation condi-

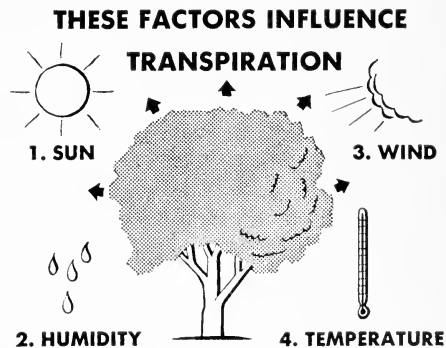


Fig. 6. Important external factors influencing transpiration other than the lack of soil moisture are sunlight, temperature, humidity and wind.

tions during the day and from day to day, such as between a foggy day and a

bright one, will cause corresponding changes in transpiration rates.

TREE RESPONSES TO SOIL-MOISTURE CONDITIONS

Experiments with several kinds of deciduous fruit in California show that the growth of fruit is retarded, and other symptoms appear when the soil containing most of the roots has been reduced to the PWP. The degree of injury depends upon the length of time the soil remains in this condition. (Fig. 7.)

During the experiments on the irrigation of deciduous orchard trees in California, many results have been obtained, and many observations made on the response of fruit trees to various soil-moisture conditions, particularly those in which the trees were allowed to remain permanently wilted for relatively long periods.

These responses may be segregated into two general classes:

1. In which the response is immediate or takes effect in the season when a change is made in the irrigation treatment.

2. In which the response appears slowly and which is sometimes only apparent after several years of following a given irrigation program.

In general, the beneficial results are chiefly those obtained during several years of good irrigation practice. Immediate results are generally harmful ones that usually follow changes in practice involving neglect or ceasing to irrigate, especially if this occurs during certain critical periods.

Increases in yield, as a rule, are among the benefits that are sometimes slow in appearing, and are the reward for the long-continued practice of keeping the trees supplied with readily available water throughout the year.

On the other hand, such responses as decreased size in many fruits, delay in maturity of pears, and a lowered percentage of well-filled shells in walnuts are

some of the results that immediately follow a failure to keep the trees supplied with ample moisture.

Briefly, the initiation of good irrigation practice does not bring about beneficial results as if by magic, but lack of moisture may cause serious loss the same season that the neglect occurs.

RESULTS OF EXPERIMENTS WITH FRUIT TREES

The following results are summarized from long-time experiments with fruit trees at Davis, and from other experiments carried on for comparatively short periods in widely separated fruit-growing areas in California.

All experiments in the field were carried out in such a way that certain plots had readily available moisture at all times, while others were subjected to dry soil conditions after the moisture from winter rains was exhausted. In some cases in-

SOME OF THE RESULTS OF POOR IRRIGATION PRACTICES ARE:

SMALLER YIELD



SMALLER FRUIT



POORER QUALITY



STUNTED TREES



Fig. 7. Experiments show that growth of fruit is retarded and other symptoms appear when the soil containing most of the roots has been reduced to the permanent wilting percentage. The degree of injury depends upon the length of time the soil remains in this condition.

intermediate treatments were also used. At Davis the irrigation treatments were greater in number, and each treatment was replicated several times.

EFFECT OF IRRIGATION ON SIZES OF TREES

One of the most noticeable responses obtained with peach and prune trees was the slow but comparatively steady gain in size, as measured by the cross-section areas of tree trunks, of the irrigated trees over the unirrigated ones.

At the beginning of the experiment, the plots were divided into treatments in such a way that the average sizes of trees and the average yields were as nearly equal as possible.

After two years, the trees in the irrigated plots showed evidence of growing faster than those in the unirrigated plots. As the experiment progressed, the unirrigated trees and those in the intermediate plots in which the soil-moisture was reduced to the PWP for varying periods, continued to grow more slowly, until the irrigated trees were distinctly the largest, with the intermediate plots in second place, and the dry plots the smallest.

Walnut trees did not respond in size to differential treatment as quickly as either the peach or prune trees. In fact, the trees in the dry treatment, which were the largest at the beginning of the experiment, remained so for several years. This may be due to the deep-rooting habit and wide spacing of walnut trees.

Gains in size due to irrigation were comparatively slow whether in prune, peach, or walnut trees.

EFFECT OF IRRIGATION ON YIELDS

The yield records for the prune orchards show that all plots produced about equally before the various irrigation treatments were begun. There was, however, a change in production starting with the first year when the plots were irrigated according to project plan. The irrigated plots moved ahead of the unirri-

gated ones, and have maintained their relative positions ever since. This change was due to the decrease in crop on the dry plots, rather than a marked increase in crops from the irrigated ones. The irrigated plots did not produce more fruit, on the average, than the intermediate ones until about seven years after the experiments were started.

The increasing differences in yields between the irrigated and the unirrigated treatments are due to the delayed effects of irrigation.

