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# ROOT SYSTEM OF SHRUB LIVE OAK IN RELATION TO WATER YIELD BY CHAPARRAL

by

Edwin A. Davis

## ABSTRACT

The root system of shrub live oak (Quercus turbinella) was studied in an initial effort to classify the major Arizona chaparral shrubs as potential users of soil water based on root system characteristics. The root system was of the generalized type with a taproot, many deeply penetrating roots, and a strong lateral root system. Roots penetrated 21 feet to bedrock through cracks and fractures in the rocky regolith. A dense network of small surface laterals radiated from the root crown and permeated the upper foot of soil. Because of its root system, shrub live oak is well adapted to utilize both ephemeral surface soil moisture as well as deeply stored moisture. Emphasis is placed on the importance of a knowledge of the root systems of chaparral shrubs and depth of the regolith in planning vegetation conversions to increase water yield.

## INTRODUCTION

Research in Arizona has shown that, under certain conditions, water yield from experimental chaparral watersheds can be increased by converting from brush to grass (Hibbert, et al. 1974). Similar vegetation conversions in California chaparral have also resulted in increased runoff (Rowe and Reimann 1961, Hill and Rice 1963). The usual explanation for the results of such conversion is that the deep-rooted brush is able to obtain more water from deeper soil layers than the shallow-rooted grasses, thus reducing the amount available for water yield.

Dense stands of chaparral frequently consist of a mixture of shrub species. Increased water yields obtained by converting these areas to grass must, therefore, be attributed to the average effect of controlling a mixture of brush species. Water use differences among species go undetected.

Knowledge of the root habits of chaparral shrubs and depth of the regolith occupied by chaparral is prerequisite to improved treatments for increasing water, wildlife, grazing, and recreational values of chaparral. Such knowledge is also basic to problems of plant establishment, adaptation, distribution, ecesis, competition, drought tolerance, soil stability, and succession following fire, herbicide treatments, or root plowing. In brush control, the relationship between rooting depth and movement and persistence of herbicides in the soil may help to explain species response differences and aid in the development of improved brush control methods.

Since the early work of Cannon (1911) with desert plants near Tucson, Arizona, little information has been added to our knowledge of the root habits of native woody plants in Arizona. Phillips (1963) reported finding what appeared to be living mesquite roots 175 feet below the original ground surface of an open pit mine in Arizona. Except for limited observations on shrub live oak (Quercus turbinella Greene) very little is known about the root systems of chaparral shrubs of Arizona. This did not limit research in water yield improvement since yield comparisons were made between mixed chaparral and grass. But a lack of knowledge concerning root systems and water use of the dominant chaparral shrubs could limit the scope of future research and management projects concerning water yield and wildlife habitat.

Shrub live oak is the dominant shrub species in much of Arizona chaparral. The root system of a typical plant was thoroughly studied by means of a quantitative determination of root mass distribution vertically and laterally, followed by further excavation and examination of a central section of the root system. Results are then interpreted as they relate to watershed management practices.

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## STUDY AREA

The shrub live oak bush was excavated in central Arizona on the Three Bar Wildlife Area, at 3300-feet elevation on the easterly face of the Mazatzal Mountain Range west of Lake Roosevelt. Chaparral at the study area consisted of a mixture of sclerophyllous woody shrubs dominated by shrub live oak. Other species included birchleaf mountainmahogany (*Cercocarpus betuloides* Nutt.), yellowleaf silktassel (*Garrya flavescens* S. Wats.), sugar sumac (*Rhus ovata* S. Wats.), and hollyleaf buckthorn (*Rhamnus crocea* Nutt.). These shrubs comprise a postfire complex of sprouting and nonsprouting shrubs that regrew following a wildfire in 1959.

The climate of chaparral zones in Arizona has a biseasonal precipitation pattern characterized by summer rainfall, fall drought, winter precipitation and spring drought. Annual precipitation at the study area averaged 25.7 inches over the past 18 years, with about 61% occurring as rain or snow from November through April.

