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Root Distribution of Young Avocado Trees on Bench Terraces

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Bench terraces have been widely used in both the Old and the New World. As an indication of their importance in permanent land use, Lowdermilk[1] found from a study of land use in Europe that only two classes of land had withstood continuous cultivation for a thousand years or more; level or gently sloping land not subject to the soil erosion processes, and land artificially leveled, in part, by bench terracing.

In the semiarid Southwest, Stewart and Donnelly (11) found evidence of numerous bench terraces that had been used by the primitive pueblo farmers of that region. At the present time, the Dutch and English in the East Indies employ bench terracing on an extensive scale in tree cropping. In California, bench terraces are used currently to a limited extent in citrus culture and to a considerable extent in avocado culture.

Little has been reported on the effect of bench terracing on root systems of tree crops. In fact, insofar as the avocado is concerned, there seem to be almost no published accounts of systematic root studies. Of 3,650 references to the avocado compiled by Condit (4) in 1939, none, if one may judge by the titles, are concerned primarily with the root system. Coit (3), in 1940, published a short but illuminating paper, illustrated with diagrams, on the general effects of soil and culture on the root system of the avocado.

Only a small body of literature on the root systems of some of the other fruit trees has accumulated, much of it appearing within the last 10 years. While no attempt will be made here to review this literature, several of the more recent references may be cited. In reporting a comprehensive study of the root systems of young apple trees, Yocum (19) gave a critical review of the pertinent literature, citing 56 titles. Rogers (9) contributed a historical survey of 118 papers bearing on root growth, with special. reference to hardy fruit plants. These 118 papers were selected from more than 1,100 works dealing with or mentioning root growth. Among recent papers that have appeared since the time of the foregoing reviews, or that were not included in them, are those by Batjer and Sudds (1), Boynton and Savage (2), Haut and Schrader (6), Lincoln (8), Rogers (10), Susa (12), and Tydeman (13, 14) on apple tree roots; by Cowart (5) and Havis (7) on peach tree roots; and by Veihmeyer and Hendrickson (15) on soil moisture as an indication of root distribution in deciduous orchards.

The principal object of the present study was to gain information on the effect of bench terracing on the root distribution, particularly the horizontal root distribution, of the avocado. Field work was carried on at the hill culture research station operated jointly by the University of California and the United States Soil Conservation Service, near San Juan Capistrano, California. This station is in the coastal section of the subtropical belt.

[1]*Lowdermilk, W. C, in oral communication to the writer*

THE FOUR TYPES OF BENCH TERRACES

Four types of bench terraces were included in the study: the preformed or preconstructed bench terrace, the level-basin bench terrace, the. Reddick bench terrace, and the Javanese bench terrace.

In the construction of the preformed terrace, a line is laid out on grade along the hillside. By repeated slices soil is moved downhill along this line by a tractor-drawn scraper until a platform nearly level in cross section is formed, which constitutes the bench proper. The steep section just below the platform or bench is called the riser. The width of the bench in the preformed terraces at Capistrano ranges between 7 and 12 feet. Avocados were planted on these preformed terraces 2 feet from the outer edge of the bench.

Level-basin terraces are constructed by manually excavating, with shovels, a circular basin, the central portion of which is level. The level-basin terraces involved in this study measure 8 feet in diameter. Avocados were planted in the center of these basins.

The Reddick bench terrace is a California adaptation of the accretionary type. In constructing this terrace, a furrow ridge is thrown up by plowing along a predetermined grade. Trees are planted on this ridge. The soil immediately adjacent to the upper side of the tree row is cultivated; the soil immediately below is maintained in ground cover. This results in a gradual movement of soil downhill on the cultivated strip and its entrapment on the uncultivated strip, a process which results in time, generally in from 2 to 10 years, in the development of a bench on the upper side of the tree. In this experiment, the horizontal distance between two adjacent ridge lines is 16 1/2 feet at a position on the hillside where the slope is average for the area so terraced.

The Javanese bench terrace, developed in the East Indies, differs from most bench terraces built in the New World in that part of the earth is moved uphill. As in the construction of a preformed terrace, a line is laid out along the hillside to a predetermined grade. Some soil is moved downhill along this line by manual or mechanical cut-and-fill methods. Part of the bench is formed by this downhill earth displacement. The remainder of the bench is formed by moving earth uphill from a strip just below the grade line. This method of bench-terrace formation lessens the extent to which subsoil is exposed at the surface by the terracing operation. As in the preformed terrace, trees are planted near the outer edge (in the present study, 2 feet from the edge) of the bench.

