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Avocado Tree Decline in Relation to Soil Moisture and Drainage in Certain California Soils[1]

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Touring the relatively short period of time in which avocados have -L' been grown commercially in California, numerous investigators have called attention to the soil conditions desirable for the successful growth of the trees. Hodgson (3) and Ryerson (9) have emphasized the susceptibility of avocado trees to a lack of adequate soil drainage. With other observers, tree decline has been associated with impaired drainage and the-consequent accumulation of free water in the soil. Donnelly (2), Home (4), Huberty and Pillsbury (5), Rounds (6, 7, 8), Smoyer (10), and Wager (11) report that free water was found in the root-zones of trees showing decline, or of trees which subsequently declined, during or soon after copious rainfall or after excessive applications of water had been made. Increases in the incidence and seriousness of decline have been observed during or following seasons when the rainfall was unusually heavy. The present report provides more detailed information concerning the relation between soil conditions and avocado tree decline.

This malady has been described by Home (4) and also by Wager (11). It takes one of two forms, namely, "decline," which is a relatively slow process, or "collapse," which is sudden. With "decline," the leaves turn a pale-green or yellow color, wilt, and gradually fall, and the twigs die back. Very little new growth occurs, and the trees assume a very thin appearance. Immature fruit usually wilts; it frequently persists for some time on almost defoliated branches, but fails to develop. The roots, also, are affected. Severely affected trees may die within a few weeks, but slightly affected trees may live many months. With "collapse," which is much less common than decline, all the leaves die, but they do not fall immediately from the trees. When the larger roots are affected, the trees usually die. "Decline" and "collapse" are associated in the field. For the purpose of the present study, they are considered together and are referred to simply as "decline."

It is frequently difficult to estimate the permeability of soils in the field, when they are relatively dry. This estimation is much more readily made during or immediately after the occurrence of rains that are sufficiently heavy to saturate the root-zone of the soil mass. Any accumulations of free water occurring in the soil at such times, as a result of poor percolation capacity, can then be more readily detected, and the duration of that free water clearly observed. Furthermore, the lateral movement of free water can usually be determined then.

The present study was conducted during and immediately after the heavy rains that occurred in the winter of 1942-43. As only a limited region could be studied in the few

[1]Paper No. 508, University of California Citrus Experiment Station, Riverside, California.
[2]For the rainfall measurements given here, we are indebted to ,The Vista Press, which maintains a standard Weather Bureau rain gauge. These measurements were in satisfactory agreement with those of two stations operated by the Vista Irrigation District, and with those of private observers.

days available at the time of such rain, the observations were largely confined to the Vista area, in the northern part of San Diego County, California. The soils of this area vary greatly, individual orchards and parts of even very small orchards presenting different conditions in respect to soil conditions and decline of the trees. Certain orchards having soil and soil-drainage characteristics which might be correlated with avocado tree decline were therefore selected for detailed study. The findings in two of the orchards are described, and certain related conditions occasionally affecting the trees in other orchards are discussed. .

PROCEDURE

During the fall and early winter of 1942-43, the rains at Vista were very light, but in the last 9 clays of January, 1943, a total of 8.56 inches[2] of rain fell. Of this amount, 5.68 inches fell on January 23 and 24, and 1.79 inches on January 27. This rainfall was supplemented by 0.65 inch on February 8-9, 1.00 inch on February 21-24, and 1.51 inches on March 4-5. This distribution of the rainfall was fortunate for the purpose of this study.

Our first inspection was made on January 26, after 6.2 inches of water had fallen in the January storm. Soil conditions were determined by the use of shovel holes, soil-tube and auger samples and holes, and by means of a steel prod 1/4 inch in diameter and 42 inches long, with a T-shaped handle and a 3/8 inch ship auger welded on its tip, a tool which is useful in determining the depth of penetration of water and the presence of free water in the soil. In one orchard, permanent observation wells 3 to 6 feet deep were installed. Further inspections were made at frequent intervals during the remainder of the rainy season, until no free water remained in most locations.

SOIL CONDITIONS CORRELATED WITH SOIL MOISTURE AND TREE CONDITION

Observations in two orchards will serve to illustrate the soil conditions frequently associated with tree decline.

