Essentials of Irrigation and Cultivation of Orchards

F. J. VEIHMEYER AND A. H. HENDRICKSON

THE COLLEGE OF AGRICULTURE
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA
1930

ESSENTIALS OF IRRIGATION AND CULTIVATION OF ORCHARDS

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

This circular has been prepared for the purpose of briefly sum-
marizing the results of experiments conducted by the writers on the
irrigation and cultivation of deciduous orchards. Work of others in
California on the irrigation of citrus trees has been drawn upon. The
results of the work of other investigators, especially those dealing
with problems of cultivation in addition to those of moisture control,
also, have been taken into account. The publications of the writers
dealing with this subject are given with the references appended and
may be consulted for fuller details.

WATER IN SOILS

Soil is a porous material composed of particles of many different
sizes touching each other at certain points. The pore space, or space
not occupied by the particles themselves, constitutes a large portion
of the volume of the soil. It is in this pore space that water is stored.
Textbooks and literature dealing with soil moisture usually present
the occurrence and forms of water in soils from the viewpoint of the
manner in which the water is held in the soil. In view of recent
experimental work, many of the sharp distinctions suggested by this
manner of classification do not seem to hold.

The fruit grower is interested in soil moisture from the standpoint
of plant growth rather than a consideration of the physical forces
involved in its occurrence and behavior. In this circular it is pro-
posed, therefore, to speak of soil moisture from the viewpoint of its
availability to plants. A clear understanding of some of the terms
used will aid in the discussions which follow.

Field Capacity.—When water is applied to a soil the pore spaces
are completely filled for a short time. During this interval the soil
is saturated. If drainage is permitted to take place, some of the water
will move downward by gravity. The water which moves downward

is called gravitational or free water. The presence of gravitational water in drained soils is of short duration. The amount of water retained by the soil after drainage has taken place is called, in this publication, the *field capacity* of that soil. At field capacity, and through a wide range of soil-moisture contents, each soil particle is completely surrounded by water, but most of the water exists in the form of wedges between the soil particles at their points of contact. It is from these wedges that plants probably derive their water.

Some of the water in the soil is capable of moving by capillarity, and is, therefore, sometimes called capillary moisture. As pointed out later, movement of water in soil by this force 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 obtained from the field, even when the soils are apparently dry. The classification of soil moisture into gravitational, or free, 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. Furthermore, there is no sharp distinction between capillary and hygroscopic moisture. In some cases, plants may use some of the so-called hygroscopic moisture; in others, they cannot use all of the capillary moisture, and in still others, they may even use gravitational water.

When growth starts in the spring in California the soil containing most of the roots is ordinarily wet to its field capacity, which usually is expressed as a percentage of the oven-dry weight of the soil. In other words, the field capacity denotes all the water a given soil will hold after the soil is drained. We may consider that a drained soil of uniform texture and structure is at its field capacity a short time, say two or three days, after a rain or an irrigation. Plow sole, or any layer of soil which hinders the movement of water, will increase the time necessary for the soil to reach its field capacity. Movement of moisture subsequent to the 2 or 3-day period may take place at a slow rate and eventually might present an increased moisture content at lower depths within or even beyond the original wetted region. This downward movement is not important in practice, however, because the extraction of moisture during the growing season by plants on cropped soils in all tests made by the writers has always been sufficiently rapid to reduce the moisture content before such downward movement could be detected.

When irrigation water is applied to a soil, that soil is moistened to its field capacity to a definite depth, which depends upon the initial dryness of the soil and upon the amount of water applied. The field capacity, therefore, may be considered as 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.

The field capacity of a soil is influenced by a number of factors, the most important of which are soil texture, structure, uniformity, and depth. Soil texture refers to the size of the particles and indicates the coarseness or fineness of the soil mass. 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, because the former have more particles in a unit volume of soil and hence more water-holding wedges than the latter. The field capacity may be increased by adding organic matter, but the effect is usually limited to the surface layer. The amount of water also may be greatly influenced by the extremely small particles known as colloids.

Structure is the manner in which the soil particles are arranged. The structure of soil influences the amount of water held at the field capacity, because a number of small particles may be held together and act as one large particle, which in turn would affect the number and size of wedges of water in a unit volume. In other cases the structure may be such that the soil is impervious to water.