Soil at the root excavation pit was typical of that on nearby experimental watersheds. It is classified in the Barkerville series. The soil is a very gravelly sandy loam derived from granitic parent material; it is slightly acid and has an A, C, R, horizon sequence. It is well drained and has infrequent surface runoff. Permeability is moderately rapid. Seismic exploration on the watersheds indicated that the coarse-grained granite is weathered and fractured 20-40 feet deep. The presence of such a deep regolith has significant hydrologic and ecologic implications.

The excavated bush, located on a 40% east-facing slope, was a vigorous, mature specimen typical of shrub live oak in the area. Charred snags indicated that it had burned in the 1959 wildfire; judging from the size and appearance of the root crown it also may have burned in previous wildfires. The 8 foot-tall bush had canopy dimensions of 18.5 x 19.0 feet. Its canopy consisted of 12-year-old regrowth stems which sprouted from the root crown following the wildfire. Sprouts came from an almost circular area 5 feet in diameter.

## METHODS

The first phase of the study consisted of a quantitative determination of root mass. A trench was cut along the north side of the bush with a bulldozer. The trench was 11 feet deep at the upslope end, 21 feet long, and 19 feet wide, with the bottom nearly level. The face exposed for sampling was about 3 feet out from the edge of the bush's root crown. Samples were taken to determine root mass distribution in four, 1-foot-thick transections (slices) of the regolith starting at the trench face and moving in toward the bush. Pattern of root distribution was determined by removing 1-cubic-foot blocks from each transection by means of picks and a pneumatic chipping hammer, separating roots from soil by passing the soil through a 1/4-inch mesh sieve, and subsequently weighing the ovendried roots. The two inner transections included parts of the root crown, but its weight was not included with the weight of roots. In constructing lateral and vertical distribution patterns only data to the 6-foot depth were used, because the number of lateral blocks varied below this depth.

In the second phase of the study, a backhoe was used to dig a 6-foot-wide pit in the bottom of the trench. At the upslope end of the pit, at a depth of approximately 20-feet, hard rock was reached that could not be broken. Roots broken during digging were identified with those protruding from the face of the pit, tagged, and later reconnected. The root system in a 1-2 foot transection of soil beneath the center of the bush was then exposed by careful excavation and reconstruction. Roots in this excavation were allowed to hang against the face of the pit. Next, a portion of the surface lateral root system was exposed in a semicircular trench, 18 inches wide and 1 foot deep, about 2 feet out from the base of the bush. Exposed roots were painted white with vinyl latex paint for photographic documentation.

## RESULTS

### QUANTITATIVE RESULTS

Roots were found in every cubic foot of soil in spite of the rocky regolith. Root weights per cubic foot block varied from less than 1 g to 2804 g. Because of the hardness of the regolith, many roots penetrated crevices, fractures, and seams of weathered material. The greatest accumulation of root mass was centered beneath the root crown, the zone occupied by the taproot. Distribution of root mass in the other transections followed the same trend; root mass decreased, in general, with lateral and vertical distance from the root crown.

Lateral distribution of root mass was determined from the two inner transections of the regolith to a depth of 6 feet. Each transection was made up of 66, 1-cubic-foot blocks. Weight of roots at each lateral location was based on 12, 1-cubic-foot blocks.

Forty-seven percent of the root mass was located in a 4-square-foot (2 x 2) column beneath the root crown; 73% was located within an 8-square-foot (2 x 4) central column. Although there was a marked decrease in root mass beyond the central 4-square-foot column of the transection, root mass did not steadily decline with distance downslope due to the lack of uniform penetrability of the regolith and the irregular distribution of large roots.

Vertical distribution of root mass to a depth of 6 feet was determined by combining data for the four transections according to depth. Weight of roots for each depth was based on 30, 1-cubic-foot blocks of soil. Vertical distribution of root weight from the soil surface downward in 1-foot increments was as follows: 26, 29, 18, 12, 9, and 6 percent. The greatest accumulation of root mass was in the top 2 feet of soil. Below 2 feet there was a gradual decrease in root mass with depth.