In this experiment, Reddick bench terraces were built on a southerly exposure, the slope ranging from 20 to 35 per cent; level basin terraces were constructed on a southerly and a northerly exposure on slopes ranging from 15 to 25 per cent; preformed terraces were constructed on both northerly and southerly exposures, with slopes ranging from 18 to 35 per cent; and the Javanese terrace was formed on a northerly exposure having a 30 per cent slope.

THE SOILS

The subjoined profiles are representative of the soils assemblage on which plantings were made. Profiles A to E, listed below, are of soils adjacent to the locations of root specimens correspondingly labeled A to E in Fig. 1.

A. Ambrose clay loam	
0 to 8 inches	Grayish-brown clay loam
8 to 24 inches	Grayish-brown silty clay, moderately compact
24 to 32 inches	Brown clay, very compact
32 ins. and below	Mixed brown and light-brown clay, friable
B. Ambrose silty clay loam	
0 to 24 inches	Dark grayish-brown silty clay loam
24 to 48 inches	Dark-brown silty clay loam, very compact
48 ins. and below	Brown to light-brown clay, slightly compact
C. Botella loam	
0 to 26 inches	Brown loam
26 to 34 inches	Brown clay, moderately compact
34 ins. and below	Brown clay, very compact
D. Altamont silt loam	
0 to 15 inches	Brown silt loam
15 to 30 inches	Light-brown silt loam, slightly calcareous
30 to 48 inches	Brown clay, very calcareous, lime in seams
48 ins. and below	Light-brown friable clay, very calcareous, lime in seams
E. Ambrose clay loam	
0 to 12 inches	Dark brown clay loam
12 to 30 inches	Very dark brown to black silty clay loam, slightly compact
30 to 48 inches	Light brown silty clay, very compact
48 ins. and below	Brown to light-brown friable clay loam
F. Tierra clay	
0 to 18 inches	Very dark grayish-brown clay, very compact
18 to 32 inches	Mixed grayish-brown and light-brown silty clay loam, moderately compact
32 ins. and below	Semi-consolidated substratum (marine shale)

Terracing modified the natural soil profiles, forming artificial soil profiles on part of the terraced area. The amount of such modification, which is the combined function of the terrace type and the degree of slope, may be defined, in a single valued manner, as the extent to which subsoil, or lower soil horizon, is exposed on the surface of the terrace bench. On a given slope such exposure would be least in the case of the level-basin terrace, of intermediate extent in the Reddick and Javanese terraces, and most extensive in the preformed terrace. Within the limits of slope for the types of terraces described in this paper, the degree of modification for a given type is a function of the sine of the angle of slope.

MATERIALS AND METHODS

One-year-old Mexicola *(Persea drymifolia)* seedlings propagated in gallon containers were planted in April and May 1939. Shortly after planting time, the space immediately adjacent to the plants was heavily mulched with barley straw. Coincidently, bare areas on the terraces received a light application of barley straw. In the fall of 1939 the benches of the Reddick, Javanese, and preformed terraces were deep-tilled (subsoiled) to a depth of 16 inches, a minimum distance of 3 feet from nearest subsoil furrow to tree trunk being maintained. In March 1940 a heavy cover crop on the benches of these same terraces was turned under by disc-harrowing, and they were clean cultivated during the following summer. Other parts of the terraced areas were not cultivated in 1940, except that summer weeds were hoed down on the risers. Unusually heavy precipitation in the winter of 1940-41 developed a dense volunteer, winter ground cover that was growing rank on most of the terraced area at the time root examinations were started.