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. The depth of soil influences the amount of water held 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 effect is not marked in soils deeper than about two 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 in 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.

Other conditions which usually exert much less influence on the field capacity are temperature and kind and amount of dissolved solids. Leaching may remove some of the salts and change the state of aggregation of the colloids and thus affect the amount of water held by the soil at the field capacity. However, texture and structure are the most important factors, the others being of less importance except in special cases.

Moisture Equivalent.—Attempts have been made to characterize soil-moisture conditions by means of laboratory tests. The method most commonly used is the moisture equivalent determination. This method consists of centrifuging samples of soil in a machine somewhat similar to a cream separator in such a way that some of the water is thrown out of the soil. The samples are prepared in a prescribed way and are centrifuged for a certain time at a definite speed. The amount of water retained by the soil against the centrifugal force (1000 times gravity) is the moisture equivalent, and is expressed as a percentage of the oven-dried weight of the soil. Moisture equivalent determinations must be made according to a definite procedure or the results obtained in one laboratory may not be the same as those from another in which the determinations are made in a different way.

The moisture equivalent is a useful measure because it agrees closely with the field capacity of most of the fine-textured soils, but usually not 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.

The moisture equivalent when divided by the factor 1.84 gives the "wilting coefficient" and it has been thought that plants will not wilt so long as the soil-moisture content was above this percentage. Although this method is still widely used, we have found that the moisture equivalent cannot safely be used as a basis to calculate the amount of water in the soil when plants wilt because a constant ratio does not exist between these two moisture percentages.

The moisture equivalent determination is, however, a relatively quick and convenient method of determining comparative moisture properties of soils, and probably is the best method yet devised for the purpose of determining the amount of water held in the soil under certain prescribed conditions. However, the limitations imposed upon it because of the arbitrariness of the method used to make the determination and, furthermore, the fact, as discussed later, that it cannot be used to measure the amount of water available for plants,

should be clearly understood by growers before accepting recommendations for the irrigation practices in their orchards which are based upon the moisture equivalent alone.

Permanent Wilting Percentage.—The permanent wilting percentage is the moisture content below which the trees cannot readily obtain water. It is the soil moisture condition at which the plants wilt and do not recover unless water is applied to the soil.[3] Because of the difficulties in obtaining precise results in soil sampling and in determining exactly when a tree is wilted, the permanent wilting percentage, as used in this paper, 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. If this wilted condition persists the following morning, it may be assumed, ordinarily, that the permanent wilting percentage has been reached. This percentage then limits the normal activities of the tree.

Readily Available Moisture.—The water in the soil cannot all be used by plants because a certain amount is held so tightly by the soil particles as to prevent the roots of the plants from absorbing it rapidly enough to keep them from wilting. It is clear, then, that soil moisture is not so readily available below the permanent wilting percentage as above it. Our experiments show that water may be used by plants with equal facility[4] throughout the entire range of soil-moisture contents between the field capacity and approximately the permanent wilting percentage. In this paper, therefore, the moisture above the permanent wilting percentage is referred to as readily available moisture.

There is no simpler way, so far as we know, of determining the amount of readily available moisture in a soil than by growing a plant on the soil and finding the permanent wilting percentage. While the field capacity of clay soils is generally greater than that of sandy soils, we have found some sandy soils that actually contained *more*

---

[3] 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 cessation of length growth, change of color of leaves, or some other manifestation, may be used to indicate lack of readily available water.

[4] Our field experiments on the rate of use of water included peach, prune, and apricot trees and have been substantiated with citrus trees in California. Similar results have been obtained in Hawaii with sugar cane and pineapple plants. Experiments in Russia (translated title, S. Kokin, "The influence of moisture in soils and the velocity of intake of water by the root system," Transactions of the Botanical Gardens, Leningrad, p. 151–167, 1925) with buckwheat, *Solanum nigrum*, beans, sunflower, *Atriplex hortensis*, *Armaranthus retroflexus*, and *Zygophyllum fabago* give results which are in agreement with ours.

readily available moisture than some clays. An examination of about 60 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 soil classification, that is, whether it was a clay, a loam, or a sand. Some soils showed about one-half of the moisture equivalent to be readily available, which is in approximate agreement with the wilting point as calculated from the extensively used ratio (1.84), but the variations from this were so numerous and wide that it is evident that this ratio should not be used.

