

Recent Investigations into the Principles of Irrigation and Cultivation of Orchards.

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THAT irrigation is indispensable in many parts of India for the best production of horticultural crops is a fact widely recognised. In many of these areas, canal water is not available and recourse must be had to lifting or pumping from underground supplies. In the canal as well as in the pumping areas, water for irrigation is relatively limited. Economical and scientific use of the available supply is therefore of vital importance.

Because of wide variations in soils and of the extreme differences in topography, the cultural and irrigation methods must vary widely in different parts of India. During his recent visit to the United States of America the writer had an opportunity to discuss the various aspects of the problem connected with the cultivation and irrigation of orchards, a subject which has been receiving considerable attention at the hands of research workers in the University of California. These investigations have definitely modified certain old and widely current beliefs and have advanced new conceptions which afford a better understanding of the subject.

The practices of irrigation and cultivation are so interrelated that it is almost impossible to discuss the principles underlying each of these separately. It must be made clear at the outset that it is not the intention of the writer to discuss in this paper all the physical forces involved in the occurrence of moisture in the soil and its behaviour, but it is proposed only to speak of soil moisture from the view-point of its availability to plants.

The water which a soil absorbs and stores for use by plant roots is held in the form of moisture films which adhere to the soil particles. 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. The amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased, is termed "Field capacity" of the soil.

The downward movement of water in the soil is due almost entirely to gravity and not to capillary movement. Recent investigations show that capillarity cannot be depended upon to distribute moisture uniformly in the soil. The belief that "the moisture content of all of the soil occupied by the roots of the trees will be raised to a certain percentage by the applications of small amounts of water, because of the downward capillary movement of the water with a consequent equalisation of the moisture content of all of the soil" is incorrect.

When water is applied to a dry soil it is moistened to its field capacity to a definite depth. According to Veihmeyer¹ "All attempts to maintain a soil moisture percentage less than that which

the soil would hold against the force of gravity, the maximum field or capillary capacity have met with failure." He further observes, however, "that the soil moisture supply could be kept above a certain minimum. The soil could be raised to a maximum content and this condition re-established when the plants had reduced the soil moisture supply to a certain minimum."

In view of the above investigations the amounts of water applied to a soil will affect only its moisture content to a certain depth and that much quantity of wetted soil will be raised to its maximum field capacity. Smaller amounts of water will wet a soil to its field capacity to a smaller depth while larger amounts will wet it to a larger depth. Hence, a light irrigation wets a shallower depth of soil to its field capacity than a heavy one does.

Soon after a soil has attained its "field capacity" the moisture content begins to decrease due to evaporation from the surface and extraction of water by roots of weeds or trees, that is, the moisture content fluctuates between "field capacity" and some percentage of moisture at which plants wilt and will not revive unless water is again applied. Soil physicists have named this stage of soil moisture as *permanent wilting percentage*, and the moisture in the soil above this condition is called the *readily available moisture*. Before we proceed to discuss as to how this readily available moisture is utilised by plants it is important to know how the water moves in the soil from one point to another. As already explained above, when water is applied, it penetrates the soil in a downward movement and laterally under the influence of gravity. Once the soil attains its "field capacity", the moisture, according to the recent investigations in the United States, remains almost stationary and is not able to move appreciably in an upward or lateral direction from the moist layers of the soil to the drier ones. In view of these investigations, therefore, the familiar conception that moisture is capable of moving in the soil in all directions through capillary forces needs modification.

Earlier investigators like King,² Hilgard,³ and Longhridge and Widtsoe⁴ have laid great stress upon the losses of moisture through evaporation from the soil surface by upward capillary movement. This theory of upward capillary movement in the soil apparently was advanced as a result of the study of the movement of moisture in soils contained in glass or metal cylinders where the lower ends remained in contact with free water. On the other hand, the study of the movement of moisture from a moist to a drier soil in the absence of water table within 6 to 10 feet depth received much less attention in early days.

² King, F. H., *Soil Management*, Orange Gudd Co., New York, 1-303.

³ Hilgard, S. W., *Soil*, The Macmillan Co., New York, 1921.

