ROOT SYSTEMS OF SOME CHAPARRAL PLANTS IN SOUTHERN CALIFORNIA

H. Hellmers, J. S. Horton, G. Juhren, and J. O'Keefe[1]
California Forest and Range Experiment Station, U. S. Forest Service, Berkeley, California

Knowledge of the characteristics of plant root systems is important in the management of vegetation for optimum soil stabilization, flood reduction, and usable water yield. Roots bind the soil and anchor the soil mass; the degree of stabilization achieved depends upon the configuration, density, and strength of the root system. Roots absorb water from the soil; the depth to which the soil is tapped for water depends upon the depth to which roots penetrate. Because of these facts, the root sytems of a considerable number of plants have been studied. However, most of the plants studied have been agricultural species (Weaver 1926).

Little is known about the rooting habits of chaparral plants that occupy the steep and rugged mountains of southern California, where erosion rates are high, flood hazard great, and water yield critically important (Sinclair 1954, Sinclair and Hamilton 1953). In the present study, information was obtained about the root systems of the more common chaparral species in these mountains to aid in evaluating the usefulness of the several species for watershed management purposes. The study was carried on in 1951 in the San Gabriel and San Bernardino Mountains.

The topography of the San Gabriel and San Bernardino Mountains is rough, characterized by deeply cut stream channels and slopes that often exceed the angle of repose for soil material. Movement of soil material on most of these slopes is rapid; as a result, there is little evidence of soil profile development.

Soil on the slopes is generally shallow and rocky. The characteristics of the soil are determined largely by the composition of the underlying rock and its susceptibility to weathering (Colman 1948). Here and there, deep deposits of soil material do occur. For example, old stream terraces often have deep clay loam soils with hardpan layers. Sometimes material accumulates at the base of a slope in a deep deposit. On old ridges and in other places where movement is slow because of gentle slope, deep soils have formed in place through long-time weathering of the underlying rock.

Most of the rock underlying the soils is intensively fractured and deeply weathered (Storey 1948). This condition provides opportunity for penetration of roots deep below the soil in many places. Fracturing and weathering is more marked in the metamorphic rocks of the San Gabriel Mountains than in the harder intrusives of the San Gabriel and San Bernardino Ranges.

The climate of the area is Mediterranean. Most of the rainfall occurs in the cool winters. The summers are hot and dry; rainless periods often last 6 months.

The vegetation of the area studied is principally chaparral, although trees grow along the streams and on the shaded sides of the canyons (McMinn 1939). The south-facing slopes are covered principally with chamise chaparrel, and the north-facing slopes with oak chaparral.

The chamise chaparral varies from dense stands of chamise (*Adenostoma fasciculatum* H. & A.) and ceanothus (*Ceanothus* spp.) to open stands of chamise and sage (*Salvia* spp.). Other common species associated with the chamise chaparral are manzanita (*Arctostaphylos* spp.), and small shrubs such as California buckwheat (*Eriogonum fasciculatum* var. *foliolosum* Stokes). Occasionally, the steeper south-facing slopes, and on gentler slopes with gravelly soil, the chamise chaparral gives way to low shrubby vegetation, with California sagebrush (*Artemisia californica* Less.), sages, California buckwheat, yerbasanta (*Eriodictyon* spp.), and deerweed (*Lotus scoparius* (Nutt.) Ottley) as the abundant species. Small-flowered melicgrass (*Melica imperfecta* Trin.) and other herbs are common.

The oak chaparral growing on north-facing slopes is dominated by California scrub oak (*Quercus dumosa* Nutt.). Its commonest associated species are hairy ceanothus (*Ceanothus oliganthus* Nutt.), Christmasberry (*Photinia arbutifolia* (Ait.) Lindl.), birchleaf mountainmahogany (*Cercocarpus betuloides* Nutt.), and occasionally canyon live oak (*Quercus chrysolepis* Liebm.).

The chaparral of the southern California mountains has long been subjected to repeated fires (Jepson 1925). All species are able to reproduce after burning. Some sprout vigorously from

[1] H. Hellmers and J. S. Horton, California Forest and Range Experiment Station, maintained by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of California, at Berkeley, California. G. Juhren and J. O'Keefe, Angeles National Forest, U. S. Forest Service, California. Acknowledgment is also made of the cooperation of California Institute of Technology at Pasadena.

the root crowns after the tops have been burned; after repeated fires these root crowns become very large and support many stems. Others are killed by fire, but numerous seeds of these species germinate shortly afterwards and some of the seedlings develop to form part of the returning cover.

Root systems of only a few chaparral species are described in the literature. These descriptions are, for the most part, based on one individual per species. Plummer (1911) mentioned the large tap root and few laterals present on chamise, which contrasted with the roots of manzanita that ramified in all directions. Cooper (1922) studied root systems of chaparral species near Palo Alto, California. The only mature chamise plant which he investigated did not have a tap root. In contrast, most of the chamise seedings that he excavated did have tap roots. He further noted that chamise, leather oak (*Quercus durata* Jepson), and woolly manzanita (*Arctostaphylos tomentosa* (Pursh) Lindl.) had abundant superficial roots besides many deeply penetrating roots. California yerbasanta (*Eriodictyon californicum* (H. and A.) Torr.) had its main roots in the top 3 inches of soil. Many shoots developed from these lateral roots, but only occasionally did a root grow more deeply into the soil. Jepson (1936) stated that chamise shrubs have strong taproots penetrating downward 3 to 8 feet or more with many strong laterals. He also stated (1939) that the species of manzanitas which do not sprout from the root crown, and which are therefore killed by fire, have shallow roots. Later writers on the chaparral have usually ignored root characteristics or mentioned them only briefly (Sampson 1944).

Method of Study

The root systems of chapparal plants were examined at 14 study sites in the San Gabriel and San Bernardino Mountains. At 6 of the sites, roots were exposed by hydraulic excavation. At 8 of the sites, observations were made on the faces of road through-cuts.

The 6 excavation sites in the San Gabriel Mountains were located along road cuts or faces of deep gullies. Plants growing within 3 feet of the edge of the road cut or gully at each site were discarded because of possible alterations in their root systems. Tank trucks equipped with power pumps were used to excavate the soil at these sites. Two types of nozzles were employed—a high pressure, single stream type and a fine spray type. The bulk of the earth around the plant being studied was removed with the high pressure nozzle. Then, to avoid breaking the fine roots, the remaining soil was washed away from the roots with the fine spray nozzle. In this way, an estimate could be made of the number and location of the fine roots.

