Distribution of Roots and Rhizomes in Different Soil Types in the Pine Barrens of New Jersey

GEOLOGICAL SURVEY PROFESSIONAL PAPER 563-C

Prepared in cooperation with the New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply; Rutgers University; and the U.S. Forest Service

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By WILLIAM A. LAYCOCK

HYDROLOGY AND ECOLOGY, PINE BARRENS, NEW JERSEY

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DEFINITIONS OF BOTANICAL TERMS

Definitions of botanical terms used in this paper are based mainly on Eames and MacDaniels (1947) and Fuller and Tippo (1954).

Aerenchyma: In a physiological sense, any loose aerating tissue.

Aerial stem: A stem that grows above the soil (see "rhizome").

Axillary bud: A bud borne in the axil of a leaf. The axillary buds of a rhizome originate in the axils of the scale leaves on the rhizome growing tips.

Cambium: Layer of meristematic cells between secondary xylem and secondary phloem tissue that contributes new cells to both.

Clone: A population resulting from vegetative (asexual) reproduction of a single individual.

Internode: The length of stem between two successive nodes.

Lateral roots: Branch roots that arise from a primary root system or taproot.

Meristematic tissue: A tissue whose cells are capable of frequent division and which is thus responsible for the first phase of growth.

Node: The part of a stem from which a leaf and a bud arise.

Nodule: On the roots of certain plants, an enlargement within which nitrogen-fixing bacteria or fungi live.

Parenchyma rays: Narrow vertically elongated bands of parenchyma cells that extend radially in stems from the pith through the xylem and in some stems through the phloem.

Perennating bud: A terminal or axillary structure on a stem or rhizome consisting of a small mass of meristematic tissue and often covered by protective scales. The part of a plant from which new stem growth originates.

Phloem: A plant tissue, consisting primarily of sieve cells, sieve tube cells, and phloem parenchyma, that conducts food in the plant. In woody stems and roots the phloem generally is outside the xylem.

Pith: The parenchyma occupying the central part of the stem inside the xylem.

Rhizome: A horizontal underground stem, often rooting at the nodes. Rhizomes may resemble roots superficially; however, they are true stems with nodes, internodes, buds, and often leaves.

Rhizome growing tip: The underground nonwoody terminal part of actively growing rhizomes that continues the elongation of the rhizome. See section on "Underground Rhizome Growing Tips" (p. C11) for a more detailed description.

Root: That part of the axis of most plants that is nongreen and grows beneath the surface of the soil. Roots lack the nodes, internodes, and leaves that are characteristic of stems. The principal functions of roots are absorption of water and dissolved minerals, anchorage, conduction of material, storage of food, and vegetative reproduction.

Rootstock: A rhizome. In the plants *Kalmia latifolia* and *Lyonia mariana*, an enlarged underground woody structure from which both roots and aerial stems arise.

Root system: The entire mass of roots produced by a plant.

Roots, fibrous: Nonwoody roots.

Roots, woody: Roots whose main bulk is secondary xylem (wood).

Scale leaves: Reduced, nongreen leaves.

Stem: That part of the plant axis consisting of nodes and internodes and bearing leaves and often reproductive structures. (See "aerial stem" and "rhizome.")

Taproot: A stout vertical root that continues the main axis of some plants. Taproots of woody plants generally are larger than the other roots and extend rather deep into the soil.

Xylem: A complex plant tissue, consisting of vessels, tracheids, and other cells, that conducts water and dissolved salts in the plant. Wood is composed of secondary xylem.

DISTRIBUTION OF ROOTS AND RHIZOMES IN DIFFERENT SOIL TYPES IN THE PINE BARRENS OF NEW JERSEY

By William A. Laycock

ABSTRACT

The Pine Barrens, which consists of upland forests and lowland swamps, covers approximately 2,000 square miles of the Coastal Plain of New Jersey. The root and rhizome systems of selected shrubs of this region were studied as part of the New Jersey Pine Barrens Hydrologic research project to determine the effects on the present and future ground-water supplies of changes in forest composition caused by controlled burning.

The form, depth, and lateral extent of the root and rhizome systems of 20 species of shrubs which grow in the upland forest and in the transition zone between the upland and lowland areas of the region are described. Two species of shrubs (*Kalmia angustifolia* and *Lyonia mariana*) in the transition zone have phreatophytic characteristics. The roots of these two species penetrate as deep as 40–58 inches to reach the underlying water table. Roots of the other species of shrubs may or may not extend to the water table.

The A_0 soil horizon contains the highest number of tree and shrub roots per square foot, and the A_1 horizon contains the next highest number. In upland soils, numbers of roots decrease sharply from the A_1 to the A_2 horizon, increase slightly in the B_1 horizon, and then decrease with depth below the B_1 horizon. The increase in the B_1 horizon does not occur in the poorly drained soils. The highest total numbers of roots in the entire profile were found in soils having thin, imperfectly leached A_2 horizons.

Sites with shrubs had significantly more roots, especially in the A_0 and A_1 horizons, than similar sites having no shrubs. A decrease in shrub cover caused by controlled burning, and the resultant decrease in roots, might permit more water to reach the water table.

INTRODUCTION

The study reported here is part of the New Jersey Pine Barrens hydrologic research project, begun in 1951 as a phase of the cooperative program of the U.S. Geological Survey and the New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply. Other cooperating agencies include Rutgers, The State University of New Jersey; the Northeastern Forest Experiment Station of the U.S. Forest Service; and several local organizations. The hydrologic research project was started to determine the effect of changes in forest composition caused by controlled burning on the present and future ground-water supplies of the area. Two small watersheds in the Lebanon State Forest, New Jersey—McDonalds Branch watershed (1,480 acres) and Middle Branch watershed (1,590 acres)—were selected as study areas.

Recording gaging stations were placed at the mouth of each watershed. A network of observation wells was established on each watershed, and a rain-gage network was installed to include the watershed areas. After a period of calibration, one of the watersheds will be subjected to controlled burning, and the other will be kept free from fire. A wildfire in 1955 burned about 450 acres of the eastern end of McDonalds Branch watershed (McCormick, 1955) so an extended period of calibration may be needed before changes in silvicultural practices can be started.

PURPOSE AND SCOPE

The purpose of the present study was to determine (1) the form, depth, and lateral extent of the root and rhizome systems of the upland and transition-zone shrubs of the region and (2) the vertical distribution of roots of trees and shrubs in different soil types found in the uplands and the transition zones of the two experimental watersheds. Transition zone is used in this paper to designate the zone between the upland and lowland areas. The water table in the transition zone is about 2–5 feet below the surface most of the year, and the characteristic plant community is the pine transition community described by McCormick (1955). The most common soil types in the transition zone are the Leon sand and the Lakehurst sand, thick A_2 variant.

Knowledge of the characteristics and distribution of root and rhizome systems of shrubs is important in watershed management. Because only a small amount of overland flow occurs in the Pine Barrens, shrub roots are less important in soil stabilization and erosion prevention than in areas where these factors are problems. However, a dense stand of shrubs undoubtedly absorbs and removes large amounts of water from the soil. The density of shrubs in upland areas in this region is greatly reduced by controlled burning (Little and Moore, 1945). This reduction or any other factor that decreases the number or changes the distribution of roots in the soil may increase the amount of water available to meet transpirational requirements of other vegetation or to replenish the ground-water reservoir. A fuller knowledge of the characteristics of the roots of the shrubs may also lead to methods of controlling shrub density.

ACKNOWLEDGMENTS

Special thanks are due Murray F. Buell, professor of botany at Rutgers, The State University of New Jersey, for his advice, assistance, and encouragement. For their many courtesies and assistance in this study, the writer wishes to thank Allen Sinnott, E. C. Rhodehamel, Seymour Subitzky, and other members of the staff of the Ground Water Branch district office, Trenton, N.J., and H. C. Barksdale, branch area chief, Atlantic Coast Area.

LOCATION AND GENERAL FEATURES OF THE AREA

The Pine Barrens of New Jersey consists of about 2,000 square miles of woodland on the Coastal Plain in the southeastern part of the State (fig. 1).

The upland vegetation of the region consists of various mixtures of oak (white oak, *Quercus alba*[1]; black oak, *Q. velutina;* chestnut oak, *Q. prinus;* and others), pine (pitch pine, *Pinus rigida;* and shortleaf pine, *P. echinata*), and scrub oak (*Q. ilicifolia*). The lowland plant communities include dense southern white cedar swamps (*Chamaecyparis thyoides*), hardwood swamps (red maple, *Acer rubrum* var. *trilobum;* black gum, *Nyssa sylvatica;* and others), and pitch pine lowlands (McCormick, 1955; Little and Moore, 1953).

The history of the region is one of recurrent fires and and repeated and extensive disturbance by man. Fires have kept most forest stands on a 25- to 50-year cycle since 1800 or earlier (Little and Moore, 1945). The forests have been cut frequently since the 17th century to supply wood for nearby cities, steamships, and railroads as well as for various local industries, such as bog-iron works, glass making, and charcoaling (Cranmer, 1952; McCormick, 1955).

Because of the prevalence of wildfires, many of the upland forest stands consist of oaks of sprout origin mixed with pine (Little and Moore, 1945). These stands produce little timber and consequently have little commercial value (Moore, 1939). Light controlled winter fires remove most of the litter creating seed-bed conditions favorable for pine reproduction (Little and Moore, 1945; Little and others, 1948; and Little, 1953). Larger pines are fire resistant and survive these controlled fires, but the above-ground parts of most of the associated oaks are killed. Subsequent cutting of the oak sprouts and burning at intervals result in almost pure stands of pine, which are more valuable than mixed stands. This controlled burning also reduces the occurrence and damage of wildfires (Moore and others, 1955).

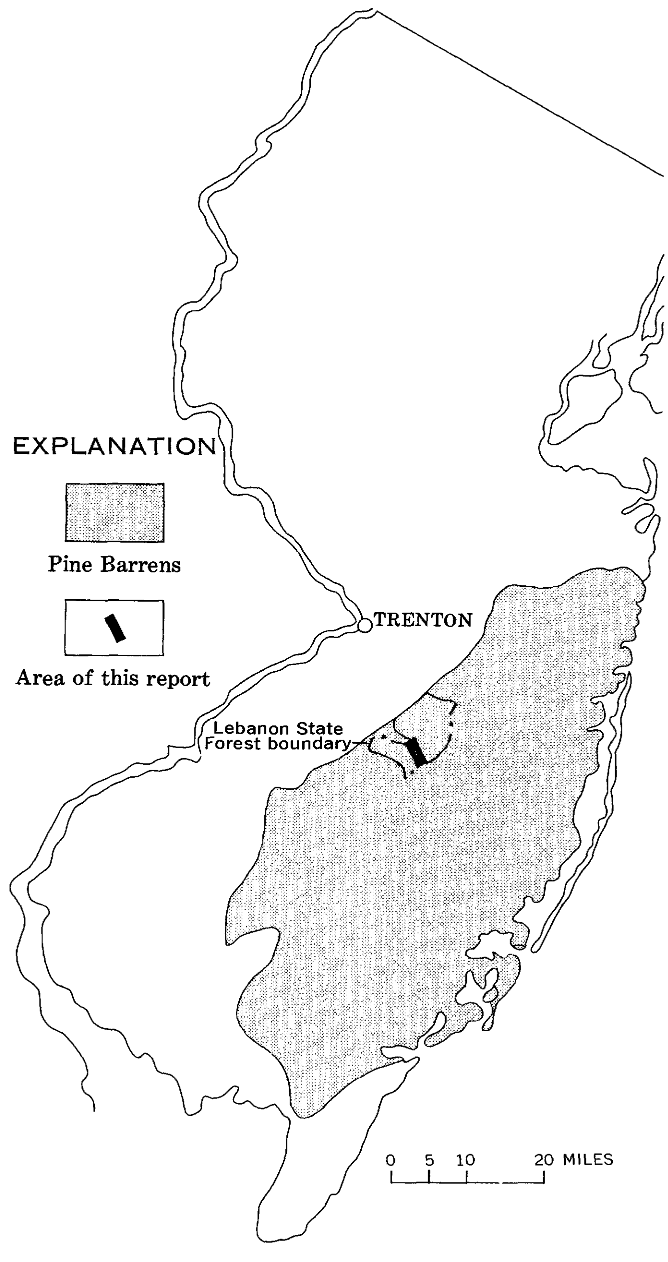

FIGURE 1.—Map of New Jersey showing the Pine Barrens (after Harshberger, 1916) and the area of this report.

[1] Nomenclature of all plant species follows Fernald (1950).

The principal geologic formation underlying the Pine Barrens is the Cohansey Sand of Miocene(?) and Pliocene(?) age. Along the west and northwest, however, the Pine Barrens are underlain by the upper beds of the Kirkwood Formation of Miocene age (Tedrow, 1952). Except for a few lenses of clay in the Cohansey Sand, both formations are composed of quartz sands and gravels in thin outcrop areas (Kümmel, 1940). Several discontinuous younger deposits of sand and gravel (Beacon Hill gravel, and Bridgeton, Pensauken, and Cape May Formations) occur in the region (Kümmel, 1940).

The thick sandy strata that underlie the Pine Barrens have been proposed as a future source of water because they form a large natural reservoir with a possible specific yield of about 20 percent of their volume (Barksdale, 1952). The average annual precipitation in the region is slightly more than 45 inches (White, 1941), and very little runs off as overland flow because of the highly permeable sandy soil and gentle slopes characteristic of the region. Barksdale (1952) estimated that about 20 inches of the annual rainfall would be available for water supply and that more than a billion gallons per day could be pumped from these formations by a network of wells without depleting the storage in the reservoir below its annual recharge potential.

Because the sandy strata underlying the Pine Barrens may be important for future water supplies, it is desirable to know which plants are phreatophytes—plants whose roots extend either to the water table or to the capillary fringe above the water table, and thus insure a more definite and continuous supply of water for the plants (Meinzer, 1927). Phreatophytes have been studied mainly in the arid parts of the Western United States. Robinson (1951, 1958) stated that phreatophytes cover about 16 million acres in the 17 Western States and may release 20–25 million acre-feet of water into the atmosphere annually. Studies of phreatophytes in the Eastern United States include the work of Hoover (1944), Dunford and Fletcher (1947), Trousdell and Hoover (1954), and Hewlett and Hibbert (1961) who determined the effects of removing trees and streambank vegetation on streamflow and water-table level in North Carolina.

The amount of ground water now being used by phreatophytes in the New Jersey Pine Barrens is probably not important because there is little demand for this water, but as the water becomes more essential to the economy of the region, the use of water by phreatophytes may have to be reduced.

PREVIOUS STUDIES

Many workers have studies plant ecology and silvicultural methods in the New Jersey Pine Barrens. So far as known, the earliest comprehensive report which describes the forest conditions in the region was prepared by Pinchot (1899). Stone (1912) studied the flora and Harshberger (1916) studied the ecology of the region. In recent years, other papers concerning special problems on plant ecology and the effects of controlled burning on the vegetation in the general area of the present study have been published by Buell and Cantlon (1950, 1953), Cantlon (1951), Buell (1955b), and Moul and Buell (1955). A vegetation map and a detailed description of the plant communities on the two watershed areas was prepared by McCormick (1955). Bacho (1955) mapped the surficial geology of the two watersheds, and Markley (1955) described and mapped the soils.

The root and rhizome systems of some of the Pine Barrens shrubs have been described by the following writers: *Comptonia peregrina* var. *asplenifolia* and *Myrica pensylvanica* (Youngken, 1919; Hall and Mack, 1960); *Ilex glabra* (Holm, 1929), and *Vaccinium angustifolium* (Hall, 1957). Coville (1910) and Mahlstede and Watson (1952) studied the roots of *V. corymbosum*, and Braun (1936) described the roots of *I. verticillata*. Both species are found in lowland areas in the Pine Barrens but were not included in the present study.

Harshberger (1916) described the roots of many New Jersey Pine Barrens species, including most of those studied in the present report. His descriptions tend to be superficial but as far as they go they are correct, with the exception of *Hudsonia ericoides* and *Leiophyllum buxifolium*. These two species are discussed on page C10.