A gross estimate of the root/top ratio of the excavated bush was made by estimating total weight of the root system based on 63.8 pounds ovendry roots in the 239 cubic feet of soil sampled. Assuming that the weighed roots represented 1/3 of the entire root system, which is a probable maximum, then the total ovendry weight of roots was 191.4 pounds, excluding the root crown. Ovendry weight of the clipped top at the start of excavation was 101.6 pounds. Thus, at this stage in the life of the plant, the weight of the root system exceeded that of the top; the estimated root/top ratio was 1.9. If the massive root crown is included in the weight of the root system, then its estimated weight is 321.8 pounds, and the root/top ratio would be 3.2.

## DESCRIPTION OF THE ROOT SYSTEM

Following the quantitative phase of the study, a central portion of the root system beneath the root crown of the bush was excavated and displayed to nearly its full extent (Figure 1). The taproot had already been removed for weighing in the quantitative transections. It consisted of a network of main roots that fused into a single, rapidly tapering root with numerous branches. The taproot was attached to the base of a massive root crown; some of its branch roots penetrated 21 feet to bedrock. The horizontal spread of vertically penetrating roots was 16 feet. A long surface lateral root extended downslope 22.7 feet before turning sharply downward. This root was only partially excavated when figure 1 was taken. A lateral growing diagonally upslope extended 11 feet before it turned downward. Downslope main laterals were more abundant than upslope laterals.

A dense network of fine surface laterals that radiated from the root crown completely permeated the upper foot of soil (Figure 2). Abundance of these roots was greater from the downslope half of the bush than from the upslope half. Diameters of roots excavated in the surface trench ranged from 1 mm or less up to 1 cm; the majority of roots were less than 2 mm in diameter.

A unique feature of this particular root system was a long, thin, dense network of intertwining roots that extended downward as a vertical plate, oriented crosswise to the direction of the slope of the hillside (Figure 3). The plate was about 10 feet long, 3.5 feet wide, and 3 inches thick; it was extremely dense, especially near the soil surface. At 8-10 feet some of the larger roots were flattened into irregularly shaped belt-like strips by their confined growth along fracture planes in the rock. These roots were 2-5 cm wide and 0.4-1.0 cm thick. The plate followed a narrow seam of highly weathered granite and sandy clay that penetrated the rocky regolith. Root grafts were common where roots were rigidly confined. Moisture, nutrient, and aeration conditions in the seam were apparently ideal for extensive root development.

The presence of bedrock at approximately 21 feet prevented further extensive root penetration; roots were forced to turn in a more or less horizontal direction and grow along a gently sloping surface of the bedrock. Diameters of these terminal roots were 1.5 to 5.0 mm. A few roots penetrated small cracks in the bedrock and may have extended a few feet deeper. Unsuberized fine roots were found growing in thin layers of soil between plates of rock at the 20- to 21-foot depth.

## DISCUSSION

Shrub live oak is well adapted to the chaparral environment in Arizona. Its vigorous capacity to sprout from the root crown allows it to thrive under a natural regimen of periodic wildfires. The root crown gradually enlarges and the number of stems increases following top removal by fire. Pond and Cable (1960) found that there were nearly six times as many live stems a year after burning than originally. Even after four annual burns the number of stems was still greater than pretreatment counts. This prodigious regenerative capacity is supported by stored energy reserves in the root crown and roots, and by supplies of water and nutrients made available by an extensive root system.

Figure 1. Midsection of the root system of shrub live oak to a depth of 21 feet. After the quantitative phase of the study a central portion of the root system beneath the root crown of the bush was excavated and displayed to nearly its full extent.

Figure 2. Downslope side of the surface lateral root system showing the dense layer of small roots radiating from the root crown, and some shallow main laterals.