Orchard A: One of the orchards studied intensively during the winter is designated as orchard "A." This orchard consists of about 8 acres of 10-year-old Fuerte avocado trees. It is nearly square in shape and is located on the lower western slope of a rolling hill, with virgin brush land above it to the east, and also on its northern and southern boundaries. The grade ranges from 5 to 10 per cent, except toward the lower end of the orchard, where it is less steep. The trees are planted and irrigated on the contour. The soil is clean-cultivated, and furrows with definite "crowns" were in place during the winter.

The relations between the soil, the free water in the soil after rains, and tree condition in various parts of this orchard are instructive. The soil types have been described by Carpenter and Storie (1), while Huberty and Pillsbury (5) have determined certain of their drainage-characteristics. In the upper eastern half of the planting, the soil is Fallbrook fine sandy loam. This is a residual soil of granitic origin. Along the eastern edge of the orchard, which runs across the face of the hill, the surface soil is 12 to 24 inches deep and is very permeable to water. The subsoil contains a large amount of clay. It was found that water penetrated this subsoil very slowly and accumulated above it. The free water existed only in the permeable surface soil. In the clay subsoil, the moisture content did not reach field capacity for some weeks after the heavy rains. Seepage from the higher brush land adjacent to the orchard was observed to occur at several points along this boundary of the orchard during and following the heavy rains of January. Free water existed in the surface soil of the unirrigated brush land, and was frequently found in the zone extending 6 inches from the surface to 24 inches from the surface; it thus occupied 18 inches of soil. A spring appeared where a cut had .been made at the edge of the orchard during the construction of the irrigation system. Seepage occurred for over 4 weeks. Our borings and inspection of the topography indicated that an enormous quantity of water moved by seepage from the unirrigated brush land to the orchard soil. The effect of this seepage on the condition of the trees in this orchard was plainly seen. First, the foliage on the trees in the top row turned yellow. In a few days, similar changes were noted progressively in the second, third, and fourth rows of trees.

About eight rows down the hill from the eastern boundary of the orchard, other conditions were observed to be related to tree conditions. A number of observations were made in a north-and-south line along this row. The depth of the Fallbrook fine sandy loam, to the clay-subsoil, was found to vary considerably. At the south end of the orchard it is only about 12 inches deep, and there the trees, which are abnormally small, were affected with decline during the winter. Free water was found to exist on top of the subsoil in this section of the orchard for at least 4 weeks. This free water was attributed partly to the rain water which fell upon the land at that place, and partly to accumulations as a result of seepage from higher land. The depth of the surface soil gradually increases to a point near the center of the orchard, a distance of about 15 trees from the northern boundary, along row 8, where the depth to clay subsoil is about 40 inches. Tree condition and tree size were observed to be progressively more normal as the depth of the surface soil increased, although about the same quantity of free water was found as in the more shallow soil to the south, on approximately the same dates.

About half way between the center and the northern end of row 8, the depth to the subsoil rapidly increases to about 6 feet. The permeable surface soil was apparently sufficiently deep to hold all the rain water that fell, at least until the middle of February, as no free water accumulated until 3 weeks after the first heavy rain. After that time as much as 18 inches of free water formed on top of the subsoil. This water emitted an odor reminiscent of sewer gas, and undoubtedly formed primarily as a result of seepage from other areas where the surface soil is shallow and the subsoil is at higher elevations. The free water did not come closer than 4.5 feet of the surface, however, and the trees did not show any ill effects. They were large and thrifty — the best in the orchard. This area of good trees is only about 8 trees long. Still farther to the north, where the same row reaches the northern boundary of the orchard, the trees are small and suffered decline during the winter. In this part of the orchard, the clay subsoil rises to within 20 inches of the surface. The topsoil became saturated to within 6 inches of the surface during the first heavy rain, and free water remained on top of the subsoil for over 5 weeks. The subsoil itself was much drier than the topsoil. It is probable that some seepage from the unirrigated brush land at a higher elevation to the north of the orchard augmented the water supply to this area. The surface soil in the brush land is also very thin and was observed to contain free water for about the same length of time. The slope of the brush land is toward this area of the orchard.