The root systems of many species of Pine Barrens trees also have been studied previously. Some of these studies should be mentioned here even though the present study did not include any trees. McQuilkin (1935) studied the root systems of pitch pine and shortleaf pine in the Pine Barrens, and Stout (1956) studied the root systems of chestnut oak, white oak, and red maple in New York.

METHODS USED TO STUDY ROOT SYSTEMS

ROOT AND RHIZOME SYSTEMS

Various methods of excavating root systems were tried during the study. Hand excavation of root systems from the side of a pit—as described by Weaver

(1919, 1920) and Heyward (1933)—was tried but found to be unsatisfactory because it did not accurately depict the lateral extent of the rhizome system of most of the shrubs. Exposing root systems by removing the soil from the sides of a pit with a stream of water (Stoeckeler and Kleunder, 1938; Tharp and Muller, 1940) was also tried and abandoned for the same reason. An attempt was made to remove the soil from the root systems with a stream of water, starting from the surface of the soil instead of the face of a pit (Cheyney, 1929, 1932; Preston, 1942), but this method also failed because of insufficient water pressure.

The method finally adopted is almost the same as the one used by Cannon (1911), Chadwick, Bushey, and Fletcher (1937), Duncan (1941), and Specht and Ratson (1957). It consisted of digging with hand tools, starting from the surface of the ground and working downward. The soil was removed from the roots and rhizomes with a small trowel and a shovel. The horizontal and vertical extent of the roots was drawn to scale on graph paper, and the diameters of roots and rhizomes, the presence and distribution of small woody or fibrous roots, and other pertinent data were recorded. Representative root systems of each species were photographed in place or on a white board having a 6-inch grid to show the scale. At each site where shrub roots were excavated, the characteristics and dimensions of the soil horizons were recorded, and various relations of root distribution to the soil horizons were noted. In areas that have a shallow water table, the position of the roots in relation to the water table was recorded.

VERTICAL DISTRIBUTION OF ROOTS

Root distribution studies were made in each of seven upland and transition-zone soil types (see p. 11). At least one site in each soil type was studied in a pine or mixed oak-pine forest stand with a good understory of shrubs. Additional sites with no shrub cover were studied in the major upland soil (Lakewood sand) and transition-zone soil (Leon sand) to determine the effect of different forest types and the presence or absence of shrubs on number and distribution of roots. The primary site in Lakewood sand was in an oak-pine stand with a good understory of shrubs. Root distribution in this soil was also studied at two additional sites in a pure pine stand; one site had a good shrub cover and one had no shrubs. For comparison purposes, these three sites will be referred to as the oak, the pine-shrub, and the pine-shrubless sites of the Lakewood sand. The primary site in the Leon sand was in a pure pine stand having a good shrub understory. One other site in this soil was studied in a turf bald area in a pine stand with no shrubs. This site will be referred to as the Leon sand turf bald site.

The method used to study root distribution was the same as described by Scully (1942). A 4- by 4-foot soil pit, 4 feet deep, was dug at each site. The pits were so located that each wall was 10 feet or more from the nearest tree trunk. Exposed roots on a 3-foot-wide section in the center of all four walls were counted and charted on graph paper to the depth of the pit. A 1-square-foot frame, divided into 3-inch squares, was used to subdivide the wall and to facilitate the counting of roots. The frame was placed on each square foot of the pit starting from the surface. Within each square foot the soil horizons were drawn to scale on graph paper and the roots were exposed, counted, and charted according to the following diameter classes: 0.01–0.05 inches, 0.06–0.10, 0.21–0.30, 0.31–0.40, 0.41–0.50, 0.51–0.60, 0.61–0.70, 0.71–0.80, 0.81–0.90, 0.90–1.00, and more than 1.00 inch. Roots more than 0.2 inch in diameter were identified as oak, pine, or shrub roots, but no distinction was made between shrub roots and rhizomes. The relative abundance of tree and shrub species immediately surrounding the pit was also recorded.

Counts on each of the four sides of the pit at each site were considered as independent observations. The average numbers of roots per square foot for the entire profile for each of the seven soil types were compared using an analysis of variance. An F value was calculated to determine whether variation in numbers of roots between soil types was greater than variation within types (Snedecor, 1956). If the computed F was significant, at the 5-percent probability level, the differences between the various means were tested for significance by the multiple-range test described by Duncan (1955).

The mean number of roots per square foot in the A_1, A_2, and B horizons in the various soil types were compared by the same method. No statistical comparison between sites was made of the roots in the A_0 and B_1 horizons because these horizons were rather thin or not present in all the soil types. However, roots in these horizons were included in the profile totals and the roots in the B_1 horizon were included in the figures for the total B horizon. Accurate counts of the smallest woody roots (0.01–0.05 inch) were difficult to make in the A_0 horizon because of the many very small fibrous roots intermingled with the humus.

The median value of each diameter class was used to compute average area in that class. This average area multiplied by the number of roots in each horizon and in the entire profile gave the exposed cross-sectional area of roots. Differences in the mean area of roots per square foot in the profile among the various soil types were compared statistically as just described.

In addition to the root-distribution studies, soil samples were collected from each soil pit with a U.S. Geological Survey sampler (Smith and Stallman, 1955). Relatively undisturbed vertical samples were obtained in sections of clear plastic tubing 6 inches long and 2 inches in diameter. At each site continuous samples were taken from the top of the mineral soil to the lower limit of the root-study pit except in thick and homogeneous horizons for which one or two samples were considered to be representative of the entire horizon. Coefficients of permeability for each sample were obtained by the variable-head and constant-head permeameter methods (Wenzel, 1942; Smith and Stallman, 1955) by the U.S. Geological Survey hydrological laboratory, Denver, Colo. The percentages of the different grades of sand and gravel in the samples were determined by weight analysis of particles separated out by sieves, and the combined percentages of silt and clay particles were determined by the hydrometer method. Particles were divided into the following size classes: clay, less than 0.004 mm; silt, 0.004–0.0625 mm; very fine sand, 0.0625–0.125 mm; fine sand, 0.125–0.25 mm; medium sand, 0.25–0.5 mm; coarse sand, 0.5–1.0 mm; very coarse sand, 1.0–2.0 mm; gravel, greater than 2.0 mm.

ROOT AND RHIZOME SYSTEMS

Root systems of each species studied were excavated to determine the distribution and most common form of the roots and rhizomes. Only the shrubs of the upland zone and transition zone communities are described. Some of the species studied also occur in the lowland zone communities, but the species that occur only in lowland areas were not studied. The relative abundance of each species, determined from field observations and from data on shrub cover given by McCormick (1955), are described by the terms "very abundant," "abundant," "common," "rare," and "very rare." Plant community names follow the classification given by McCormick. The scientific and common names of plants mentioned in this report are given in table 13 (p. 25).

Buell and Cantlon (1953) found that frequent controlled burning reduced cover of *Gaylussacia baccata* more than *Vaccinium vacillans*. Special attention was given to the roots and rhizomes of these species to determine why they differ in ability to recover after burning.

ROOTS AND RHIZOMES OF THE MOST COMMON SHRUBS

UPLAND SHRUBS

GAYLUSSACIA BACCATA (BLACK HUCKLEBERRY)

Black huckleberry is abundant in all upland communities, common in the pine lowland and pine transition communities, and common in the cedar swamp and hardwood swamp communities. Several aerial stems arise from an extensively branched rhizome system (fig. 2). In areas having an A_0 horizon the rhizome usually is partly in this layer and partly in the top inch of the A_1 horizon, but in areas having no A_0 horizon the rhizome is in the top 2–3 inches of the mineral soil (A_1 horizon). The diameter of the rhizome usually is ¼–¾ inch but may be as much as 2 inches. Individual short roots occur all along the rhizome, and on some rhizomes there is a cluster of fibrous roots around the base of each aerial stem in the A_0 horizon or the top part of the A_1 horizon. Larger roots as much as 2 feet long originate near a fork of the rhizome or near the base of an aerial stem. These roots usually are confined to the A_0 or A_1 horizons, but they sometimes extend as deep as 8 inches. The characteristics of the root and rhizome system of *Gaylussacia baccata* and the other shrubs studied are summarized in table 14 (p. 26).

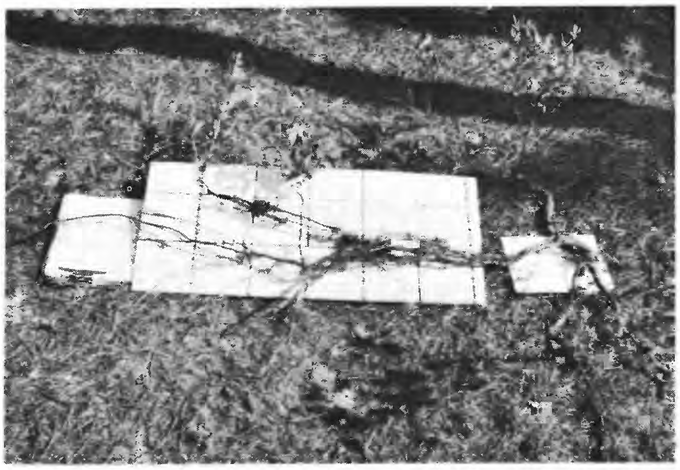

FIGURE 2.—Part of a much-branched rhizome system of *Gaylussacia baccata.*

VACCINIUM VACILLANS (LOWBUSH BLUEBERRY)

Lowbush blueberry is abundant in the upland communities, common in the pine transition community, and rare in the lowland communities. Several to many aerial stems, connected by an extensive branching rhizome, arise a few inches to several feet apart. The rhizome is ¼–⅝ inch in diameter and is usually found in the top 2 inches of the A_1 horizon, but some occur as deeps as 6 inches. Unlike the rhizome of *Gaylussacia baccata*, the rhizome of *Vaccinium vacillans* seldom occurs in the A_0 horizon, even where this horizon is well developed. A few small roots are scattered along the rhizome, and dense clusters of fine short fibrous or woody roots occur at the base of the aerial stems. A well-developed root may arise near the base of an aerial stem or near the fork of a rhizome (fig. 3) and may extend as deep as 25 inches; a few reach a depth of about 48 inches. The top part of this type of root and the part of the rhizome from which it grows may be nearly 2 inches in diameter, but the root tapers rapidly and is much-branched near the end. In areas where the water table is near the surface, any well-developed roots that are present extend horizontally instead of vertically, and the finely branched end parts may be in the A_0 horizon.

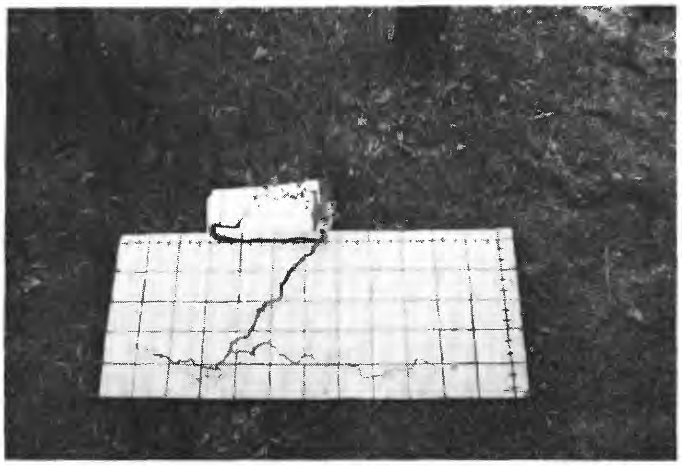

FIGURE 3.—A root of *Vaccinium vacillans* that extended 13 inches deep into the soil, then branched, both branches extending horizontally in the B_1 horizon. The top of the board represents the ground surface, and the grid is 3 inches.

QUERCUS ILICIFOLIA (SCRUB OAK)

Scrub oak is very abundant in some upland communities, and scattered individuals are found in the pine transition community. The aerial stems come from the thickened, often irregular, upper portion of the taproot that usually is 2–4 inches thick but may be as thick as 7 inches. Five main patterns of roots are found: (1) one main taproot that extends downward 20–36 inches having lateral roots only near the surface of the ground; the main taproot branches at the bottom to form an extensive network of roots; (2) one main taproot, as described above, that also has several well-developed horizontal or oblique laterals along its whole length (fig. 4); (3) one main taproot that extends obliquely; (4) two or more main roots that grow vertically or obliquely; and (5) one taproot that forks within a few inches of the surface; then the two branches extend horizontally at a depth of 4–8 inches. Figure 5 shows these five types of root systems. Types 1, 2, and 4 are most common, and types 3 and 5 are rare.

The roots of the scrub oak do not grow into the water table even in areas where the water is within 1 or 2 feet of the surface. The plant occasionally grows in such areas, but the root system is always very shallow (type 5, fig. 5).

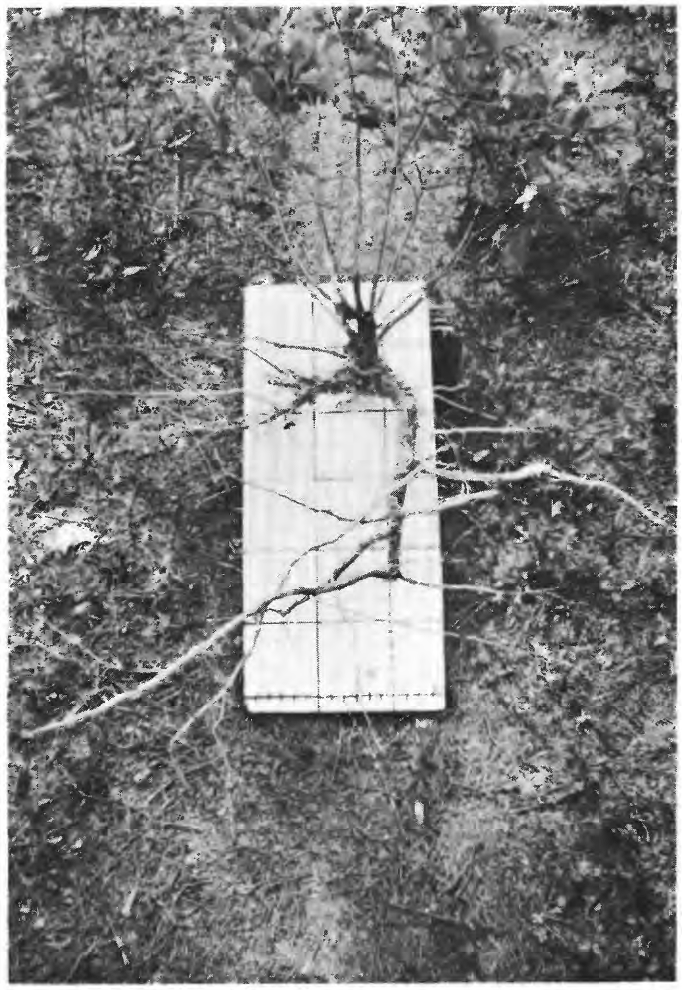

FIGURE 4.—Taproot of *Quercus ilicifolia* (type 2, fig. 5).

QUERCUS MARILANDICA (BLACKJACK OAK)

Blackjack oak generally attains tree size, but in frequently burned areas it sometimes grows in the same shrubby form as scrub oak. Only the roots of the shrubby forms were studied. The upper part of the taproot is similar to scrub oak, but a large vertical taproot, similar to type 2 described for *Quercus ilicifolia* (fig. 5), is always present and has short or well-developed laterals at various levels.