It was impossible to measure the maximum depth of penetration of roots that disappeared down cracks in the rocks. Therefore, in addition to the sites sued for hydraulic excavation, 8 recently cut roadbanks in the San Gabriel and San Bernardino Mountains were examined for root penetration. No observations were made on root development in the surface layers of soil in these cuts. Only through-cuts were utilized because rooting depths could not be ascertained with sufficient accuracy in hillside cuts. In through-cuts, the shortest distance to the original soil surface could be determined. Where roots could not be traced directly to the proper crown they were identified by their anatomical structure. Unfortunately, some species studied by the hydraulic method were not found growing along the road cuts that were examined.

Information recorded for each site and plant studied included: (1) soil character and depth; (2) size and condition of the plant tops; (3) length, depth of penetration, and radial spread of roots; (4) zones of feeder root concentrations; and (5) other pertinent data such as root grafting and adventitious roots.

Description of the Sites

The sites used for hydraulic excavation varied greatly as to soil character and depth. They were all located in the San Gabriel Mountains and were chosen purposely to provide a wide range of soil and vegetation conditions.

An old terrace deposit was excavated at the San Dimas site (2,500 feet elevation). The soil was a clay loam underlain with an impervious hardpan 3 to 5 feet below the surface. This hardpan contained a few cracks through which roots penetrated. The vegetation on this southern exposure was dense chamise chaparral containing many hoary leaf ceanothus (*Ceanothus crassifolius* Torr.) plants and a few black sage (*Salvia mellifera* Greene) shrubs as well as some small-flowered melicgrass. The area had not been burned for 31 years.

At George's Gap (3,600 feet elevation), the soil was a coarse, loose gravel, at least 12 feet deep on a steep east facing slope. The underlying rock was Lowe granodiorite (Miller 1934). The vegetation was open chamise with scattered bigberry manzanita (*Arctostaphylos glauca* Lindl.), chaparral whitethorn (*Ceanothus leucodermis* Greene), and many small shrubs, principally white sage (*Salvia apiana* Jepson), in the openings. The vegetation on this site had not been burned for 54 years.

The soil of the Tie Summit site (5,000 feet elevation) was 2 to 5 feet deep and was underlain with hard but deeply fractured Lowe granodiorite. The top foot of soil was a sandy loam and the rest was decomposed rock becoming harder with depth. The vegetation on this northwestern exposure was low dense chamise chaparral containing chamise, Eastwood manzanita (*Arctostaphylos glandulosa* Eastw.), Mojave Desert ceanothus (*Ceanothus greggii* var. *vestitus* (Greene) McMinn), and an occasional birchleaf mountainmahogany. There was no record of fire within the past 72 years for this site.

The Colby site (3,300 feet elevation) had soil similar to that at Tie Summit, but shallower. The sandy loam soil was only about 6 inches deep. The underlying rock was anorthosite, with the zone of weathering about 2.5 feet deep. The chamise chaparral on this northeastern exposure contained chamise, bigberry manzanita, hoaryleaf ceanothus, and chaparral whitethorn. This vegetation also had been unburned for 72 years.

The soil at the Mt. Lowe site (4,500 feet elevation) consisted of a shallow layer of loose coarse sand, averaging 6 inches deep, over a layer of broken and slightly weathered Lowe granodiorite rock approximately 12 inches thick. The weathered rock was underlain by hard rock with few cracks. The vegetation on this south facing slope was open chamise chaparral containing Eastwood manzanita and chaparral whitethorn. Openings contained California buckwheat and chaparral yucca (*Yucca whipplei* Torr.). Fire had not occurred on this site for 28 years.

The Brown Mountain site (2,500 feet elevation) was on the north side of a rounded ridge of deeply weathered Wilson diorite. The loam to clay loam soil was 2 to 6 feet deep except in spots where weathered rock almost extended to the surface. In contrast to the shallow litter layers occurring at the other excavated sites, the litter and humus on the soil at this site was 3 to 6 inches in depth. Part of the site was covered with a dense growth of chamise and hoaryleaf ceanothus, and part with oak chaparral containing California scrub oak, hairy ceanothus, and Christmasberry. This site burned 16 years previously and was the most recently burned area studied.

Roots of 11 plants were examined on the face of 8 new road cuts. These cuts were located on two major highways in process of construction. Three cuts were on the City Creek road northeast of the city of San Bernardino in the San Bernardino Mountains and 5 were on the Tujunga highway in the western end of the San Gabriel Mountains. The cuts varied from 23 to 50 feet in depth. The materials cut through were either gravel terraces or granitic rock. Some cuts were through hard rock and others through deeply fissured and weathered rock. The vegetation at the road-cut sites on the City Creek highway was chamise chaparral. The vegetation at one road-cut on the Tujunga highway was chamise chaparral, two were in oak chaparral, and two contained species from both types of chaparral.

Observations

The species studied separate into three distinct groups in respect to the general character of their roots (Table I).

1. Woody shrubs with coarse major roots growing downwards: chamise, Eastwood manzanita, chaparral whitethorn, Christmasberry, canyon live oak, and California scrub oak. For these 6 species, depth of downward penetration was greater than radial spread. Chamise and the two species of oak had the greatest penetration (about 25 feet).

2. Woody shrubs with coarse major roots growing laterally: bigberry manzanita, hoaryleaf ceanothus, Mojave Desert ceanothus, hairy ceanothus, and birchleaf mountainmahogany. Radial spread of roots of these 5 species was usually much greater than downward penetration. Hairy ceanothus, though its radial spread was relatively short, had a vertical penetration about equal to other members of this group.

3. Subshrubs with fibrous root ssytems: bush monkeyflower (*Diplacus longiflorus* Nutt.), yerbasanta (*Eriodictyon crassifolium* var. *nigrescens* Brand.), California buckwheat, deerweed, white sage, black sage, and chaparral yucca. These 7 species varied considerably in radial spread but none had roots penetrating more than 5 feet.

The woody shrubs which had their major roots growing downward also had the greatest ability to extend their roots into cracks in unweathered rock. Roots of the first group of species penetrated 2 feet or more into the fine cracks in the hard rock material of the Tie Summit, Colby, Mt. Lowe, and Brown Mountain sites. Because of the hardness of the rock at these sites, the roots were not excavated to their full depth (Table I).

