

Importance of Root Aeration in Avocado and Citrus Trees

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Aeration of roots, by which oxygen is secured, is essential for the healthy growth of the tops and roots of avocado and citrus trees. Oxygen occurs in the pore space of soils not occupied by the soil moisture and is dissolved in the soil moisture itself. Nitrates, peroxides and other chemical compounds may furnish very limited amounts of oxygen to the roots. In soils containing organic matter and living organisms, oxygen is also required in the processes of decomposition or oxidation of the various soil components.

Unless soils contain oxygen other than that occurring in the soil moisture, the supply of oxygen soon is reduced to levels that are accompanied by injurious effects in the growth of the tree. Irrigation water greatly reduces the oxygen supply by filling, for varying periods, the entire pore space of certain areas of the soil mass. The removal of oxygen from the pore space is compensated for in part by the fact that irrigation water or rainfall may contain considerable dissolved oxygen. One hundred parts of water can dissolve 2.61 cc of oxygen at 30° C and greater amounts at lower temperatures, 4.89 cc being dissolved at 0° C. Hence large amounts of soil moisture may carry considerable dissolved oxygen. But even this supply of oxygen is soon exhausted in the event that the free water is unable to drain away and allow air to take its place.

Avocado

Every investigator of the growth of avocado trees is aware of the fact that the trees are injured or succumb when the soil in which they are grown is water-logged for even relatively short periods, or in which there is a greatly retarded or an absence of drainage. The period of soil saturation required to defoliate and greatly set back the growth of the tree, or to kill it outright, varies according to the temperature of the air and soil, the stage or season of growth and other factors. In partially saturated soil where large amounts of calcium carbonate occur, an excess of water may also increase hydrolysis to such an extent as to raise the pH of the soil and contribute to a deficiency or unavailability of the heavy metals such as iron, zinc, manganese or copper.

The prevailing conception in regard to the conditions surrounding the growth of avocado trees in their natural habitat is that there are intermittent downpours of rain in certain seasons and that before the next shower occurs the excess soil moisture has largely drained away through the porous organic acid soil.

It may be of interest to refer to data obtained with samples* of soil taken close to the roots of a large avocado tree of unknown variety in the town of Santa Maria de Jesus at an elevation of about 5000 feet in northern Guatemala. The tree near which the samples were taken was about 30 feet high and 25 feet in spread. The rainfall was

confined to a six-month period and was approximately one and one-half times that of Southern California, with frequent heavy fogs or cloudiness the remainder of the year. The tree was growing in its native state with a natural heavy growth of grasses, ferns and subtropical "flora," waist-high and fairly thick, with soil moisture plentiful. Fairly constant temperatures occurred day and night, with some little variation between the rainy and the dry season. The temperature seldom exceeded 85° F and there was frost perhaps once in 10 years. The pH values of the Guatemalan soil, as shown in Table 1, were acid even at a dilution of 1 part of soil to 5 parts of water. The soil had an extremely high moisture equivalent.

Table 1
pH and Moisture Equivalent of Soil Samples Taken Close to a Large
Avocado Tree in Its Native Habitat in Guatemala

Depth of Soil Sample,	1 to 5 Soil-Water Ratio Suspension,	Moisture Equivalent,*
Feet	pH	Per Cent
0.5	6.76	48.5
1.0	6.69	45.8
1.5	5.93	47.8
2.0	6.32	48.2
2.5	6.41	51.9
3.0	6.24	51.7

*Moisture equivalent is the amount of water retained by a soil against a centrifugal force of 1000 times gravity and is expressed as a percentage of the oven-dried weight of the soil.

Temporary Water Saturation of the Soil in Avocado Cultures

An experiment was conducted with avocado seedlings in soil in 5-gallon-capacity tinned containers in order to study the effect of intermittent periods of water saturation of the soil in which the supply of oxygen to the roots necessarily is involved. Equal quantities of pasture soil (Hanford type) from near the Citrus Experiment Station were used in each container. Seeds of approximately the same size were secured from fruits of the Mexicola variety and were planted in the cultures on January 15, 1940. Four equally spaced plants in each container of soil constituted a culture. Three vertical rows of holes an inch apart and the holes about one-fourth inch in diameter were punched in each side extending from the top to the bottom of the containers. The bottom of each container had three rows of similar holes. The holes in the containers were made to allow water to quickly saturate the soil mass and to rapidly drain away. One container had no holes in the sides or bottom.