QUERCUS PRINOIDES (DWARF CHESTNUT OAK)

Dwarf chestnut oak is common in the upland or the extreme upland side of the pine transition community. The upper part of the taproot resembles that of the other oaks and there are two general patterns of roots: (1) a taproot that extends vertically as deep as 4 feet and has well-developed laterals and (2) a very extensive

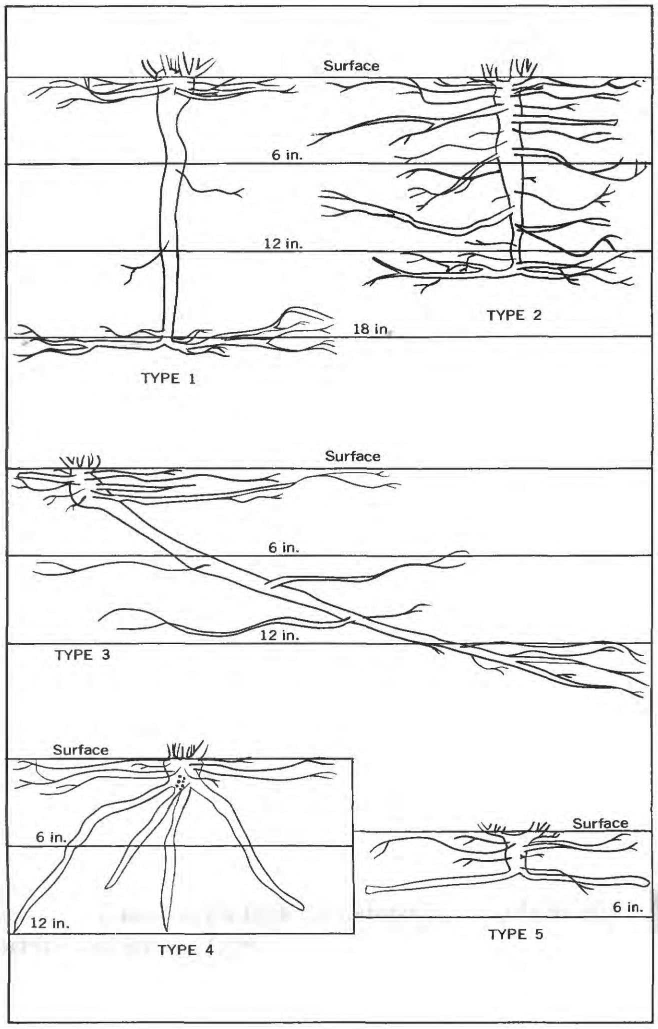

FIGURE 5.—The different types of root systems of *Quercus ilicifolia.*

main root that extends obliquely, similar to type 3 described for *Quercus ilicifolia* (fig. 5). One plant examined had a root that extended obliquely 10 feet, at which distance it was about 2 feet deep, and then branched, the longest branch being more than 7 feet long. One or more roots of *Q. prinoides* commonly extend to the water table if it is within 3–4 feet of the surface.

GAULTHERIA PROCUMBENS (TEABERRY)

The very small teaberry shrub is abundant both in the pine transition community and the upland communities that have an A_0 soil horizon. Many single aerial stems are connected to a rather straight but occasionally branched rhizome. The distance between aerial stems is 5–12 inches, and the diameter of the rhizome is about 1/16 inch. The rhizome is entirely in the A_0 horizon or partly in this horizon and partly in the top inch of the A_1 horizon. Small finely divided fibrous roots are scattered along the rhizome, and generally one small root originates at the base of each aerial stem.

TRANSITION ZONE SHRUBS

KALMIA ANGUSTIFOLIA (SHEEP LAUREL)

Sheep laurel is very abundant in the pine transition community and is common in the parts of the upland communities adjoining the pine transition community. Many aerial stems are connected by a much-branched brittle rhizome. The aerial stems arise singly or in groups and may be several inches to 2 feet apart on the rhizome. The rhizome can be as much as 1/2 inch in diameter and is very irregular in direction and pattern, frequently doubling back and crossing over itself. The rhizome may be partly or completely in the thick A_0 horizon in the pine transition community where this shrub is so abundant. Short fibrous roots are scattered along the rhizome, and dense clusters of fibrous roots occur at the bases of the aerial stems and on the rhizome within a few inches of the stems. These fine roots become enmeshed with each other and with the organic matter of the A_0 and the top part of the A_1 horizon. This intermeshing, together with the complex, brittle rhizome system, forms a very firm sod which makes it impossible to excavate and remove much of the rhizome system intact. Inasmuch as part of the rhizome grows in the A_0 horizon, fires in the past may have severed parts of a rhizome and isolated groups of aerial stems. All these factors make it difficult to determine the number of aerial stems connected by a common rhizome and to establish whether a complex stand is actually only one clone.

Many of these shrubs have roots that originate near the base of an aerial stem and extend to or below the water table. The water table in the pine transition community fluctuates throughout the year, but during the summer it is about 18 inches below the land surface at the side nearest the cedar swamp and 36–40 inches below the surface on the upland side. The root shown in figure 6 extended more than 13 inches below the water table, and the roots in the water table were very lightweight and corky after drying, evidently containing much aerenchyma.

In the past, blocks of sod held together by the roots and rhizomes of sheep laurel were cut and used by charcoalers to cover stacks of wood to exclude air during the charcoaling process. Similar blocks of sod were used in making cranberry-bog dams. These practices left circular turf balds which are still quite distinct and free of shrubs although the charcoal industry became inactive 75–100 years ago (McCormick, 1955).

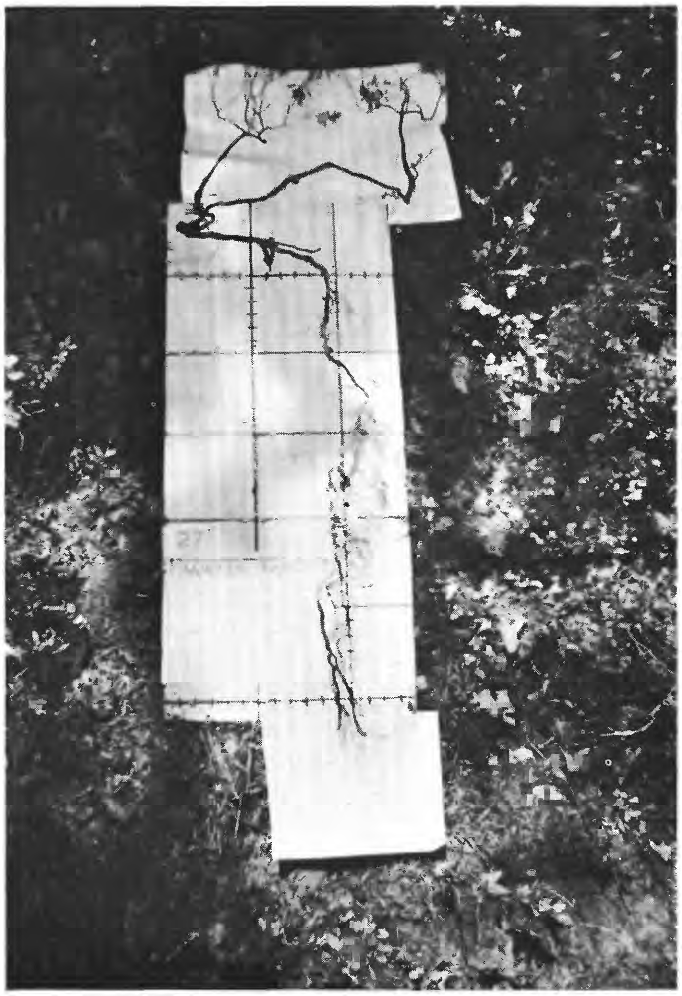

FIGURE 6.—Root of *Kalmia angustifolia* that extended 40 inches below the soil surface and 13 inches below the water table.

CLETHRA ALNIFOLIA (SWEET PEPPERBUSH)

Sweet pepperbush is abundant in the hardwood swamp, common in the cedar swamp and pine transition communities, and rare throughout the upland. Aerial stems arise singly or in pairs from a branching rhizome system and may be as close together as 3–4 inches or as far apart as 8 feet. In areas where the A_0 horizon is very thin or absent, the rhizome is in the top 2 inches of the A_1 horizon, but where a thick A_0 horizon is present the rhizome may be partly or completely in this layer. The diameter of the rhizome ranges from 1/8 to 3/8 inch. Small short roots are scattered along the rhizome and clustered at the base of the aerial stems. Longer roots may arise on the rhizome near the base of an aerial stem. These roots generally extend horizontally, but they may extend to the water table in the pine transition community (fig. 7).

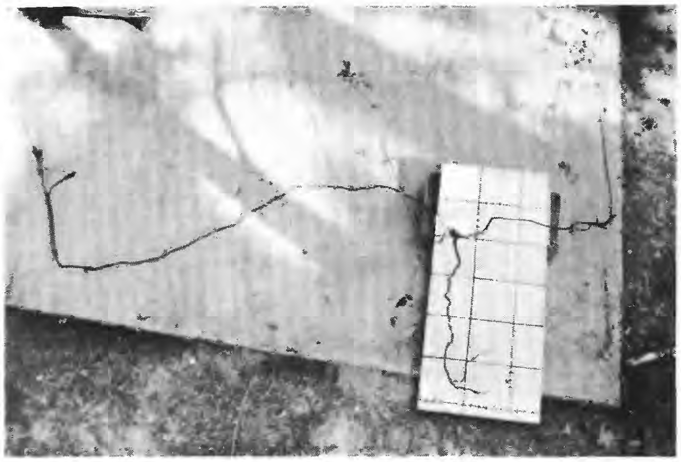

FIGURE 7.—Part of a rhizome of *Clethra alnifolia* having a root that extended 22 inches into the soil.

LYONIA MARIANA (STAGGERBUSH)

Staggerbush is common in the pine transition community and the lower edges of the upland communities bordering it. Aerial stems arise singly or in groups from an extensive rhizome system in the A_1 horizon. A few small, short roots are scattered along the rhizome or clustered at the bases of the aerial stems. The shrub often forms small clones having a few to many aerial stems connected to a central rootstock. One well-developed clone (fig. 8) had several roots that originated from the thick rootstock and extended 40 inches to the water table. Groups of aerial stems connected by a rhizome, but not in such a compact clone, also usually have a deep root that departs from a thickened area on the rhizome. One small clone of *Lyonia mariana* had the deepest penetrating root of any of the shrubs studied. This root extended 58 inches to the water table

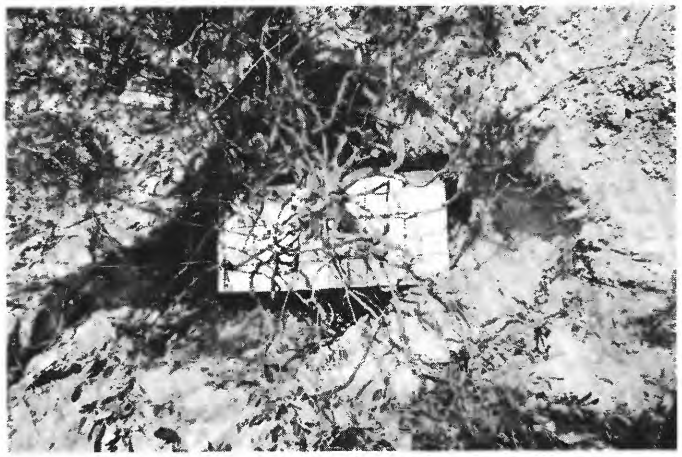

FIGURE 8.—Top view of a clone of *Lyonia mariana*. This clone had several roots that extended 40 inches to the water table.

where it was broken during excavation (fig. 9). These deeper roots generally are sparsely branched near the surface but may have many branched and rebranched laterals at lower depths.

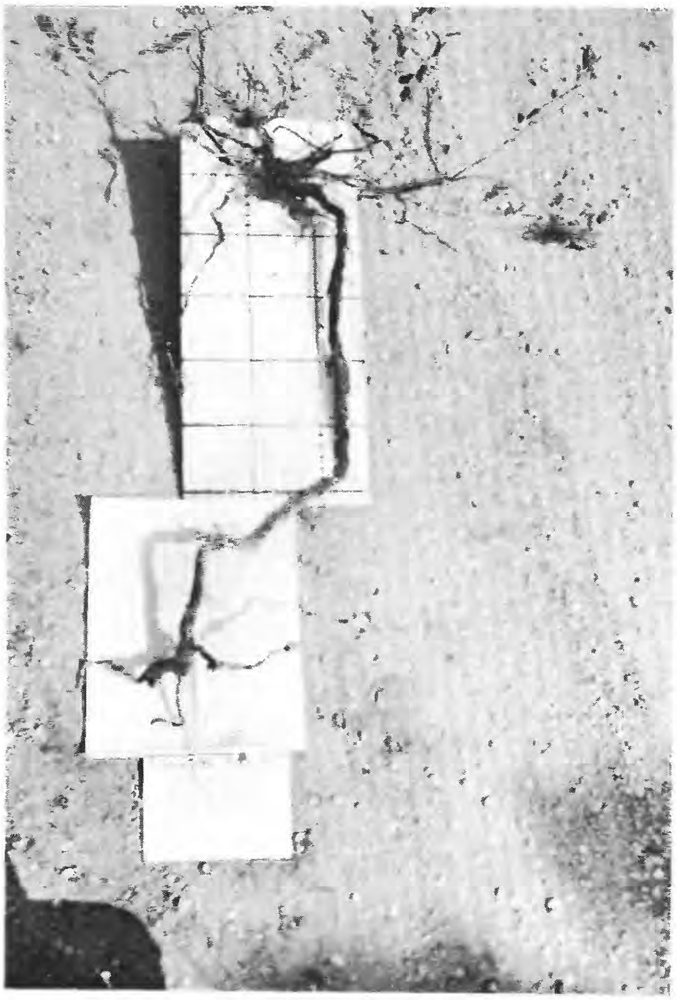

FIGURE 9.—Root of *Lyonia mariana* that extended 58 inches to the water table where the root was broken during excavation.

The rhizomes of all the other species studied are smooth, but those of *Lyonia mariana* have small, spirally arranged woody projections along their entire length. Examination of transverse sections of the rhizome revealed that these projections are broad parenchyma rays that are continuous with the pith. They probably originated as auxiliary buds and were continued by the cambium as the rhizome increased in diameter.

GAYLUSSACIA FRONDOSA (DANGLEBERRY)

Dangleberry is abundant in the cedar swamp, hardwood swamp, pine lowland, and pine transition communities and is common but scattered in the upland communities. Two or more aerial stems arise from an extensive branched rhizome system. The stems may be closely spaced on the rhizome, but they usually are 2–6 feet apart. The rhizome ranges from 1/8 to 3/8 inch in diameter and may be entirely in the A_0 horizon or partly in this horizon and partly in the top 2 inches of the A_1 horizon. The rhizome may be completely devoid of small roots or it may have a few small short roots scattered or in patches on the rhizome. On some shrubs a root as much as 48 inches long originates near the base of an aerial stem or near the fork of a rhizome, but generally the roots are less than 9 inches long. All roots occur in the same level as the rhizome.

MYRICA PENSYLVANICA (BAYBERRY)

Bayberry is rare and is found mainly in the pine transition community, but some isolated plants are found in upland areas. One or more aerial stems arise from a rhizome which is 3/16–1/2 inch in diameter. The shrub usually occurs where an A_0 horizon has formed, and the rhizomes may be completely in it or partly in it and partly in the top half inch of the A_1 horizon. A few short roots grow along the rhizome, and longer roots, as much as 12 inches in length, are occasionally found. Some roots extend as deep as 20 inches in the pine transition community and as deep as 24–30 inches in the upland communities. A nodular swelling was found on one root system.

ILEX GLABRA (INKBERRY)

Inkberry is rare to common in all the lowland communities and in the pine transition community but is very rare in the upland communities. Several aerial stems arise singly or in groups from a rhizome that ranges in diameter from 3/16 to 1/2 inch. The rhizome grows in the A_0 horizon or the upper 2 inches of the A_1 horizon. A few small fibrous or woody roots occur along the entire rhizome. Larger roots, as much as 48 inches long, occur at infrequent intervals and may extend to the water table if it is near the surface.