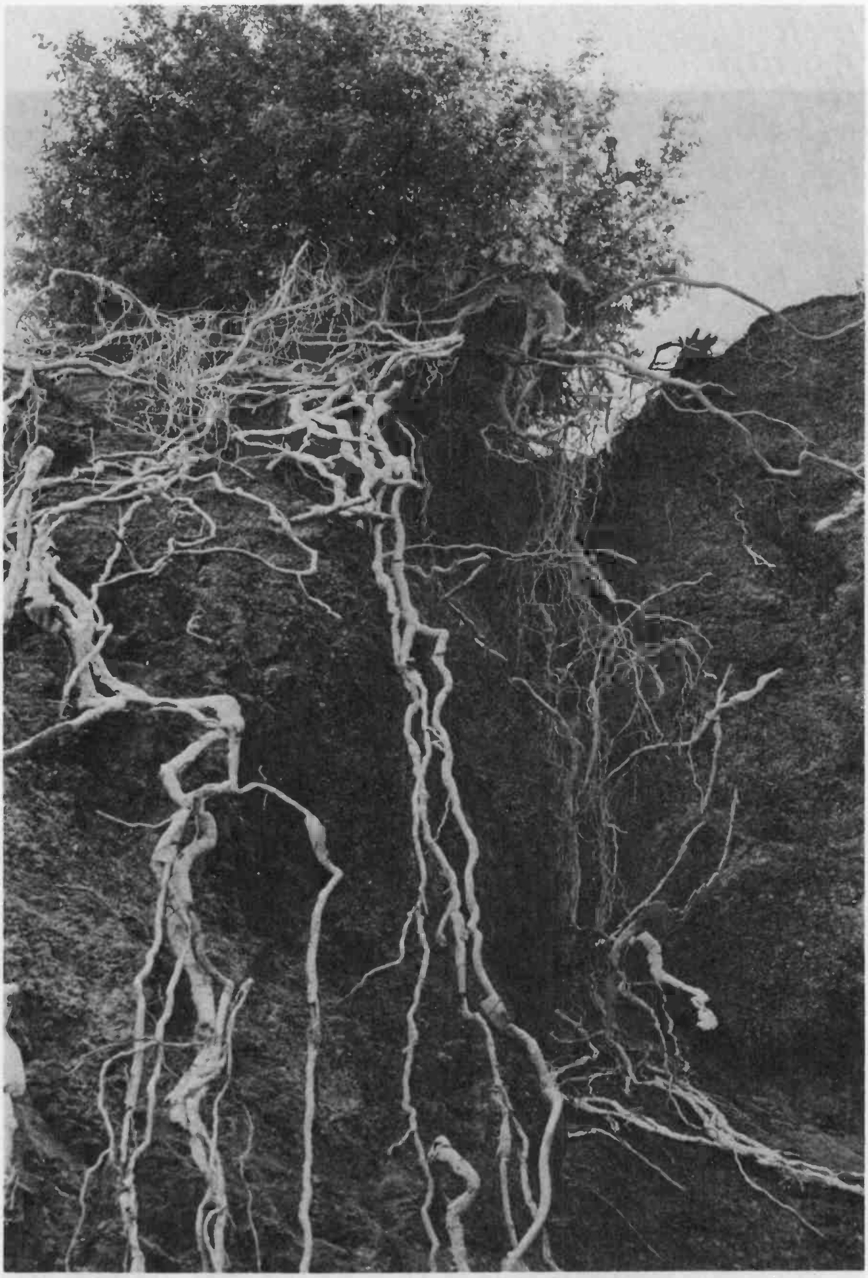

Figure 3. Roots penetrated fractures in the rocky regolith forming plates of roots along fracture planes. Some roots were flattened into irregularly shaped belt-like strips. Numerous self-grafts occurred where roots grew in the rigid confines of cracks and fractures.

In accordance with the terminology used for classifying root systems (Cannon 1911, 1949; Weaver and Clements 1938) shrub live oak is of the generalized type in which both taproot and laterals are well developed. Its extensive, deeply penetrating root system allows it to draw upon deep soil moisture during periods of drought. Thus, it can maintain an active physiological state for a longer period of time than less extensively rooted plants. Shrub live oak also has a highly developed surface root system to utilize ephemeral surface soil moisture. A dense layer of surface roots gives it a competitive advantage over grasses, and may explain the difficulty in establishing and maintaining perennial grasses in stands of burned shrub live oak in which regrowth is not suppressed. Dominance of the oak in stands of mixed chaparral may also be explicable in terms of competitive advantages associated with its extensive root system.