The amount of readily available moisture 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. 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 proportion of water may be taken from the barrel while only a small portion may be removed from a high faucet. Some soils are like barrels with low faucets and others like those with high faucets.

Optimum Moisture.—The belief that there is an "optimum" or best soil-moisture content for plant growth is widespread. Generally, this 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.—The apparent moisture condition of a soil may not necessarily be a safe criterion by which to judge whether a soil contains readily available moisture. It may be possible to have a soil which appears moist but from which a plant cannot secure enough moisture to prevent its wilting, and in this sense will be dry. The old expedient of compressing the soil in the hand, and judging

if it contains sufficient water for plant growth by the way in which the particles stick together, is not always dependable.

As used in this paper, the term wet soil means one which contains readily available moisture, while dry soil does not. In other words, dry soil means one which has been dried by extraction of water through roots of plants. This is the condition which exists in a soil occupied by roots when the plant permanently wilts. Furthermore, this dry condition persists with but little change until the soil is again moistened. The surface soil, however, may be drier than the lower depths occupied by roots because of direct evaporation. When the percentage of moisture is expressed numerically, the calculations are usually based on the dry or water-free weight of soil.

THE SOIL AS A RESERVOIR FOR WATER

The soil in which most of the roots of a tree are growing may be considered a reservoir containing varying 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, except in sections where the winter rainfall is insufficient, or following winter seasons of light rainfall. Without replenishment in mature orchards where drainage is unrestricted the readily available soil moisture in the soil occupied by roots is exhausted before the end of the growing season, and the trees remain wilted until the fall rains renew the supply. In other words, the trees use all the water they can secure and then exist as best they can. No effective way of remedying this situation, except by adding water to the soil when needed, is known.

HOW SOILS ARE WETTED

After an irrigation the soil throughout the region wetted is at a uniform moisture content as far as can be detected with the means of sampling which are now available. The downward movement of water in soil is due almost entirely to gravity and not to capillary movement. Capillarity cannot be depended upon, therefore, to distribute moisture uniformly in the soil. Hence, a light irrigation or a small application of water simply wets a shallower depth to its field capacity than a heavy one does. It does not result in bringing about a moisture content less than the field capacity. In other words, soils cannot be partially wetted, but must be wholly so or not at all. Of course, in undrained soils the field capacity may be exceeded. In this connection, it may be mentioned that when the furrow system is

used if furrows are too far apart portions of the soil will remain dry since lateral movement by capillarity is very limited. The occurrence of a plow sole or decided differences in soil texture or structure will increase the lateral movement. In some clay soils considerable lateral movement may take place before the water moves down.

USE OF WATER BY TREES

Transpiration.—The water removed from the soil by trees is almost entirely given off as water vapor through the leaves. This process is called transpiration and may be likened to evaporation from a piece of wet paper. Unlike simple evaporation, transpiration by plants may be controlled to a slight extent by internal conditions within the plant. The important external factors influencing transpiration are sunlight, temperature, humidity, and wind. The amount and quality of the sunlight probably exerts more influence than the other factors. High temperatures are usually accompanied by low humidities and this condition tends to increase transpiration. Transpiration may be less on a calm day than on a windy one, but transpiration does not increase in direct proportion to the wind velocity. The effect sometimes noticed on leaves following a period of strong winds is probably due to the combination of low relative humidity of the air, high temperatures, intense sunlight, and mechanical injury.

The amount of water used by a tree is determined by the size of the tree, which usually means the leaf area of the tree. Large trees with great leaf areas transpire more water than small ones 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 the 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, a similar comparison may not be applicable to fruits which differ as widely as the olive and the orange. The use of water by evergreen trees extends throughout the year, but the amounts used in the winter usually are much less than in the summer.

Soil Moisture.—The extraction of water from the soil by trees is not affected by soil moisture until moisture is reduced to about the permanent wilting percentage. The use of water by trees is influenced by the factors previously discussed, but the effect of these is much more

marked when the moisture is above the permanent wilting percentage than when it is below. At the permanent wilting percentage or below, absorption of water is very slow in spite of climatic conditions favorable to transpiration. The rate of extraction varies with the environmental conditions, and may not be the same during each hour throughout the day, although experiments in deciduous orchards under fairly uniform climatic conditions show that the rate of extraction of moisture is substantially constant day by day until the soil moisture is reduced to about the permanent wilting percentage. Of course, changes in evaporation conditions from day to day, such as between a foggy day and a bright one, will cause corresponding changes in transpiration rates. Similar results have been obtained recently by others in studies on the irrigation of citrus trees.