The yields of the intermediate plots indicate that some irrigation while the crop is on the trees is better than none at all, but this treatment is inferior to that where irrigation is frequent enough to provide readily available moisture at all times.

Similar results were obtained with peaches. The immediate effect of stopping irrigation during the growing season was a reduction in crop. This was largely due to a reduction in the size of the fruit which left a large percentage unmarketable. The intermediate plots (at PWP for short periods) fell behind the irrigated ones in production during the third summer of differential treatment.

RELATION OF SIZES OF TREES TO YIELDS

The experiments dealing with the irrigation of peach and prune trees indicate a general relationship between sizes of trees and yields. These results are in accord with observations in many places that indicate that fruit trees grown in areas where irrigation is not possible are generally smaller and yield less than those in areas where irrigation water is applied when needed. These results also indicate the relatively slow response, where yields are concerned, of trees to irrigation, particularly in areas similar to Davis where winter rainfall is ordinarily sufficient to provide water for a considerable portion of the growing season.

EFFECT OF IRRIGATION ON SIZES OF FRUIT

Maintenance of readily available soil moisture allows the fruit to grow normally according to the characteristic of the particular kind of fruit. Lack of readily available soil moisture while the fruit is growing causes an immediate check in growth. Slow growth of fruit on peach, pear, and prune trees has been repeatedly found at Davis when the soil moisture in the upper 5 or 6 feet of soil is reduced to the PWP. Similar results have been observed in the San Joaquin Valley on Japanese plums, on soils holding a comparatively small amount of available moisture.

In some early sections, where the winter rainfall is ample and the soil holds a comparatively large supply of moisture, certain early fruits may be grown to maturity without irrigation and reduction in size of fruit, because the amount of moisture is sufficient to supply the needs of the tree at least until the crop is mature. Late fruits in these areas, however, show the characteristic responses to lack of moisture.

Almond and walnut fruits grow rapidly during the spring months and usually attain full size before the available soil moisture is exhausted. Reduction in sizes of almonds and walnuts is generally only noticeable in unirrigated areas following winters of exceptionally light rainfall.

Size of some kinds of fruits is also related to the numbers of fruits on the trees. If the fruits are not thinned, the final sizes may be unsatisfactory in spite of good irrigation. Of course, if the trees do not get sufficient water while the crop is growing, the fruits will be very small.

On soils holding comparatively large amounts of readily available moisture in the cool coastal regions, fruits may grow to normal size even though unirrigated.

In general, fruits may be expected to attain normal size, if the usual thinning practice is followed, and if the soil mois-

ture does not fall to the PWP while the fruits are growing.

Fruits stunted in growth because of the lack of moisture, begin to grow more rapidly than previously if the supply is replenished, but they always remain smaller than similar fruits not allowed to suffer for water.

EFFECT OF IRRIGATION BEFORE READILY AVAILABLE MOISTURE IS EXHAUSTED

Sometimes water is applied so frequently that the available supply is maintained well above the PWP. Experiments at Davis indicate that there are no outstanding responses in growth or yields, either immediate or delayed, to this type of treatment. Certain of the irrigated plots of prunes, peaches, and walnuts have been irrigated for a number of years when there was still an ample supply of moisture in the soil. Neither the growth of trees nor yields have been increased by this treatment.

If trees have readily available soil moisture, no measurable beneficial results may be obtained by adding more water. It is not possible to obtain the positive result of increasing yields by irrigating copiously or frequently following the idea that if a little is good, more is better.

Experiments show that no measurable increases in the rate of growth of apples, peaches, pears, plums, prunes, and walnuts are obtained by irrigating while the soil moisture is still above the PWP.

EFFECTS OF LACK OF AVAILABLE SOIL MOISTURE

Lack of soil moisture during the growing season is almost always followed by immediate and harmful effects. The most common is a reduction in final size of fruits. Reduction in size is particularly serious in that it not only reduces the total yield, but it materially reduces the amount of the marketable crop with those fruits that must meet a certain legal minimum size to be salable.

Walnuts grow rapidly during the early part of the season. They ordinarily attain full size before the soil moisture from winter rains is exhausted. Lack of soil moisture later in the season, however, results in a larger proportion of blanks or partly filled shells. The weight-volume, or number of pounds of walnuts per cubic foot, of Concord Walnuts at Davis has been consistently lower in the dry plots during the past several years than in the irrigated ones.

The foregoing responses to lack of soil moisture during the growing season are fairly common. They occur year after year in many orchards. They are not cumulative in effect nor are they generally carried over from one year to the next.

If a grower has small fruit one year because he was unable to irrigate at the proper time, he may rightly expect to produce fruit of normal size the following season, provided he does not let the moisture become exhausted again.

