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SOME FUNDAMENTALS OF IRRIGATION

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Since the soil constitutes the reservoir in which rainfall and irrigation water is stored and from which it is extracted by plant roots, correct irrigation practice, unless it be accidental, can only be obtained as a result of an understanding of the two important subjects (1) how water occurs and behaves in soils and (2) how it is used by plants. While the method and time of applying irrigation water vary according to supply, soil, slope, weather and other factors, and consequently may and usually do differ for each and every parcel of land, good irrigation practice may be had under almost any condition of supply, soil, weather or topography but only as a result of a correct understanding of these two fundamentals. And, fortunately as a result of extended investigations conducted in recent years, our knowledge of these subjects is much more specific and satisfactory than ever before, although there is still much to be learned before we can speak with certainty on the water requirements of all of the commercial crops grown in California. In any event certain old and widely current beliefs have definitely been disproved and new conceptions advanced which explain much better the observed facts as they relate to the application of irrigation water and its use by plant roots.

How Water Occurs in Soils

When dry soils are wetted either by rainfall or irrigation the distribution of the water they receive and consequently the depth of wetting is determined by two factors (1) the water holding capacity of the soil in question and (2) the absolute amount of water which penetrates the soil.

Soil Porosity—All soils are porous, a considerable part of their volume consisting of air space between the soil particles. The amount of pore space is largely a function of the average *size* of the constituent particles but also to some extent of the way in which they are arranged or aggregated in the soil. Thus a fine soil, consisting of a large number of small particles has a greater air space than a coarse soil made up mainly of fewer but larger particles. But a compacted fine soil will have somewhat less air space than a soil of the same fineness but of more open structure. On the other hand the course soil will absorb water more rapidly, even with less air space than a finer soil, on account of the much larger size of the spaces between the particles.

Water Holding Capacity—The water which a soil absorbs and stores for use by plant roots, however, does not occur in the spaces between the soil particles; it is held in the form of moisture films which adhere to the soil particles themselves. A fine soil with its much greater number of particles and consequent greater internal water holding surface, therefore, has a much greater water storing capacity than a coarser soil with fewer particles and smaller internal surface.

How Soils are Wetted—When water is applied to soils it distributes itself about the soil particles wetting each to its maximum film thickness as it passes downward under the influence of gravity. Eventually, if the soil is deep enough, all of the water is distributed in this manner and its downward movement ceases, the pull of gravity being equaled by the combined forces of adhesion to the soil particles and the surface tension of the water films themselves. The soil below this point remains unwetted but all of the soil above is uniformly wetted to the full thickness of the moisture films which the sizes of the individual particles will hold. The thickness of this film is presumably largely a matter of the size of the particle; the smaller particles exert a greater adhesive attraction and have a greater surface tension to their water films and, therefore, carry thicker films than do the larger particles. This point of maximum film thickness to which all soil particles when wetted attain is known as the *normal moisture capacity* or *field capacity* of the soil.

When a soil is wetted, therefore, it is *completely wetted* to the depth the amount of water applied will go. The depth of wetting is determined entirely by the internal surface of the soil, the amount of water already present, and the amount of water applied. Thus a fine soil may be wet to a depth of eight inches by an inch of rainfall while a coarser soil will be wetted twice as deep by the same amount of water. But two inches of rainfall will wet the fine soil (or the coarse soil) to twice the depth accomplished by one inch. And in all cases the soil is completely wetted to the full depth of water penetration and not wetted at all (by that particular application) below that point. Obviously the same amount of water will wet a soil still containing some water to a greater depth than it will one from which the water has been depleted.

A few practical applications to irrigation practice may now be made

I. Soils *cannot be halfway wetted;* they are *either completely wetted or not at all.*

Irrigation water must *actually penetrate to the full depth of the root area* or some of the roots are certain to suffer from lack of water.

II. The only soil moisture constant which it is possible to maintain is the *normal moisture or field capacity.*

It is impossible to wet a soil up to any point *(optimum* or otherwise) which is less than the field capacity since the soil is either completely wetted or not at all wetted.