⁴ Widtsoe, J. A., *Principles of Irrigation Practice*, New Ed., The Macmillan Co., New York, 1914, 1-496.

¹ Veihmeyer, F. J., "Some factors affecting the irrigation requirements of deciduous orchards", *Hilgardia*, 1927, 2, No. 6.

However, as early as 1913 Rotmistrov⁵ from Russia drew attention "that water percolating beyond a depth of 40 to 50 centimetres does not return to the surface except by way of roots." Harris and Turpin⁶ and Alway and McDole⁷ were some of the early investigators in the U.S.A. to study the movement of moisture from moist soils to soils containing lesser amounts of moisture. Their investigations indicated, though not very conclusively, that the movement of moisture, especially in an upward direction from moist soils to drier soils is not at all appreciable when the source of the moisture supply is not saturated soil in contact with a free water surface. The most outstanding of the present-day investigations in this respect are those of F. J. Veihmeyer¹ of the University of California. His extensive experiments in pots as well as in the field have demonstrated that the capillary movement of moisture from the moist to drier soil when the soil is not in contact with a free water surface is too limited in extent and rate to be effective for use by plants. After the water applied to the soil becomes uniformly distributed by gravity, or in other words when the soil attains "field capacity", the upward as well as lateral movement of moisture from the surface layers of soil is due to direct evaporation and the loss from the lower layers occurs chiefly by way of roots of trees or weeds growing on it. Mulching is useful in so far as it removes weeds, etc., which deprive the soil of its moisture. Commenting on the phenomenon of upward capillary movement of soil moisture Keen⁸ observes, "Upward capillary movement of water is now known to be effective over short distances only. Hence, the conception of a mulch as breaking the capillary channels and thus preventing water from actually reaching the soil surface is invalid, unless a permanent or temporary water table exists within some 6 feet from the surface." It may be assumed, therefore, that in the presence of a permanent or temporary water table within 6 to 10 feet distance, the water in the soil moves by capillarity, the distance and rate being determined largely by the fineness of the soil particles.

Under these conditions capillary movement is most rapid in the coarser soils (sands), but only for a short distance. In the finer soils (clays) movement is slower but occurs to a greater distance. Such a capillary movement of moisture also occurs from the bottom of the irrigation furrows so long as water is running in them. It also takes place in shallow soils underlaid by hard pan after irrigation due to the hard pan serving as a temporary water table. However, in well-drained orchard soils of good depth and

structure but with a low water table the capillary movement of water is of no practical consequence in irrigation practice.

If we were to find that the moisture in the soil after it has attained the stage of "field capacity", does not appreciably move in any direction in absence of a water table, as has been also the field observations of the writer in the Bombay Deccan soil, we should then unhesitatingly lay down the following principle for irrigation practices:—

"That whatever the system of irrigation adopted, it must ensure that all of the soil in the root zone is wetted. If the irrigation water wets a part of the root zone, only the roots in the wetted area will have water and the roots in the non-wetted area will suffer from lack of it."

Having learnt how water occurs in the soil we now direct our attention to study under what conditions plants can make the best use of it. The important factors affecting the rate of use of water by plants are the extent and vigour of the transpiring leaf surface, atmospheric temperature, humidity of the air and air movement. The larger the leaf surface the greater will be the loss of water from leaves. The atmospheric combination under which the greatest use of water occurs is that of high temperature, low humidity and high wind velocity, conditions so very common in the arid zones of California and which are very similar to the severe weather conditions obtaining in most parts of Northern and Central India.

The consumption of a certain quantity of water by the plant is determined by its leaf surface and weather conditions irrespective of the kind of soil on which it grows, the soil merely serving as a reservoir from which water is extracted by the plant in accordance with its needs. Since 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 are 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 soil.

The amount of water to be applied at each irrigation varies with the kind and depth of soil to be wetted and the moisture content at the time of irrigation. There is no advantage in applying water to soils already wet as it merely passes on downwards and is lost. The soil is said to be over-irrigated when enough water is applied to deep soils to cause percolation below the roots or waterlogging of shallow soils and when the applications are so frequent as to affect aeration of the soil.