TREE RESPONSES TO SOIL-MOISTURE CONDITIONS

Experiments at this station, with peaches, show that the growth of the fruit is decidedly retarded when the moisture of the soil containing most of the roots has been reduced to about the permanent wilting percentage and that the degree of injury is influenced by the length of time the soil remains in this condition. The trees likewise show injury by drooping and loss of some leaves. When the soil remained at the permanent wilting percentage for only a short time, no measurable effect was noted. No difference in the quality and size of peaches was observed between trees which were irrigated before the readily available moisture was exhausted and those which had just reached the permanent wilting percentage even though the trees were watered shortly before the fruit was picked. These results substantiate those obtained with prune trees, and lead to the conclusion that the growth of trees or fruit cannot be influenced by irrigation when the moisture is still above the permanent wilting percentage provided the soil is not kept saturated long enough to produce adverse conditions. The only result of adding water to a soil which already contains readily available moisture is to replenish the supply before it is exhausted.

IRRIGATION DURING THE GROWING SEASON

Assuming a mature orchard with the trees 24 feet apart on the square system, and with the majority of the roots in the upper 5 feet of soil, there are 2880 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 2880 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 permanent wilting percentage is reached an application of water 3 inches deep would be required to wet each foot of soil. Of course, if the entire 5 feet of soil is not reduced to the permanent wilting percentage, 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 of 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, one-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.

After the leaves are formed, the trees begin to draw upon the soil moisture and continue to do so until it is reduced to the permanent wilting percentage. Thereafter, little or no moisture is removed by the trees. After irrigating, this process is repeated. In practice, of course, the orchard should be irrigated before the trees wilt. The number of times that this cycle of events takes place during the growing season in any particular orchard depends upon the size of the trees, the climatic conditions, and the kind and depth of soil. The total amount of water that a tree will use will not be greater on a clay soil than it is on a sandy soil if both are fertile and are supplied with readily available water at all times. Usually on sandy soils, however, the water must be supplied more frequently and in smaller quantities than on clay soils.

With the advent of warm weather, readily available water is quickly used by the trees and the supply should be replenished. The orchardist, himself, should be in a better position to judge when his trees need water than any one else because of his close association with his trees 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, these weeds are deep-rooted enough to indicate by their wilting, which usually is a decided drooping of the leaves, a depletion of the readily available moisture in the part of the soil occupied by 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 permanent wilting percentage, and may at other times anticipate when this condition will be reached, and thus avoid the possibility of injury which might result if the trees actually wilted. Where only small streams of water are available, the time necessary to cover the orchard may be so long that trees which are last irrigated may be decidedly affected. Hence the anticipation of the time when the permanent wilting percentage will be reached is very important in order that irrigation may be started soon enough.

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 in the summer varied from three weeks in a sandy soil to six weeks in a clay loam soil. On loam soils mature prune trees in the Santa Clara Valley exhausted the readily available soil moisture in from four to six weeks during the hottest part of the season.

Recent experiments with citrus trees in northern San Diego County show that on sandy loam soils from 4 to 6 feet in depth the interval between irrigations during the summer irrigation period should not exceed 45 days. In soils of lesser depths, this interval should be shortened, soils 2 to 3 feet in depth requiring an irrigation every 30 to 35 days with lesser amounts of water applied at each irrigation. In Orange County on the lighter soil types the irrigation interval will range from 30 to 40 days, while on the loam soils the interval would be from 40 to 45 days. Observations in citrus orchards in 1922, on heavy soils in Orange and Los Angeles counties, indicated that better results were obtained with the interval between irrigations of 60 days than with a 30-day interval.