If the field capacity or normal moisture capacity is not favorable to root growth it is obvious that for good root activity the soil moisture content *must decrease;* in other words it must fluctuate between the field capacity and some point nearer the wilting point.

In the case of plants for which this is true, injury is *certain to occur from attempts to maintain the soil moisture at a uniform content.*

Movement by Capillarity—In irrigation practice in the past much reliance has been placed on the so-called and claimed "capillary movement" of water from wet soils to dry soils. Thus it has been assumed that it was unnecessary to wet all of the soil in the root area because water would pass fairly rapidly from the wet soil masses to the dry areas and thus tend to distribute itself uniformly through all the soil. It was also believed that water could be stored in the lower soil layers below the root zone, reliance being placed on its later movement upward to replace that removed by root action.

It is now definitely proven that capillary movement of moisture in soils is a factor of relatively minor importance in good irrigation practice, such movement being so slow under ordinary conditions as to be negligible. It has been shown that there is no appreciable movement of water from soils wet to field capacity to adjoining soil masses of a lower water content, even after months or years. This is true whether the direction of movement be either vertical or horizontal.

In ordinary field practice, therefore, soil-masses once wetted tend to remain wet unless the water is extracted by root action. They do not distribute their moisture to adjoining dryer areas, either to one side or upward. Thus plant roots may dry a soil down to the wilting point and suffer from lack of moisture with completely wet soil areas close by, either laterally, above or below. Expressed in other words, soil moisture stays "put."

It is true, however, that under conditions of free or gravitational water in the soil, such as are provided by a permanent or temporary water table, water does move by capillarity, the distance and rate being determined largely by the fineness of the soil particles. Capillary movement is most rapid in the coarser soils but also to the shortest distances. In the finer soils movement is slower but occurs to greater distance. This explains why a water table is dangerous at a much greater depth in a heavy soil than in a light soil. For a period after irrigation some temporary capillary movement of water occurs in soils underlain by plowsole or hardpan; it also takes place from the bottoms of the irrigation furrows as long as water is running in them. This explains why the surface soil is wet on shallow soils even where the water never overflows the furrows, and also why the nitrates tend to accumulate between the furrows as the irrigation season progresses.

In well drained soils of good depth and structure, however, the capillary movement of water is of no practical consequence in irrigation practice and cannot be relied upon to accomplish uniform distribution.

This being true we can now make more applications to irrigation practice.

III. The system of distribution must insure that *all of the soil in the root area is wetted.*

If this is not done only the roots in the wetted areas will have water; the others must suffer from lack of it.

The length of spacing of furrows must be adapted to the soil and slope and water must be applied so that all the soil is wetted. If this is not practicable the largest possible area should be wetted.

IV. *There is no advantage in applying water to wet soils* or wet soil masses since it merely passes on downward and is lost.

In other words the time and method of application of irrigation water should be determined by soil moisture conditions as found by examination.

How Plants Use Water

Plants absorb water from the moisture films surrounding the soil particles, absorption occurring either through the root hairs or the fleshy root tips in contact with the moisture films.

Root Activity—Absorption occurs mainly at or near the growing root tips. Consequently in order for maximum absorption to occur conditions must be favorable for root growth. It thus becomes important to discuss the conditions that favor root growth and, therefore, largely determine the absorptive capacity of the plant. The factors which govern root growth are essentially the same for all plants although the requirements for satisfactory root growth vary markedly with different species. Studies made in recent years have elucidated greatly the conditions under which citrus root growth is active but with most other fruit trees we still have inadequate information and must await the conducting of much needed investigations.

Temperature—Soil temperature is one of the factors of greatest importance in its effects on root growth and absorption. All plants have a definite range of soil temperatures in which the growth of roots and the absorption of water and nutrients takes place, above or below which these activities are practically at a standstill. These temperature ranges vary markedly for different plants, some requiring relatively high temperatures for activity and others being active at much lower temperatures. Thus the citrus tree shows no root activity below 55°F., and exhibits its maximum rate of root growth at approximately 80°F. Above this temperature the rate of growth and activity falls off rapidly and at 90° practically ceases. On the other hand the deciduous trees in general start root growth at soil temperatures of 40 to 45°F. and make rapid growth at 60 and 70°F. The maximum temperatures for the root growth of this class of fruit trees have not yet been determined.