Another immediate and sometimes disastrous response is obtained when an orchard hitherto irrigated is suddenly deprived of water. This is not difficult to understand. The size of the aerial portion of the tree and the amount of crop set are largely determined by the treatment given the trees in previous years. The large leaf area rapidly exhausts the available moisture. Unless the moisture is replenished the tree wilts, the fruits slow down in growth, and some of the new shoots may die.

In the experimental orchards at Davis there have been two experiences that illustrate the points mentioned above.

In order to have uniform trees to work with an entire orchard was given uniform treatment. Part of this treatment consisted of regular irrigation. After a number of years in which a study was made of the growth and yields of all the trees, certain plots were laid out and differential irrigation was begun. All trees had been kept supplied with readily

available moisture at all times, and naturally those trees now in the dry plots were subjected to the greatest change in soil-moisture conditions. All trees, having had the same treatment up to the time the experiment was started, set a uniformly heavy crop. The trees in irrigated plots received water according to schedule. The trees in the dry plots exhausted the supply of moisture before the fruits attained full size. The result was a reduction of crop from the trees in these dry plots, and a reduction in the size of fruits.

The average yield of prunes from the irrigated plots in 1932 (before differential treatment) was 147 pounds, while from the dry plots it was 163 pounds.

In 1933 the respective yields were 290 pounds from the irrigated plots and 172 pounds, or over a hundred pounds less, from the dry plots.

The irrigated plots produced an average of 21.6 per cent of large fruit in 1933. The dry plots produced only 2.7 per cent.

In the peach experiment the average yields of all the plots before differential treatment were substantially the same. The first year of differential treatment found the average yield from the irrigated plots to be 232 pounds. The dry plots averaged 149 pounds.

Data on size of fruit for 1931 are lacking, but judging from the records of later years a very large proportion of the crop from dry plots was unmarketable because it did not reach the minimum size stipulated by the canneries.

In other words, a double loss was incurred—first the reduction in total yield, and second the fact that nearly all the fruit from the dry plots was unsalable.

EFFECT OF IRRIGATION ON VARIOUS QUALITIES IN FRUITS

Many growers have believed that irrigation at certain periods of the growing season has an immediate and injurious effect on fruit quality. Our experiments have shown that this is definitely not the case. The highest quality is obtained

when trees are supplied with moisture throughout the year.

Experiments with canning peaches showed that maintaining readily available moisture in the soil up to and including harvest time did not injure either the shipping or canning quality.

On the other hand, lack of moisture for several weeks before harvest produced peaches of tough, leathery texture.

Under similar conditions of dry soil, pears frequently have a high pressure test, indicating later maturity, than those kept watered; but this difference in hardness tends to disappear in storage. Delay in maturity may be serious in districts where early shipping is desired.

Quality in prunes, as measured by the specific gravity, is apparently not greatly affected by the irrigation treatment. It seems to be associated with climatic conditions during the summer.

The drying ratios of prunes do not seem to be materially affected by the irrigation treatment. They are chiefly dependent on the amount of fruit on the

trees. Years of large crops have high drying ratios while those of light crops have low ratios.

BENEFITS FROM GOOD IRRIGATION PRACTICE MAY BE SLOW IN APPEARING

The benefits derived from good irrigation practice are cumulative. Increased crops result chiefly from increased sizes of trees which in turn depend on the trees being kept healthy and vigorous. One of the chief factors in keeping trees vigorous is an irrigation plan providing readily available soil moisture at ALL times.

There appears to be no irrigation formula that will QUICKLY improve crops of deciduous fruits. Sometimes the benefits from irrigation may be slow in appearing, and are only apparent after several years.

On the other hand, immediate responses to changes in irrigation treatments result when the watering of trees is suspended. These responses are not only immediate, but they are often injurious.

IRRIGATION DURING THE GROWING SEASON

Assuming a mature orchard with the trees 24 feet apart on the square system, and with the majority of roots in the upper 5 feet of soil, there are 2,880 cubic feet of soil from which each tree may obtain water. This volume of soil is essentially a reservoir that contains, when filled to its field capacity, a definite amount of readily available moisture.

As an example taken from actual measurements, a peach orchard in one of the largest peach-growing sections on clay loam soil with a field capacity of 25 per cent, two-thirds of which is readily available, contains approximately 260,000 pounds of dry soil in the 2,880 cubic feet. A 25 per cent moisture content of this soil is 65,000 pounds of water or 1,040 cubic feet. Two-thirds of this, or about 700 cubic feet of water, is readily

available to the trees, and this quantity is equivalent to a depth of about 15 inches of water.

In other words, when the PWP is reached, an application of water 3 inches deep would be required to wet each foot of such soil.

Of course, if the entire 5 feet of soil is not reduced to the PWP, 15 inches will not be needed.