Ordinarily, there are more roots in the upper layers, excluding the cultivated surface, than in the lower. In the experiments with peach trees, previously referred to, the readily available moisture was exhausted more rapidly in the upper layers than in the lower. Furthermore, when the readily available moisture was exhausted in the top 2 or 3 feet of soil, the peach trees wilted, even though there was wet soil below. The trees were using moisture from below this depth, but could not secure it rapidly enough to keep them from wilting. Like-

wise, when the readily available moisture in the upper 3 feet in prune orchards was exhausted, the trees wilted. Recent studies in the irrigation of citrus groves show that an average of not more than 5 per cent of the moisture extracted was taken from the fifth foot 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 were in the top foot of soil.

On water-logged soil, entirely different conditions may exist. The presence of a high water table may, in some cases, result in upward movement of water rapidly enough to replenish moisture in the upper layers, but, 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 types of soil even where 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 dependence should not be placed on a high water table to supply moisture during the growing season, and drainage may be necessary.

Use of Covercrops During the Growing Season.—Covercrops in the orchard during the growing season do not conserve soil moisture. The combination of trees and covercrops needs more water during the growing season than trees alone. The reduction of evaporation losses by shading the soil by the covercrop 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 transpiration by the covercrop is very slight. Experiments with alfalfa in a mature peach orchard on sandy soil indicate that about one and one-half times as much water was required as when the orchard was given clean cultivation.

Maintenance of Readily Available Water.—The moisture content in the soil during the growing season ordinarily fluctuates between the field capacity and the permanent wilting percentage. If the soil-moisture content goes above the field capacity for any reason and remains there for any great length of time, the trees may be seriously affected. In several experiments, however, peach trees were kept with standing water around them for two weeks 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, as a rule, it is safer to avoid having standing water around the roots.

Both the leaves and fruit are affected when the soil moisture is reduced to about the permanent wilting percentage. Fruit on trees

on dry soil grows more slowly than that on trees having readily available moisture. It is exceedingly important, therefore, to see that the soil-moisture content does not remain at or below the permanent wilting percentage for more than a few days. The trees will not be affected, however, if water is applied to the soil when it already contains readily available water.[5] If the trees wilt when the upper two or three feet are dry, it will be necessary to wet them even though readily available water is present below.

If possible, the soil should be wetted at each irrigation to the depth in which most of the roots occur even though the lower layers still contain some readily available water, since it would be less expensive to wet this depth at this time than later. In the fall, when early rains may be anticipated it is not necessary to wet the deeper layers. Wetting the soil to a depth of 5 or 6 feet will usually be sufficient with most deciduous fruit trees, and to a somewhat shallower depth with citrus trees. If there is an impervious layer within the depths mentioned, just enough water should be applied to wet the soil above this layer. The term ''overirrigation'' is often used to mean frequent irrigation which results in the maintenance of the readily available moisture at a high level. In fact, however, overirrigation is accomplished only when enough water is applied to deep soils to cause percolation below the roots, or the waterlogging of shallow soils, and when the applications are frequent enough to affect the oxygen supply of the soil. Of course, leaching may take place if applications of irrigation water are too frequent or too great in amount.

The amount of water to be applied 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 is reduced to the permanent wilting percentage, less will be required to wet a certain depth than would be required if the moisture content were reduced to this percentage. The apparently better penetration obtained in some early irrigations than in later ones is due to the water being put on before the soil is dry. Where salts occur in irrigation water in large amounts, special irrigation treatment may be necessary. The question of the suitability of water for irrigation is discussed in several references in the appended list.

---

[5] W. R. Schoonover, Specialist in Agricultural Extension (Citrus), who has had wide experience in citriculture, believes that in some citrus groves, when the trees are in a weakened condition, it is essential that they be allowed to deplete the soil moisture at the permanent wilting percentage or below. He recommends, however, that soon after this moisture condition is reached a portion of the soil be irrigated to prevent prolonged wilting and to aid in the renewal of absorbing surfaces from the old roots already present in the other, or unirrigated portion of the soil.

IRRIGATION DURING THE SPRING

Irrigation during the spring is desirable in some cases.   If the winter rainfall has not been sufficient to moisten the soil to the desired depth, this deficiency may be made up by spring irrigation.   Again, if the covercrop has been allowed to grow so late that the readily available soil moisture is almost depleted, spring irrigation is necessary.   If the covercrop has not depleted the soil moisture, the first irrigation may be delayed until the readily available soil moisture is nearly exhausted, particularly if only one irrigation can be given before the crop is harvested.