When all of the avocado seedlings had made a good start (March 5, 1940), the saturation of the soil cultures with distilled water was begun. The 5-gallon-capacity soil cultures were lowered by means of removable handles into 12-gallon earthenware containers. Sufficient distilled water was added to each 12-gallon container until the level of the water was above that of the soil in the 5-gallon container. In a short time the soil was saturated with water.

The avocado soil cultures were allowed to remain in a saturated condition for various

periods—1, 2, 3, 4, 6, and 8 hours, respectively. One culture without drainage holes received sufficient distilled water applications to the soil surface as to maintain a suitable soil moisture content at all times.

The saturated cultures were lifted out of the water at the end of their respective periods and were supported in such a manner as to drain back into their respective 12-gallon reservoirs. This method of saturating the soil cultures with water was employed on Tuesday and Friday of each week. After June 17, 1940, the cultures were saturated three times instead of twice each week, namely, on Monday, Wednesday and Friday. The growth period extended from January 15 to September 23, 1940. At intervals throughout the growth period, similar applications of nitrogen were made in each culture in the form of calcium or ammonium nitrate. Sufficient distilled water was added from time to time to each 12-gallon container in order to maintain approximately the same volume of solution as well as the same solutions for saturating the soil cultures. Adjustment of the pH values of the drainage waters to pH 5.0 was made at various times. It was early noted that the cultures immersed for periods of 1 and 2 hours respectively showed practically no difference in their growth rates. After June 17, 1940, the culture formerly saturated for 1 hour was saturated for 24 hours.

Growth measurements were made at intervals of one to two months. The measurements made at the termination of the experiment are shown in Table 2. The data do not indicate that growth was interfered with as a result of the repeated temporary saturation of the soil with water. The leaves were dark green in color, with no obvious deficiency symptoms.

Table 2
Growth of Mexicola Avocado Seedlings in Soil Saturated at Intervals for Varying Periods

Period of immersion of respective soil cultures in water	Leaves			Trunk Length	Trunk		Branches Length	Roots	
	Number	Fresh Weight	Dry Weight		Fresh Weight	Dry Weight		Fresh Weight	Dry Weight
HOURS	GRAMS			INCHES	GRAMS		INCHES	GRAMS	
2	178	197	62	170.3	184	59	14.8	130	32
3	192	227	70	172.5	169	55	36.5	139	35
4	232	228	71	161.0	168	56	68.5	109	27
6	180	226	69	168.3	172	57	27.8	122	30
8	161	221	64	164.5	154	48	16.8	92	22
24*	154	194	63	143.0	207	71	15.5	162	40
0	154	197	62	146.0	142	48	24.5	125	30

*1 hour until June 17, 1940, 24 hours thereafter.

The results of this experiment make it appear that the injury to avocado trees resulting from water saturation of the soil in the field must be due largely to the prolonged length of the saturation period, because water saturation for relatively short periods had no injurious effects in the soil type used.

Soil moisture that saturates the soil and moves at too slow a rate may fail to renew the oxygen supply rapidly enough and hence may bring about root injury. This is frequently

accompanied in the field by the shedding of fruits of various sizes and the loss of leaves. Cultural difficulties may also occur. When the temporary soil saturation period is extremely short it may mean that the soil has a low water holding capacity and care must be exercised during the irrigations in order not to waste the water or carry valuable plant nutrients below the root zone. It is commonly stated that the depth to which soils are aerated determines in a large degree the growth and distribution of roots and consequently the utilization of soil moisture.