ROOTS AND RHIZOMES OF LESS COMMON SHRUBS

KALMIA LATIFOLIA (MOUNTAIN-LAUREL)

Clumps of mountains-laurel are scattered throughout the cedar swamp, pine transition, and upland communities. Many aerial stems come from an irregularly shaped knobby solid rootstock 10 inches or more in its largest dimension and several inches thick (fig. 10), and many small fibrous roots occur at the base of each aerial stem. Larger roots grow from the sides and bottom of the rootstock and extend either vertically or obliquely downward from a few inches to more than 30 inches deep. The size of the roots at the junction with the rootstock ranges from 1/16 to 2 inches, but the roots are extremely brittle and it is almost impossible to trace them to their end. In very old plants the central rootstock may be rotted apart and separated into various groups of aerial stems connected to one or more roots. This species is probably less abundant in the area now than in the past because plants have been removed for ornamentals and the rootstocks have been dug to make tobacco pipes (McCormick, 1955).

FIGURE 10.—Rootstock and larger roots of *Kalmia latifolia.*

HUDSONIA ERICOIDES (GOLDEN HEATHER) AND LEIOPHYLLUM BUXIFOLIUM (SAND MYRTLE)

Hudsonia ericoides is a small shrub which is rare in most of the upland communities but is abundant along roads and in clearings. *Leiophyllum buxifolium* is a small prostrate shrub that occurs mainly in the pine transition community. The low bushy aerial parts of these plants arise from a single group of roots. One small woody root commonly extends about 6 inches deep, and a group of fibrous roots originates just below ground level and extends obliquely downward 1–4 inches (fig. 11). The only evidence of a root graft in the species studied was found in *H. ericoides.* Two branches of a woody root of one plant had grown around and apparently fused with the woody root of another plant.

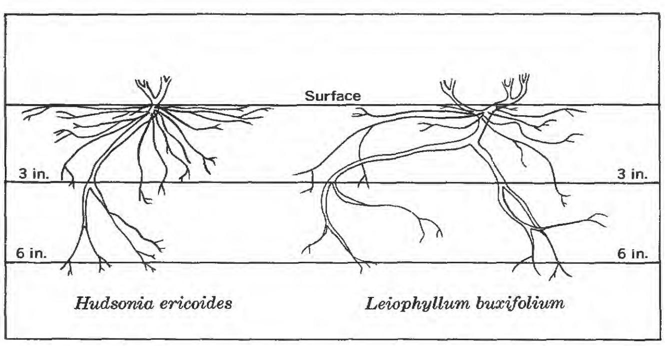

FIGURE 11.—Diagram of root system of *Hudsonia ericoides* and *Leiophyllum buxifolium.*

Harshberger (1916) stated that both these species had rhizomes; however, numerous plants of both species were excavated and no evidence of a rhizome was found.

LYONIA LIGUSTRINA (MALEBERRY)

Maleberry is common in the hardwood swamp, pine transition, and pine lowland communities but very rare in the upland communities. The description given for the root and rhizome system of *Gaylussacia frondosa* (p. C9) applies to this species except that the aerial stems of *Lyonia ligustrina* may be as much as 13 feet apart on the rhizome (fig. 12).

FIGURE 12.—Part of a very extensive system of *Lyonia ligustrina.* The grid on the board is 6 inches.

COMPTONIA PEREGRINA VAR. ASPLENIFOLIA (SWEET FERN)

Sweet fern is rare in the upland communities, the pine transition community, and the pine lowland community but is common in disturbed areas such as gravel pits. An irregularly branched rhizome, 1/4–3/4 inch in diameter, gives rise to one or more aerial stems that are usually 2–12 inches apart. The rhizome generally occurs in the upper 2 inches of the A_1 horizon. A few small short sparsely branched roots are scattered along the rhizome, and a few longer roots may extend as deep as 10 inches.

VACCINIUM ANGUSTIFOLIUM (LOW SWEET BLUEBERRY)

Low sweet blueberry does not grow in most areas on the watersheds in the Lebanon State Forest, but it may occur in some upland communities and in the pine lowland community. Two or more aerial stems arise from a thin rhizome 1/8–3/16 inch in diameter. The rhizome grows both in the A_0 horizon and the top inch of the A_1 horizon. Small short fibrous or woody roots as much as 6 inches long are scattered along the rhizome and grouped at the bases of aerial stems or near a fork in the rhizome. A few roots as much as 3 feet long and extending 3–5 inches deep are fairly common.

Hall (1957) found a distinct taproot in *Vaccinium angustifolium* var. *laevifolium* in Canada. In the Pine Barrens this type of deep-growing root was found in *V. vacillans* but not in *V. angustifolium.*

AMELANCHIER CANADENSIS (SERVICEBERRY) AND PYRUS MELANOCARPA (BLACK CHOKEBERRY)

Serviceberry and black chokeberry are rare, occurring mainly in the lowland communities or in the pine transition community. One to several aerial stems arise from a branching rhizome system in the A_0 horizon and the upper inch of the A_1 horizon. The rhizomes range from 3/16 to 3/4 inch in diameter in *Amelanchier canadensis* and are as much as 1/4 inch in diameter in *Pyrus melanocarpa.* A few small short fibrous or woody roots are scattered along the rhizome, and occasionally a longer root, as much as 15 inches long, arises near the fork in a rhizome and extends 3–4 inches deep.

UNDERGROUND RHIZOME GROWING TIPS

Underground rhizome growing tips are the nonwoody terminal parts of actively growing rhizomes. They were found on at least some plants of all the rhizomatous species studied. Root tips were not studied. The rhizome growing tips are usually white or yellowish-white and range from 1 to 4 inches in length and from 1/16 to 1/8 inch in diameter at the base. Spirally arranged scale leaves, which are the same color as the tip, are always present. The leader of the rhizome that terminates in the growing tip is the same diameter as the base of the tip and generally does not taper much between the junction with the rest of the rhizome and the base of the growing tip. The leader may be a few inches to several feet long and usually is lighter in color than the rest of the rhizome, especially near the growing tip. Scale leaves similar to the ones on the rhizome growing tip occur on the leader near the tip, but these leaves become less and less distinguishable as the distance from the tip increases.

One or two rhizome growing tips commonly occur on a rhizome branch that has previously terminated in an aerial stem. They arise from axillary buds just back of the point where the rhizome turns upward and in some species these tips may arise and grow entirely in the A_0 horizon. Trevett (1956) described in detail the process of rhizome elongation and origin of new aerial stems of *Vaccinium angustifolium* and related species.

Some rhizome growing tips turn upward and give rise to new stems. Numerous rhizome growing tips may arise from the same region of a rhizome but of these tips only one or two appear to be vigorous and evidently dominate the others. The underground rhizome growing tips of *Comptonia peregrina* var. *asplenifolia*, *Gaultheria procumbens*, and *Myrica pensylvanica* have the same aroma when crushed as the leaves, but the woody parts of the rhizomes have no aroma.

Underground growing tips commonly found in *Kalmia angustifolia* suggest that this shrub is capable of extending vegetatively into areas unoccupied by vegetation. However, *K. angustifolia* has not reinvaded the turf bald areas, which remain almost free of any shrubs. The reason for the absence of vegetation in these areas are not known.

SEEDLINGS

All small shrubs that appeared to be seedlings were carefully excavated. However, almost all small shrubs of the rhizomatous species were simply new aerial stems from a rhizome. One seedling of *Lyonia mariana* and one seedling of *Clethra alnifolia* were the only ones of rhizomatous species found. Numerous seedlings of *Qercus ilicifolia* were found in many areas and many were still attached to the acorn. Many small *Hudsonia ericoides* plants were found which presumably were of seedling origin. The ecological significance of the lack of seedling reproduction of most shrub species in the Pine Barrens is not known. Additional research is needed to determine if these species produce viable seed and, if they do, to determine why seedlings do not become established, particularly in areas made shrubless by burning or bare by removal of shrubs.

RELATION OF ROOT DISTRIBUTION TO DIFFERENT SOIL TYPES

SOIL PROFILES

The slopes and lowlands of the experimental watersheds are veneered with deposits of pale-yellow-orange sand, primarily remnants of the underlying Cohansey Sand, mixed with gravel from the Bridgeton-Pensauken complex which caps the tops of most of the divides. A small amount of Beacon Hill Gravel is present at the eastern end of McDonalds Branch watershed (Bacho, 1955). Most of the soils of the watersheds are derived from the Cohansey Sand, but the Downer sand (proposed name), leached phase, and the Lakeland sand, leached A_2 phase, which occupy the higher divides, are mainly derived from the Bridgeton-Pensauken complex (Markley, 1955).

In this report, soil profiles are described as they were observed in one soil pit for each soil type with the exception of the Lakewood and Leon sands. Descriptions of the soil horizons are based on field observations and are similar to those reported by Markley (1955). Terminology follows the U.S. Department of Agriculture Soil Survey Manual (1951). The percentage of each watershed covered by the various soil types was given by Markley (1955).

Certain characteristics are common to most of the soils, namely, a single grain structure, an abrupt boundary between horizons (transition zone less than 1 in.), and a smooth (nearly plane) topography of the boundaries between soil horizons. Descriptions of colors are quite general and are based on dry-field conditions. In most of the well-drained soils the B_2 horizon grades gradually into the C horizon, and the boundary is so diffused that there is no definite demarcation.

Four soil types to which Markley (1955) assigned only numbers in the original description are given names in this paper. The Lakewood sand, clay substratum variant, was originally referred to by Markley (1955) as soil type 9A16; the Downer sand (proposed name), leached phase, was referred to as soil type 9E16; the Lakeland sand, leached A_2 phase, was referred to as soil type 9Y16; and the Lakehurst sand, thick A_2 variant, was referred to as soil type 9526.

The Lakewood sand pine-shrub and Lakewood sand pine-shrubless sites are located on McDonalds Branch watershed, and the site in the Lakewood sand, clay substratum variant, is near an old clay pit just outside the watershed boundary near the McDonalds Branch gaging station. All other sites are on Middle Branch watershed.

Where it could be determined, the depth to the water table is included in the description of the soil profiles. Where no depth is indicated, the water table is well below the bottom of the soil pit (4 ft deep).

Because of the scanty spring and summer rainfall in 1957, the depth to the water table in some of the soils may be below average. The 1957 precipitation records from the network of rain gages in the Lebanon State Forest show only about 12.9 inches of rain from April through September, but the 1948–57 average of a nearby station for this period was 22.1 inches (E. C. Rhodehamel, written commun., 1958). Furthermore, in October 1957, water levels in shallow observation wells in Lebanon State Forest were 1–2 feet below the October 1956 levels (E. C. Rhodehamel, written commun., 1958).

Results of the mechanical analyses and permeability measurements for each horizon of the various soil types are given in table 1. Separate percentages of silt and clay are not reported for most horizons, and the combined clay-silt percentages appear to be unusually low for most of the soils. More than half of all horizons contain from 97 to 99.9 percent sand. Samples of Lakewood sand on the controlled-burned plots on the western end of Middle Branch watershed were analyzed by the Soils Department of Rutgers University. These samples contained 1.0–12.9 percent clay, 2.2–15.4 percent silt, and 73.0–96.6 percent sand (S. J. Toth, written commun., 1958). Although the soils are not necessarily comparable, the values for the Lakewood sand from the burned plots are consistently higher in silt and clay and lower in sand than the values shown in table 1 for the other soil samples.

The names of the plant communities at each site are based on the vegetation map prepared by McCormick (1955). The presence and abundance of the trees and shrubs immediately surrounding the soil pit is given in table 2.

LAKEWOOD SAND—9706

The well to excessively drained Lakewood sand, formed on coarse unconsolidated siliceous sand, is highly leached, rather acid, and has a low moisture-holding capacity and low nutrient status (Tedrow, 1952). It is the most common soil type on the watersheds, covering 25 percent of Middle Branch watershed and 45 percent of McDonalds Branch watershed. At the site studied the A_{00} horizon was 1 inch thick and the A_0 horizon was ¾ inch thick. The A_1 horizon extended from 0 to 2½ inches and was black to dark gray. The light-gray A_2 horizon extended from 2½ inches to 12½ inches. The irregular B_1 horizon had a strong-brown color and a very weak blocklike structure, and ranged in thickness from 0 to 1½ inches, the average being about ¼ inch. Extending downward from about 13 inches, the B_2 horizon was strong yellow at the top and with depth graded to darker yellow or yellow brown and showed no evidence of mottling. All horizons contained slightly more than 97.0 percent sand (table 1). An extremely small amount of gravel was present in all the horizons, but this soil type often contains much more gravel (Markley, 1955). The permeability ranged from 8.0 inches per hour in the B_1 horizon to 22.0 inches per hour in the B_2 horizon (table 1). The site chosen for study was in a chestnut-oak community, and the abundance of the trees and shrubs immediately surrounding the soil pit is given in table 2.

LAKEWOOD SAND, CLAY SUBSTRATUM VARIANT—9A16

The well-drained Lakewood sand, clay substratum variant, is developed from a sandy material underlain by a clay stratum which in turn is underlain by other sand beds (Markley, 1955). It is found only in one small area, covering less than 1 percent of the watershed, on the eastern end of McDonalds Branch watershed.

At the site studied, the A_{00} horizon ranged from ½ to 1 inch in thickness; the A_0 horizon had the same

TABLE 1.—*Mechanical analysis and permeability data of the soils studied*

Soil	Horizon	Analysis, in percent of—									Permeability (in. per hour)
		Clay	Silt	Total sand	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	All gravel	
Lakewood sand (oak site)	A_1	2.6		97.4	4.8	30.4	44.6	16.4	1.2	0.1	10.0
	A_2	2.0		98.0	5.8	32.1	43.2	15.3	1.6	.1	15.4
	B_1	3.0		97.0	5.9	32.8	41.3	15.1	1.9	.1	8.0
	B_2	.8		99.2	3.3	28.7	47.1	18.6	1.5	.1	22.0
Lakewood sand (pine-shrub and pine-shrubless site).	A_1	4.7		95.3	3.2	15.5	51.3	21.4	3.9	.6	15.4
	A_2	.1		99.9	1.3	11.0	49.8	30.5	7.3	1.3	20.0
	B_1	2.9		97.1	3.2	15.4	52.0	22.0	4.5	2.0	20.7
	B_2	2.4		97.6	2.1	14.7	52.1	20.8	7.9	9.6	53.4
Lakewood sand, clay substratum.	A_1	6.1		93.9	4.3	19.6	38.6	24.3	7.1	5.4	12.0
	A_2	8.8		91.2	4.5	19.2	35.3	23.1	9.1	11.8	24.0
	B_2[1]	10.0		90.0	4.2	17.0	32.9	24.4	11.5	19.1	----------
	B_2[2]	18.5		81.5	5.0	17.3	28.4	21.8	9.0	38.0	10.7
	D_1	66.6	28.8	4.6	.4	.2	1.6	1.4	1.0	0	.002
	D_2	9.0		91.0	1.7	8.5	49.7	25.2	5.9	.5	----------
Downer sand, leached phase	A_1	4.4		95.6	4.9	23.9	43.5	19.1	4.2	.4	46.8
	A_2	3.8		96.2	5.3	24.4	42.2	19.3	5.0	.3	42.8
	B_2[1]	3.2		96.8	4.1	24.4	45.5	18.0	4.8	3.1	42.8
	B_2[2]	6.7		93.3	4.4	14.5	20.5	21.9	32.0	70.3	41.4
	D_1	9.1		90.9	5.4	18.6	26.7	22.4	17.8	16.7	8.0
Lakeland sand, leached A_2 phase.	A_1	9.3		90.7	3.4	21.0	38.0	23.7	4.6	.3	8.0
	A_2	4.3		95.7	5.4	25.9	37.7	21.0	5.7	.6	7.3
	B_1	4.0		96.0	3.5	19.6	35.6	26.7	10.6	2.1	8.0
	B_2	3.8		96.2	6.0	30.3	40.0	15.8	4.1	2.4	10.7
Lakehurst sand	A_1	2.7		97.3	5.3	30.2	47.5	13.6	.7	0	12.0
	A_2	2.6		97.4	7.0	33.9	43.4	12.2	.9	.2	6.0
	B_1	2.9		97.1	5.4	30.2	46.2	14.1	1.2	0	12.0
	B_2	2.5		97.5	5.4	32.1	45.2	13.7	1.1	.1	17.4
Lakehurst sand, thick A_2 variant.	A_1	2.5		97.5	.3	7.6	43.4	39.9	6.3	.5	24.0
	A_2	.7		99.3	1.1	15.4	48.1	29.4	5.3	4.0	28.1
	B_1	2.3		97.7	1.7	17.6	46.4	25.9	6.1	9.0	12.0
	B_2	2.7		97.3	.8	19.8	47.4	25.0	4.3	10.5	18.0
Leon sand	A_1	2.0		98.0	4.1	15.0	60.9	16.9	1.1	0	23.4
	A_2	2.4		97.6	5.7	35.2	44.5	11.1	1.1	0	17.4
	B_1	4.7		95.3	5.5	31.7	42.4	13.2	2.5	.5	4.5
	B_2	1.7		98.3	3.2	28.5	44.7	16.9	5.0	1.6	36.4
Leon sand (turf bald site)	A_1	2.5		97.5	1.9	17.0	49.7	27.3	1.6	.2	16.8
	A_2	1.4		98.6	3.1	20.6	43.7	25.7	5.5	1.1	30.7
	B_1	1.3		98.7	.6	17.2	51.5	23.9	5.5	1.0	4.0
	B_2	1.0		99.0	.3	10.3	47.9	33.0	7.5	4.4	34.8

[1] Top of sample.
[2] Bottom of sample.