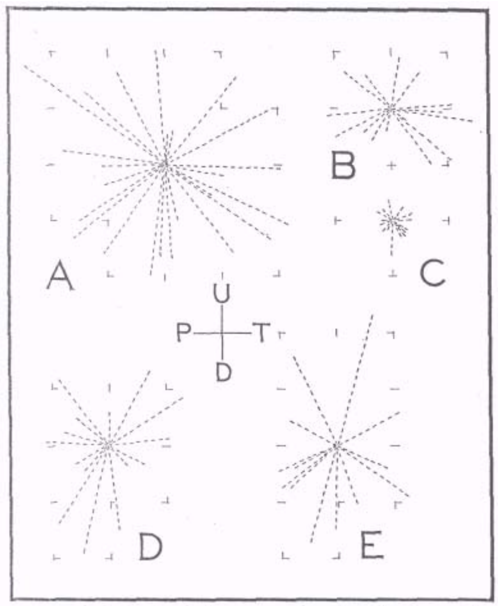

FIG. 1. Idealized diagram showing horizontal distribution of primary lateral roots of representative young avocado trees on bench terraces. A, Level-basin terrace; B, Preformed bench terrace, northerly exposure; C, Preformed bench terrace, southerly exposure; D, Reddick bench terrace; E, Javanese bench terrace. Crossed lines indicate orientation, which was uniform for all the projections; U-D, up and down hill; P-T, parallel to the edge of the terrace. Intervals are spaced at 2 feet.

Water from a tank-wagon supply was added to the soil of all of the plants in the summer of 1939 and to that of most of the plants in the summer of 1940. The amount of water added is tabulated below. Precipitation was above normal during the experimental period.

	Water Added to Soil of Each Plant (Liters)	
	Summer 1939	Summer 1940
Reddick bench terraces	53	27
Level-basin terraces	61	None
Preformed terraces, northerly exposure	61	45
Preformed terraces, southerly exposure	68	45
Javanese terrace	61	27

Top development of trees was measured, and their general condition was evaluated with respect to the several soils, exposures, and terrace types in January 1941. In the period February to May 1941, roots of the avocado trees were excavated for examination. Three methods were used in these excavations: (a) A circular trench was dug around the plant at a distance from the tree trunk greater than the maximum lateral root length; the trench was then gradually advanced inward, the roots being exposed by removing the enclosing soil with a sharp-pointed tool, (b) Linear trenches were dug in certain directions with respect to the tree axis and the axes of the terraces, the root distribution being examined in the walls of these trenches. This method is similar to the bisect method of root examination described and extensively utilized by Weaver (16, 17, 18) and his co-workers in the study of the roots of grasses and field and vegetable crops, (c) To supplement the information gained by the two previous methods, two trenches intersecting at right angles were dug at certain tree locations to determine the lateral root spread up and down the hill and along the terrace contour.

RESULTS

Top Growth:—Top growth of the young avocado trees on the several bench terraces is summarized in Table I. It will be noted that there are divergences in this table between the rank determined by the growth index and that determined by the condition of the trees. These are explained in the paragraphs below.

TABLE I—SUMMARY OF TOP GROWTH OF YOUNG AVOCADO TREES ON BENCH TERRACES AT SAN JUAN CAPISTRANO, CALIFORNIA*

Soil	Type of Terrace	Exposure	Average Height (Feet)	Average† Diameter (Inches)	Relative Growth Index	Condition of Trees
Tierra clay	Preformed	Southerly	2.1	11/16	0.9	Very poor
Ambrose clay loam	Preformed	Southerly	2.7	10/16	1.0	Poor
Botella clay loam	Preformed	Southerly	3.1	12/16	1.4	Fair
Ambrose clay	Reddick	Southerly	3.1	14/16	1.7	Very good
Botella loam	Preformed	Southerly	3.7	14/16	2.0	Fair
Altamont silt loam	Reddick	Southerly	3.9	19/16	2.8	Excellent
Ambrose silty clay loam	Preformed	Northerly	4.2	18/16	2.9	Good
Ambrose clay loam	Javanese	Northerly	5.1	18/16	3.6	Excellent
Ambrose clay loam	Level-basin	Southerly	4.8	30/16	3.8	Very good
Ambrose clay loam	Level-basin	Northerly	6.7	28/16	7.3	Very good

*Growth measurements made January 6, 1941. Conditions of trees evaluated January 16, 1941.
†Diameters were measured at a point 1 inch above ground surface.

Root Development, General:—The root system of the avocado investigated in this study consists, in its major elements, of an imperfect taproot and the primary lateral roots that issue from it. A short distance from the surface, generally from 6 inches to 1 foot, the taproot divides into branches, which may bend to assume a lateral position. The primary lateral roots divide, mainly by forked branching, into secondary lateral roots. A fourth order of roots branch at a high angle from the secondary lateral roots; these may be called tertiary lateral roots. The fine roots prevalent in the upper layer of the soil under some conditions are secondary and tertiary lateral roots. With the exception of the development of fine near-surface roots, the root habit was essentially the same on all four types of terraces.