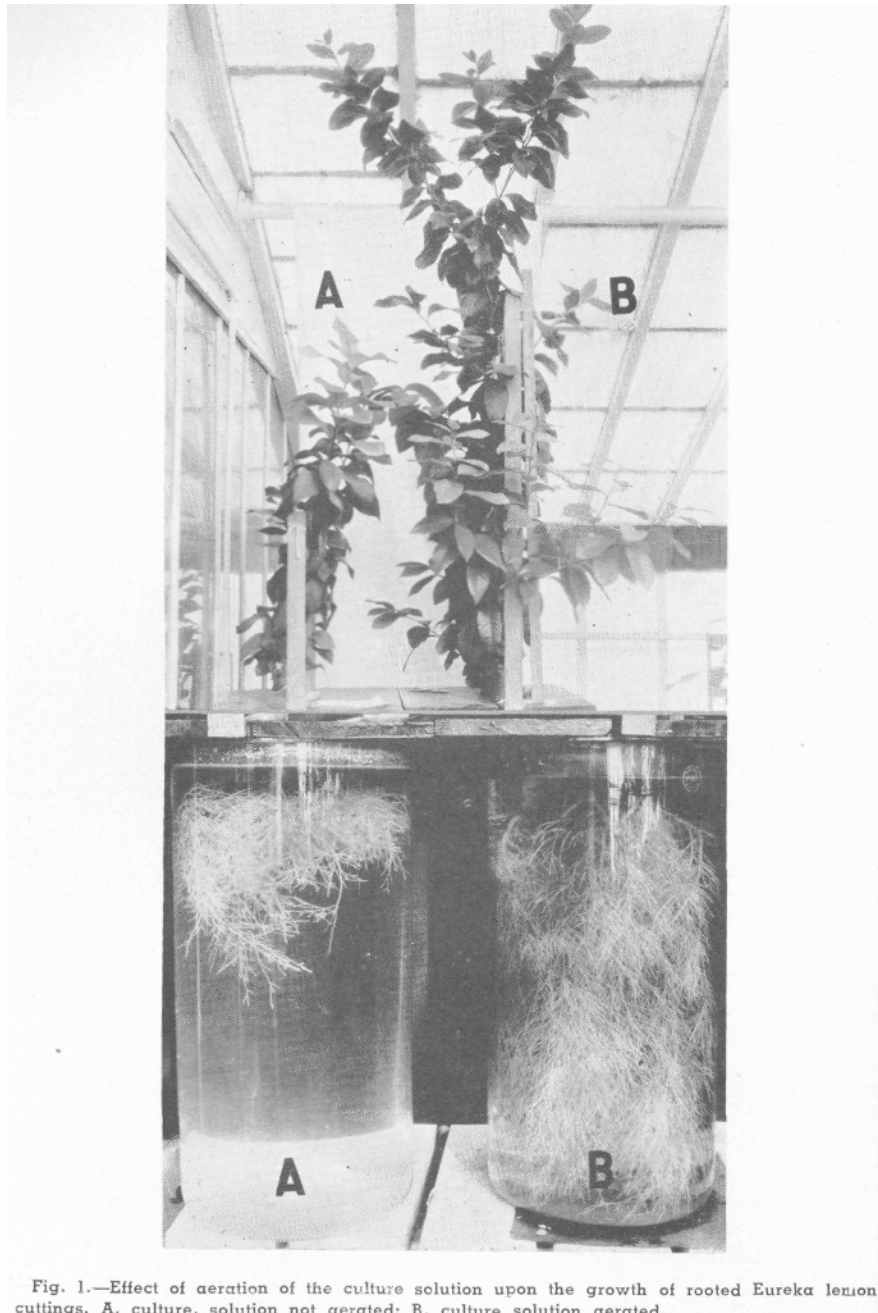


Fig. 1.—Effect of aeration of the culture solution upon the growth of rooted Eureka lemon cuttings. A, culture, solution not aerated; B, culture solution aerated.

Rooted Lemon Cuttings in Solution Culture

From the results of an experiment in the glasshouse, with lemon cuttings in solution culture, it is equally true that the depth to which a solution is aerated determines the depth to which roots will grow.