TABLE 2.—*Presence and abundance of trees and shrubs immediately surrounding the soil pit in each soil type*

[VA, very abundant; A, abundant; C, common; S, scarce; R, rare; 0, absent]

Plant	Well drained soils						Imperfectly drained soils		Poorly drained soils	
	1	2	3	4	5	6	7	8	9	10
Trees:										
Pinus rigida	C	A	A	C	A	A	C	C	A	C
Quercus velutina	C	C	S	C	0	0	C	0	0	0
Q. marilandica	0	0	S	0	S	S	0	S	0	0
Q. prinus	A	0	0	A	0	0	A	0	0	0
Q. stellata	0	S	S	0	0	0	0	0	0	0
Pinus echinata	0	0	S	S	0	0	0	0	0	0
Q. alba	0	0	R	0	0	0	0	0	0	0
Acer rubrum var. *trilobum*	0	0	0	0	0	0	0	0	R	0
Shrubs:										
Vaccinium vacillans	A	A	A	C	A	0	A	A	0	0
Gaylussacia baccata	C	A	A	A	A	0	A	A	0	0
G. frondosa	S	C	S	A	0	0	A	C	A	0
Q. ilicifolia	0	C	C	S	0	0	S	S	0	0
Kalmia angustifolia	0	S	0	0	0	0	0	R	VA	0
Clethra alnifolia	0	0	0	0	0	0	S	C	C	0
Lyonia mariana	0	S	0	0	0	0	0	0	S	0
Gaultheria procumbens	C	C	0	0	0	0	0	0	0	0
Myrica pensylvanica	0	0	0	0	0	0	0	0	C	0
Ilex glabra	0	S	0	0	0	0	0	0	0	0
Comptonia peregrina var. *asplenifolia*	0	R	0	0	0	0	0	0	0	0

1. Lakewood sand (oak site).
2. Lakewood sand, clay substratum variant.
3. Downer sand, leached phase.
4. Lakeland sand, leached A_2 variant.
5. Lakewood sand (pine-shrub site).
6. Lakewood sand (pine-shrubless site).
7. Lakehurst sand.
8. Lakehurst sand, thick A_2 variant.
9. Leon sand.
10. Leon sand (turf bald site).

range, the average being ¾ inch. The A_1 horizon was black to very dark gray and extended from 0 to 2 inches, and the gray A_2 horizon extended from 2 to 8 inches. The B_1 soil horizon was not distinguishable. The B_2 horizon was distinguished from the A_2 horizon primarily by its strong-yellow color, and the horizon extended from 8 to 18 inches. A zone of sand, silt, clay, gravel, and irregular development of ironstone concretions marked the unconformity between the bottom of the B_2 horizon and the top of the clay layer (D_1 horizon). The light-yellow D_1 horizon contained 66.6 percent clay, 28.8 percent silt, and 4.6 percent sand (table 1), had a blocky or columnarlike structure, and extended from 18 to 42 inches. The clay layer is a feature of deposition, and the upper horizons of the profile did not develop from this material. An irregular formation of ironstone concretions was found at the boundary between the bottom of the clay layer and the top of the strong-yellow sandy layer (D_2 horizon). The A_1, A_2, top part of the B_2, and D_2 horizons contained 90.0 percent sand or more, and the bottom of the B_2 horizon contained 18.5 percent clay and silt and 81.5 percent sand (table 1).

The site studied was in a pine, black oak, and scrub oak community; the vegetation immediately surrounding the soil pit is listed in table 2. Several of the shrubs at this site—*Lyonia mariana*, *Kalmia angustifolia*, and *Ilex glabra*—are usually confined to areas where their roots can extend to the water table and very seldom occur in any abundance on upland sites. During the growing season in the New Jersey Pine Barrens, an average of 8–11 days per month have 0.01 inch or more precipitation (Martin and Corbin, undated). The relatively impervious clay stratum of this soil (permeability of 0.002 in. per hr as compared with 24.0 in. per hr in the A_2 horizon; see table 1) probably retards the percolation of water from these frequent rains and may improve the water conditions above the clay layer enough to make conditions favorable for these shrubs.

DOWNER SAND, LEACHED PHASE—9E16

The well-drained Downer sand, leached phase, differs from the Lakewood sand in that it has a sandy-loam or a loamy-sand subsoil and a rather thin A_2 horizon. It covers 10 percent of the area of both watersheds. At the site studied the A_{00} horizon was ½–1 inch thick, and the A_0 horizon ranged from ½ to 1½ inches in thickness, the average being ¾ inch. The A_1 horizon was black to very dark gray and extended from 0 to 2½ inches, and the gray A_2 horizon extended from 2½ to 7 inches. No B_1 horizon could be distinguished. The B_2 horizon extended from 7 to 38 inches and was distinguished from the A_2 horizon primarily by its strong-yellow color. Much gravel mixed with the sand (70.3 percent by weight; see table 1) was found from 23 inches to the bottom of the B_2 horizon. Below the B_2 horizon, the strong-yellow D_1 horizon had a slightly blocklike structure. The permeability of the D_1 horizon (8.0 in. per hr) was much lower than the permeability in any other horizon (table 1). Markley (1955) found the D_1 horizon nearer the surface than the horizon encountered here; Markley's D_1 horizon also was underlain by loose sand, but a lower sand layer was not present down to 4 feet at this site. The site chosen for study was in an oak-pine community; the trees and shrubs immediately surrounding the soil pit are listed in table 2.

LAKELAND SAND, LEACHED A_2 PHASE—9Y16

The well-drained Lakeland sand, leached A_2 phase, has an extremely shallow leached horizon and covers 8 percent of the area of Middle Branch watershed and 6 percent of the area of McDonalds Branch watershed. At the site studied the A_{00} horizon ranged in thickness from 1 to 1½ inches, and the A_0 horizon was 1 inch thick. The A_1 horizon was black to very dark gray and extended from 0 to 2 inches, and the gray A_2 horizon extended from 2 to 5 inches. The irregular B_1 horizon had a strong-brown color and a very weak blocklike structure; it ranged in thickness from ½ to 2½ inches, the average being 1 inch. Extending downward from 6 inches, the B_2 horizon was strong yellow at the top and graded to light yellow brown with depth. According to Markley (1955), gravel is more common in Lakeland sand than in Lakewood sand, but little gravel was present at this site. All horizons contained more than 90 percent sand, and permeability values ranged from 7.3 inches per hour in the A_2 horizon to 10.7 inches per hour in the B_2 horizon (table 1). The site studied was in an oak-pine community, and the trees and shrubs immediately surrounding the soil pit are listed in table 2.

LAKEHURST SAND—9726

The Lakehurst sand is well drained at the surface but is imperfectly drained in the subsoil. It occurs where the water table is within 4–10 feet of the surface, and it covers 32 percent of Middle Branch watershed and 20 percent of McDonalds Branch watershed (Markley, 1955). At the site studied the A_{00} horizon ranged from ½ to ¾ inch in thickness, and the A_0 horizon was ½ inch thick. The A_1 horizon was black to very dark gray and was 2½ inches deep. The light-gray A_2 horizon extended from 2½ to 12 inches. The discontinuous B_1 horizon had a dark-brown color and very weak blocklike structure; it ranged in thickness from 0 to 1¼ inches, the average being ½ inch. Extending downward from 12½ inches, the B_2 horizon was a strong yellow at the top and became light yellow with depth. Indistinct mottling was found at 48–50 inches, and gravel was also present, mixed with sand at this depth. All the horizons contained more than 97 percent sand, and permeability values ranged from 6.0 inches per hour in the A_2 horizon to 17.4 inches per hour in the B_2 horizon (table 1). The site chosen for study was in an oak-pine community; the trees and shrubs immediately surrounding the soil pit are listed in table 2.

LAKEHURST SAND, THICK A_2 VARIANT (GRADING TOWARD LEON SAND)

The deeply leached Lakehurst sand, thick A_2 variant, is intermediate between Lakehurst sand and Leon sand in natural-drainage characteristics and occupies sites where the depth to the water table is usually no more than 3 to 4 feet (Markley, 1955). This soil covers 5 percent of Middle Branch watershed and less than 1 percent of McDonalds Branch watershed. At the site studied the A_{00} and A_0 horizons were less than ¼ inch thick. The A_1 horizon was very dark gray to black and extended from 0 to 2½ inches. The A_2 horizon was light-gray to white sand and extended from 2½ to 31 inches. The strong-brown B_1 horizon had a weak blocklike structure and ranged in thickness from 1 to 7 inches, the average being slightly less than 3 inches. The light-yellow B_2 horizon extended downward from 34 inches. At the time of the fieldwork (July, 1957), the water table was about 50 inches below the surface, but it would have been less during a summer that was not so extremely dry. All horizons contained more than 97 percent sand (table 1), and some gravel extended downward from 16 inches. Permeability values ranged from 12.0 inches per hour in the B_1 horizon to 24.0 inches per hour in the A_1 horizon (table 1). The site chosen for study was in a pine transition community, and the trees and shrubs immediately surrounding the soil pit are listed in table 2.

LEON SAND—9736

The Leon sand is developed where the water table is 1–2 feet below the surface during the winter and as much as 5 feet below during the summer. It covers 12 percent of Middle Branch watershed and 2 percent of McDonalds Branch watershed (Markley, 1955). At the site studied the A_{00} horizon ranged in thickness from 1 to 5 inches, and the A_0 horizon was 1 inch thick. The A_1 horizon was black to very dark gray and extended from 0 to 3 inches. The A_2 horizon was very light gray and extended from 3 to 21 inches. The strong-brown B_1 horizon had a weak blocklike structure and ranged from 1½ to 6 inches in thickness, the average thickness being 3 inches. Extending downward from 24 inches, the B_2 horizon had a strong-yellow color with depth. All horizons contained more than 95 percent sand, and permeability values ranged from 4.5 inches per hour in the B_1 horizon to 36.4 inches per hour in the B_2 horizon (table 1). The site chosen was in a pine transition community. *Pinus rigida* was the only tree species present, but roots extended into the pit from a red maple (*Acer rubrum* var. *trilobum*) about 30 feet away in an adjoining hardwood swamp. A dense cover of *Kalmia angustifolia* and other shrubs also were present (table 2).

ADDITIONAL SITES: LAKEWOOD SAND—9706

Two other sites in Lakewood sand—one supporting pine with shrubs and the other pine with no shrubs—were studied to contrast the distribution of roots in the same soil at sites having different types of vegetation. The two sites were about 60 feet apart in a pine and blackjack oak community. The Lakewood sand pine-shrub site had a good shrub cover of *Vaccinium vacillans* and *Gaylussacia baccata*, but the Lakewood sand pine-shrubless site had no shrubs within 20 feet of the pit (table 2). The pine-shrubless site had a scattered cover of *Carex pensylvanica*, but the fibrous roots and rhizomes of this species were not included in the study. Several acres in this vicinity have little or no shrub cover, a condition which may have been caused by Indian activities when this locale was used as a semipermanent camp (McCormick, 1955). The root distribution at these two sites was compared with the distribution at the Lakewood sand oak site (p. C12).

The Lakewood sand pine-shrubless site had no A_{00} or A_0 horizons, but these horizons were each about ½ inch thick at the Lakewood sand pine-shrub site. At both sites the A_1 horizon was black to very dark gray and extended from 0 to 2½ inches. The light-gray A_2 horizon extended from 2½ to 14 inches, but irregular tongues extended into the B_1 and B_2 horizons as deep as 25 inches. The irregular B_1 horizon was strong brown, was slightly blocklike in structure, and ranged from 0 to 2 inches in thickness, the average thickness being less than ½ inch. Extending downward from 14½ inches, the B_2 horizon was strong-yellow at the top but darkened slightly with depth. Because the two sites were so close together, soil samples were taken from the Lakewood sand pine-shrubless site only. All horizons contained more than 95 percent sand, and some gravel was mixed with the sand below 16 inches at both sites (table 1). Permeability values ranged from 15.4 inches per hour in the A_1 horizon to 22 inches per hour in the B_2 horizon (table 1).

ADDITIONAL SITE: LEON SAND—9736

An additionnal Leon sand site in a turf bald in a pine transition community was chosen, and the root distribution was compared with the distribution in the Leon sand in a pine transition community (p. C15). The tree cover at the turf bald site consisted only of *Pinus rigida* and there were no shrubs (table 2). There was a scattered cover of *Carex pensylvanica*, but its root distribution was not studied. The A_{00} and A_0 horizons were absent, and the A_1 horizon extended from 0 to 2½ inches. The A_2 horizon was thicker than at the other Leon sand site, extending from 2½ inches to 25 inches. The descriptions and dimensions of the B_1 and B_2 horizons at the Leon sand site (see p. C15) apply to this site also. At the time of the fieldwork (August 1957), the water table was 36 inches below the surface. All soil horizons contained more than 97 percent sand, and there was a small amount of gravel below 30 inches (table 1). The permeability values ranged from 4.0 inches per hour in the B_1 horizon to 34.8 inches per hour in the B_2 horizon (table 1).

DEVELOPMENT OF ROOTS

NUMBER AND AREA OF ROOTS IN THE PROFILE

The total numbers of roots in the profile of the seven soil types having comparable vegetation are shown in table 3. An analysis of variance indicated that there was a significant difference in numbers of roots among the sites studied (table 4). The Lakeland sand; the Lakewood sand, clay substratum variant; the Lakehurst sand; and the Downer sand have the greatest number of roots per square foot in the entire profile. Duncan's multiple range test (1955) indicated that the total numbers of roots in these four soils were not significantly different at the 5-percent level (table 5). However, the total numbers of roots in these soils were significantly greater than the numbers in the Lakewood sand (oak site) and the Lakehurst sand, thick A_2 variant.