Roots of species in the second group penetrated only short distances, less than 2 feet, into the fine cracks in unweathered rock which were readily penetrated by species of the first group. Roots of the second group could always be traced to their full depth. Roots of species with fibrous systems did not always grow to the full depth of

TABLE I. *Growth characteristics of the chaparral species*

Species	Number of plants†	Average height†	Maximum length of roots†	Maximum vertical depth of root penetration: Hydraulic sites	Maximum vertical depth of root penetration: Road-cuts	Maximum radial spread of roots†	Average maximum radial spread: Roots†	Average maximum radial spread: Tops†	Root/top‡
		Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Ratio*
Woody shrubs with major roots growing downwards									
Chamise	13	4.9	16.0	8.0*	25.0	12.0*	5.5	2.8	2.0
Eastwood manzanita	4	2.3	13.5	9.0*	17.0	9.0	5.2	1.8	2.9
Chaparral whitethorn	4	4.8	21.0	12.0*	12.0	10.0	8.4	3.6	2.3
Christmasberry	1	4.0	7.0	6.5*	....	5.0	5.0	2.5	2.0
Canyon live oak	..	...	...	...	24.0	...	...	...	...
California scrub oak	3	5.0	15.0	8.0*	28.0	10.0	6.3	2.5	2.5
Woody shrubs with major roots growing laterally									
Bigberry manzanita	4	6.6	31.0*	8.5	...	21.0*	12.5	3.6	3.5
Hoaryleaf ceanothus	7	6.6	14.0	4.5	...	10.0	7.3	2.7	2.7
Mojave Desert ceanothus	2	2.5	13.0	4.5	...	11.0	9.8	1.6	6.1
Hairy ceanothus	3	7.0	8.0	6.0	...	5.5	4.2	2.6	1.6
Birchleaf mountain-mahogany	2	5.0	12.3	5.0	...	9.0	8.5	3.3	2.6
Subshrubs with fibrous roots									
Bush monkeyflower	2	1.3	3.5	2.5	...	3.0	2.5	0.6	4.2
Thickleaf yerbasanta	1	3.0	...	4.5	...	...	...⁑	...	...
California buckwheat	4	1.3	8.0	4.0	...	5.0	3.6	1.3	2.8
Deerweed	2	1.0	5.0	3.7	...	3.0	1.8	1.0	1.8
White sage	1	2.0	9.0	5.0	...	6.0	6.0	2.0	3.0
Black sage	2	3.8	7.0	2.0	...	6.0	5.0	2.3	2.2
Chaparral yucca	2	1.9	13.0	2.5	...	11.0	11.0	2.5	4.4

*Indicates that the deepest or longest root extended farther than recorded.
†Data given only for the plants growing on sites used for hydraulic excavation.
‡Ratio of average maximum radial spreads. ⁑Root sprouts.

the soil and rarely penetrated even short distances into cracks in unweathered rock.

The characteristic rooting habit of each species often was modified by the hardness of the substratum. If the soil was shallower than the usual depth of root penetration and the underlying rock was not sufficiently weathered to permit passage of roots, a layer of roots usually grew on the soil-bedrock interface, the roots entering any cracks present. Roots growing in rock cracks were usually compressed, and feeder roots often formed a mat which filled the cracks. Over the years, organic material had accumulated in the cracks, thus increasing the moisture and nutrients available to the roots.

Roots frequently changed direction, probably in response to hard soil or some other obstacle in their path. Occasionally, roots grew in one direction for several feet only to turn back. One chamise root extended downward for 2 feet, reversed direction, grew upward to within a few inches of the surface and less than a foot from where it had started, and then grew horizontally to become a major lateral root.

On steep slopes, roots were commonly found growing up the slope. These roots often remained at a fixed depth from the soil surface.

Root grafting between individuals of the same species was found only in California scrub oak. No root grafting between different species was found, even though, plants of several species were growing with root sytems so interlocked that they could not be separated intact.

The root crowns of sprouting species were greatly thickened if the tops had been repeatedly removed by fire or other causes. These thickened crowns had been the source of both new shoots and roots.

Nodules were observed on all species of ceanothus. These nodules were similar to those described by Jepson (1936). Van Rensselaer and McMinn (1942) reported that nodules occur on the roots of some species of ceanothus in great abundance but that they do not appear to harbor nitrogen-fixing bacteria. Kittridge (1948) indicated that the nodules might be nitrogen-fixing.

The roots of all species extended laterally much farther than the aerial branches, usually 2 or more times as far, irrespective of the type of root system (Table I). This is in agreement with Weaver and Clements (1938) who stated, "In the majority of both native and cultivated species the root systems are, in proportion to the tops, deeply penetrating and very extensive." Rogers (1935) and Garin (1942) observed that roots of various orchard and forest trees would occupy the entire soil mass between trees even though the trees were widely spaced. For several of the chaparral species, the large root-top ratio may possibly be caused by the shallowness of the soil. These were indications that the root spread of the deep-rooted species and some of the shallow-rooted species varied inversely with the depth of penetration.