Pyrex glass jars 12 inches in diameter by 24 inches high, with split glass covers, were used in the growing of rooted Eureka lemon cuttings in culture solution. Although many cultures were grown and the results confirm one another, only a single pair of typical cultures will be used in the following discussion. Two cuttings were grown in each jar. Heavy black paper wrapped about the jars served to exclude the light from entering the sides of the jars, black roofing paper protected the bottom, while split wooden covers coated with Gilacoat black paint covered the glass lids and excluded the light from the top.

The jars held approximately 39 liters of culture solution of the following composition (parts per million): Na 7, K 185, Ca 159, Mg 54, Cl 10, NO₃ 718, SCO₄ 216, B 1, Mn 6, Al 7, Fe 0.1. In addition, 0.1 parts per million of I, Ti, Br, Sr, and NH₄ were present in each solution. The iron supply was frequently renewed, and the water lost by transpiration was replaced with distilled water. In adding this water, some dissolved oxygen also was added but the water additions were made with the setting up of a minimum of convection currents.

One culture had an open glass tube 1/4" to 3/8" in diameter) extending to the bottom of the glass container. By means of this tube, air was bubbled through the solution from the bottom to the top. Another culture was similar in every way to the aerated culture, except that it was not aerated.

The rooted lemon cuttings were placed in the culture solutions (pH 5.0) on August 9, 1937. After growth was well advanced (December 1, 1937), phosphate was added to each culture solution as to give a concentration of 105 parts per million. The pH of the culture solutions frequently were adjusted to pH 4.5-5.0. The cultures were grown in this manner until November 18, 1938, without renewing the culture solutions, for to renew the solutions would seriously disturb the oxygen content of the solutions and would remove oxygen-consuming sloughed-off organic matter that settles to the bottom of the containers.

On November 18, 1938, the fresh weight of the two cuttings in the aerated culture was 1230 grams while that of the cuttings in the non-aerated culture was 315 grams. Figure 1 shows the growth of the tops and roots as affected by the aeration of the culture solution. In the non-aerated culture the root growth is confined to the upper portion of the solution in the container where oxygen could be dissolved by surface contact of the solution with the atmosphere and where the additions of distilled water introduced appreciable amounts of oxygen into the culture solution. The use of mechanical stirring, which would set up convection currents and would mix these supplies of oxygen deeper into the culture solution, might induce a somewhat deeper root growth than that shown in the non-aerated culture in Figure 1.

The aerated culture flowered and produced several half-grown lemon fruits while the non-aerated culture did not flower. The root systems in both cultures were light colored

and healthy in appearance, the chief difference being the very short, much branched rootlets in the non-aerated culture. During the period from April 6, 1938, to November 8, 1938, the cuttings in the non-aerated culture transpired 27.8 liters of water while those in the aerated culture transpired 139.3 liters.

Tests were made (Winkler's method) of the oxygen content in the aerated and non-aerated cultures on November 19, 1938. On a liter basis, the aerated culture solution contained, by weight, 6.2 milligrams of oxygen in the solution four inches below the surface, 6.0 milligrams in the solution at half the depth of the solution, and 6.1 milligrams in the solution near the bottom of the container. The oxygen values obtained for the same relative depths in the non-aerated culture were: 2.4, 2.2, and 2.8 milligrams respectively. In the non-aerated culture the most oxygen at any one time was near the bottom of the solution where there were no roots, although here the oxygen was in reality probably less in total amount over a given period because of the renewal of the oxygen supply near the surface of the solution and as is shown by the extent of root growth in Figure 1.

In aerated cultures containing healthy large lemon trees in 110-liter-capacity containers, the oxygen content on the same basis was 9.1, 9.3, and 9.3 milligrams respectively.

When water samples from the aerated and non-aerated culture solutions were collected under oil, the oxygen values on the same basis were 10.1 and 3.6 milligrams respectively for the aerated and non-aerated cultures at half the depth of the containers. Small differences in the repetition of the determinations are likely to result from slight convection currents set up in the solution while sampling. Even so, the oxygen values obtained show considerable differences in the aerated and non-aerated cultures. Samples taken from an aerated culture solution (110-liter capacity) in which a large healthy Valencia orange tree was growing showed, when the solution was collected under oil, an oxygen content of 10.1 milligrams per liter at half the depth of the container. Many other cultures than those described have been grown with and without air with the same results as were obtained for the two cultures the more fully discussed here. Other methods of collecting the samples for oxygen analysis are known and could have been used, but the methods used suffice for the present requirements.