All of the tropical and subtropical fruits studied thus far show a relatively high temperature requirement for root growth, a condition to be expected in plants adapted to regions of relatively high mean annual temperatures. There can be no doubt whatever that the major reason why citrus and avocado trees become relatively dormant in California during the winter period is because soil temperatures at that time are too low for growth activity. It is also a practical certainty that soil temperatures in the spring months are frequently too low for good root activity with these plants and sometimes this results in inability to set and mature good crops. The June drop problem in citrus is undoubtedly largely tied up with unfavorable soil temperatures during the blooming and setting period.

Oxygen—All living cells respire and, therefore, require oxygen, the amount obviously bearing a direct relation to the rate of activity. The oxygen requirement for root growth varies notably with different plants, however, with some being high and with others low. Carefully conducted experiments have shown that citrus trees must have a relatively high oxygen supply in the soil atmosphere or root growth is either depressed or inhibited. No data are available on the requirements of the avocado, but field observations indicate that they are similar to citrus and probably even more exacting in their oxygen requirement.

Available fertility—Still another requirement for root growth is the presence of available nutrients. Root growth soon stops in the absence of the mineral elements and other nutrients which all plants require. Most soils contain adequate amounts of the mineral elements but all are likely to become deficient either in available or total nitrogen. This element is utilized mainly in the form of nitrates to which form all organic and most chemical nitrogen fertilizers are eventually reduced by the bacterial flora of the soil. In the processes involved in nitrate formation the essential minerals are also rendered available for use by the plant roots.

The nitrifying bacteria, like the plant roots themselves, have a definite range of temperature and oxygen requirements for their activity, above and below which they are inactive and do not render nitrogen and essential minerals available for plant use. Extensive studies of these requirements show that the nitrifying bacteria are most active at relatively high temperatures, 85 to 95°F. and require a plentiful supply of oxygen in the soil atmosphere.

Absence of Toxic Substances—Freedom from injurious or toxic materials is also a general requirement for root growth. These substances may consist of excess amounts of certain salts, such as the so-called alkalis, the presence in minute amounts of certain highly toxic minerals such as boron, or the presence of certain poisonous organic compounds which are produced by bacterial activity of an undesirable type which occurs when aeration is deficient. Soils insufficiently aerated may, therefore, become poisonous to plant roots and thus temporarily unsuited to plant growth.

The Influence of Moisture Fluctuations—The most important application of these general principles of root growth has to do with the influence which the presence of moisture exerts on (1) soil temperature (2) the soil oxygen supply and (3) the making available of fertility. It is well know that a wet soil is a cold soil and that soils warm up as their moisture content decrease. Consequently root growth and absorption are definitely retarded by keeping the soil too wet and are specifically accelerated by permitting it to decrease in moisture content (dry out). As a soil loses moisture it absorbs air since something must take the place of the water extracted and there can be no vacuum in a soil. Consequently a natural means by which soils are ventilated and aerated has to do with fluctuations in moisture content; air is driven out when the soil is wetted and returns when it dries out. The warming up of the soil and its increased aeration accomplished by its drying out also provide conditions favorable to increased bacterial activity, the result of which is increased fertility available to plant roots.

It must, be evident, therefore, that for plants like the citrus fruits and the avocado with relatively high temperature and oxygen requirements it is highly beneficial, if not actually necessary, to permit the soil moisture to fluctuate markedly from the field capacity to some point approaching the wilting coefficient. Root activity and the making available of fertility are both promoted in this way and both are essential for normal growth and fruit bearing.

The specific applications of the foregoing which we may now make to citrus and avocado irrigation practice are the following points:

V. *Fluctuations in soil moisture content* from the field capacity to some point approaching the wilting point, if not necessary, *are definitely desirable and beneficial.*

The grower, should, therefore, abandon the idea of endeavoring to maintain any given moisture content in the soil. (As previously mentioned the only moisture content possible to maintain *is* the field capacity.)