The combination of fruit trees and cover crops needs more water during the growing season than trees alone; therefore, in the rainless districts they should never be attempted unless there is an abundant water supply available from canals or rivers. The Philippine Department of Agriculture are conducting a series of experiments on the value of permanent cover crops in alternating rows with Citrus trees under very heavy rainfall conditions. The permanent thick bushes of *Crotalaria* sp. and such other legumes are expected in this scheme of cover cropping to

⁵ Rotmistrov, V. G., "The nature of drought according to the evidence of the Odessa Expt. Station, 1913, Russian ed.," 1911-1913, 1-66 (English translation), Sta. M. of L. and A., Dept. of Agri., Odessa.

⁶ Harris, F. S., and Turpin, H. W., "Movement and Distribution of Moisture in Soil," *Jour. Agr. Res.*, 1917, 10, 113-153.

⁷ Alway, F. V., and McDole, G. R., "Relation of movement of water in a soil to its hygroscopicity and initial moistness," *Jour. Agr. Res.*, 1917, 10, 391-428.

⁸ Keen, B. A., "The Physical properties of the soil," *The Rothamsted Monographs on Agr. Science.*, Longmans, Green & Co., London, 1931.

absorb the extra amount of water during periods of torrential rains and prevent erosion of the soil, as well to prevent leaching of manures.

As has already been stated, the loss of moisture stored in the soil is caused by extraction by the roots of the trees and other plants or weeds growing in the orchard and by evaporation directly from the surface of the soil. Viehmeyer's¹ experiments show that "The amount of water used in transpiration comprises a predominant part of the total losses from the soil under California conditions". While considering the problems of storage and loss of soil moisture we should not overlook the part the tillage plays in manipulating the soil for successful orcharding. According to Viehmeyer's¹ investigations cultivation alone does not help to conserve moisture in absence of a water table and if a water table does exist within 6 to 10 feet from ground level and water is lost by capillarity, there is a greater need for drainage in such soils rather than a mulch to conserve moisture. In the case of dry farming of grain crops, cultivation may help to some extent to prevent loss of moisture through soil cracks if they are of sufficiently large size; but the loss of water by evaporation from the small surface cracks under uniform soil conditions in an orchard takes place at such a low rate that probably nothing would be gained by covering them before the next irrigation is due.

The main purpose of cultivation in the light of recent investigations in California is to avoid weed competition or any other influence the weeds may have rather than the other effects such as soil aeration. Surface cultivation does not increase aeration in the soil depths occupied by the roots of the majority of our fruit trees and sufficient aeration ordinarily takes place in orchard soils regardless of whether or not the soil is stirred at the surface; and rapid nitrification may take place below the depths affected by tillage. On the other hand, unfavourable 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 for long.

The usual practice of hand digging orchard soils at intervals after irrigation in the Bombay Deccan is certainly beneficial in a restricted sense in so far as it makes the soil more absorbent of irrigation water, but it should not be overdone with a view to aerating the roots or to conserving moisture.

In addition to the removal of weeds, cultivation is indispensable for planning irrigation methods, for preparing seed beds and incorporating cover crops and manures, for facilitating the control of certain pests and aiding in the absorption of water where it is a case of an impervious condition of the soil.

Deep tillage is often harmful in orchard soil inasmuch as it tears the roots of many shallow rooted trees. All tillage operations, therefore, in the orchard should be as shallow and only as few as necessary to accomplish the useful purpose given above.

The root activity of the tree is very much affected by soil temperature, soil oxygen supply and the presence of available nutrients in the soil. The wet soils are supposed to be cold. The soils naturally warm up as their moisture content decreases. Root growth and absorption are definitely retarded by keeping the soil too wet

and are accelerated by permitting it to decrease in moisture content. 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. With the return of the air the soil warms up and the bacterial activity increases resulting in increased fertility available to plant roots. Different plants are said to have different ranges of soil temperatures at which their roots make active growth or remain dormant. The tropical and sub-tropical fruits are known to have relatively high temperature requirements for root growth.