TABLE 3.—*Actual number of roots and number and total cross-sectional area of roots per square foot of vertical profile in each horizon and in the entire profile*

[Area per square foot given in square inches]

Soil type	Root unit	Horizon						Total and average, entire profile
		A_0	A_1	A_2	B_1	Top 1 ft of B_2	Rest of B_2	
Sites having comparable vegetation								
Lakewood sand (oak site)	Actual No.	233	585	428	25	534	291	2,096
	No. per sq ft	311	225	42	83	45	13	43
	Area per sq ft	1.68	1.48	0.16	0.20	0.28	0.04	0.23
Lakewood sand, clay substratum variant	Actual No.	335	528	498	B_1 absent	708	[1] 1,307	3,377
	No. per sq ft	399	176	100		69	54	69
	Area per sq ft	1.25	1.68	0.59		0.33	0.22	0.36
Downer sand, leached phase	Actual No.	356	526	360	B_1 absent	947	[2] 682	3,045
	No. per sq ft	494	189	88		79	35	63
	Area per sq ft	1.48	0.82	0.91		0.74	0.09	0.38
Lakeland sand, leached A_2 phase	Actual No.	614	439	268	220	927	1,096	3,564
	No. per sq ft	614	222	99	234	77	36	73
	Area per sq ft	3.11	1.94	0.56	0.75	0.47	0.15	0.40
Lakehurst sand	Actual No.	529	495	504	66	792	752	3,138
	No. per sq ft	1,058	193	53	118	66	32	65
	Area per sq ft	3.15	1.73	0.69	0.53	0.30	0.20	0.44
Lakehurst sand, thick, A_2 variant	Actual No.	----------	650	962	40	22	2	1,676
	No. per sq ft	----------	243	35	14	2	1	35
	Area per sq ft	----------	0.95	0.07	0.04	0.003	0.0003	0.10
Leon sand	Actual No.	592	723	522	98	100	----------	2,035
	No. per sq ft	592	228	28	34	9	----------	55
	Area per sq ft	5.09	2.02	0.24	0.23	0.09	----------	0.48
Sites having different vegetation								
Lakewood sand (pine-shrub site)	Actual No.	193	438	430	27	438	165	1,691
	No. per sq ft	508	183	44	117	36	7	35
	Area per sq ft	3.14	1.53	0.23	0.17	0.19	0.02	0.21
Lakewood sand (pine-shrubless site)	Actual No.	----------	228	181	19	305	112	845
	No. per sq ft	----------	107	14	53	25	5	18
	Area per sq ft	----------	0.29	0.16	0.53	0.08	0.01	0.09
Leon sand (turf bald site)	Actual No.	----------	340	422	8	19	----------	789
	No. per sq ft	----------	134	19	4	2	----------	22
	Area per sq ft	----------	0.24	0.03	0.005	0.01	----------	0.04

[1] Data given are for D_1 horizon. Data for D_2 horizon, below the D_1 horizon are:
Actual No. 1
No. per sq ft 1
Area per sq ft 0.003

Data for D_1 horizon below B_2:
Actual No. 174
No. per sq ft 18
Area per sq ft 0.07

TABLE 4.—*Analysis-of-variance computations for determining differences between the number of roots per square foot in the entire profile among the various soil types*

	Sum of squares	Degrees of freedom	Mean square
Total	5,610	27	
Between soils	4,699	6	783.2
Within soils (error)	911	21	43.4

Calculation:
$F=783.2 \div 43.4=18.1$.
Needed F (5-percent probability) =2.6.

When the cross-sectional area of roots is considered, the relative rank of the various soil types is somewhat different (table 3). The Leon sand, which is fifth in the number of roots, has the greatest area of roots per square foot in the profile. However, differences among the various soil types lack significance at the 5-percent level (table 5). The two soils with the smallest root area—the Lakewood sand (oak site) and the Lakehurst sand, thick A_2 variant—also have the smallest number of roots.

TABLE 5.—*Results of multiple-range test comparing the average number of roots in the entire profile and in each horizon and the average area of roots in the entire profile among the seven soils having comparable vegetation*

[Averages followed by common letters are not significantly different at the 5-percent level, as determined by Duncan's multiple-range test (1955); for example, the average number of roots per sq ft in the entire profile of the Lakeland sand, leached A_2 phase, is not significantly different at the 5-percent level from the average number in the Downer sand]

Soil	Average number of roots per square foot				Average area of roots (sq in) per sq ft entire profile
	Entire profile	A_1 horizon [1]	A_2 horizon	Total B horizon	
Lakeland sand, leached A_2 phase	73 a	222	99 d	52 f	0.40 g
Lakewood sand, clay substratum variant	69 a	176	100 d	51 f	.36 h
Lakehurst sand	65 a b	193	53 e	45 f	.44 g
Downer sand	63 a b	189	88 d	44 f	.38 g h
Leon sand	55 b	228	28 e	14	.48 g
Lakewood sand (oak site)	43 c	225	42 e	24	.23 h i
Lakehurst sand, thick A_2 variant	35 c	243	35 e	3	.10 i

[1] For the A_1 horizon, the F test in the analysis of variance was not significant at the 5-percent level, so there is no significant difference in number of roots in this horizon among the 7 soils.

The relation of the number of roots to the area of the roots in the profiles for all soil types and sites is shown in figure 13.

NUMBER AND AREA OF ROOTS IN THE VARIOUS HORIZONS

The number and area of roots per square foot in each horizon in the various soils studied are given in table 3. General relations of root distribution in the various horizons are discussed in the following sections.

A_0 HORIZON

Where it is present, the A_0 horizon contains the highest number of roots per square foot of any horizon. This organic layer evidently offers rather good conditions for the development of roots and rhizomes. Various authors have observed a similar concentration of roots in organic soil layers in other areas. Waterman (1919) found that the roots of shrub species growing on dunes in Michigan were largely confined to the leafmold layer on the surface of the sandy soil or to pockets of buried organic matter. Proportionately more roots, especially finer ones, often occur in the organic layer of podzol soils than in other horizons (Swetloff, 1931), and roots from lower horizons occasionally extend upward into this organic layer (Partridge and Veatch, 1932). Partridge and Veatch (1931), Beckenbach and Gourley (1933), and Oosting and Reed (1952) have reported a larger number of roots of various species concentrated in a humus layer or A_0 horizon.

A_1 HORIZON

The A_1 horizon is second only to the A_0 horizon in number and area of roots per square foot except in the Lakeland sand in which the B_1 horizon contains the second highest number of roots. Where no A_0 horizon is present, the A_1 horizon contains the highest number and area of roots. At all sites, the A_1 horizon probably is the most uniform with respect to texture (table 1), organic matter content, and thickness. The lack of statistical significance between the mean number of roots per square foot in this horizon among the various sites (table 5) is further evidence of this uniformity. Coile (1937) and Scully (1942) found that the A_1 horizon contained the highest number of roots per square foot in various forest types. According to Specht and Ratson (1957), many heath plants in Australia have much of their root systems in the A_1 horizon. Other authors have reported concentration of tree roots in the A horizon (Korstian and Coile, 1938; Partridge and Veatch, 1932; and Hopkins and Donahue, 1939).

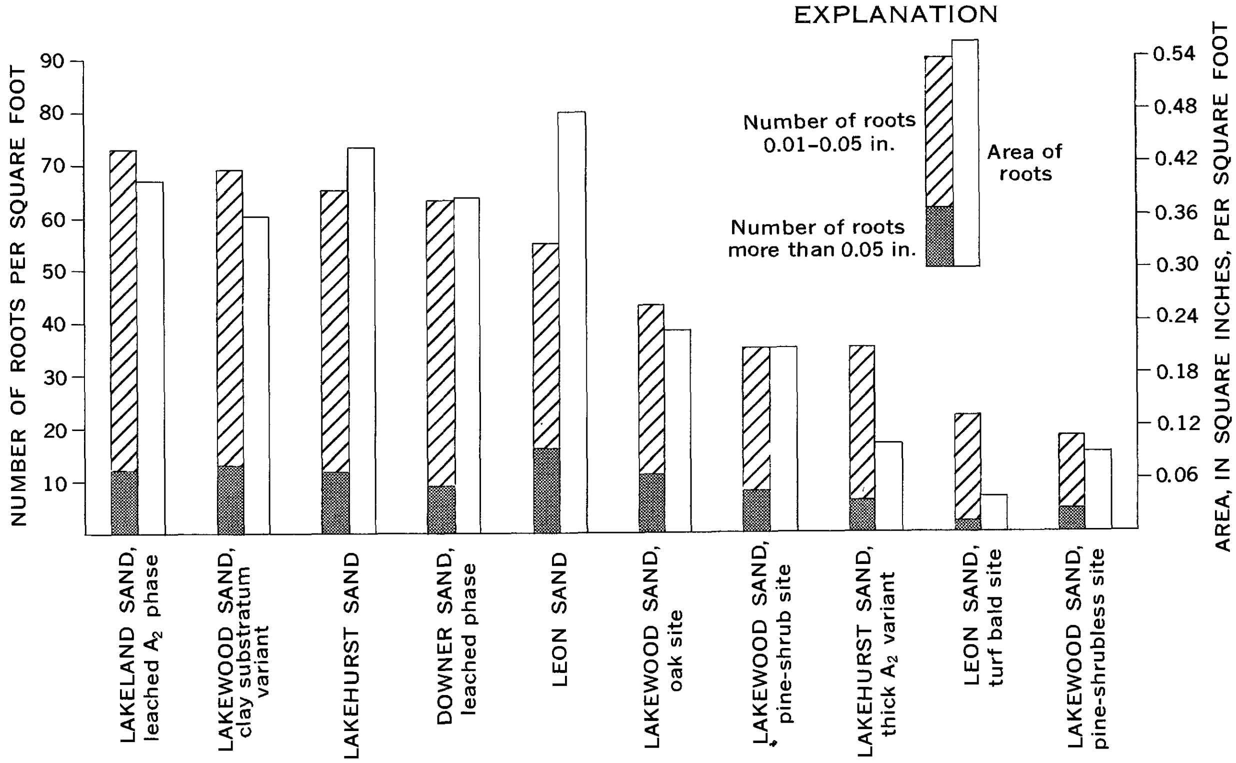

FIGURE 13.—Relation of the number of roots to the area of the roots per square foot in profiles for different soil types.

The percentage of the total number of roots found in the A_0 and A_1 horizon ranges from 25 percent in the Lakewood sand, clay substratum variant, to 65 percent in Leon sand (table 6). The percentages of total root area in these horizons vary more than the numbers, ranging from 15 percent in the Lakewood sand (pine-shrubless site) to 65 percent in the Leon sand. The following conditions in the upper part of the soil have been proposed to explain this concentration of roots: better moisture, nutrient, and aeration conditions (Lunt, 1934; Stephenson and Schuster, 1937); higher content of fine soil particles and organic matter (Lutz and others, 1937); better structure (Lutz and others, 1937); and better temperature conditions (Swetloff, 1931; Woods, 1957).

TABLE 6.—*Relation of roots in A_0 and A_1 horizons to total roots in entire profile, in percent*

Soil	Number of roots	Area of roots
Sites having comparable vegetation		
Lakewood sand (oak site)	39	45
Lakewood sand, clay substratum variant	25	34
Downer sand	29	18
Lakeland sand, leached A_2 phase	30	31
Lakehurst sand	33	28
Lakehurst sand, thick A_2 variant	39	[1] 56
Leon sand	65	65
Sites having different vegetation		
Lakewood sand (pine-shrub site)	37	49
Lakewood sand (pine-shrubless site)	27	[1] 15
Leon sand (tuft bald site)	43	[1] 41

[1] No A_0 horizon.

A_2 HORIZON

The number of roots per square foot decreases sharply from the A_1 to the A_2 soil horizon. The area of roots also decreases in all soils but the Downer sand, but the decrease in area is smaller than the decrease in numbers. The leached condition and lack of nutrients in the A_2 horizon probably is the main factor in limiting number of roots found there. The three soils with thin or imperfectly leached A_2 horizons—the Lakewood sand, clay substratum variant; the Lakeland sand; and the Downer sand—have significantly more roots per square foot in this horizon than any of the other soils (table 5). The higher number of roots in the poorly developed A_2 horizon probably is one reason why these three soils are among the top four in number of roots in the entire profile.

B_1 HORIZON

In the Lakehurst sand and all the upland soils, the number of roots per square foot in the B_1 horizon is at least double the number in the A_2 horizon. This increase of roots in the B_1 horizon was noted by Tedrow (1952), who attributed it to a higher concentration of available nutrients there. Minerals, organic matter, and clay are leached from the upper horizons and accumulate in the B_1 horizon. This accumulation results in better root development in the B_1 than in the A_2 or B_2 horizons, at least in the upland soils. The number of roots per square foot in the B_1 horizon does not increase in the imperfectly or poorly drained soils studied, except for a small increase in the Leon sand. The B_1 horizon is much thicker and better developed in these soils than in the well-drained soils, but it is also deeper and very near the water table. Poor aeration because of this proximity to water in the soil probably causes the poor root development in the B_1 horizons of these soils.

The longer roots of many of the species of shrubs studied are not necessarily confined to any one soil horizon. However, these roots may show differences in shape or in amount of branching in the B_1 horizon. Roots of shrubs within the thick B_1 horizon of the Leon sand are often twisted and may extend horizontally several inches before entering the top of the B_2 soil horizon. Some roots begin to branch profusely at the point of entry into the B_1 soil horizon (see the root of *Kalmia angustifolia*, fig. 6). The B_1 horizon of upland soils is not as thick as that of the Leon sand, but it also may affect root development. The two horizontal branches of the root of *Vaccinium vacillans* shown in figure 3 were largely confined to the B_1 horizon of the Lakewood sand.

B_2 AND OTHER LOWER HORIZONS

In the upland soil types, the top 1 foot of the B_2 horizon generally contains about as many roots per square foot as the A_2 horizon (table 3). The number of roots decreases sharply from the top foot to the remainder of the B_2 horizon. For the sites with comparable vegetation, the two soils with the shallowest water table—the Leon sand and the Lakehurst sand, thick A_2 variant—have the fewest roots in this horizon, evidently because of the poor aeration in the B horizon. The three soils with the thin A_2 horizons are among the soils having the most roots in the B horizon.

Progressive downward decreases in the number of roots in the B horizon evidently is a characteristic of most soils. This phenomenon has been reported by Swetloff (1931), Yeager (1935), Coile (1937), Garin (1942), and others.

DISTRIBUTION OF ROOTS IN DIFFERENT VEGETATION TYPES

The Lakewood sand pine-shrubless site contains significantly smaller numbers and areas of roots in every horizon than the other two Lakewood sand sites (table 7). The Lakewood sand oak site contains more roots in the A_1 horizon, B horizon, and the entire profile than the Lakewood sand pine-shrub site, but the difference in the area of roots in the profile and number of roots in the A_2 horizon is not significant between these sites.

The Leon sand site with a good shrub cover has a significantly greater number and area of roots in the entire profile and in every horizon than does the Leon sand turf bald site with no shrubs.

TABLE 7.—*Results of multiple-range test comparing the average number of roots in the entire profile and in each horizon and the average area of roots in the entire profile among the three Lakewood sand sites supporting different vegetation*

[Averages followed by common letters are not significantly different at the 5-percent level, as determined by Duncan's multiple-range test (1955); for example, the average number of roots per sq ft in the A_2 horizon at the oak site is not significantly different at the 5-percent level from the average number at the pine-shrub site]

Lakewood sand site	Average number of roots per square foot				Average area of roots (sq in) per sq ft, entire profile
	Entire profile [1]	A_1 horizon [1]	A_2 horizon	Total B horizon [1]	
Oak	43	225	42 a	24	0.23 b
Pine shrub	35	183	44 a	17	.21 b
Pine shrubless	18	107	14	13	.09

[1] All differences are significant for the entire profile, A_1 horizon, and B horizon.

DISTRIBUTION OF ROOTS IN 6-INCH LAYERS

The actual numbers of roots in the various 6-inch layers show the distribution of roots within thick horizons more clearly than the number of roots per square foot in the horizon as a whole. However, the data for the 6-inch layers encompassing rather thin horizons, such as the A_1 horizon at most sites, differ only slightly from the data for the total horizon. As indicated previously, the A_0 horizon contains the highest number of roots per square foot, where it is present. The top 6 inches of the mineral soil contains the next highest number (table 8). A further decrease in the number of roots from the top 6-inch layer to the second 6-inch layer occurs in all soil types, reflecting the drop in the number of roots from the A_1 to the A_2 horizon. The smallest decreases from the top 6-inch layer to the second 6-inch layer occur in the three soils with the very thin A_2 horizons—the Lakewood sand, clay substratum variant; the Downer sand; and the Lakeland sand. Comparisons of the cross-sectional area of roots in each 6-inch layer show the same relationships as the number of roots in these layers and are not presented here.