VI. *It is clearly undesirable to keep the soil wet in the spring months.* All possible means of promoting its drying out to a reasonable degree should be employed. Irrigation should certainly not be started too early in the season.

Moisture Use as Affected by Supply—We will now consider the actual use of water by plant roots, and insofar as our knowledge permits, the specific use made of it by the roots of citrus and avocado trees. It was formerly believed that the moisture content of the soil had an important effect on its rate of use by plant roots, water being available in greatest amount and with least resistance when the moisture films are at their maximum thickness (total water holding or field capacity) and becoming less readily available as the wilting point is approached when the moisture films become relatively thin.

Recent researches on the use of water by the roots of deciduous fruit trees have quite definitely shown that the absorption of water by the roots of these plants is independent of the supply in the soil within the definite limits of the field capacity on one extreme and the wilting point on the other. Expressed in other words it appears that the rate of water intake by the roots of deciduous trees is the same whether the soil be at full field capacity or just approaching the wilting point. The tree has no greater difficulty in meeting its needs if the soil is approaching dryness than immediately following on irrigation. The soil may, *therefore,* be regarded as a reservoir, filled up periodically by rainfall or irrigation and emptied by extraction through plant roots, the rate of extraction being independent of the water holding capacity of the reservoir. If this be true for citrus and avocado roots, and numerous field observations and some experimental evidence confirm the conclusion, these plants cannot suffer from lack of water if the soil moisture fluctuates so long as it does not actually reach or go below the wilting point. Moreover as we have already observed, such fluctuation is definitely favorable to root growth and activity and the making available of fertility.

We may now add another point to our list of applications, namely.—

VII. *Fluctuations in soil moisture content are desirable for root growth and activity and do not decrease the availability of water but by making possible greater root growth actually increase the absorptive capacity of the plant.*

Water Loss From Soils Due Principally to Root Action.—In this connection it should be pointed out that since soil moisture stays "put" and does not move appreciably by cappillarity virtually the only means by which it is lost from the soil is through extraction by the roots. The influence of cultivation in conserving moisture, excepting insofar as it kills weeds the roots of which extract water, has been shown to be practically negligible. Consequently the only means left by which the soil moisture supply is exhausted is its removal by root action. Hence we may now make two additional applications.

VIII. *Soil areas which dry out contain active roots and therefore require irrigation or the elimination of the roots* (in case they belong to weeds).

Cultivation or weeding is the method for accomplishing the latter.

IX. *Soil areas which remain permanently wet do not contain active roots* and steps should be taken to establish active roots in them.

The means of so doing involve removing the moisture in the most practicable manner (growing cover crops, discontinuance of irrigation, etc.) so as to render conditions favorable for the establishment of new active feeder roots.

Factors Affecting the Rate of Use of Water

We come now to a consideration of the factors which influence the rate of use of soil moisture by plants.

Extent and Vigor of Leaf Surface.—Obviously the loss of water from plants, which from an irrigation point of view constitutes use, is primarily a function of the evaporating or transpiring surfaces exposed, principally leaf surface. Other things being equal, the larger the leaf surface the greater will be the loss of water. Thus a large tree or plant will use many times as much water as a small plant and the use of water by fruit trees increases from year to year as they grow larger with consequent expansion in total leaf surface. The age and vigor of the leaves also affects their loss of water, the older leaves being less efficient and consequently transpiring more water than younger leaves. Healthy leaves also transpire more water than weak devitalized leaves. Thus a large vigorous healthy citrus or avocado tree will transpire many times as much water as an adjoining tree of smaller size and impaired health and vigor. Yet in ordinary orchard practice both receive the same amount of irrigation water. It must be apparent therefore that one or the other is either over irrigated or under-supplied, and as previously shown with both citrus and avocado trees, the former is fully as injurious as the latter, if not more so.

The importance of uniformity in size and health of trees in orchard plantings now becomes apparent as also the difficulties involved in establishing young trees in old orchards and the reasons why so large a percentage of top-worked trees fail to succeed, even though successfully budded or grafted. In all these cases the usual irrigation application results in too much water for the younger or smaller trees or tree with suddenly reduced leaf surface. Leaf area, a dimensional factor, is therefore of primary importance in determining water use by the plant.