Toward the lower western edge of orchard "A," the soil gradually changes from Fallbrook fine sandy loam to Merriam sandy loam, an old secondary soil also derived from granitic sources. The surface soil is only 8 to 12 inches deep, and the subsoil is a very dense clay. The trees in the lower part of the orchard are very small; all of them suffered severe decline during the period of heavy rains, and a number collapsed and died. In some places the surface soil was completely saturated with water, and surface runoff occurred during the heavy rain storms, the flow continuing for about 2 weeks. The quantity of water that flowed out of this small orchard was surprisingly large; it formed a stream about 3 feet wide and 6 inches deep in a recently cultivated dry-farmed field west of the orchard, and washed away all the topsoil in the stream bed. The compact nature of the Merriam subsoil is indicated by the fact that the exposed clay was not appreciably softened by the water flowing over it, and 2 months after the first heavy rain the moisture content of the subsoil was below field capacity at a depth of 2.5 feet. After the surface runoff from the orchard had ceased, one small spring located above the clay subsoil, at a depth of 12 inches from the surface, continued to flow for 3 weeks longer.

Orchard B: Another orchard, "B," is located on soil classified as Vista sandy loam (1), a residual granitic soil. This 10-year-old orchard is located on the lower part of a gently sloping hill, but below other orchard properties. The western part of this orchard slopes toward and encompasses a swale or small valley, which originates in the higher elevations and extends down the hill. In this part of the orchard, the depth of the surface soil varies from 10 inches to 3 feet, within a distance of 140 feet, being deepest in the bottom of the swale. The variations in depth of surface soil are due to erosion in past years. The subsoil is rather uniformly brown clay underlaid with gray clay. This subsoil is very plastic and is variable in thickness. Decomposed granite forms the bedrock below the clay. Observations made during the winter of 1942—43 indicated that seepage water moved on top of the clay layers, from the higher elevations toward the bottom of the swale.

Although the surface soil was deepest at the bottom of the swale, free water accumulated there to within a few inches of the surface! Seepage must have continued for a long time in considerable volume, and thus maintained the excessively high moisture content of the surface soil, for a tractor became stuck in the mud in the swale on April 12, 1943, 2½ months after the first heavy rain. Many of the avocado trees in this western part of the orchard had died in previous years; others died this winter, some gradually and some as a result of collapse. A few trees located farthest from the swale and apparently not subjected to seepage from above, did not deteriorate. Although the clay subsoil in the vicinity of these trees was only 16 inches from the surface, the amount of free water that accumulated was not great. Apparently, the slope of the subsoil was such as to prevent the accumulation of water.

The eastern part of orchard "B" is quite different from the western part, and is separated from it by a driveway and a planting of ornamentals. Here the trees are planted on contour across the face of the hill. The soil type is also Vista sandy loam, but it is variable as regards the presence of a brown or gray clay subsoil and the depth to the clay. Where the clay does not exist, the surface soil is directly on top of decomposed granite; this material also underlays the clay subsoil, where it exists. This area of the orchard is partially isolated from adjacent plantings above it by a cut made for a roadway along the northern property line. Apparently, most of the water found in the soil originated from the rain that fell on the area. The orchard is in Bermuda and weed sod, and as no provision had been made for the removal of surface water, most of it penetrated the soil. The surface soil was observed to be very permeable, but were clay exists, in. the subsoil, free water was found in the surface soil during and following the heavy rains, and seepage was observed.

In this part of the orchard, the condition of the trees was correlated with the depth of the surface soil to the clay subsoil. In areas where clay subsoil exists, the extent of tree decline was also modified by the size of the areas at higher elevations which could contribute water by seepage. These observations may be illustrated by describing conditions along one contoured row (no. 6) about midway of the planting. Tree 1 (Fig. 1), at the eastern end of that row, is small and suffering from severe decline. A clay subsoil was found only 12 inches from the surface in this location.

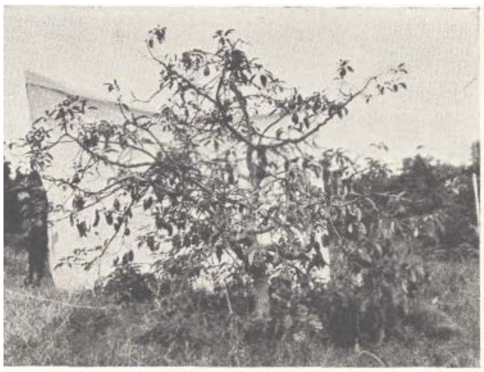

FIG. 1. Avocado tree showing severe decline. This tree (no. 1), in orchard B (row 6), is on heavy soil having a compact clay stratum 12 inches from the soil surface.