According to Prof. Hodgson⁹ of the University of California the Citrus tree shows no root activity below 55° F. and the roots grow most actively at approximately 80° F. Above 80° F. the rate of growth falls rapidly and at 90° F. it practically ceases. The root growth in relation to soil temperatures under tropical conditions may behave differently. It is imperative, therefore, that the study of soil temperatures in relation to root growth should occupy our immediate attention in orchard practices.

The problem of the setting of blooms in Citrus and other semi-tropical fruits in the Bombay Deccan is almost as much dependent on soil temperature as on a change of weather and the writer believes that the present exhaustive method of root exposure to force flowering of the above fruits could easily be replaced by a more rational system of judicious watering so as to allow moisture to fluctuate widely between the field capacity and the permanent wilting percentage. On the other hand, the problem of flower and fruit drop especially in arid regions and under hot severe weather conditions is often tied up with the lack of proper humidity in the orchard at the time of setting and the excessive transpiration taking place under these conditions. Much harm can be averted at this time by flooding the orchard at close intervals and maintaining a strong wind-break around the orchard. Again, the Dieback disease of Citrus trees in the Deccan in the retentive black soils with impervious sub-soils is as acute a problem as one connected very probably with the defective oxygen supply and the resulting low temperatures in the soil. The nitrifying bacteria also require a fairly high soil temperature (85° to 95° F.) and high oxygen requirements for their activity, conditions only possible if the soil moisture fluctuates far below the field capacity and above the permanent wilting percentage.

In view of the above remarks, it is necessary to allow soil moisture to fluctuate in wide limits in order to allow the soil to attain the required high temperatures.

Viehmeyer's experiments on deciduous fruits¹ (Prunes, Peaches and Apricots) and with various kinds of soils (clay, sands, loams) in North California show that plants are not at all adversely affected unless the soil is depleted of its moisture to the permanent wilting percentage. According to his investigations it makes no difference to the abovementioned trees so far as its normal growth and fruiting is concerned, however low the soil moisture may fluctuate between field capacity and the permanent wilting percentage. According

⁹ Hodgson, R. W., "Some fundamentals of irrigation," *Year Book of the Calif. Avoc. Assoc.*, 1927.

to his findings there is no particular optimum water content for growth in the soil between field capacity and permanent wilting percentage at which plants grow best. This is a revelation to orchardists in India who are given to thinking that by keeping the soil moisture content at a high level by flooding the orchard, at close intervals during the maturing period, they are able to swell the fruits to larger size. Veihmeyer and Hendrickson¹⁰ while experimenting in the North and Central California Fruit Valley found that the size of the peaches and grape berries did not seem to be affected by irrigation near the time of picking.

The principle of depleting soil of its moisture to a condition approaching the permanent wilting percentage is not only in common practice in the cultivation of deciduous fruits in North and Central California but it is now also engaging the attention of the growers of evergreen fruits like the Avocado and Citrus in Southern California. The writer believes, however, that with the scanty knowledge of the requirements of tropical fruit trees and of soil moisture conditions in India, it would be risky to allow the soil moisture to fluctuate very close to the permanent wilting percentage in the principal root zone of the trees, but it seems that some minimum safely above the danger point of wilting should be the limit.

Naturally the question arises as to how without the aid of scientific apparatus one should be able to judge whether the soil has enough readily available water or if it is very near the danger point of wilting. In fact the orchardist himself should be in a better position to judge when his trees need water than any one else because of his close associations with his trees as well as the soil. The best method by which the grower can decide when to apply water is by cautiously prolonging the irrigation intervals in a small portion of his orchard and watching the condition of his trees and feeling the moisture in the soil of the principal root zone by hand. After a few trials of this kind he will soon become familiar with the degree of soil moisture which would be safe for his trees and the condition of soil dryness which would cause wilting. Experienced practical irrigators usually foretell the approach of soil moisture to wilting percentage from a flabbiness and a slight change of colour in the leaves and stalk of the plants. The lack of readily available moisture is easy to detect in the case of succulent trees like the Papaya and the Banana but it is not always easy to detect this condition from many stiff leaved plants. In such cases Veihmeyer¹ suggests that some kind of broad-leaved weeds, if allowed to grow in the orchard, would serve as indicators of soil moisture. Generally these weeds in California are deep rooted enough to indicate by their drooping of leaves a depletion of the readily available moisture in the part of the soil occupied by roots of the trees. Where only small streams of water are available, as in most fruit areas in India, the anticipation of the time when the permanent wilting percentage will be reached is very important in order that irrigation

may be started in good time to cover the whole orchard.