While an application of 15 acre-inches to the acre may seem too great when ordinary irrigations are considered, it must be remembered that ordinarily water is applied before all the readily available moisture is exhausted, or the soil is not wet to 5 feet.

Another experiment with clay loam soil showed it to have a field capacity of about 25 per cent, half of which was

readily available. Only about 500 cubic feet of water could be used readily by the trees and it would require approximately 10½ inches of water to replenish the supply.

USE OF WATER BY TREES DURING THE GROWING SEASON

After the leaves are formed, the trees begin to draw upon the soil moisture and continue to do so until it is reduced to slightly beyond the PWP. After irrigating, this process is repeated. In practice, of course, the orchard should be irrigated before the trees wilt.

The number of times this cycle of events takes place during the growing season depends upon the size of the trees, the climatic conditions, and the kind and depth of the soil.

The total amount of water that comparable trees will use will not be greater on a clay soil than it is on a sandy soil if both are fertile and have readily available water at all times. Usually on sandy soils, however, water must be applied more frequently and in smaller amounts than on clay soils.

With the coming of warm weather, the readily available water is quickly used by the trees. This should be replenished.

WEEDS LEFT IN THE ORCHARD MAY AID IN JUDGING WHEN TREES LACK READILY AVAILABLE MOISTURE

The orchardist should be able to judge when his trees need water because of his close association with them and his daily observation of their condition.

When wilting or any other evidence of lack of readily available moisture is hard to detect in the trees themselves, the best method by which the grower can decide when this condition is reached is by watching some of the broad-leaved weeds which may be left as indicator plants in various places in the orchard. Generally, such weeds are deep-rooted enough to

indicate by their wilting a lack of readily available water in the soil occupied by the roots of the trees.

The soil at this time will show, under examination, its condition of dryness, and the grower may become familiar enough with it to recognize when the moisture content is close to the PWP. At other times he may anticipate when this condition will be reached. This could avoid possible injury to the trees by actual wilting.

Where only small streams of water are available, the time necessary to cover the orchard may be so long that the trees which are irrigated last may be decidedly affected before they receive water. It is very important, therefore, to anticipate when the PWP will be reached so that irrigation may be started soon enough.

OBSERVATIONS ON USE OF WATER IN SOME CALIFORNIA FRUIT-GROWING AREAS

Experiments with mature peach trees in the Sacramento and San Joaquin valleys show that the interval between depletions of the readily available moisture in the upper 5 feet of soil in the summer varied from 3 weeks in a sandy soil to 6 weeks in a clay loam soil.

On shallow, hardpan soils, trees should be irrigated more frequently with smaller applications of water than on deep soils.

Mature prune trees on loam soils in the Santa Clara Valley exhausted the readily available soil moisture in from 4 to 6 weeks during the hottest part of the season.

In the central coastal region, under low evaporating conditions, one irrigation during the growing season was sufficient for apple and pear trees on deep fine-textured soil.

In years of normal rainfall, citrus growers on the coastal plain areas of San Diego County will have a summer irrigation requirement of from 12 to 15 acre-inches of water per acre. The irri-

gation interval ranges from 4 weeks on the lighter soils to a maximum of 6 weeks on the heavier soils.

In the interior valleys of San Diego County and the intermediate areas of Orange County, the seasonal transpiration use by mature trees in good condition ranges from 18 to 22 acre-inches per acre. July and August are the months of heaviest use.

In San Bernardino County the use of water by a citrus grove with a heavy summer crop of weeds increased the seasonal use by 8 acre-inches of water per acre. In this orchard a maximum use of $7\frac{1}{2}$ acre-inches per acre was observed during July which required irrigation at two-week intervals.

It should be pointed out that evergreen trees use water later in the fall and earlier in the spring than deciduous trees. They even use some moisture on clear warm days during the winter.

In most of our experiments, the distribution of roots of deciduous trees has been such that a uniform use of water has occurred in the top 5 to 6 feet of soil. (Fig. 8.)

Studies in the irrigation of citrus groves show that an average of not more than 5 per cent of the moisture used was taken from the fifth foot of soil, which indicates that most of the roots were above this depth. In fact, in soils less than 3 feet in depth 50 to 60 per cent of the roots probably are in the first foot of soil or below the cultivated layer.

On the other hand, walnut trees on a fairly uniform soil extracted the moisture to a depth of 12 feet or more.