The avocado roots are spotty in distribution. Large sections of ground around trees that made vigorous growth showed no roots. This spottiness in root distribution appears to be a genetic characteristic as it occurred under all conditions of growth.

Maximum root penetration was slightly over 5 feet in a soil represented by profile D (see section on "The Soils"). This maximum penetration was on a Reddick bench terrace on a southerly exposure. Maximum lateral root spread of 8 feet, measured radially from the tree trunk, took place in Ambrose silty clay loam on a level-basin terrace on a northerly exposure. Profile E is representative of the soil in which maximum root spread occurred.

The heavier soils caused a reduction in the number, and an increase in the size, of roots that did develop. Conversely, lighter soils caused an increase in the total number of roots and favored the development of finer roots. Frequently, a primary lateral root, on entering a soft, permeable soil zone, subdivided into many fine secondary lateral roots. Roots were found sparingly or not at all in poorly aerated compact soil zones in which soil moisture and other conditions were favorable for growth. A high level of soil aeration appears to be as essential for vigorous root growth as adequate soil moisture.

Root Development on Preformed Terraces; South Exposure:—Root growth on the heavy soils on this exposure (Tierra clay and Ambrose clay loam) was extremely poor. In many instances they were restricted entirely to the column of soil, about a foot in diameter, formed by the fill-back soil in the hole dug to receive the plant at planting time. Downward penetration, below the initial depth of planting, was nil in some specimens and did not exceed 6 inches in any instance. Top development was characterized by a spindling trunk, elongated unduly with respect to its diameter.

Root growth on Botella clay loam and Botella loam was considerably better than that in Tierra and Ambrose clays. Here again, the top growth was characterized by a spindling trunk. The group of plants on the Botella loam have a slightly higher growth index than those on the Ambrose clay or Reddick terraces (cf. lines 4 and 5, Table I). The plants on these Reddick terraces were in a much healthier condition all through the experiment, although averaging less in height, than those in Botella loam on the preformed terraces.

Root growth was so limited on south-facing preformed terraces that terrace shape could have exerted only a small effect on root distribution. In some specimens roots were more numerous in the section of ground parallel to terrace edge. This section was occupied by filled soil that, in some instances, was more favorable for root development than adjoining ground on the terrace bench and on the terrace riser.

In general, the effect of preformed bench terraces on this southerly slope was to make an initially poor site worse.

Root Development on Preformed Terraces; North Exposure:— Root growth on the Ambrose silty clay loam on the northerly preformed terraces was fair. Penetration, measured from the surface of the bench, ranged from 1½ to 4 feet. Lateral spread, measured from the trunk, ranged up to 3 feet. There was a slight development of fine near-surface roots on the mulched terrace risers and on the mulched areas on the terrace benches in the immediate vicinity of the plant.

There was a definite tendency for the roots on these northerly preformed terraces to be larger in number and size in the soil sectors parallel to the edge of the terrace. Individual specimens showed much variation in horizontal distribution, however. In some, the primary lateral roots were larger in size and number on the uphill side, in others, the roots were larger and more numerous on the downhill side. Viewed in transverse profile (vertical section at right angle to terrace edge), primary lateral roots seemed little affected by the terrace shape.

Indications in the fall of 1940 were that the avocados on northerly .preformed terraces were being adversely affected by soil changes induced by this type of terracing. Their condition was inferior at that time to those on the same slope and in similar soils on level-basin and Javanese terraces. It seems probable that this adverse effect would have become more pronounced as the trees became larger.

Root Development on Javanese Bench Terrace:—Roots grew well in Ambrose clay loam (see profile E in section on "The Soils") on the Javanese bench terrace (northerly exposure). Measured from the terrace bench, root penetration ranged up to 4 feet. Lateral root spread from the trunk ranged *up* to 5 feet. Primary lateral roots were most numerous on the downhill side; a moderate development of fine near-surface roots was also found on this side. This preponderance of primary lateral roots on the downhill side may be ascribed to the fact that in constructing the terrace, topsoil is concentrated in this region. Development of fine near-surface roots resulted from the conservation of surface moisture by mulch.

The trees on the Javanese bench terrace were in excellent condition when evaluated. This condition, somewhat superior to that of nearby trees on level-basin terraces in similar soil, is believed accounted for by the favorable drainage qualities of the Javanese bench terrace.