Temperature. A second factor affecting water use is atmospheric temperature, the atmospheric evaporating power increasing rapidly as the temperature rises. Thus on hot days plants use much more water than on cool days and the peak of the water loss or transpiration curve generally occurs about midday when the temperature is highest. Citrus and avocado trees frequently use as much water in a two weeks hot spell in late summer as they do in two months in early spring.

Humidity. Still another factor affecting the use of water by the plant is atmospheric humidity. The dryer the air (the lower the humidity) the greater is its capacity for extracting water from the plant, and conversely the higher the humidity the lower is the atmospheric pull for moisture. Thus plants growing in a greenhouse use much less water than plants in the open where the humidity is lower. Usually as the temperature rises the humidity drops for which reason it is generally during periods of very high temperatures and accompanying low humidity that plants have their greatest need for water. Quite commonly during such periods the water supplying power of the plant is taxed to its full capacity with the result that temporary wilting or drooping of the leaves and shriveling of the fruits occurs. Exceedingly low atmospheric humidity may accompany relatively low temperatures, however, a fact not sufficiently realized. Thus there are frequently periods of moderate temperatures but very low humidity when plants use water rapidly even though the weather is not warm. Weather conditions of this kind are commonly experienced in the San Joaquin and Sacramento Valleys in the summer and in Southern California in the fall months.

Air Movement. A fourth and closely related factor is that of air movement. Water losses from plants are markedly accelerated by wind to the point where not uncommonly the supplying power of the plant is overtaxed and the leaves and young tender growth are literally burned, such damage being known popularly as "scorch" or "wind-burning". Low temperature dry winds occurring in late fall or early winter have in recent years caused extensive losses to southern California avocado and citrus orchards. And hot temperature dry winds every year causes serious injury to the citrus orchards of the San Joaquin and Sacramento Valleys.

Some of the inter-relations of these factors have been alluded to but collectively it may be said that they constitute the principal difference between a humid and an arid climate. The combination under which the greatest use of water occurs is that of high temperature, low humidity and high wind velocity—a condition not uncommon in California. That in which water use is lowest is moderate temperature, high humidity, and absence of wind, which characterize the regions where citrus and avocado trees originated and to which they are adapted.

It will be observed that the last three factors discussed are climatic in nature and therefore not subject to much control by man. Since the weather varies from hour to hour and from week to week and differs markedly in different localities, the use of water by plants is equally variable and dependent primarily on weather conditions. It must, therefore, be apparent that irrigation on any definite schedule of periodic applications cannot possibly meet the needs of citrus or avocado trees, since they change from day to day and that what is a sufficient amount of water in one locality may be altogether insufficient in another perhaps only a few miles away but where the climatic situation is different.

We may now make a final practical application or two.

X. The *requirements of the plant for water are independent of soil type* and are determined by leaf surface and weather conditions.

The soil merely serves as a reservoir from which water is extracted by the plant in accordance with its needs. Since a light soil has a low water holding capacity its supply is more quickly exhausted than a heavier soil with a higher water storage capacity. Consequently irrigations on light soils should be lighter and more frequent.

The amounts of water used by plants of similar leaf area and under the same climatic conditions are precisely the same, whether growing on light or heavy soils.

Obviously in the hotter, drier and windier interior regions the trees require and must be supplied with more water than is needed in the more equable coastal regions, and must therefore be irrigated more frequently.

It is manifectly impossible to assign any specific water requirement to the citrus fruits or the avocado. They vary with the age, vigor and size of the trees and in accordance to weather conditions, being lowest in the coastal areas and highest in the interior regions.

Irrigation practice must, therefore, be determined primarily on the basis of the water requirement of the trees, the water holding capacity of the soil and the amount of moisture in the soil as determined by periodic examinations. The method of distribution must be governed by the topography and supply and must be so arranged as to guarantee uniform distribution and penetration. These in turn can be determined only by trial and experiment and frequent examination of the soil.