Description of Root Systems

The root systems of all species studied have

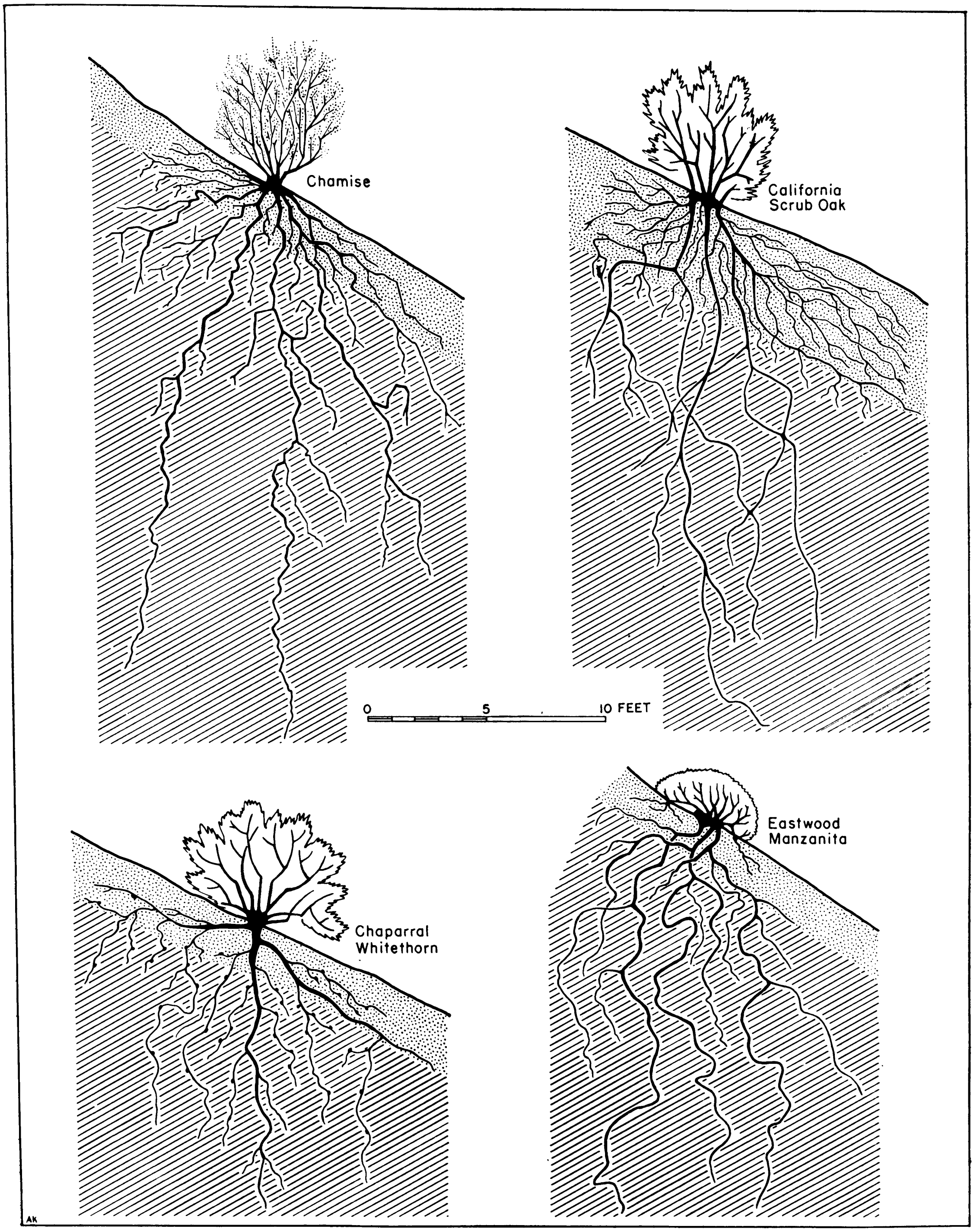

Fig. 1. Diagrammatic sketch of typical root systems of woody shrubs with deeply penetrating roots.

distinctive characters. The features of each species are discussed separately. The species are considered in the same order as their appearance in the tables.

CHAMISE (*Adenostoma fasciculatum* H. & A.) —Chamise is a shrub that sprouts readily from the root crown after fire or cutting. Its root system was generally found to be deeply penetrating, but the roots were of small diameter (Fig. 1). An occasional root was as thick as 1.5 inches, but most main roots were less than 1 inch in diameter. Fine roots were observed in tiny cracks in unweathered rock 25 feet below the surface. Some individuals had a single, deeply penetrating root growing downward from the root crown, but usually several large roots penetrated deeply. Laterals developed from the enlarged root crown, and horizontal branches grew from the main roots. Usually these branch roots grew horizontally for only a short distance and then began to turn downward. The roots were much twisted and changed direction frequently as they grew.

EASTWOOD MANZANITA (*Arctostaphylos glandulosa* Eastw.).—Eastwood manzanita is a shrub sprouting readily from an enlarged root crown. The root systems excavated were similar to roots of chamise (Figs. 1 and 2), though somewhat thicker (up to 3.0 inches in diameter) and more frequently branched. One individual had a single large lateral root which followed the rock surface below-ground for more than 8 feet. In road cuts, roots were observed to a depth of 17 feet. Roots of this species seemed able to penetrate into rock cracks too fine for roots of chamise. Adventitious roots occasionally developed from branches in contact with the ground.

CHAPARRAL WHITETHORN (*Ceanothus leucodermis* Greene).—This ceanothus is a shrub which sprouts readily from the root crown. The specimens excavated had sparsely branched, deeply penetrating root systems. This plant differed from most of the other chaparral species in having a prominent tap root which extended 12 feet or more into gravel deposits or into rock crevices (Fig. 1).

CHRISTMASBERRY (*Photinia arbutifolia* (Ait.) Lindl.).—Christmasberry is a large vigorously sprouting shrub, 10 to 15 feet high, at maturity. One shrub of this species only 2.5 feet high was excavated at the Brown Mountain site. Its root system was much-branched, with many roots about 0.4 inch in diameter growing down and laterally from the root crown. Many roots extended deeper into cracks in unweathered rock than it was possible to excavate. Feeder roots were

FIG. 2. The roots of this Eastwood manzanita growing at the Tie Summit site had penetrated more than 9 feet of a fine crack in hard rock. At that depth the root was still 0.4 inch in diameter. Note the enlarged root crown and the well-branched root system. (R-82)

abundant in the surface humus layer around the base of the shrub and elsewhere throughout the root system. Though this species did not occur on the road cuts that were observed, the one specimen indicated that the shrub would produce deeply penetrating roots at maturity.

CANYON LIVE OAK (*Quercus chrysolepis*

Liebm.).—This tree species was observed only on road cuts, where roots were found at a maximum depth of 24 feet below the ground surface in fractured rock.

California scrub oak (*Quercus dumosa* Nutt.)—The root system of this sprouting species was extensive and contained many branches up to 3 inches in diameter (Fig. 1). These large roots were somewhat contorted and usually angled downward. California scrub oak had the deepest root penetration of all species observed; roots of one shrub grew through fractured rock to a depth of 28 feet below the ground surface. Many fine branch roots grew in all directions from the main roots, but few feeder roots were found in the top 6 inches of soil. This was the only species in which root-grafting was observed.

Bigberry manzanita (*Arctostaphylos glauca* Lindl.).—The major roots of this nonsprouting species were large laterals (up to 3 inches in diameter at the crown) radiating in all directions in the top 2 feet of soil (Figs. 3, 4, and 5). One shrub had a lateral root ½ inch thick 31 feet (root length) from the root crown where it disappeared into a crack in rock too hard for excavation. Even in deep gravel, the roots were largely confined to the top 2 feet of soil, though a few roots penetrated 8.5 feet deep. In shallow soils, there was little penetration of roots into fractured or weathered rock. This species seems to have little ability to send roots into rock crevices which chamise and Eastwood manzanita penetrate readily.