The roadside cut previously referred to limits the quantity of seepage water toward tree 1. Tree 3 is somewhat larger and in much better condition, and the depth to clay is 24 inches. In the case of tree 5, the clay is also about 24 inches from the surface; but this tree is in the path of seepage water from an area above, in which a shallow clay subsoil predominates, and the tree has severely declined. Trees *7,* 9, and 11 are weak replants similarly subject to seepage. The clay near these trees is only about 12 inches from the surface, and the original trees had died as a result of decline. Trees 13 and 15, although also located on shallow surface soil, are out of the area which is thought to carry the most seepage water. These trees are of medium size and are in moderately good condition with respect to decline. Trees 16 and 17 (Fig. 2) are in fine condition and large for their age. They are situated on surface soil which is only 18 inches deep, but the subsoil consists of decomposed granite. In this case, the decomposed granite apparently drains rapidly, as free water was never observed in the soil under the two trees.

FIG. 2. Healthy avocado trees (no. 16 in the right foreground and no. 17 in the background) in orchard B (row 6), on soil that is free of clay strata.

At the lower end of the eastern part of the orchard, a deep ditch exposes the line of contact between the surface soil and clay subsoil. Seepage occurred at that line for at least 4 weeks after the first heavy rain, and was particularly evident below that area of the orchard where the clay subsoil is widespread.

FACTORS CONTRIBUTING TO OR MODIFYING TREE DECLINE IN VARIOUS ORCHARDS

Observations which appear to be of importance in relation to soil and soil-moisture conditions and avocado tree decline were made in various orchards.

1. *Surface Drainage from Adjacent Areas:*—Conditions in certain orchards illustrated the damage caused by allowing surface drainage water to enter avocado orchards. The harmful effects of accumulations of drainage water from public roadways or private drives, and from the roofs of buildings and from domestic areas were observed. Although the areas which shed the water frequently appeared small, the discharge of the runoff water into small sections of orchards increased, by many times, the amount of water which those sections received directly during a rainstorm, and was sufficient to saturate a portion of the soil in the root-zones of the trees and cause decline.

2. *Removal of Surface Water from Orchards During Rainstorms:*—The apparently beneficial effects of reducing water infiltration in avocado orchards during periods of heavy rainfall by facilitating the prompt removal of surface water, were also observed. In one orchard which is planted on contours, the irrigation furrows are more than25 trees long. Although this orchard is in Bermuda sod, shallow but broad furrows, which are on a uniform grade, were kept free of growth and obstructions throughout the fall and winter of 1942-43. The result was that during the heavy rains of January, and during subsequent storms, a very large volume of water flowed out of the orchard before it

could enter the soil. Erosion did not occur in this case, as the furrows emptied into a concrete drain. The trees in this orchard are, in general, in very good condition.

Contrasting conditions were observed in other plantings where no furrows were provided, or where the furrows were matted with Bermuda. In one orchard the furrows were on a very flat grade; furthermore, they had been filled up at intervals by the passage of orchard tools. The result was the accumulation of surface water at local areas, where it stood in pools until absorbed. There was little runoff front these orchards, and decline appeared to be prevalent.

3. *Artificial Drainage:*—Where a very permeable surface soil overlays an impermeable subsoil, it would appear that accumulations of free water could be reduced or prevented by the installation of adequate artificial drainage systems. The effectiveness of such systems in the Vista and Fallbrook soil series is suggested by observations on the lateral movement of soil water in the surface soil, and by observations on the results of tile drains installed by a very limited number of orchardists. Although some of these systems are not adequate in extent or in design, large volumes of water were removed from soils of these two soil series by their use during 1942-43. In some instances they appeared of considerable practical benefit, for the orchards in which they are installed are superior to adjacent orchards.

4. *Free Water in the Soil Near the Tops of Hills:*—Soil samples and other observations in several orchards indicated that at or near the tops of rounded hills the surface soil was sometimes saturated for a few days after heavy rains. Tree decline occurred in these locations, where the surface soil was shallow and overlying a clay subsoil. It was evident that more rainfall had occurred than was necessary to raise the moisture content of the surface soil to field capacity. The bulk of the water in excess of normal field capacity had to be removed by slow lateral seepage as free water on top of the clay subsoil.