WATER TABLES MAY BE HARMFUL

The presence of a high water table may, in some cases, result in upward movement rapid enough to replenish water in the upper layers. In others, the upward movement may not be sufficient to take care of the needs of the trees. Thus, it has been observed in some cases that frequent surface irrigations are necessary on certain

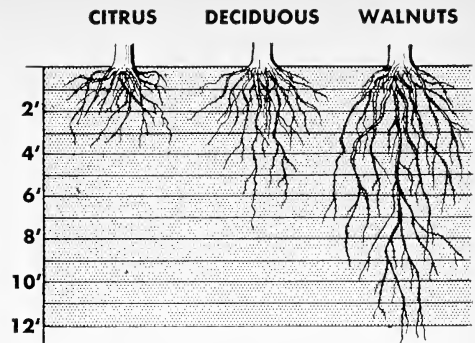


Fig. 8. All kinds of trees do not root to the same depth. Observations indicated that most of the roots of citrus trees extracted moisture from the first four feet of soil; deciduous trees from the top five to six feet; and walnut trees to a depth of twelve feet or more.

types of soil even when the water table is fairly close to the surface.

Marked fluctuation of the water table during the growing season may produce harmful results. Under these conditions, a high water table should not be relied upon to supply moisture during the growing season, and drainage may be necessary. In addition harmful concentration of salts may accumulate if the water table is near the surface.

USE OF COVER CROPS DURING THE GROWING SEASON

Cover crops in the orchard during the growing season do not conserve soil moisture.

The combination of trees and cover crops needs more water during the growing season than trees alone.

The reduction of evaporation losses due to shading the soil by the cover crop is negligible when compared with the amount used by the plants. Furthermore, lessened transpiration by the trees because of the increased relative humidity brought about by cover crop transpiration is very slight.

Experiments with alfalfa in a mature peach orchard on a sandy soil indicate that about one and a half times as much water was required as when the orchard was given clean cultivation.

MAINTENANCE OF READILY AVAILABLE WATER DURING THE GROWING SEASON

The moisture content in the soil during the growing season ordinarily fluctuates between the field capacity and the PWP.

If the soil-moisture content goes above the field capacity and remains there for any great length of time, the trees may be seriously affected. In several experiments, however, prune trees were kept with standing water around them for relatively long periods, with apparently no serious effects. Other trees, such as pears on French root, have been known to withstand saturated soils for long periods without apparent injury; but it is safer to avoid this condition.

Both the leaves and the fruit are affected when the soil moisture is reduced to the PWP. Fruit on trees on dry soil grows more slowly than fruit on trees having readily available moisture. It is exceedingly important, therefore, to see that the soil-moisture content does not remain at or go below the PWP for more than a few days.

The trees will not be affected, however, if the soil is irrigated when it already contains readily available water.

If the trees wilt when the upper 2 or 3 feet of soil are dry, it will be necessary to wet them even though readily available water lies below.

SEASONAL IRRIGATION

SPRING

In some cases, irrigation during the spring is desirable.

If the winter rainfall has been insufficient to moisten the soil to a depth of 6 feet or more, this may be made up by spring irrigation. Again, if a cover crop has been allowed to grow so late that the readily available soil moisture is almost depleted, spring irrigation may be necessary. If a cover crop has not depleted the soil moisture, the first irrigation may be delayed until the readily available soil

If possible, the soil should be wetted at each irrigation to the depth in which most of the roots lie even though the lower layers still contain some readily available moisture. It is less expensive to wet this depth at this time than later.

Wetting the soil to a depth of 5 or 6 feet will usually be sufficient with most deciduous trees, and to a shallower depth with citrus trees. If there is an impervious layer within the depth mentioned, just enough water should be used to wet the soil above this layer.

The term "overirrigation" is often used to mean frequent irrigation resulting in the maintenance of readily available moisture at a high level. Actually, overirrigation results when enough water is used on deep soils to cause percolation below the roots, or waterlogging.

Leaching may take place if irrigations are too frequent or too great in amount.

The amount of water to be used at each irrigation varies with the kind and depth of soil to be wetted, and with its moisture content at the time of irrigation. If water is applied before the soil moisture content has reached the PWP, less water will be required to wet a certain depth.

The apparently deeper penetration of water obtained in some early irrigations over later ones is due to irrigation before all the readily available moisture is exhausted.

moisture is nearly exhausted, particularly, if only one irrigation can be given before the crop is harvested.

FALL

Many deciduous orchards in California are allowed to remain in a dry condition for a long period each fall.

As long as leaves remain on the trees and can function, some transpiration takes place if evaporation conditions are favorable.

Very often after the crop is picked,

either no further water, or only one irrigation, is given. As a result, the trees may reduce the soil-moisture content to the PWP, and then remain in a wilting condition for a long time. This affects some kinds of trees more than others. If it is necessary, however, to omit one irrigation from the regular schedule, the one in the fall may be eliminated with less danger of serious injury than if one in midsummer is left out.

Many growers believe that trees watered late in the season continue growing and do not mature their young growth and buds in time for them to withstand winter temperatures. No injury that could be attributed to lack of maturity has been produced in our experiments on prune, peach, or apricot trees, or on grapevines by watering late in the season.

With citrus fruits it is particularly important to maintain a supply of readily available water during the fall. In order to secure best results, trees should have readily available moisture in the fall as well as during the other seasons.