Hoaryleaf ceanothus (*Ceanothus crassifolius* Torr.).—The root system of this nonsprouting species was shallow and composed of many laterally spreading roots, 0.5 inch or less in diameter (Fig. 3). The larger roots were usually sparsely branched but many fine feeder roots grew from roots of all sizes. At the San Dimas site, roots did not penetrate the hardpan, though cracks in this layer were penetrated by chamise roots. Also, hoaryleaf ceanothus roots were not found in fine cracks in unweathered rock readily penetrated by other species. If cracks in the rock contained considerable weathered material, the roots did penetrate. This species of ceanothus was not excavated in deep soil but the individual at the Brown Mountain site showed the greatest unrestricted development. The stem of this plant merged into a rapidly tapering carrot-shaped taproot, 4.0 inches thick at the ground line and 0.5 inch thick at a foot in depth. At this depth, the root behaved as a lateral and grew in an almost horizontal direction. Maximum depth of root penetration of this individual was 4.5 feet and maximum root spread was 4.0 feet. Other shrubs of this species growing in soils 2 feet deep or less and underlain by unfractured rock often had a horizontal spread as great as 10 feet.

Mojave Desert ceanothus (*Ceanothus greggii* var. *vestitus* Greene).—The 2 specimens of this nonsprouting species that were excavated at the Tie Summit site had roots similar to hoaryleaf ceanothus except that the spread of the root systems was somewhat greater.

Hairy ceanothus (*Ceanothus oliganthus* Nutt.).—This ceanothus also is a nonsprouting shrub. The root systems of 3 hairy ceanothus plants excavated at the Brown Mountain site had prominent tap roots and many well-branched but relatively short laterals (Fig. 3). These root systems were shorter than those of all of the other woody species. Maximum length of roots measured from the base of the plant was never more than 6 feet in any direction. The roots were not observed growing into rock cracks. The uppermost lateral roots grew in the top inch of soil.

Birchleaf mountainmahogany (*Cercocarpus betuloides* Nutt.).—The two individuals of mountainmahogany excavated at the Tie Summit site were comparatively small, probably young, plants growing in shallow soil over relatively unfractured rock. The root systems were sparsely branched, widely spreading, and confined mainly to the shallow soil layer and the few rock crevices. The excavation of these shrubs did not give any information as to the comparative ability of roots of this species to penetrate rock crevices, because the shrubs were growing alone.

Bush monkeyflower (*Diplacus longiflorus* Nutt.).—The much-branched, shallow, fibrous root system of this subshrub extended downward a maximum of only 3 feet even where the soil was considerably deeper (Fig. 3). Most feeder roots were concentrated in the surface 3 inches of soil.

Thickleaf yerbasanta (*Eriodictyon crassifolium* var. *nigrescens* Brand.).—The only specimen of this subshrub excavated was growing in deep gravel at the George's Gap site. The main roots followed the slope in all directions about 1 foot below the surface. Only occasionally did a branch root grow deeper even though the soil presented no barrier to root development. These roots were excavated for a maximum distance of 7 feet from the center of the plant, though they apparently went much farther. Numerous stems sprouted from the shallow roots and spread the plant laterally for considerable distances.