5. *Planting in Deep Tree Holes:*—In one orchard, decline was observed although the surface soil was about 30 inches deep and there was no reason to suspect serious accumulations of water above the clay subsoil. The soil under the trunks and the crown roots of the trees was found, however, to be saturated with water. It developed that tree holes about 5 feet in depth and 3 or more feet in diameter had been blasted before planting. The clay soil had apparently been mixed with the surface soil and so compacted by the blasting that practically impermeable basins were formed, in which the water remained close to the surface for comparatively long periods of time. Similar observations made in other orchards helped to explain the cause of tree decline.

DISCUSSION AND CONCLUSIONS

Field observations made during and following the heavy rains of the winter of 1942-43 indicate that the surface soils of Vista and Fallbrook sandy-loam soils are very permeable and generally of insufficient depth to hold all the rain water that occasionally falls upon them. The subsoil was found to vary greatly within short distances, but it frequently consisted of a clay stratum at varying depths from the soil surface. The clay was relatively impermeable to water, and accumulations of free water, as a result of heavy rains, were observed in the surface soil just above the clay subsoil. With Merriam sandy-loam soil, the conditions were similar, but the accumulations of water were more severe, owing to more uniform and compact clay subsoil. These observations are in agreement with the conclusions of Huberty and Pillsbury (5) regarding water movement in typical examples of these soil types. The accumulated free water existed for periods of a few days to several weeks. Water accumulations were seldom found where the surface soil rested upon decomposed granite; when they were found, they were transient and not extensive.

Decline of avocado trees was associated with the presence of free water. This agrees with the observations of several investigators. The degree of decline was furthermore correlated with the extent to which the free water inundated the root-zones of the trees, as well as with the length of time the free water existed in the soil. Regardless of the ultimate cause of decline in these particular soils, *the predisposing* cause is apparently the accumulation of free water in the soil. The most fundamental preventive or remedial measure, therefore, is the prevention of accumulations of excessive amounts of free water.

The natural accumulations of water, as a result of rainfall, were found to be aggravated in certain orchards where surface drainage permitted the accumulation of rain water from other land. This could generally be prevented.

The accumulation of free water above clay subsoils was found to result in lateral seepage through the pervious surface stratum of these soils. Where seepage was toward areas occupied by orchard trees, tree decline was aggravated. Seepage toward orchards was not responsible for all cases of decline, however, for affected trees were occasionally observed near the tops of hills where the surface soil was shallow and ; rested on clay subsoil.

In a few orchards located on Vista and Fallbrook soils, large quantities of free water were removed by means of tile drains. The trees in these orchards were generally in better condition than those in nearby plantings. This suggests that subsurface drainage of these soils ma)' be beneficial where the conditions are satisfactory for the operation of artificial drains, and where drains are properly installed. Critical comparisons and experimental evidence on this point are not available, however. In low areas and in soils with a very shallow or a more impervious surface stratum, drainage may be very difficult.

In a few orchards, the penetration of rain water into the surface soil was reduced by the maintenance of suitable open furrows between the rows, to facilitate runoff during heavy rainstorms. Erosion was prevented by emptying the furrows into concrete drains at the ends of the tree rows. The results appeared to be beneficial, as judged by tree condition. Additional evidence on the value of such furrows is desirable. It is evident that they must be kept free of Bermuda grass or other obstructions, and that they should be laid out on a sufficient grade to insure prompt removal of water. Apparently, the land immediately adjacent to surface drains of this type should slope slightly toward them.

The planting of avocado trees in deep tree holes blasted out of impervious clay subsoils was observed to result in the formation of practically impermeable basins and the accumulation of free water, with consequent decline of the trees. This was the only condition which accounted for the death of some trees.

Inasmuch as the variability of the subsurface conditions of the Vista and Fallbrook soils is pronounced, even over very small areas, it would appear desirable for growers to have detailed knowledge of their soil conditions, in order to more effectively prevent or alleviate the accumulation of free water in areas where the drainage conditions are unsatisfactory. Observations made during and immediately after periods of heavy rainfall appear to be particularly helpful.

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