As a rule it is necessary to wet the soil in the fall only to a depth sufficient to supply the needs of the trees until rains begin. For example, if the orchard is irrigated late in September or October, only 2 or 3 feet of soil need be wetted.

Irrigation, also, is necessary for planting certain cover crops that seem to grow best when established early in the fall.

WINTER

In some districts winter irrigation is practiced in deciduous orchards. This is unnecessary if the winter rainfall is sufficient to wet the soil to the depth containing most of the roots. If the rainfall has been insufficient for this purpose, irrigation during the winter is desirable. There must be readily available moisture present during the winter months even though the trees use little water at this time of the year.

Winter irrigation rests, in part, upon the desire to fill up the soil reservoir with cheap water for use in the growing season. As we have seen, the soil can only be filled to its field capacity and any additional water above that required to wet the soil occupied by the roots moves down, when drainage is unrestricted, and may be lost by deep percolation unless it is later recovered by pumping.

When drainage is restricted, however, winter irrigation may cause unfavorable soil-moisture conditions, because of the accumulation of free water above the hardpan, particularly in the low places in the orchard.

THE INFLUENCE OF IRRIGATION ON ROOT DISTRIBUTION

Some growers believe that by withholding irrigation, trees may be made to send their roots deeply into the soil; that light irrigation tends to encourage shallow rooting; and that irrigating on one side of the tree only will result in confining the roots to that side. These ideas are not correct.

Our experiments show that if soils are wet only to a certain depth, and if the soil below this depth is at the PWP, the roots will be confined within the wetted area.

On the other hand, plants which are normally deep-rooted cannot be made to keep their roots in the upper layers of soil if those at lower depths have a readily available supply of moisture and if no other adverse condition for root development lies below.

If the soil is wet to the full depth to which the roots would normally go at the beginning of the growing season, then later applications of water during the summer will have no influence on the extent of the distribution of the roots, unless

they be frequent enough to produce conditions unfavorable for root growth.

The presence of water in amounts

above the field capacity, a condition often called waterlogging, may injure the roots of some trees.

CULTIVATION OF ORCHARDS

LOSSES OF MOISTURE FROM SOILS

Many growers believe that cultivating the soil to form a soil mulch is effective in saving moisture. Our experiments, as well as those of others, on the losses of water from soil, and the effect of cultivation on these losses, very clearly show that cultivation of itself does not conserve moisture.

The losses of moisture stored in the soil are caused by extraction by the roots of trees and other plants in the orchard, and by evaporation directly from the soil surface. Experiments show that the amount of water used in transpiration comprises a major portion of the total losses from the soil under California conditions.

A study of uncropped soils, both cultivated and uncultivated, in tanks and in field plots, showed that tillage of the soil did not save water. The soil dried out to the same extent and depth whether cultivated or not. The loss, furthermore, which occurred within the first week after water was applied approximated 50 per cent of the total loss within 80 days. Therefore, even if cultivation did reduce evaporation, it would not be effective because so large a portion of the loss occurs before the surface soil is dry enough to be properly cultivated.

OBSERVATIONS ON MOISTURE LOSSES BY EVAPORATION

The loss of moisture by evaporation during periods longer than those usual between irrigations was confined to relatively shallow depths of soil, because the movement of moisture by capillarity from moist to drier soil is extremely slow in rate as well as slight in extent. (Fig. 9.) A large portion of the loss was in the upper 4 inches. A much smaller amount

was lost from the next 4 inches. Moisture below these upper 8 inches of soil was lost at an extremely slow rate.

In California where water is applied in such amounts that considerable depths of soil are wetted, the loss by evaporation from the surface layers is a small portion of the total.

Where a water table is relatively close to the surface evaporation losses may be greater than those indicated.

CRACKING IN SOILS

These experiments were made on different soils, including clays which cracked badly on drying when crops were grown on them, but which cracked only to very shallow depths when kept bare. Cracking is the result of drying, which in turn is brought about by the extraction of water by plants. In most soils, cracking does not take place until the moisture content is reduced below the field capacity. In a few others, principally adobe soils, cracking may start before the soil is drained to its field capacity. In this case, cracking occurs while the soil is still too wet to be cultivated safely.

The loss of water by evaporation from the small cracks in the soil takes place at such a slow rate that probably nothing would be gained by covering them.

With large cracks, however, which form before the readily available moisture is exhausted, some water may be saved by the mulch where it is possible to cultivate the soil without puddling.

STUDIES SHOW CULTIVATION DID NOT INFLUENCE DISTRIBUTION OF WATER

In these studies cultivation had no influence on the distribution of water in the soil.