TABLE 8.—*Total number of roots and number of roots per square foot in each 6-inch layer of the soil profiles*

Soil type	Unit	A_0 horizon	6-inch layer							
			0–6	6–12	12–18	18–24	24–30	30–36	36–42	42–48
Lakewood sand (oak site)	No.	233	829	182	271	269	152	69	68	23
	No. per sq ft	311	138	30	45	45	25	12	11	4
Lakewood sand, clay substratum variant.	No.	335	830	544	386	404	404	271	186	17
	No. per sq ft	399	138	91	64	67	67	45	31	3
Downer sand	No.	356	816	525	445	320	241	123	130	89
	No. per sq ft	494	136	88	74	53	40	21	22	15
Lakeland sand, leached A_2 phase	No.	614	907	511	454	346	328	279	89	36
	No. per sq ft	614	151	85	76	58	54	47	15	6
Lakehurst sand	No.	529	714	286	413	419	310	229	139	99
	No. per sq ft	1,058	119	49	69	70	52	38	23	17
Lakehurst sand, thick A_2 variant	No.	----------	934	302	200	137	58	31	12	2
	No. per sq ft	----------	156	50	33	23	10	5	2	1
Leon sand	No.	592	930	223	70	91	67	62	----------	----------
	No. per sq ft	592	155	37	12	15	11	10	----------	----------
Lakewood sand (pine shrub site)	No.	193	720	154	228	221	106	39	23	7
	No. per sq ft	508	120	26	38	37	18	7	4	1
Lakewood sand (pine shrubless site)	No.	----------	331	62	106	174	92	46	23	11
	No. per sq ft	----------	55	10	18	29	15	8	4	2
Leon sand (turf bald site)	No.	----------	525	177	53	8	6	20	----------	----------
	No. per sq ft	----------	88	30	9	1	1	3	----------	----------

DISTRIBUTION OF ROOTS OF DIFFERENT SIZES AND TYPES

ROOTS OF DIFFERENT SIZES

Roots of the smallest size class (0.01–0.05 inch) make up 71–89 percent of all roots in the profile in the various soil types. Even though they are fewer in number, roots more than 0.05 inch in diameter influence the total area of roots more than the smaller roots. For example, the high area of roots compared to the number of roots in the Leon sand (fig. 13) is due to the large proportion of larger roots. The pine transition community in which the Leon sand was studied has a very dense cover of shrubs whose large roots and rhizomes are very abundant in the A_0 and A_1 horizons. These larger shrub roots and rhizomes in these horizons are responsible for the high area of roots in the profile.

Further evidence of the effect of larger roots on area is shown in the Lakewood sand pine-shrub site and the Lakehurst sand, thick A_2 variant, which have an equal number of roots (fig. 13). The area of roots in the Lakewood sand is double that in the Lakehurst A_2 variant because of the high proportion of roots more than 0.05 inch in diameter in the Lakewood sand.

ROOTS OF DIFFERENT TYPES

All roots more than 0.2 inch in diameter at the two shrubless sites—Leon sand turf bald and Lakewood sand pine-shrubless—are pine roots. At the other eight sites the number and percentage of shrub, pine, and oak roots in the entire profile varies considerably (table 9). However, in seven of the eight sites, more than 80 percent of all roots larger than 0.2 inch in diameter in the A_0 and A_1 horizons are shrub roots and rhizomes. Percentages of pine roots in these horizons range from 4 to 49. Very few oak roots more than 0.2 inch in diameter are found in the A_0 and A_1 horizons, even at sites having a large proportion of oak roots in the entire profile.

Table 10 contrasts the combined number of different types of roots more than 0.2 inch in diameter in the five soils having oak-pine-shrub vegetation with comparable data for the three soils having pine-shrub vegetation. The three types of roots are about equally abundant in the profile at the oak-pine sites. At the three pine sites, shrub roots are relatively more important, making up 71 percent of the total roots in the profile.

Shrub roots make up 71 percent of the total roots in the A_0 and A_1 horizons at the oak-pine sites and 90 percent at the pine sites. The studies of individual root systems indicated that the majority of the roots and rhizomes of most shrubs are concentrated in the A_0 and A_1 horizons. This fact is further demonstrated by the very high percentages of all shrub roots and rhizomes more than 0.2 inch in diameter found in the A_0 and A_1 horizons—98 percent in the oak-pine sites and 86 percent at the pine sites.

If the totals of the different types of roots less than 0.2 inch in diameter are proportional to those of more than 0.2 inch, any differences in the total numbers at any two sites having good shrub cover apparently would be due to the number of tree roots. Shrub roots are concentrated in the A_1 horizon, and there is no statistically significant difference between the total roots in this horizon among any of the sites having a good shrub cover (table 5). However, as previously pointed out, sites having no shrubs do have significantly fewer

TABLE 9.—*Number of shrub, pine, and oak roots more than 0.2 inch in diameter in the A_0—A_1 horizons and in the entire profile*

Soil	Unit	A_0—A_1 horizons				Entire profile			
		Shrub	Pine	Oak	Total	Shrub	Pine	Oak	Total
Sites having comparable vegetation									
Lakewood sand (oak site)	No.	37	5	2	44	43	18	19	80
	Percent	84	11	5	100	54	22	24	100
Lakewood sand, clay substratum variant.	No.	18	26	9	53	18	32	51	101
	Percent	34	49	17	100	18	32	50	100
Downer sand	No.	15	2	0	17	15	32	18	65
	Percent	88	12	0	100	23	49	28	100
Lakeland sand, leached A_2 phase.	No.	46	8	0	54	47	32	36	115
	Percent	85	15	0	100	41	28	31	100
Lakehurst sand	No.	25	3	2	30	25	23	42	90
	Percent	83	10	7	100	28	25	47	100
Lakehurst sand, thick A_2 variant.	No.	16	1	0	17	19	4	1	24
	Percent	94	6	0	100	79	17	4	100
Leon sand	No.	53	8	[1] 1	62	66	22	[1] 9	97
	Percent	85	13	2	100	68	23	9	100
Sites having different vegetation									
Lakewood sand (pine-shrub site).	No.	44	2	0	46	47	11	7	65
	Percent	96	4	0	100	72	17	11	100
Lakewood sand (pine-shrubless site).	No.	0	2	0	2	0	21	0	21
	Percent	0	100	0	100	0	100	0	100
Leon sand (turf bald site)	No.	0	1	0	1	0	5	0	5
	Percent	0	100	0	100	0	100	0	100

[1] Maple root.

TABLE 10.—*Average number of shrub, pine, and oak roots more than 0.2 inch in diameter in five soil types* [1] *having oak-pine vegetation and a good shrub cover and in three soil types* [2] *having only pine and shrub vegetation*

Roots	5 sites with oak-pine vegetation [1]				3 sites with pine vegetation [2]			
	Shrub	Pine	Oak	All roots	Shrub	Pine	Other	All roots
Entire profile:								
Average No.	30	27	33	90	44	12	6	62
Percentage	33	30	37	100	71	20	9	100
A_0-A_1 horizons:								
Average No.	29	8	3	40	38	4	1	42
Percentage	71	22	7	100	90	9	1	100

[1] Lakewood sand (oak site), Lakehurst sand, Downer sand, Lakeland sand, and the clay substratum variant of the Lakeland sand.
[2] Lakehurst sand, thick A_2 variant; Leon sand; and Lakewood sand (pine-shrub site).

roots in almost every horizon than similar sites having a good shrub cover.

EFFECT OF DECAYING ROOTS IN THE SOIL

One or more small roots growing inside a decaying root was commonly observed, especially in the A_2 horizon. Most of the smaller roots in the thick A_2 horizon of the Lakehurst sand, thick A_2 variant, are growing inside decaying roots or are surrounded by a ring of organic matter indicating the presence of another root at one time. A large decaying root may have as many as 12 small roots growing inside it. Any accumulation of decaying organic matter in the mineral soil will have many fibrous and small woody roots of all species very closely intermingled with the decaying particles, a condition much like that found in the A_0 horizon. This phenomenon was also reported by Swetloff (1931), Scully (1942), and others.

EFFECT OF SOIL TEXTURE ON ROOT DISTRIBUTION

There are conflicting ideas about the influence of soil texture on root development, but most authorities agree that root development is generally poorer, in terms of number of roots per unit volume of soil, in sandy soils than in soils with a higher content of silt and clay. Livingston (1906), Aldrich-Blake (1929), Bügsen and Münch (1929), and Garin (1942) found that roots in sandy soils are longer but have fewer branches than roots in finer soils. This condition would result in more roots in a finer soil or horizon than in a sandy soil or horizon. Turner (1936) and Lutz, Ely, and Little (1937) reported that horizons with higher amounts of silt and clay contained more roots than horizons with lower amounts. Lutz, Ely, and Little (1937) also reported that root development was poor or absent in soils containing more than 90 percent sand

and that when strata of fine-textured material occur in sandy soils the majority of the roots are concentrated in these strata.

Haasis (1921, 1923), however, found longer, less-branched roots in a clay soil than in a rocky loam soil, and Anderson and Cheyney (1934) found more roots on tree seedlings grown in coarse soils. Hopkins and Donahue (1939) stated that there is no correlation between the percentage of clay in the soil and root distribution. These varying results by different investigators were probably due to differences in textures, drainage, or compactness of the soils studied.

In the present study the clay layer (D_1 horizon) which underlies the B_2 horizon of the Lakewood sand, clay substratum variant, greatly alters the distribution of roots. The number of roots per square foot in the sandy B_2 horizon and in the top 1 foot of the clay layer are very nearly equal, and there is a small decrease in the number of roots from the top 1 foot to the remainder of the clay layer (table 3). There is, however, a very sharp decrease in roots in the sandy D_2 horizon below the D_1 horizon. This decrease seems to indicate that the clay is more favorable for root development than the sand above and below it and, consequently, offsets the normal downward decrease in the number of roots. Smaller roots (approximately as much as 0.1 in. in diameter) in the clay layer are found only in cracks and are very much flattened. Larger roots in general have a normal shape and are present throughout the horizon instead of only in cracks. Partridge and Veatch (1932) noted that roots in clay soils follow cracks, and Stephenson and Schuster (1937) found that roots in heavy clay horizons were compressed. Scully (1942) stated that roots less than 2 mm in diameter followed cracks in a sandy-clay B_2 horizon and were flattened because of the horizon's resistance to penetration.

Gravel in a soil may also affect root distribution. The taproot or one *Quercus marilandica* examined in Lakewood sand extended downward about 22 inches to the top of a layer of gravel, then turned and grew horizontally about 12 feet along the top of the gravel layer.

RELATION OF ROOT DISTRIBUTION TO THE WATER TABLE

Poor aeration in parts of the soil near the water table or in poorly drained soils generally causes poor root growth of many species. Partridge and Veatch (1932), Oskamp and Batjer (1932), and Diebold (1933) found that shallow rooting of apple trees is generally a result of a high water table. The same situation was reported by Hoffman and Schlubatis (1928) for raspberries. Stephenson and Schuster (1937) found that poorly aerated soils contained few roots in the lowest part of the profile. Cooper (1926) related the distribution of different types of vegetation on alluvial fans to the depth of the water table and to aeration of the soil.

In the soils investigated, those at the three sites having the shallowest water tables—the Leon sand, the Leon sand turf bald, and the Lakehurst sand, thick A_2 variant—have a rather large percentage of the total number of roots concentrated in the A_0 and A_1 horizons (table 6). The soils at these sites have a much thicker A_2 horizon than any of the other soils, and this thick, rather sterile horizon—together with the shallow water table and the resultant poor aeration—evidently causes this poor root development below the A_1 horizon. Two of these soils—the Leon sand turf bald and the Lakehurst sand, thick A_2 variant—are among the lowest in total root number and root area in the profile, but the Leon sand site has the highest area of roots per square foot and the fifth highest number of roots per square foot in its profile of all sites studied. The Leon sand site is located in a pine transition community which has an extremely dense cover of shrubs, mainly *Kalmia angustifolia*, whose larger roots and rhizomes are very numerous in the A_0 and A_1 horizon (table 9). Even though the lower horizons of the Leon sand are wet and probably poorly aerated, the shallow water table is, at least in part, responsible for the extremely dense shrub cover. *K. angustifolia* and some of the other shrubs commonly growing in the Leon sand in the pine transition community have larger roots which extend to the water table and thus are insured an adequate supply of water. The roots that extend to the water table evidently are not inhibited by submergence or poor aeration.

The shrubs of the region generally fall into three categories in relation to the water table: (1) phreatophytes—shrubs whose roots usually extend to the water table, (2) facultative phreatophytes—shrubs whose roots extend to the water table in lowland areas but do not reach the water table in upland areas, and (3) nonphreatophytes—shrubs whose roots never extend to the water table even where it is shallow (table 11). The majority of the nonphreatophytes very seldom grow where the water table is shallower than 3–4 feet. However, *Quercus ilicifolia* and *Vaccinium vacillans* grow both in upland areas and in areas where the water table is near the surface. The roots of both these species penetrate 36 inches or more in the upland communities but grow horizontally within a few inches of the surface in areas having a high water table. Apparently the roots of these species cannot tolerate the conditions in the saturated zone of the water table or in the capillary fringe above the water table.

TABLE 11.—*Relation of roots of the Pine Barrens shrubs to the water table*

Phreatophytes	Facultative phreatophytes—Continued
Kalmia angustifolia	*Kalmia latifolia*
Lyonia mariana	*Lyonia ligustrina*
Chamaedaphne calyculata [1]	*Myrica pensylvanica*
Gaylussacia dumosa [1]	*Pyrus melanocarpa*
Ilex verticillata [1]	*Quercus prinoides*
Leucothoe racemosa [1]	*Vaccinium angustifolium*
Pyrus arbutifolia [1]	**Nonphreatophytes:**
Rhododendron viscosum [1]	*Comptonia peregrina* var. *asplenifolia*
Vaccinium corymbosum [1]	*Hudsonia ericoides*
Facultative phreatophytes:	*Leiophyllum buxifolium*
Amelanchier canadensis	*Quercus ilicifolia*
Clethra alnifolia	*Q. marilandica*
Gaultheria procumbens	*Vaccinium vacillans*
Gaylussacia baccata	
G. frondosa	
Ilex glabra	

[1] Species limited to lowland areas and not included in the present study.

Most of the shrubs listed in table 11 as facultative phreatophytes are classified as such because they grow both in the lowland and upland communities. Their roots do not extend to the water table in the upland areas, but it must be assumed that even superficial root systems of the plants in the lowlands do grow into the water table or the capillary fringe most of the year. However, *Quercus prinoides*, listed as a facultative phreatophyte, does not occur in the lowland communities. In the pine transition community the roots of this species may extend to the water table, but in upland areas the water table is too deep for the roots to reach it.

Exclusive of the strictly lowland species, which were not studied, only two species could be classified as true phreatophytes, *Kalmia angustifolia* and *Lyonia mariana*. *K. angustifolia* is the most characteristic shrub species of the pine transition community and undoubtedly occurs so abundantly there because its roots can extend to the water table, which is 18–40 inches deep during the summer (fig. 5). *L. mariana* also occurs in the pine transition community and has one or more roots that extend to the water table (fig. 7). Both shrubs are found in widely scattered locations in upland communities, but the two shrubs seem to be confined mainly to areas having a high water table. In some places in the pine transition community, *Clethra alnifolia* may have a root that extends 24–30 inches to the water table (fig. 6). However, this species also grows both in upland areas where the water table is very deep and in lowland communities where the water table is very near the surface, so it must be classified as a facultative phreatophyte rather than a true phreatophyte.

Very little is known about comparative use of water by different species under field conditions. Sartz (1951) stated that plants whose roots extend to the water table transpire more than plants whose roots obtain moisture from other sources. On this basis, it appears that the plants in the cedar swamp and other lowland communities whose roots are in the water table or capillary fringe most of the year would be much more important in the consumption of ground water than the vegetation of the pine transition community where not all roots extend to the water table. In addition, the lowland areas are much more extensive than the pine transition community, at least in the Lebanon State Forest (McCormick, 1955); therefore any attempt to control the use of water by vegetation probably should be concentrated on the lowland areas.