The effectiveness of irrigation for protection against frost is discussed in one of the appended references.

IRRIGATION DURING THE FALL

Many deciduous orchards in California are allowed to remain in a dry condition for a long period each fall.   So 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 reduce the soil-moisture content to the permanent wilting percentage, and they remain in a wilted condition for a long period.   This drought affects some kinds of trees more than others.

The idea is prevalent 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.   Thus far in the experiments referred to no injury has been produced on prune, peach, or apricot trees by watering late in the season that could be attributed to lack of maturity.   On the other hand experiments with walnuts have been reported which show that dry soil during the fall may result in injury. With citrus fruits it is particularly important to maintain a supply of readily available water during the fall.   In order to secure best results the trees probably 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 the rains begin.   For example, if the orchard is irrigated late in September or in October, only 2 or 3 feet of soil need be wetted.   Irrigation, also, is necessary for planting certain covercrops.

IRRIGATION DURING THE WINTER

Winter irrigation is practiced in deciduous orchards in some districts. This practice is unnecessary if the normal winter rainfall is sufficient to wet the soil to the depth that contains most of the roots. If the winter rainfall is insufficient for this purpose, irrigation during the dormant season is a desirable practice, because there must be readily available moisture present during the winter months, even though the trees use but little water at this season of the year. The practice of winter irrigation rests, in part, upon the desire to fill up the soil reservoir with cheap water for use during the growing season. As we have seen, the soil can be filled only to its field capacity and any additional water above that required to wet the soil occupied by the roots moves down, when the drainage is unrestricted, and may be lost by deep percolation. 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 of the commonly accepted ideas are that root distribution may be affected by irrigation during the growing season; 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. Observations indicate that if soils are wet only to a certain depth, either by rainfall or irrigation, and if the soil below this depth contains less moisture than the permanent wilting percentage, the roots will be confined within the wetted area; on the other hand, plants which normally are 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 is present below. If the soil is wet to the full depth to which the roots of the trees would normally go at the beginning of the growing season, then subsequent applications of water during the summer, unless they be frequent enough to produce unfavorable oxygen conditions or the detrimental effects which have been observed to follow certain practices in citrus irrigation, will have no influence on the extent of the distribution of the roots. Waterlogging the soil, however, may injure the roots of some trees.

CULTIVATION OF ORCHARDS

Losses of Moisture from Soils.—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. These results are contrary to the long accepted belief that cultivating the soil to form a soil mulch is effective in saving moisture.

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

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

The loss of moisture by evaporation during periods longer than those usual between irrigations was confined to relatively shallow depths of soil. A large portion of the loss was confined to the upper 4 inches; a much smaller amount was lost from the next 4 inches. Moisture below the upper 8 inches of soil was lost at an extremely slow rate.

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, the reduction being due to plant transpiration. In a few others, principally adobe soils, cracking may take place before the soil is drained to its field capacity. In the latter case cracking occurs when the soil is too wet to be cultivated safely. The loss of water in the form of vapor from the soil cracks takes place at such a slow rate that probably

nothing would be gained by covering them. The movement of moisture by capillarity, furthermore, from moist soil to drier soil not in contact with free water has been found to be extremely slow in rate as well as in extent.

In these experiments cultivation had no influence on the distribution of water in the soil and there was no evidence that stirring the surface influenced the upward movement of moisture. The part cultivation has been supposed to play in preventing the upward rise of moisture is based upon the familiar teaching that moisture can move in the soil in all directions through capillarity and 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 of moisture 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.

Numerous experiments have been carried on to measure the effectiveness of cultivation by means of yields produced. The results of many of these experiments are valueless because too many variables are introduced, but where cause and effect can be segregated, it is evident that the increased yields resulting from cultivation can be attributed to removal of weed competition or any other influence the weeds may have and not the other supposed effects of cultivation such as improved physical condition of the soil and increased soil aeration. A number of reports on the subject of tillage all lead to these conclusions.

Deep Tillage.—The effect of deep tillage has 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 subsoiling." 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 root pruning. On the other hand, subsoiling or blasting may be desirable under special conditions where particular kinds of hardpan are present. These special conditions exist where the hardpan is not too far from the surface, not too thick, will not resume its original impervious condition upon being wetted again, and where the soil is pervious below.