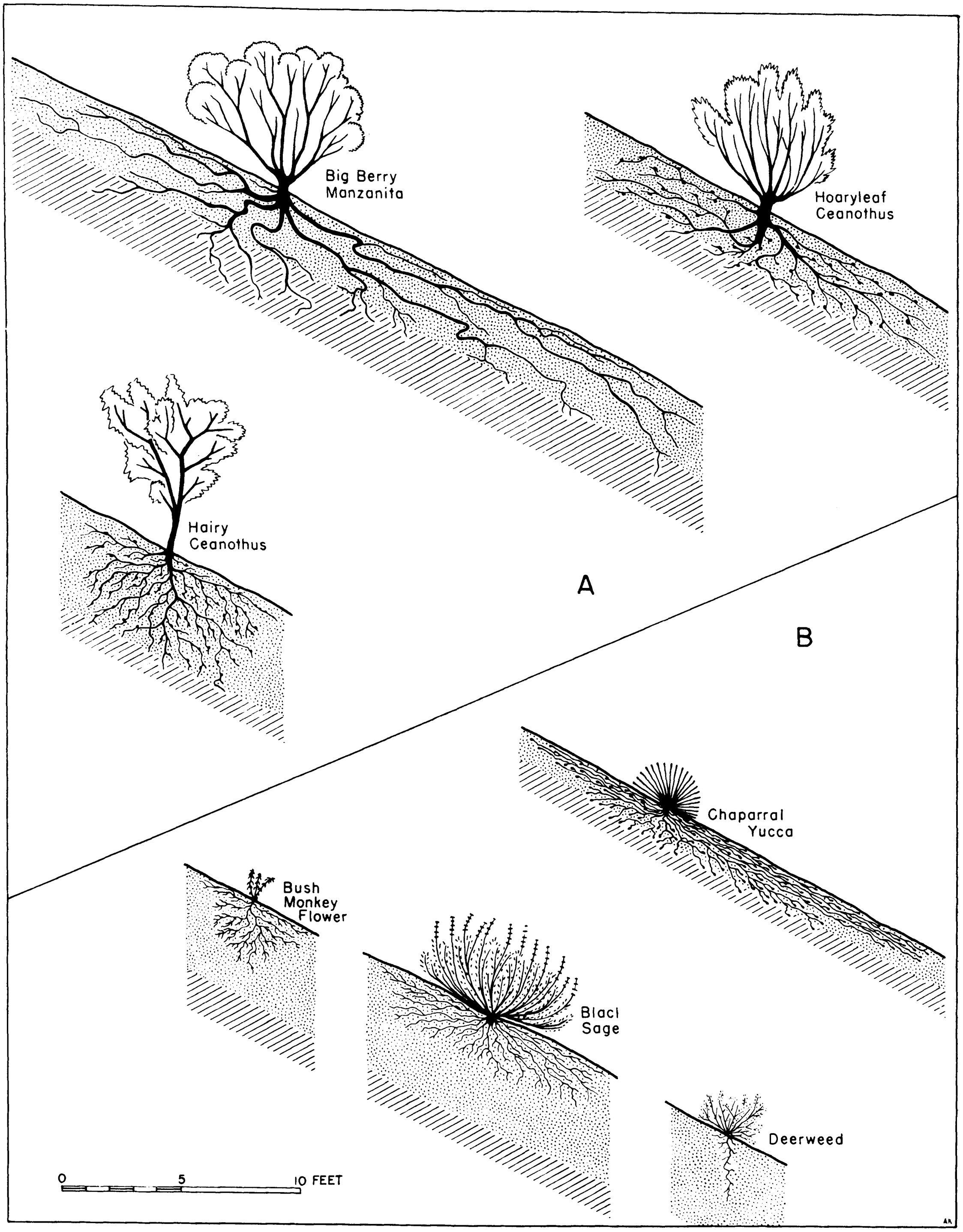

FIG. 3. Diagrammatic sketch of the root systems of, A, woody shrubs with shallow roots and, B, subshrubs with fibrous roots.

CALIFORNIA BUCKWHEAT (*Eriogonum fasciculatum* var. *foliolosum* Stokes.).—This subshrub had a fibrous much-branched root system, with very brittle roots that were rarely over 0.5 inch, and usually less than 0.3 inch, in diameter. In the deep soil at the George's Gap site, the roots penetrated 4 feet and extended laterally only 2.5 feet. Other specimens growing in very shallow soils at the Mt. Lowe site had the bulk of their roots just above the soil-rock interface and extending laterally a maximum of 5 feet. One plant had its entire root system in a 6-inch layer of soil and broken rock fragments which were underlain by unfractured rock. Adventitious roots developed from branches lying on the ground.

DEERWEED (*Lotus scoparious* (Nutt.) Ottley). —The 2 plants of deerweed excavated at the Brown Mountain site differed from the other subshrubs in having clearly defined taproots (Fig. 3). Inasmuch as the maximum diameter of these taproots was only 0.3 inches and the laterals even smaller, this species is grouped with the fibrous-rooted subshrubs. One plant had a taproot extending straight down for 3.7 feet, with laterals about 6 inches long. The other had a taproot extending down 2 feet to a hard layer in the soil and then horizontally for 3 feet. On this plant, the laterals were less than 6 inches long. No nodulation was observed on the roots of this legume.

WHITE SAGE (*Salvia apiana* Jepson).—The single specimen of this sub-shrub studied had developed a shallow root system in the deep gravel at the George's Gap site. The largest lateral root, 9 feet long, grew slightly uphill and at its terminus was a depth of 5 feet from the surface. This was the plant's greatest depth of penetration. Though the majority of the feeder roots grew from the rootcrown, many developed from the large roots and were concentrated in the upper foot of soil. Adventitious roots grew from stems lying on the ground.

BLACK SAGE (*Salvia mellifera* Greene).—The root system of this subshrub closely resembled that of white sage except that the black sage roots did not penetrate as deeply (Fig. 3). The deepest root excavated was 2 feet below the surface in soil 3 feet deep. The greatest concentration of roots was in the top 5 inches of soil.

CHAPARRAL YUCCA (*Yucca whipplei* Torr.).— This species had a spreading fibrous root system with most roots concentrated in the upper foot of soil (Fig. 3). No roots were observed to penetrate downward more than 2.5 feet. Approximately an equal number of roots grew in all lateral directions from the plant but those growing downhill extended 11 feet while those growing uphill extended less than 6 feet. The root tips averaged 0.2 inch in diameter; the older portions of the roots were only half as thick.

DISCUSSION

The species of plants which make up the southern California chaparral vary in the character of their root systems. The maximum root variability that can occur within any one species probably was not observed because of the shallowness of the soil and the relatively few plants per species studied. However, comparing the different species, the roots exhibited marked differences in depth of penetration, lateral spread, number and size of main and branch roots, and penetration into fractured rock.

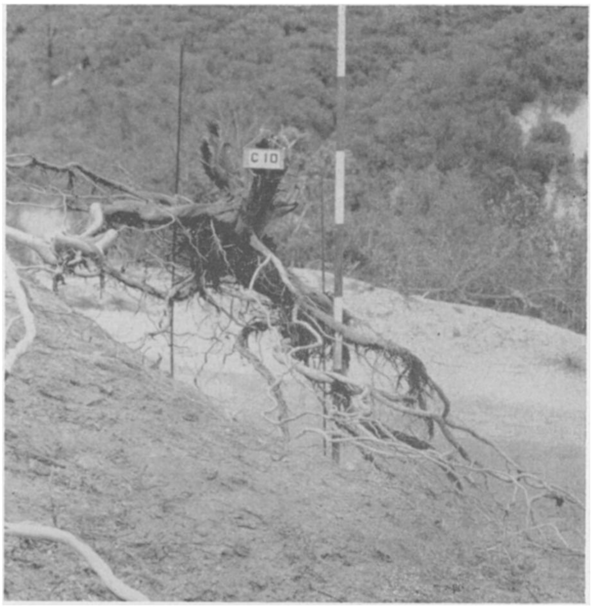

FIG. 4. This bigberry manzanita root system at the Colby site illustrates the characteristic development of a strong surface system. Note the lack of deeply penetrating roots. (R-114)

Species which develop root systems that penetrate deeply (more than 10 feet) into fractured rock structures are Eastwood manzanita, California scrub oak, canyon live oak, and probably Christmasberry. Their root systems are strong, much-branched, and fairly wide-spreading. Chamise has a similar deeply penetrating system but the roots are smaller. Chaparral whitethorn differs in usually having a single taproot instead of the much-branched systems of the other species. All 6 of these species sprout vigorously from the rootcrowns after fire.

Bigberry manzanita is the best example of a widely spread, shallow root system (less than 10 feet). Hoaryleaf and Mojave Desert ceanothus have similar shallow root systems, but neither species spreads as widely as the bigberry manzanita. Hairy ceanothus has a root system somewhat similar in shape to other members of this group, but its roots apparently neither spread as widely nor penetrate as deeply. All of these species are nonsprouters. The sprouting mountainmahogany appears to have a spreading, shallow root system, but the 2 small plants excavated may not have given a reliable indication of the penetration of mature root systems.

The subshrubs, California buckwheat, white sage, and black sage, have much-branched fibrous root systems. Bush monkeyflower has a similar but smaller root system. Deerweed has a slender taproot with comparatively few branch roots. Yucca has shallow but widely spreading roots. Buckwheat and white sage form adventitious roots along the prostrate stems.