There was no evidence that stirring the surface soil influenced the upward movement of water. The part cultivation has been supposed to play in preventing the upward rise of moisture is based upon the theory that moisture can move in the soil in all directions through capillarity and that by cultivation the upward movement is lessened. The loose dry soil is assumed to act as a blanket, shutting off evaporation. The loosening of the soil reduces the number of points of contact between the particles, and is supposed to lessen the capillary pulling power.

Since evaporation losses are confined so largely to a shallow surface layer, and since movement by capillarity is extremely slow, especially when the soil is not in contact with free water, movement of moisture from a lower depth does not take place rapidly enough to replace that lost by evaporation.

INCREASED YIELDS RESULTING FROM CULTIVATION CAN BE ATTRIBUTED TO REMOVAL OF WEED COMPETITION

Numerous experiments have been made to measure the effectiveness of cultivation by means of yields produced. Results of many of these experiments are valueless. They contain too many varying factors. But where cause and effect can be segregated, the increased yields resulting from cultivation can be attributed to the removal of weed competition.

DEEP TILLAGE

The effects of deep tillage have been studied in a number of states.

One report concludes that "average results of a series of years show no measurable effect on crop yield as a result of sub-soiling."

A still later report states that "deep plowing and subsoil dynamiting experiments in Illinois as well as in other states indicate that these tillage methods cannot be expected materially to increase crop yields."

An added objection to deep tillage in orchards is the probable injury due to root pruning.

On the other hand, subsoiling or blasting before planting may be desirable under special conditions where particular kinds of hardpan are present. These exist when the hardpan may be broken up economically by these methods, and it will not resume its original impervious condition upon being wetted again, and where the soil is pervious and fertile below.

CULTIVATION AND SOIL AERATION

Literature concerning cultivation contains abundant evidence that tillage, of itself, does not increase yields. Therefore, the idea that cultivation is beneficial for soil aeration and results in increased fertility and yields does not seem justified.

Experiments indicate that sufficient aeration ordinarily takes place in orchard soils.

Experiments in California have shown that rapid nitrification takes place below the depths affected by tillage.

On the other hand, unfavorable conditions for aeration result if water is applied frequently enough to fill the pore space in the soil and maintain this saturated condition too long.

It may be well to point out again that our experiments show that the loss of soil moisture by evaporation is relatively unimportant under California conditions. Much of this loss occurs before the soil can be properly cultivated. The movement of moisture upward from the lower moist layers is extremely slow, and cultivation has no real effect on the distribution of water in the soil.

Experiments of others show that crop yields are not increased by stirring the surface of the soil, and that cultivation does not increase aeration in the soil occupied by the roots of the trees.

Frequent cultivations may change the soil structure so that infiltration of water is retarded.

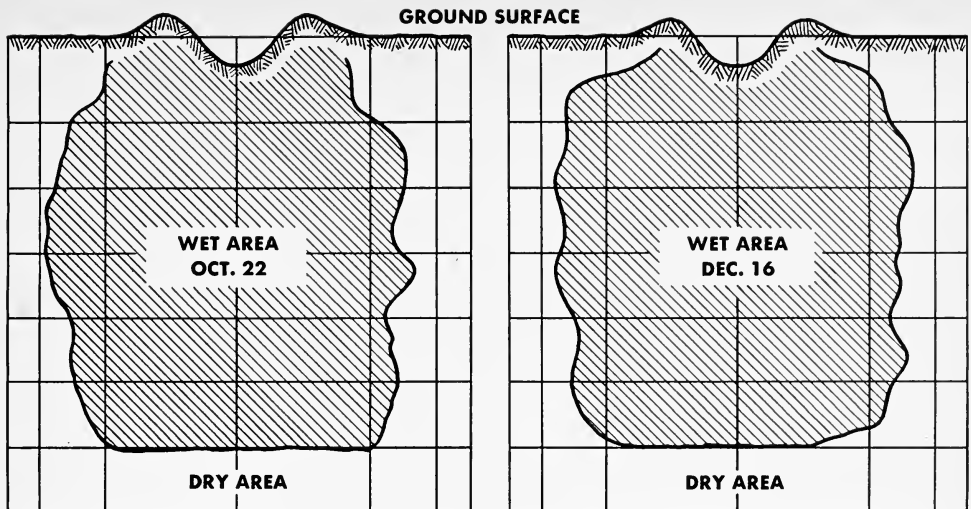


Fig. 9. Water does not move rapidly either upward, sideways, or downward by capillarity, and it will stay until removed by plants. This graph is taken from actual measurements in an irrigation furrow. The soil is loam. After the water disappeared from the irrigation furrow, a trench was cut across it and the line of demarcation between moist and dry soil was noted. The trench was then covered. Fifty-six days later, it was opened, a new face was cut, and the line of demarcation was again determined, but the moisture movement was too slight to measure.