Cultivation and Soil Aeration.—The literature concerning cultivation contains abundant evidence that tillage, of itself, does not increase yields. Therefore, the contention that cultivation is beneficial for soil aeration with resulting increase of fertility and increased yields does not seem to be justified. Experiments indicate that sufficient aeration ordinarily takes place in orchard soils regardless of whether or not the soil is stirred. Experiments in California have shown that rapid nitrification takes place below the depths affected by tillage. On the other hand attention is called to the fact that unfavorable conditions for aeration may be produced if water is applied frequently enough to fill the pore space in the soil and maintain this saturated condition too long.

It appears, therefore, that the reasons usually advocated for frequent cultivation and deep tillage are not sound. 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 amount of water lost nor on the distribution of water in the soil. Experiments of others show that crop yields are not increased simply by reason of stirring the surface of the soil, and that cultivation does not increase aeration in the soil occupied by the roots of the trees.

Purposes of Orchard Cultivation.—A certain amount of cultivation is usually required in orchards, but it seems clear that this should be directed toward some useful purpose. Apparently these purposes are: to remove noxious weeds and weed competition; to facilitate subsequent orchard operations, such as irrigation, harvesting, brush removal, and spraying; to incorporate covercrops and manures; to prepare the soil as a seed bed for covercrops; to facilitate the control of certain pests; and to 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 covercrops, if allowed to grow too late in the spring, are serious competitors with the trees for moisture. 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 facilitated when irrigation levees are smoothed

down and furrows filled up. On steep slopes cultivation may cause the water which otherwise would run off to be intercepted mechanically.

Plow sole is a condition formed by the compacting of the layer of soil just below the depth of tillage. Ordinarily, it is most pronounced where cultivation is practiced when the soil is too wet. The possibility of the formation of plow sole may be lessened if only necessary cultivations are given, and the operation is delayed until the soil at the depth tilled is in such a condition that it will not be puddled by the implement used. There is no accurate way of determining how dry a soil may be before it can be cultivated without forming a plow sole. Experience with each soil is the best guide. The tendency in most cases is to till the soil when too wet rather than when too dry. Since cultivation, in the absence of weeds has no influence in conserving moisture, there is much to be gained by keeping off the ground until there is least danger of forming a plow sole. Frequently, when plow sole has been formed, deep tillage is used in attempts to overcome it, but sometimes, experience has shown that leaving the soil untilled is the best remedy. All tillage operations, therefore, in the orchard should be as shallow and only as frequent as necessary to accomplish the useful purposes given above.

Outline of Economical Orchard Irrigation and Cultivation.—Many California fruit growers have applied the principles discussed in this circular and have materially changed the practices in their orchards during the past several years. In general, cultivation has become less frequent and shallower than formerly. Furrows or levees are often used for two or more irrigations, instead of breaking them down and making new ones each time the water is applied. Levees on soils which crack on drying may have to be cultivated between irrigations. Considerable saving in the cost of cultivation has been effected in many cases, because of the lessened number of cultivations.

The plan adopted by these growers is essentially as follows. The orchard is plowed or disked in the spring to incorporate the covercrop or weed growth with the soil. The soil is left with a sufficient amount of loose soil on the surface 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. The soil is not cultivated again until after the first irrigation unless the weeds are too numerous and large. The orchard in some cases is cultivated after the first irrigation, but, in others, it is not, depending upon 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 the weeds themselves. The same general procedure follows subsequent 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 the levees. If tree props are used, it is sometimes necessary to cultivate the orchard early enough before harvest to permit the placing of the props. Deciduous orchards usually are irrigated after harvest. After the last irrigation no cultivation is given unless a covercrop requiring seed bed preparation is used, or it is necessary to break down the levees to make it possible to spray or remove pruning brush during the winter season.

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.

SELECTED REFERENCES ON THE IRRIGATION OF ORCHARDS AND THE EFFECTS OF CULTIVATION

BATCHELOR, L. D., and H. S. REED.
  1919. Winter drying or die-back of the walnut. California Agr. Exp. Sta. Cir. **216**:1–20.

BECKETT, S. H., H. F. BLANEY, and COLIN H. TAYLOR.
  1930. Irrigation water requirement studies of citrus and avocado trees in San Diego County, 1926 and 1927. California Agr. Exp. Sta. Bul. **489**: 1–51.