Thickleaf yerbasanta has a strikingly different root system. It has widely spreading lateral roots which frequently send up a shoot to form a new plant. This method of propagation often extends the plant over a wide area.

These differences in root systems have important implications in watershed management. On some areas, an increase or other change in the vegetation may bring about benefits such as greater soil stabilization, increased flood regulation, or improved water yield. If manipulation of vegetation is intended, then knowledge of the root systems allows selection of species best adapted to the objectives of management.

Soil stability implications

Plants with roots that penetrate deeply through the soil mantle and into cracks in the underlying rock tend to reduce the mass slumping of material, especially the type of movement originating at a soil-rock interface. Plants with widespreading roots tend to hold surface soil layers in place, but species with only surface roots do not bind the soil as effectively to the underlying rock as those with deeply penetrating roots.

On slopes where the mass movement of soil is to be reduced, Eastwood manzanita, the oaks, and Christmasberry would be desirable species. These species because of their very deep and strong root systems are especially valuable for planting on road fills to reduce the possibility of mass movement. Chamise and chaparral whitethorn are somewhat less desirable because of their smaller or less-branched root systems.

On slopes where soil may be eroded by surface runoff or where surface soil may creep or slide during the dry season, the most desirable plants are those which furnish a continuous cover (Anderson 1949) and grow closely spaced. Those plants which spread laterally by sprouts from shallow roots or by adventitious roots developing from decumbent stems are especially desirable. The subshrubs, California buckwheat, white sage, and thickleaf yerbasanta are in this category, and therefore appear to be the most valuable to reduce this kind of soil movement. However, these species as well as other natives have a high ratio of root-to-top spread, and do not form a continuous cover on south slopes. The high ratio indicates that there is considerable competition between plants for moisture and nutrients and also suggests a possible reason for the sparseness of the native cover (Hellmers, Bonner, and Kelleher 1955).

On some sites, such as road fills, both surface erosion and mass movement may occur. There planting would be recommended using a mixture of deep-rooted woody shrubs and fibrous-rooted spreading subshrubs.

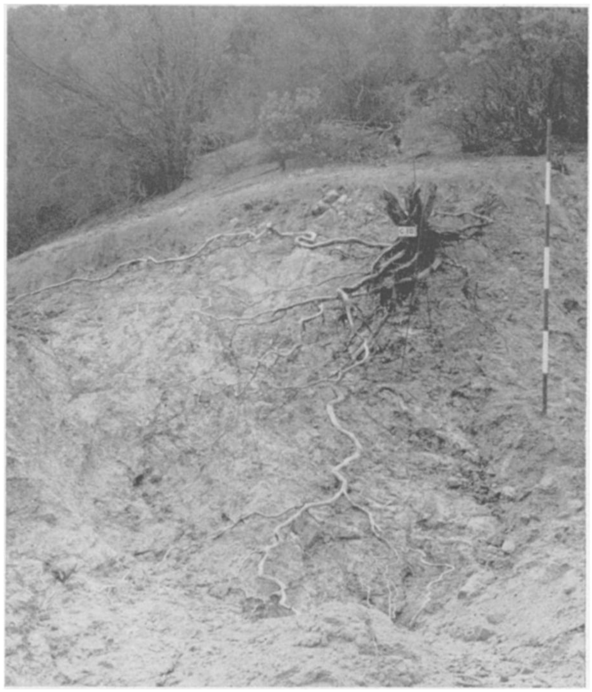

FIG. 5. The same shrub as illustrated in Figure 4. Two large laterals are shown radiating from the root crown. One of these extended more than 21 feet from the base of the shrub and measured 31 feet in length. (R-111)

Water flow implications

Plants with deep roots utilize water from deeper soil and rock layers than plants with shallow roots. This fact is of importance in the management of watersheds both for water yield and for flood control. In the southern California mountains, most of the available water within the root zone is removed by evapo-transpiration during the summer. The moisture content within the root zone must be brought to field capacity by winter rainfall before water is available for entry into the rock structures below the root zone (Kramer 1952, Rowe and Colman 1951).

Where soils are deep, deeply rooting plants make a greater summer drain on soil moisture than shallow-rooting plants. There replacement of vegetation with deep roots by vegetation with shallow roots increases the quantity of water percolating through the soil and thence into streams. In shallow soils, where roots of both shallow- and deep-rooted plants penetrate to the underlying rock, either type of plant uses all available soil water. Where the soil is shallow but the rock cracks can be deeply penetrated by roots, there can be only a small difference in water yield whether deep or shallow rooted species occupy the area. This is due to the fact that the amount of available water held in the rock is quite small in southern California watersheds. Rowe and Colman (1951) reported that in a typical area of the San Gabriel Mountains fractured metamorphic rock below the soil profile could hold no more than 0.05 inch of water available for plant growth, per foot of rock depth.

To increase water yield where mass movement of soil is not probable and where soil is deep, the woody shrubs with shallow, spreading root systems, or the subshrubs, are desirable species to favor in watershed management. Shrubs recommended for this use are bigberry manzanita, hoaryleaf ceanothus, and Mojave Desert ceanothus. They and the subshrubs do not dry the soil as deeply as do the deep-rooted species, and therefore bring about some saving in water. In areas with shallow soil and underlying rock impervious to root penetration, use of water would be much the same regardless of the type of shrubby vegetation.

The deeper drying of the soil-rock mantle by deep-rooted species has another implication for consideration in watershed management. In southern California, some major floods are caused by heavy rains falling upon watersheds whose soil is wet through. Much of the excess water enters the stream as subsurface flow rather than as surface runoff (Lassen, Lull, and Frank 1952). The depth of root penetration influences the amount of space available to store water in the soil at the start of the rainy season. Increased water-storage space made available by removal of soil water by deeply penetrating roots can reduce flood flows during storms, especially if the storms occur early in the season before the soil-rock mantle is wet through. In shallow soils, where roots of both shallow- and deep-rooted species penetrate to the rock, there is no difference in available storage space between the two types of root systems.