It is impossible to assign any specific water requirements for particular orchard trees. They vary with the age, vigour and size of the trees and in accordance to weather conditions, being lowest in the humid regions and highest in the drier regions. Irrigation practice must, therefore, be determined primarily on the basis of the water requirements of the trees, the water-holding capacity of the soil and the amount of moisture in the soil as determined by periodic examinations by means of a soil augur or some such instrument. In California it is a common sight to see Citrus growers testing soil moisture by means of big iron augurs.

The method of irrigation must be governed by the topography and supply and must be so arranged as to guarantee uniform distribution and penetration of water. Whatever may be the system of irrigation flood, basin, ring or furrow, water must penetrate to the lowermost root zone of the tree to obtain best results. The length of spacing of the furrows and duration of running water into the furrow will have to be adjusted according to the rate of downward and lateral percolation of water while irrigating that particular kind of soil. The soil between furrows drawn too far apart is likely to remain unwetted. Where irrigation furrows are drawn in the space between two tree rows and beyond the drip of the tree-crown as is the practice in Citrus orchards of Southern California, the roots underneath the crown of the tree will benefit from the irrigation water to the extent the irrigation water runs and percolates laterally in a definite length of time through the first furrow on the side of the tree row. In this method of soil management, manure and water having been applied from the time of planting mainly beyond the drip of the trees, the feeding zone of the roots is largely built up in the irrigated area near and beyond the drip quite unlike the feeding root zone of fruit trees very near the tree trunk in the Bombay Deccan and in many parts of India where the irrigation and manuring system consists in providing a round basin or a pit close to the trunk.

Systems of irrigation are a mere outcome of circumstances in different countries and different localities in the same country. The grape-vine orchards in Northern and Central California where water supply is plentiful are simply flooded in long strips of beds, the tree row being in the centre of the bed. In the new virgin soils of these vine-growing areas no necessity has yet been felt to manure or fertilise the orchards and there is no danger of leaching the fertilisers due to heavy overhead flooding in large basins. On the other hand, in more arid zones of South California leaching of nitrogenous fertilisers in Citrus orchards is a great problem to be guarded against. In the arid areas, the furrow method of irrigation is found to prevent leaching of fertilisers very efficiently. Flood irrigation is especially desirable in fine silty soils where there is any amount of objectionable salts or alkali present as in the soils of the lower Indus Valley, Rajputana and in many places in the U. P. and the Central Provinces.

In such alkali soils flooding in basins can be used to great advantage to leach down the harmful salts down below the root zone of the trees.

¹⁰ Hendrickson, A. H., and Veihmeyer, F. J., "Irrigation experiments with grapes," *Proc. Amer. Soc. Hort. Sci.*, 1931.

Orchards planted on more sandy soils should not be flood irrigated as these soils have a tendency to take too much water at the upper head. The irrigation furrows on sandy soils should be necessarily short as long furrows in porous soils waste much water by deep percolation (much far below the root zone of trees) in their upper lengths.

In the arid zones of southern California where irrigation water has to be brought from long distances, very elaborate and economical devices have been constructed to give a measured quantity of water just sufficient to wet the required depth in a definite period. In the Citrus orchards of California water is no longer conveyed in open dirt ditches but it is most economically carried through underground pipe lines. As the water reaches the orchard it is taken from the main pipe line and distributed by underground pipes to each tree row. Underground pipe lines are laid deep enough (3'—5') to be out of the way of cultivation implements and are provided with concrete hydrants or stand pipes for each row of trees. These hydrants are usually fitted with valves for regulating the flow of water into them and have adjustable gates through which the water flows to the irrigation furrows. The flow of water is so regulated by the gates as to control its very gradual seepage into the sides and bottom of the furrows. The water reaches the end of the furrow in about one-fourth the time of the period of an irrigation. The practice in many groves is to run water to the end of the furrow quickly and then reduce the flow for the rest of the period of irrigation. Penetration at top and bottom run is thus about the same. A ditch is provided at the other end of the furrow to drain away the surface water running through the furrow during the period of irrigation. This drained water is re-used by pumping back for irrigating in the same orchard or for any other useful purpose. In California, application of water by this system, over a period of about 48 hours, is found sufficient for completely wetting the soil of the root zone of Citrus trees.