CALL, L. E., and M. C. SEWELL.
  1917. The soil mulch. Jour. Am. Soc. Agron. **9**:49–61.

CATES, J. S., and H. R. COX.
  1912. The weed factor in the cultivation of corn. U. S. Dept. Agr. Bur. Plant Ind. Bul. **257**:1–35.

CHILCOTT, E. C., and J. S. COLE.
  1918. Subsoiling, deep tilling, and soil dynamiting in the Great Plains. Jour. Agr. Res. **14**:481–521.

CONRAD, J. P., and F. J. VEIHMEYER.
  1929. Root development and soil moisture. Hilgardia **4**:113–134.

GAINEY, P. L., and L. F. METZLER.
  1917. Some factors affecting nitrate-nitrogen accumulation in soil. Jour. Agr. Res. **11**:43–64.

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

HENDRICKSON, A. H., and F. J. VEIHMEYER.
  1929. Part I—Irrigation experiments with peaches in California. Part II— Canning quality of irrigated peaches, P. F. Nichols. California Agr. Exp. Sta. Bul. **479**:1–63.

HENDRICKSON, A. H., and F. J. VEIHMEYER.
  1929. Some facts concerning soil moisture of interest to horticulturists. Proc. Am. Soc. Hort. Sci., **1929**:105–108.

KELLEY, W. P., and S. M. BROWN.
  1928. Boron in the soils and irrigation waters of southern California and its relation to citrus and walnut culture. Hilgardia **3**:445–458.

KELLEY, W. P., and E. E. THOMAS.
  1920. The effects of alkali on citrus trees. California Agr. Exp. Sta. Bul. **318**:305–337.

McLAUGHLIN, W. W.
  1920. Capillary movement of soil moisture. U. S. Dept. Agr. Bul. **835**:1–70.

PROEBSTING, E. L.
> 1930. Concentration of certain constituents of the soil solution under orchard conditions. Hilgardia 5:35–59.

SCHOONOVER, W. R., R. W. HODGSON, and F. D. YOUNG.
> 1930. Frost protection in California orchards. California Agr. Ext. Serv. Cir. 40:1–73.

SCOFIELD, C. S.
> 1927. The effect of absorption by plants on the concentration of the soil solution. Jour. Agr. Res. 35:745–756.

SEWELL, M. C.
> 1919. Tillage: A review of the literature. Jour. Am. Soc. Agron 11:269–290.

SHAW, C. F.
> 1927. The normal field capacity of soils. Soil Sci. 23:303–317.

SMITH, R. S.
> 1925. Experiments with subsoiling, deep tilling, and subsoil dynamiting. Illinois Agr. Exp. Sta. Bul. 258:155–170.

THOMAS, E. E.
> 1922. Studies on the irrigation of citrus groves. California Agr. Exp. Sta. Bul. 341:353–370.

THOMPSON, H. C.
> 1927. Experimental studies of cultivation of certain vegetable crops. Cornell University, Agr. Exp. Sta. Mem. 107:1–73.

VAILE, R. S.
> 1924. A survey of orchard practices in the citrus industry of southern California. California Agr. Exp. Sta. Bul. 374:1–40.

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 16:1–61.

VEIHMEYER, F. J.
> 1927. Some factors influencing the irrigation requirements of deciduous orchards. Hilgardia 2:125–291.

VEIHMEYER, F. J., and A. H. HENDRICKSON.
> 1928. The relation of soil moisture to cultivation and plant growth. Proc. and Papers, First Int. Cong. Soil Sci., Washington, D. C. 3:498–513.

VEIHMEYER, F. J., and A. H. HENDRICKSON.
> 1928. Soil moisture at permanent wilting of plants. Plant Physiol. 3:355–357.

VEIHMEYER, F. J., J. OSERKOWSKY, and K. B. TESTER.
> 1928. Some factors affecting the moisture equivalent of soils. Proc. and Papers, First Int. Cong. Soil Sci., Washington, D. C. 1:512–534.

WIMER, D. C., and M. B. HARLAND.
> 1925. The cultivation of corn; weed control vs. moisture conservation. Illinois Agr. Exp. Sta. Bul. 259:175–196.