Summary

A study was made of the roots of 18 species of shrubs and subshrubs found in the chaparral of southern California. Measurements and observations made on 68 plants at 14 locations in the San Gabriel and San Bernardino Mountains showed the following:

1. Chaparral species and their root systems can be placed into three categories: (a) woody, usually sprouting shrubs with deep-penetrating and wide-spreading systems; (b) woody, usually non-sprouting shrubs with shallow but wide-spreading systems; and (c) subshrubs with shallow, fibrous systems.
2. Roots of some species grew through fractures in the rock or through weathered rock to a depth of at least 28 feet. Subterranean rock crevices were often filled with a mat of living roots.
3. The depth of soil and the extent to which the underlying rock is weathered and fractured modified the characteristics of the root systems.
4. The roots spread wider than the branches in all species studied.
5. Roots of many species grew up hill, parallel to the soil surface.
6. Root grafting was not common. It was found only in one species in this study, California scrub oak.
7. Nodules were found on the roots of all species of Ceanothus.

These findings have important implications for vegetation treatment in watershed management. Species with deep root systems are to be favored for stabilization of the soil mass. Subshrubs which can grow closely spaced, and especially those species which root from decumbent stems or sprout from shallow roots, are useful for reduction of surface soil movement. To reduce some flood flows deep-rooted species should be used on deep soils. To increase water yield on deep soil areas not susceptible to overland water flow, shallow-rooted species should be favored.

References

Anderson, H. W. 1949. Flood frequencies and sedimentation from forest watersheds. Trans. Amer. Geophys. Union **30**: 567-586.

Colman, E. A. 1948. Soil surveying on wildlands: the problem and one solution. Jour. Forestry **46**: 755-762.

Cooper, W. S. 1922. The broad-sclerophyll vegetation of California. Carnegie Inst. Wash. Publ. **319**.

Garin, G. I. 1942. Distribution of roots of certain tree species in two Connecticut soils. Conn. Agr. Expt. Sta. Bull. **454**.

Hellmers, H., J. Bonner, and J. M. Kelleher. 1955. Soil fertility: a watershed management problem in the San Gabriel Mountains of southern California. Soil Science. In press. 80:

Jepson, W. L. 1925. Manual of the flowering plants of California. Univ. of California Press, Berkeley, Calif.

———. 1936. A flora of California. Vol. 2. Univ. of California Press, Berkeley, Calif.

———. 1939. A flora of California. Vol. 3. Univ. of California Press, Berkeley, Calif.

Kittredge, J. 1948. Forest influences. McGraw-Hill Book Co., New York.

Kramer, P. J. 1952. Plant and soil water relations on the watershed. Jour. Forestry 50: 92-95.

Lassen, L., H. W. Lull, and B. Frank. 1952. Some fundamental plant-soil-water relations in watershed management. U.S. Dept. Agr. Circular 910.

McMinn, H. E. 1939. Illustrated manual of California shrubs. Stacey, Inc., San Francisco.

Miller, W. J. 1934. Geology of the western San Gabriel Mountains of California. Univ. of California, Los Angeles, Pubs. Math. and Phys. Sci. 1(1): 1-114.

Plummer, F. G. 1911. Chaparral. U. S. Dept. Agr. Forest Service Bull. 85.

Rogers, W. S. 1935. Soil factors in relation to root growth. Trans. 3rd Inter. Cong. Soil Sci. 1: 249-253.

Rowe, P. B., and E. A. Colman. 1951. Disposition of rainfall in two mountain areas of California. U.S. Dept. Agr. Tech. Bull. 1048.

Sampson, A. W. 1944. Plant succession on burned chaparral lands in northern California. Calif. Agr. Exp. Sta. Bull. 685.

Sinclair, J. D. 1954. Erosion in the San Gabriel Mountains of California. Amer. Geophys. Union. 35: 264-268.

Sinclair, J. D., and E. L. Hamilton. 1953. A guide to the San Dimas Experimental Forest. Calif. For. and Range Exp. Sta. Misc. Paper No. 11.

Storey, H. C. 1948. Geology of the San Gabriel Mountains, California, and its relation to water distribution. Calif. Dept. Nat. Res., Div. of Forestry.

Van Rensselaer, M., and H. E. McMinn. 1942. Ceanothus. Santa Barbara Botanic Garden.

Weaver, J. E. 1926. Root development of field crops. McGraw-Hill Book Co., New York.

Weaver, J. E., and F. E. Clements. 1938. Plant ecology. 2nd ed. McGraw-Hill Book Co., New York.

A FIELD STUDY OF THE ACTIVITY OF THE MOLE (*TALPA EUROPAEA*)

Gillian K. Godfrey (Mrs. Crowcroft)
Zoological Society of London

Little is know about the activity pattern of the mole (*Talpa europaea* L.) but it is generally believed to be active during both day and night. Some workers (*e.g.*, Kuzyakin 1935) report greater activity by night than by day, while others (*e.g.* Stein 1950) maintain that there is no difference between the amounts of night and day activity. The frequency of the active periods is unknown although there is a widespead belief among mole-catchers that digging occurs every four hours.

Previous work on the activity of small mammals has been carried out either under laboratory conditions or in the field using indirect methods. The activity of moles has not been investigated in the laboratory, and the only field study is that of Hamilton (1939) who observed the rate of reopening of tunnels in *Parascalops breweri*.

This paper describes an attempt to obtain direct information about the activity pattern of *Talpa europaea* by labelling individuals with radioactive material and locating them at frequent intervals with a Geiger-Müller counter unit.

Material and Methods

Moles were studied in two different habitats.

1. *Pasture* (part of New Fen) at Lakenheath, Suffolk. New Fen, which forms part of the extensive East Anglian fenland, was first cultivated in 1940. It is drained by a series of ditches which cut it up into fields of about ten acres in size. The soil is typical fen peat, with a high humus content. Moles are abundant on New Fen but intensive trapping is confined to the banks of the main drain; elsewhere the animals merely suffer from the effects of agricultural practice. The fields were reseeded in 1947, following severe flooding, and since then have been used only for grazing.

Two females and one male were observed during March and April 1954. Breeding was just beginning, and by the end of this period one of the females was known to be pregnant.

2. *Arable fields* (part of Higham Estate) near Newmarket, Suffolk. The fields used are on light, sandy soil with a low humus content. They were ploughed in May and sown with a mixture of chicory, cocksfoot grass and white clover. The observations were made during the six weeks following sowing, before the crop had grown sufficiently to obscure the moles' shallow tunnels.

Five individuals were studied: one adult female and four juvenile males. Breeding had finished, and the female was in anoestrous condition. The juveniles were sexually immature but had almost reached adult body weight.