THE PURPOSES OF ORCHARD CULTIVATION

Cultivation in orchards should be directed toward certain useful purposes. Some of these are to:

1. Remove noxious weeds and weed competition.
2. Facilitate subsequent orchard operation, such as irrigation, harvesting, brush removal, and spraying.
3. Incorporate cover crops and manure.
4. Prepare the soil as a seed bed for cover crops.
5. Facilitate the control of certain pests.
6. Aid in the absorption of water where tillage or other orchard operations have produced an impervious condition of the soil.

Weeds, during the growing season, and cover crops, if allowed to grow too late in the spring, are serious competitors with the trees for moisture and nutrients. Cultivation is the best means of removing this competition.

Several orchard operations are greatly facilitated by having the soil in proper condition.

Better levees or furrows can be made when there is sufficient loose, dry soil on the surface than where the surface is hard or cloddy.

Picking of such crops as prunes and almonds is much easier from a loose, fine surface than from among clods or weeds.

Spraying and brush removal are made easier when irrigation levees are smoothed down and furrows filled up.

On steep slopes contour cultivation may stop water from running off and being wasted.

PLOW SOLE

Plow sole is a more or less impervious, dense layer of soil formed just below the depth of tillage.

Ordinarily, a plow sole will form if the soil is cultivated while too wet.

The possibility of a plow sole forming may be lessened if only necessary cultivations are given at a time when the soil is in such a condition that it will not be puddled by the implement used.

There is no accurate way to determine

how dry a soil must be before it can be cultivated without forming a plow sole. Experience with each soil is the best guide.

Since cultivation, in the absence of weeds, has no influence in conserving moisture much is to be gained by keeping off the ground until there is least danger of forming a plow sole.

Experience has shown that leaving the soil untilled is sometimes the best remedy in overcoming a plow sole.

REPEATED CULTIVATION MAY DECREASE SOIL PERMEABILITY

Cultivation of a compacted surface layer may increase permeability of soil to water, but this lasts only for a very short time.

Repeated cultivation tends to decrease soil permeability. All tillage operations, therefore, in the orchard should be as shallow and only as frequent as necessary to accomplish the useful purposes already described.

CONTROL OF WEEDS BY OIL SPRAYS

The use of oil sprays for controlling weeds has been followed in citrus orchards for a number of years, and to a limited extent in deciduous orchards.

Where this method has been used, growers report improved soil conditions. No harmful effects have been observed to date.

It should be remembered, however, that the oil-spray method has been used for only a relatively short period in deciduous orchards.

ECONOMY IN ORCHARD IRRIGATION AND CULTIVATION

During the past several years, many California fruit growers have applied the principles set forth in this circular. In so doing they have materially changed previous practices in their orchards.

In general, cultivation has become less frequent and shallower. Furrows or

levees are often used for two or more irrigations, instead of breaking them down and making new ones each time water is used.

The sides of levees used more than once may have to be cultivated lightly between irrigations. This is not to break down the levee, but to provide soil which fills the cracks in the levee resulting from drying. By following this procedure, levees may be used one or more times even on clay soils.

Because of the lessened number of cultivations there has been considerable saving in many cases in the cost of cultivation.

A RATIONAL PLAN

The orchard is plowed or disked in the spring to incorporate the organic matter with the soil. The soil is left with a sufficient amount of loose surface soil to construct furrows or levees later in the season. If rains occur before the first irrigation, cultivation may again be necessary. But the soil is not tilled merely for the sake of stirring it. It is not cultivated again until after the first irrigation unless the weeds are too numerous and large. In some cases, the orchard is cultivated after the first irrigation. In others, it is cultivated according to the amount of weed growth and cost of water.

Sometimes the original furrows or levees are left for several irrigations if it costs less to replace the water used by weeds than it does to remove them. The same general procedure follows later irrigations, the orchards being irrigated only when the readily available soil moisture is about exhausted.

Ordinarily the orchard is cultivated and smoothed before harvest to facilitate picking of crops like prunes and almonds, and to avoid jolting fresh fruit crops by hauling them over levees.

If tree props are used, it may be necessary to cultivate the orchard early enough before harvest to permit the placing of the props.

Usually the soil in deciduous orchards is dry after harvest. Irrigation is then necessary. After the last irrigation no cultivation is given unless:

1. A cover crop requiring seed-bed preparation is used.

2. It is necessary to break down the levees for spraying or removing pruning brush during the winter.

In all cases the irrigation schedule should be planned so that it does not in-

terfere with spraying and harvesting operations.

IN CONCLUSION, and briefly stated, the most important purpose of cultivation of orchard soils is to remove weed competition.

The purpose of irrigation is to provide readily available moisture in the soil *throughout* the year.

Coöperative Extension work in Agriculture and Home Economics, College of Agriculture,
University of California, and United States Department of Agriculture coöperating.
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J. Earl Coke, Director, California Agricultural Extension Service.

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