Self-grafts of shrub live oak roots were common. Grafting occurred when roots grew in the restrictive confines of fractures. Saunier and Wagle (1965) observed self-grafts of shrub live oak as well as intraspecific grafts. Of several California chaparral shrubs observed by Hellmers et al. (1955), Quercus dumosa (California scrub oak), a close relative of shrub live oak, was the only species in which root-grafting was observed. Root grafts have also been reported for several other oak species (Graham and Bormann 1966).

Most of the observed roots of the excavated oak, including the surface laterals, were suberized. Since the plant responds rapidly to soil moisture following drought and to soil-applied herbicides following rain, it is possible that the suberized roots are active absorbers of water. Direct measurements by Chung and Kramer (1975) clearly indicate that suberized roots usually constitute the major absorbing system of woody plants.

The wide lateral spread of surface laterals has important hydrologic and ecologic implications. What may be a fairly open stand of shrub live oak above ground, depending on the length of time following a wildfire, may actually be a relatively closed one from the standpoint of overlapping root systems.

Final root pattern and growth potential are genetically determined when soil factors are favorable but may be profoundly modified by soil structure, water content, and aeration (Weaver and Clements 1938, Pearson 1974). Roots of shrub live oak are capable of penetrating deeply either in a highly weathered regolith or in fractured and jointed rock underlying the solum. When downward growth is prevented by an impenetrable layer, however, the roots are necessarily restricted to the upper soil layer. Shrub live oak bushes have been observed growing in 6 to 10 inches of soil overlying highly indurated sediments (Saunier and Wagle 1967). This indicates that its distribution is not restricted to deep soils or weathered and fractured subsoils.

Quercus dumosa was reported by Hellmers et al. (1955) to have the deepest root penetration of the California chaparral shrubs they observed. In roadcut observations its roots were found penetrating fractured rock to a depth of 28 feet below ground surface. Unlike the shrub live oak in this study, Q. dumosa had few feeder roots in the top 6 inches of soil.

Present vegetation manipulation practices for the conversion from brush to grass for water yield improvement are not intentionally selective from the standpoint of brush species. Some selective hand applications of pelleted herbicides have been made in which desirable browse species were not treated (Davis and Pase 1969). Since differences in water use by chaparral shrubs have not been defined, treatment selectivity on this basis has not been possible. The deeper and more extensive a plant's root system the longer the plant can remain active and transpire during dry seasons. In well-aerated soils deep-rooted species can remove water from considerable depths. Deep-rooted shrubs are potentially much heavier water users than shallow-rooted species in areas with deep soils and limited rainfall. Although the greatest differences in rooting depth occur between grasses and trees or shrubs, considerable variation may occur within each group. Possible differences among chaparral shrubs may provide a partial basis for identifying low and high water users.

The sprouting ability of a shrub can have a bearing on the extent of its root system. Sprouting species have the potential for developing deeper and wider spreading root systems than nonsprouters. In areas that have wildfires, sprouting species are older than nonsprouters since they survive the effects of fire. Consequently, they should have more extensive root systems. Differences in root systems may occur among sprouting species due to hereditary factors. Plants in arid and semiarid regions are adapted by virtue of a variety of morphological, anatomical, and physiological characteristics, and may or may not be deep rooted. Many desert plants do not have deep root systems (Barbour 1973), but have other attributes that aid their survival (Gindel 1973). It is possible, therefore, that differences exist in the root habits of Arizona chaparral shrubs. Striking differences in root systems were found to occur among California chaparral species (Hellmers, et al. 1955). Differences were also noted in the abilities of various species to penetrate rock crevices.

A more detailed knowledge of characteristics of the major Arizona chaparral shrubs would allow for more effective management for multiple use objectives, assuming the availability of a suitable, registered brush control herbicide for chaparral conversions. Needed is a classification of chaparral shrubs which includes water-use characteristics, type and depth of root system, susceptibility to single and repeated burns, response to herbicides, sprouting ability, and browse value. In some of these categories considerable information is already available; but for others there is little or no information. This study of shrub live oak represents an initial effort to increase our knowledge of the root systems of chaparral shrubs.

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