While discussing the adoption of different methods of irrigation as circumstances would demand, the unique practice of Island irrigation as followed in the flood swept area of South East China need a special mention. The type of Agriculture found in this country is exceedingly well adapted to the low lying, water-logged soils where rice is the chief staple crop cultivated and rotated with vegetables. The fruit and vegetable cultivation in this country comprises a very elaborate and intensive system of canals, dikes, raised beds and ditches.

The soils of these areas are of alluvial origin and their texture is very fine, being mostly clay, silt or fine loam. Most of these soils are very deep and of high organic content. The whole delta region is subject to heavy floods when the rivers are high in the summer monsoon and the ocean tide holds back their waters. The fields and houses of the area are protected by numerous mud dikes which are specially built round the land to keep back the floods. The inner protected delta land is used for the cultivation of rice, lotus and other water crops while the surrounding dikes are planted with fruits like Lychee, Lungan, Oranges, Peaches, and Papayas. Often the inner rice land is reclaimed for fruit and

vegetable culture by dividing the low lying land into a system of raised beds and ditches. The raised beds, 15 to 20 feet wide, are planted out with fruits and the ditches 2½ to 3 feet wide serve as irrigation channels as well as drains. Water is taken from the canal into the ditches at the time of high tide in the river and is driven out when it is low. To begin with, the ditches are very narrow and shallow and the beds are wide; but the beds gradually get narrower and higher by the gradual process of widening and deepening the trenches which get filled up by the deposited silt and have to be cleaned out each year and the mud smeared back over the beds as a fertiliser.

By the time the trees reach their most productive age, the constant deepening and widening of the trenches reduces the width of the bed to about 15 feet and depth of the trenches becomes 5 to 6 ft. Often the water table in such soils is fairly high and the water rises above to the tree roots on the raised beds by capillarity from the wide and sufficiently deep trenches which hold standing water for a considerably long time. The beds are kept scrupulously clean by weeding and other shallow cultural operations by hand. In a system of this kind of irrigation and cultivation, the soils however clayey and retentive, do not suffer from the packing action of overhead watering or hard pans brought about by tillage operations in irrigated lands in other parts of the world. Both sides of the raised bed having been provided with open drains there is absolutely no danger of oxygen deficiency in spite of the continuous capillary rise of water from the permanent water table of the beds close at hand or the flood waters standing in the ditches for a considerably long period. No effort is made to maintain any kind of mulch except that the muck from the trench smeared over the bed is allowed to crack. The constant supply of water in the trenches makes unnecessary any effort to prevent evaporation.

This system could doubtless be employed to advantage in some of the swampy areas in deltas of our big rivers which are low and subject to a flood or to submersion at high tide from the sea. In this regard we can draw much inspiration from the unique orcharding of the world's best pummelo gardens in Ban Mai in Siam situated in the delta of the Tachin River located about 50 kilometers southwest of Bangkok.

According to the investigations of Prof. Groff¹¹ of the Lingnan University, Canton, China, during the dry weather (between January and July) the tidal flow extends far inland and in the lower part of the river the water becomes extremely salty containing as much as 2% sodium chloride (very nearly approaching sea-water containing 2.7% sodium chloride). In this region the type of cultivation and irrigation is the same as the system of water farming of raised beds and ditches as followed in Southeast China. It is in these salty swamps that the world famous seedless pummelo called "The Kao Pan" attains excellence of quality unrivalled in any other part of the world.

¹¹ Groff, G. W., and Reinking, O. A., "The Kao Pan Seedless Siamese Pummelo and its culture," *The Philippine Journal of Science*, October 1921, 19, No. 4, Manila.