Use of water by vegetation can be reduced in two ways: (1) lower the water table beyond the roots of the plants (consumptive drain would automatically accomplish this), and (2) remove species that are heavy users of ground water or replace them with species that use less water. Hoover (1944) and Hewlett and Hibbert (1961) found that clear cutting of trees on a watershed in North Carolina significantly increased the water yield, and Dunford and Fletcher (1947) found that cutting the trees along a stream on the same watershed eliminated diurnal fluctuation of streamflow during the growing season. Wilm and Dunford (1948) reported that cutting of lodgepole pine increased water for streamflow, and Croft (1950) found the same thing when streamside aspens were replaced with herbaceous species. Veihmeyer (1953) and Fletcher and Rich (1954) noted that the replacement of shrubs with grasses and forbs resulted in an increased amount of water available for streamflow. In North Carolina, a rise in the water table resulting from the clear cutting of loblolly pine was reported by Trousdell and Hoover (1954). The wide scale killing of spruce trees by the Englemann spruce beetle resulted in a significantly greater streamflow on a watershed in Colorado (Love, 1955).

If necessary, the shrubs of the pine transition community can be controlled to reduce the use of ground water. Controlled burning is one method, but only severe burning that destroys the litter prevents vigorous resprouting of the shrubs of this community. (Little, 1953; Little and Moore, 1953.) This method alone probably would be impractical as a method of control. Egler (1949) found that proper spraying with herbicides kills *Kalmia angustifolia*, which is the dominant shrub and probably one of the major users of ground water in the pine transition community. The combined use of controlled burning and herbicide spraying probably would be the most efficient method of controlling shrub density in this community. Much more needs to be known of the water requirements of the phreatophytes and other plants in the Pine Barrens before adequate measures can be devised to control or reduce their use of water.

EFFECTS OF FIRE

EFFECTS ON ROOTS AND RHIZOMES

Because of the long history of frequent fires in the region, all shrubs of the Pine Barrens undoubtedly have the ability to recover after burning. Lutz (1934) studied the effects of fire on the pines and some of the oaks of the Pine Barrens but did not include any of the shrub species. The oaks (*Quercus ilicifolia*, *Q. marilandica*, and *Q. prinoides*) sprout vigorously after a fire. This recovery is probably related to the massive taproot found in these species.

The rhizomatous shrub species also recover after burning, but the rhizomes that occur in the A_0 horizon are susceptible to fire damage. Parts of the roots or rhizomes of all the rhizomatous species except *Comptonia peregrina* var. *asplenifolia*, *Lyonia mariana*, and *Vaccinium vacillans* extend into the A_0 horizon. A severe ground fire usually consumes all the organic matter on the surface of the soil, damaging or completely destroying the part of the rhizome in the A_0 horizon. Such a fire could separate rhizome systems, and it is therefore impossible to determine the original extent of clones of most species. The compact clone of *L. mariana* (fig. 8) described previously was the only relatively complete clone found. A contributing factor to the existence of this clone probably is the fact that the rhizomes of this species rarely occur in the A_0 horizon.

A wildfire in July 1955 burned across several of the vegetation lines and quadrats established by McCormick on McDonalds Branch watershed. Six of these burned upland quadrats were resurveyed in October 1955, October 1956, and September 1957. Table 12 shows the effect of this fire on *Vaccinium vacillans* and *Gaylussacia baccata*, and their recovery after the fire. The data represent the average percentage of shrub cover on six lines each 10 meters long, and the data for unoccupied space represent the average percentage of bare space on these same lines. *G. baccata* made up a greater percentage of cover than *V. vacillans* on the original survey. Both species had a very low cover 3 months after the burn (first resurvey). *V. vacillans* contributed more to the cover than *G. baccata* 15 months after the fire (second resurvey); 26 months after the fire (third resurvey) there was more than twice as much *V. vacillans* as *G. baccata* and the amount of *G. baccata* cover had decreased since the previous survey. The summer of 1957 was extremely dry and many of the aerial stems of the shrubs on the burned area appeared to be dead at the time of the third resurvey. The mortality rate of *G. baccata* stems was several times that of *V. vacillans*. Thus *V. vacillans* not only recovers from fire more quickly, as reported by Buell and Cantlon (1953), but it apparently is also more drought resistant than *G. baccata*.

TABLE 12.—*Effect of July 1955 wildfire on shrub cover*

[Figures are average percentage cover of 6 lines 10 meters long]

Species or unoccupied space	Original cover	Resurvey		
		First, Oct. 1955	Second, Oct. 1956	Third, Sept. 1957
Gaylussacia baccata	38.2	4.8	11.7	7.7
Vaccinium vacillans	29.9	2.3	15.5	18.2
Unoccupied space	21.8	86.8	62.3	60.7

Differences in the positions of the rhizomes and the depth of roots most probably explain this difference in ability to survive after a fire and drought. The rhizome of *Vaccinium vacillans* almost always grows only in the mineral soil but parts of the rhizome of *Gaylussacia baccata* occur in the A_0 soil horizon. Any ground fire, no matter what its intensity, would damage the rhizomes of *G. baccata* much more than those of *V. vacillans*. Well-developed roots of *V. vacillans* usually extend 25–48 inches deep in upland areas but roots of *G. baccata* seldom extend deeper than 6–8 inches. The deeper, better developed roots of *V. vacillans* may be the most important factor in this greater fire and drought resistance because a fire or extreme drought dries the surface part of the soil below the wilting point. Because the deeper roots of *V. vacillans* extend into soil that may not be so extremely dry, they are able to absorb moisture and maintain the upper parts of the plants. The shallower roots of *G. baccata* however, are confined to the upper soil which may become too dry for the roots to be able to absorb water.

Leach (1925, 1956) reported a similar difference in fire resistance of two species. In Great Britain's heath lands, *Calluna vulgaris* is generally the dominant plant, but after a fire *Vaccinium myrtillus*, which has roots and rhizomes that are 8–9 inches deep, sprouts vigorously. Specht and Ratson (1957) found that most of the heath species in Australia have their perennating buds below the surface and are able to survive a fire even though the aerial parts are destroyed.

EFFECTS ON GROUND-WATER SUPPLIES

Controled burning is known to reduce the shrub cover in the New Jersey Pine Barrens (Buell and Cantlon, 1953; Little and Moore, 1949, 1953). The present study indicates that the A_0 and A_1 horizons contain a large proportion of the total roots in the profile and that many of these roots are shrub roots in areas having a good shrub cover. This concentration of roots near the surface, especially in unburned areas, may absorb most of the water from light rains during the growing season and prevent it from being stored in the soil and from eventually reaching the lower soil horizons or the water table.

Besides reducing shrub cover, controlled burning also reduces the amount of litter. In many burned areas, however, the litter is replaced by mosses. Moul and Buell (1955) found that this cushion of moss absorbed and held as much as one-half inch of water. The amount of water retained by litter in unburned areas of the Pine Barrens is also approximately one-half inch (Bernard, 1963). Thus, a rain of more than one-half inch would be required to wet the soil under a moss cushion or a well-developed layer of litter. In Wisconsin, Curtis (1960) found that both hardwood and pine litter 2–3 inches thick retained more than 90 percent of the moisture of storms whose total precipitation was one-quarter inch or less and retained approximately 65 percent of the moisture of storms of ¼–½ inch.

Comparisons of areas with and without shrub cover on the same soil type clearly show that an area with no shrubs contains far fewer roots, especially in the surface horizons. Since the litter layer of an unburned area absorbs approximately the same amount of moisture as the cover of mosses that may develop after burning, then the differences between burned and unburned sites, as far as water supply is concerned, probably would be related to changes in the shrub layer. The reduced number of shrub roots in the soil (decreasing absorption) together with the reduced shrub cover above ground (reducing interception) probably would increase the amount of water penetrating to the lower soil layers during the growing season. The influence of a good stand of shrubs on soil moisture was shown by Eschner (1960) in an oak-pine area in eastern Pennsylvania similar to the Pine Barrens. The top 18 inches of soil under ericaceous-shrub ground cover was drier than that under any other vegetation type; this fact indicates that ericaceous shrubs are the major users of soil moisture in the upper part of a soil. The species of shrubs studied by Eschner also occur in the Pine Barrens.

Use of water during the growing season is not the only factor influencing ground-water supplies, however. Because much of the recharge of the water table takes place during the winter when there is little transpiration, the density of shrub roots in the upper horizons may not affect water-table levels much. Furthermore, tree roots in the deeper layers of the soil may utilize much of the water that penetrates beyond the surface regardless of the amount of shrub cover. McQuilkin (1935) found that mature pitch pines often had taproots with well-developed laterals as deep as 8 feet in the sandy soil of the New Jersey Pine Barrens. Detailed soil-moisture studies at various depths in burned and unburned areas are needed to determine how shrub roots affect the amount of water reaching the water table.

TABLE 13.—*Scientific and common names of plants of the Pine Barrens mentioned in the paper*

Scientific name	*Common name*
Trees:	
Acer rubrum var. *trilobum*	Red maple
Chamaecyparis thyoides	Southern white cedar
Nyssa sylvatica	Black gum
Pinus echinata	Shortleaf pine
P. rigida	Pitch pine
Quercus alba	White oak
Q. coccinea	Scarlet oak
Q. marilandica	Blackjack oak
Q. prinus	Chestnut oak
Q. velutina	Black oak
Shrubs:	
Amelanchier canadensis	Serviceberry
Chamaedaphne calyculata	Leatherleaf
Clethra alnifolia	Sweet pepperbush
Comptonia peregrina var. *asplenifolia*	Sweet fern
Galtheria procumbens	Teaberry
Gaylussacia baccata	Black huckleberry
G. dumosa	Dwarf huckleberry
G. frondosa	Dangleberry
Hudsonia ericoides	Golden heather
Ilex glabra	Inkberry
I. verticillata	Black alder
Kalmia angustifolia	Sheep laurel
K. latifolia	Mountain-laurel
Leiophyllum buxifolium	Sand myrtle
Leucothoe racemosa	Fetterbush
Lyonia ligustrina	Maleberry
L. mariana	Staggerbush
Myrica pensylvancia	Bayberry
Pyrus arbutifolia	Red chokeberry
P. melanocarpa	Black chokeberry
Quercus ilicifolia	Scrub oak
Q. prinoides	Dwarf chestnut oak
Rhododendron viscosum	Swamp honeysuckle
Vaccinium angustifolium	Low sweet blueberry
V. corymbosum	Highbush blueberry
V. vacillans	Lowbush blueberry
Herbaceous plants:	
Carex pensylvanica	Sedge

TABLE 14.—*Summary of the characteristics of the root and rhizome systems of the Pine Barrens shrubs studied*

[VA, very abundant; A, abundant; C, common; R, rare; VR, very rare; AB, absent; N, no rhizomes]

Shrub or tree	Abundance			Rhizome			Roots		Aerial stems, distance apart on the rhizome (inches)
	Upland	Transition zone	Lowland	Diameter (inches)	Depth in soil (inches)	Does rhizome grow in A_0 soil horizon?	Depth of deepest root (inches)	Do roots ever extend to the water table?	
Amelanchier canadensis	VR	R	R	3/16–3/4	0–1	Yes	4	Yes	6–24
Clethra alnifolia	R	C	A	1/8–3/8	0–2	Yes	30	Yes	3–96
Comptonia peregrina var. *asplenifolia*	R	R	R	1/4–3/4	0–2	No	10	No	2–12
Gaultheria procumbens	A	A	C	1/16	0–1	Yes	1	Yes	0.2–5
Gaylussacia baccata	A	C	C	1/4–2	0–3	Yes	8	Yes	12–48
G. frondosa	C	A	A	1/8–3/8	0–2	Yes	4	Yes	3–72
Hudsonia ericoides	R	AB	AB	N	N	N	6	No	N
Ilex glabra	VR	C	C	3/16–1/2	0–2	Yes	24	Yes	6–18
Kalmia angustifolia	R	VA	C	1/4–1/2	0–1	Yes	40	Yes	2–24
K. latifolia	R	R	R	2	0–4	Yes	30	Yes	6–24
Leiophyllum buxifolium	VR	R	AB	N	N	N	6	No	N
Lyonia ligustrina	VR	C	C	1/8–3/8	0–2	Yes	4	Yes	As much as 156
L. mariana	R	C	R	3/8–3/4	0–3	No	58	Yes	12–48
Myrica pensylvanica	VR	R	VR	3/16–1/2	0–1/2	Yes	30	Yes	6–36
Pyrus melanocarpa	VR	R	R	3/16–1/4	0–1	Yes	4	Yes	6–24
Quercus ilicifolia	VA	R	AB	N	N	N	36	No	N
Q. marilandica	C	AB	AB	N	N	N	36	No	N
Q. prinoides	C	R	AB	N	N	N	48	Yes	N
Vaccinium angustifolium	R	R	R	1/8–3/16	0–1	Yes	6	Yes	6–18
V. vacillans	A	C	R	1/4–5/8	0–6	No	48	No	12–48

SUMMARY

The deep sandy strata under the Pine Barrens of New Jersey have been proposed as a future source of water. Controlled burning is being used to increase the proportion of pine in the oak-pine forests of the region. This burning also greatly reduces the shrub cover. In 1951, the Pine Barrens hydrological research project was initiated to determine how this change in forest composition will affect ground-water supplies. This paper, as part of the project, (1) describes the root and rhizome systems of the upland and transition zone shrubs of the region and (2) compares the vertical distribution of roots in seven upland and transition zone soil types on two experimental watersheds in the Lebanon State Forest.

Vaccinium vacillans and *Gaylussacia baccata* are the most common upland shrubs, and, of the two, *V. vacillans* is the more fire and drought resistant. The rhizomes of *V. vacillans* are confined to the mineral soil and its roots extend 25–48 inches deep, but both the roots and rhizomes of *G. baccata* are superficial and often occur in the A_0 horizon. A ground fire that destroys the A_0 horizon or a drought that dries the surface soil would be expected to damage *G. baccata* more than *V. vacillans*.

The roots of *Quercus ilicifolia* and *Vaccinium vacillans* extend rather deep in upland areas, but in the pine transition community where the water table is shallow the roots are superficial. The roots of these species apparently cannot tolerate the poor aeration and other conditions associated with the saturated zone of the water table.

Kalmia angustifolia and *Lyonia mariana* have roots that extend to the water table where it is 2–5 feet below the surface. Many other species may or may not have roots that extend to the water table. The use of water in this area by these and other species is not a problem at present, but when ground-water supplies fail to adequately supply the demands, the amount used by plants will have to be reduced. One method of reducing this use is to lower the water table beyond the roots of the plants, and another is to remove species that are heavy users of ground water or replace them with species that use less water.

The highest total number of tree and shrub roots were found in the Lakehurst sand; the Lakewood sand, clay substratum variant; the Lakeland sand; and the Downer sand. The latter three soils have thin, imperfectly bleached A_2 horizons.

The A_0 horizon, where it is present, contains the highest number of roots per square foot, and the A_1 horizon contains the next highest number in all soil types. More than 85 percent of the shrub roots and rhizomes are found in the A_0 and A_1 horizons. The number of all roots decreases sharply from the A_1 to the A_2 horizon. In the well-drained upland soils the number of roots per square foot increases from the A_2 to the B_1 horizon and decreases below that. This increase in the B_1 horizon was not found in the imperfectly or poorly drained soils.

The number of roots in the B horizon decreased downward in all soils except the Lakewood sand, clay substratum variant, which had a 2-foot-thick layer of clay below a thin B_2 horizon. Clay evidently favors root development and counterbalances the normal downward decrease in number of roots.

A large proportion of the numerous roots in the A_0 and A_1 horizons are shrub roots and rhizomes at all

sites having a good shrub cover. This concentration of shrub and other roots near the surface may absorb much of the water from light rains during the growing season, and thus prevent it from reaching the lower soil levels or the water table. The sites with no shrubs had significantly fewer roots in all horizons than any site with shrubs. A decrease in shrub cover caused by controlled burning and the resultant decrease in the number of roots might permit an increased amount of water to reach the water table.

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