When viewed in transverse profile, upper primary roots conformed in vertical distribution to the profile of the terrace. Such roots on the bench side were approximately horizontal; on the riser side (downhill) they dipped at an angle roughly corresponding to the dip of the surface of the terrace riser.

Root Development on Reddick Bench Terraces:—On these southerly Reddick bench terraces root growth was fair to good in Ambrose clay and excellent in Altamont silt loam. In the silt loam, root penetration ranged up to 5 feet, as measured from the bench surface adjacent to the tree; lateral root spread ranged up to 5 feet from the tree trunk. Root penetration in the Ambrose clay was slightly less than in silt loam, but root spread was considerably less, being in the main less than 3 feet. Systems in clay averaged fewer roots and a smaller proportion of finer primary and secondary roots than those in silt loam.

A layer of mulch to a depth of from 1 to *3* inches had accumulated on the terrace risers by the winter of 1940-41. Under this, fine near-surface roots were found to a slight extent in the clay and to a moderate extent in the silt loam. No fine near-surface roots were found on the bench portions of the terraces and none were expected, as these portions of the terraces had undergone clean cultivation in 1940.

Upper primary roots on the riser side of the terraces conformed in distribution, as seen in transverse profile, to the dip of the riser surface. On the bench portions no correlation was observed between vertical distribution of primary roots and the attitude of the bench. In some specimens there was a tendency for roots to be more numerous in the zone parallel to the edge of the terrace. On the whole, however, no definite correlation could be shown between horizontal distribution of the main lateral roots and terrace shape.

Top growth of trees on Reddick bench terraces was closely correlated with root development. When top evaluation was made trees on Reddick terraces were in better condition than might have been expected. As in the case of trees on the Javanese terraces, this is believed to be the result of favorable drainage.

Root Development on Level-Basin Terraces:—On the level-basin terraces root growth was excellent. Although exhibiting characteristic spottiness, previously discussed, roots were fairly well distributed horizontally and vertically. The average lateral spread of roots on these level-basin terraces was greatest for any of the terrace types studies. Within this group, root and top growth were found to be substantially larger on the northerly than on the southerly terraces. On the southerly terraces, spread of the primary lateral roots was, in the main, less than 5 feet; on the northerly terraces, it was, on the average, greater than 6 feet. Average penetration of roots on the southerly terraces was slightly less than on the northerly terraces. Top growth on the two exposures correlated closely with root growth.

On the downhill side there was a slight but noticeable preponderance of roots, in comparison with those on the uphill side. The soil in the shallow layer of the downhill side was composed entirely of topsoil, part *in situ* and part filled in by soil moved from the upper side. This change in the soil layering, inherent in the terrace, accounts for the eccentricity in root distribution.

A mulch layer about 2 inches deep on the southerly terraces and ranging up to 4 inches deep on the northerly terraces, had accumulated in the basin by the winter of 1940-41. Under this layer a dense accumulation of fine near-surface roots was found on the northerly terraces. Development of these fine roots was less extensive under the mulch of the southerly terraces. Distribution of these fine roots was not confined to the soil proper; many lay on the surface of the soil and some extended upward into the mulch.

During wet weather, water is impounded in the basins of these terraces, thereby impairing the aeration of the soil. This factor resulted in a depression of the trees on level-basin terraces in the winter of 1940-41. Thus the trees are rated in Table I as being in a very good, rather than in an excellent condition. This depression was temporary, and, with the advent of dry weather, an excellent top-growth condition reappeared.

DISCUSSION

The Tierra and Ambrose soils involved in this study have a genesis similar to some of the soils of commercial avocado groves on which mature avocado trees declined and died in large numbers after the unusually wet winter of 1940—41. The most notable feature of these soils is their low infiltration rate, a factor that results in soil drowning in exceptionally wet weather or when heavily irrigated.

It should be borne in mind that the avocado trees in this experiment were grown under essentially dry-land conditions. Most avocado trees grown in California, and practically all of those grown commercially, are supplied with irrigation water.

The circular trench section appears to be the best method of uncovering the roots of the avocado for study. Because of the spottiness of avocado roots, the bisect method is not well adapted for this study. In detailed studies of fine near-surface root development in the avocado, hydraulic methods of root excavation may be indicated.

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