Fig. 2.—Effect of aeration upon culture A (formerly not aerated) of figure 1. The tops showed a marked improvement while relatively little change occurred in the roots.

In some experiments with two-year-old Valencia orange trees grown in 12-gallon containers of soil, relatively large amounts of nitrogen were added in the form of calcium nitrate or ammonium sulfate and the soil was maintained continually in a water-saturated condition (as shown by a glass tube extending from the bottom of each of the crocks to the level of the soil). The soil used was a heavy black soil obtained from near El Toro, California. After sixteen months of this water saturation, the trees in the ammonium sulfate-treated cultures were dead while those in the calcium nitrate-treated cultures were still alive and able to recover following drainage. In the field, the nitrate content is relatively very much lower than the amounts used in these cultures and therefore, while nitrate may be beneficial in supplying oxygen to roots, the very small amounts usually present in soils cannot for long be expected to exert such an effect.

In the non-aerated culture shown in Figure 1 the roots appeared to be of a healthy color,

and ordinarily it would be taken for granted that a marked recovery resembling the condition of the aerated culture would follow in quick order once the aeration of the formerly non-aerated culture was started. Since the culture solution in the original aerated culture was adequate to grow large plants it was assumed that the poor growth in the non-aerated culture did not remove much of the nutrient salts from the culture solution.

The culture solution that was not aerated prior to November 19, 1938, was then aerated. Growth in the tops soon occurred, with little or no change in the root growth. The transpiration loss was as follows: November 19, 1938, to June 19, 1939 (7 months), 104.5 liters; June 19, 1939, to January 19, 1940 (7 months), 173 liters; and January 19, 1940, to May 24, 1940 (4 months), 216.5 liters. During the previous non-aeration period of 7 months the transpiration loss was 27.8 liters.

With aeration from November 19, 1938, to September 26, 1939, the roots of the formerly non-aerated culture failed to make any marked growth response even though the tops had made several cycles of growth during the same period. It was possible that growth in the tops and the fruit production were factors retarding the root growth and that certain nutrient salts had become deficient in the culture solution. Some of the veins of the dark green lemon leaves were becoming slightly yellow, indicating the likelihood of a low nitrogen supply since the roots did not appear to be dark colored or rotted, which might interfere with nitrogen absorption. Analysis of the I culture solution showed 0.12 parts per million of nitrogen. On September 28, 1939, the culture solution was renewed, including phosphate and the minor elements, and aeration was continued.

On May 24, 1940, the experiment was terminated and the culture appeared as shown in Figure 2. Twelve fruits were produced. The fresh weight of the two cuttings and their 12 fruits on May 24, 1940, was 4358 grams. One additional fruit of 516 grams fresh weight became detached on April 27, 1940. When cut open, this fruit contained germinating seeds with long primary roots. Although the extracted fruit juice had a pH of 2.70, it is not known whether the roots of the seedling plants were in full contact with acid of this strength.

Even though the roots of the non-aerated culture appeared healthy, they nevertheless reacted as though injured by this treatment, despite the subsequent long period of aeration. Root observation was readily accomplished at any time during this experiment by simply unwrapping the paper wrapper from the glass containers.

In soil of much greater depth than these 24-inch-deep cultures, water saturation of the soil at various depths may injure roots to such an extent as to retard their full or partial recovery for a period of years. In the solution cultures, an aeration period of 16 months, while beneficial, was insufficient to overcome in that time the effect of the previous period of non-aeration. The movement of air in soil can best be brought about by degree of growth and distribution of roots.

*These small soil samples were sent to Mr. Harvey W. Lamb of Encinitas, California, by Mr. Paul H. Ford of Pasadena, who had been in Guatemala. Mr. Dean F. Palmer who acquired the samples kindly made them available for any useful purpose.