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The root systems of forest trees are of interest in the study of forest soils because of the intimate association between the soil and the roots of trees, and the effect of soil properties on the absorption of water and nutrients. The extent and efficiency of the root system determines to a large degree the quantity absorbed of the available water and nutrients in the soil.

The purpose of this investigation was to determine the distribution of roots in ponderosa pine stands in the different soil horizons and, if possible, to relate their distribution to soil texture.

Relatively little information is available on the extent of root systems of mature, forest-grown trees. Much of the information has been obtained by excavating the root systems of individual trees, and since this is a laborious and expensive method, few observations have been made. Weaver and Kramer (9) found that the roots of mature bur oak extended laterally 20 to 60 feet and vertically to a depth of 14 feet through soil which was fairly heavy in texture.

Longleaf pine growing on a sandy soil was found by Heyward (6) to have a tap root over 14 feet deep and lateral roots up to 75 feet long. McQuilkin (8) reported that pitch pine, 12 to 30 years old, growing on sandy soils had lateral roots 25 to 35 feet in length.

In a study of root distribution on Colorado watersheds, Berndt and Gibbons (1) noted that ponderosa pine, Douglas fir, and lodgepole pine roots reached maximum depths between 4 and 5.6 feet, except where downward penetration was limited by bedrock. Quaking aspen had some laterals up to 48 feet in length; other tree species had laterals less than one-half this length.

Coile (3) studied the root concentration in five forest types in the lower Piedmont of North Carolina. He found that the concentration of roots less than 0.1 inch in diameter increased rapidly in the A_1 and A_2 horizons during the first 20 to 30 years of the pine stage in the succession toward an oak-hickory climax forest. Concentrations increased at a much slower rate after this stage. Subsoil root concentrations did not increase after the pine stands were 20 years of age. He concluded that after fully stocked forest stands have reached a certain age, the number of small roots in the surface soil reaches a near constant. This is considered to be the root capacity of the soil.

In a study of the soil characteristics influencing the distribution of white pine roots in New Hampshire, Lutz, Ely and Little (7) reported the greatest concentration of roots to be in the upper soil horizons. Factors causing the concentration of roots in this area were: more favorable soil texture and structure; higher moisture holding capacity; higher organic matter content; higher content of total nigrogen; and higher total exchange capacity and higher content of exchangeable bases.

Gaiser and Campbell (5) found that the concentration and weight of roots one-fourth inch and less in diameter decreased rapidly in succeedingly deeper soil horizons in white oak stands in Ohio. Root concentrations were found to be nearly constant after the stands reached an age of 30 years, and were not affected by site quality, topography, or stand density.

Methods

Even-aged ponderosa pine stands on each of three soil types were selected as locations for soil wells from which data on the distribution and concentrat of roots were obtained. The stands were growing on a coarse-textured, a mediu textured, and a fine-textured soil. The mean ages of the stands were 51, 75, and 78 years.

Soil wells were located with one end of the vertical face tangent to the trunk of a dominant ponderosa pine. The face of the well extended outward from the reference tree along a contour. The wells were 120 inches long and 48 inch deep. One wall of the trench was divided into 12-inch squares by means of a gr made of cord. Root ends were charted on cross section paper, using symbols to denote the various size classes recognized. In order to avoid missing any root it was necessary carefully to work over the vertical wall with a sharp pointed instrument. Boundaries of all soil horizons were mapped.

The soil profile was described and samples taken from each horizon for lab ratory analyses. Mechanical composition was determined by the hydrometer metho (2). The pH of the samples was determined electrometrically with a Beckman met

The age, height, and diameter of the trees of the stand were recorded. Th density of the species comprising the ground vegetation was noted on four one-quarter mil acre quadrats located adjacent to the soil wells.

Soils

The three soils in which root distribution was studied belong to the Gray Wooded great soil group. The Gray Wooded soils are characterized by a well-developed platy A_2 horizon, a blocky B horizon with a distinct accumulation of clay, and an overall gray appearance (4). If developed from calcareous parent material, a zone of calcium carbonate is usually present; but two of the profile examined, which were developing in non-calcareous materials, contained no free lime. Although the prominent gray A_2 horizon would seem to indicate leaching comparable to that occurring in the Podzols, the Gray Wooded soils are usually neutral to mildly acid in reaction above the calcareous materials. One of the most striking features of these soils is their high base status which in the B_2 horizon may be 8 to 10 times that of a typical Podzol profile (10).

The three sites selected for this study were on a coarse-textured soil, Half Moon sandy loam, a medium-textured soil, Greenough silt loam (tentative series name, subject to final correlation), and a fine-textured soil, Lubrecht loam (tentative series name, subject to final correlation).

Half Moon sandy loam is a minimal Gray Wooded soil developing in coarser textured glacial-lacustrine sediments. The profile sampled exhibited a duff mul humus layer 2 inches thick. Texture graded from a sandy loam surface soil to a silt loam subsoil (Table 1, Fig. 1). Horizons were poorly differentiated and boundaries were indistinct. Soil reaction was very slightly acid.

The medium-textured Greenough soil is a medial Gray Wooded soil developing in calcareous Tertiary age sediments, the so-called Bozeman "lake beds". The mineral soil was overlain with a duff mull humus layer from 2 to 3 inches in thickness. Horizon development was pronounced. The texture varied from a silt loam surface soil, through a clay loam B horizon, to a silt loam parent material (Table 1, Fig. 1). Soil reaction varied from medium acid in the A horizon to moderately alkaline in the parent material.

The Lubrecht series are maximal Gray Wooded soils developing in the same parent materials as the Greenough soils. The striking features of the profile examined were the prominent light colored A_2 horizon and the very strongly developed blocky clay B_2 horizon; the latter had prominent clayskins on the surface and in the pores of the peds. The clay content, as shown in Table 1 and Figure 1, is quite high. Soil reaction was slightly acid to strongly acid. The duff mull

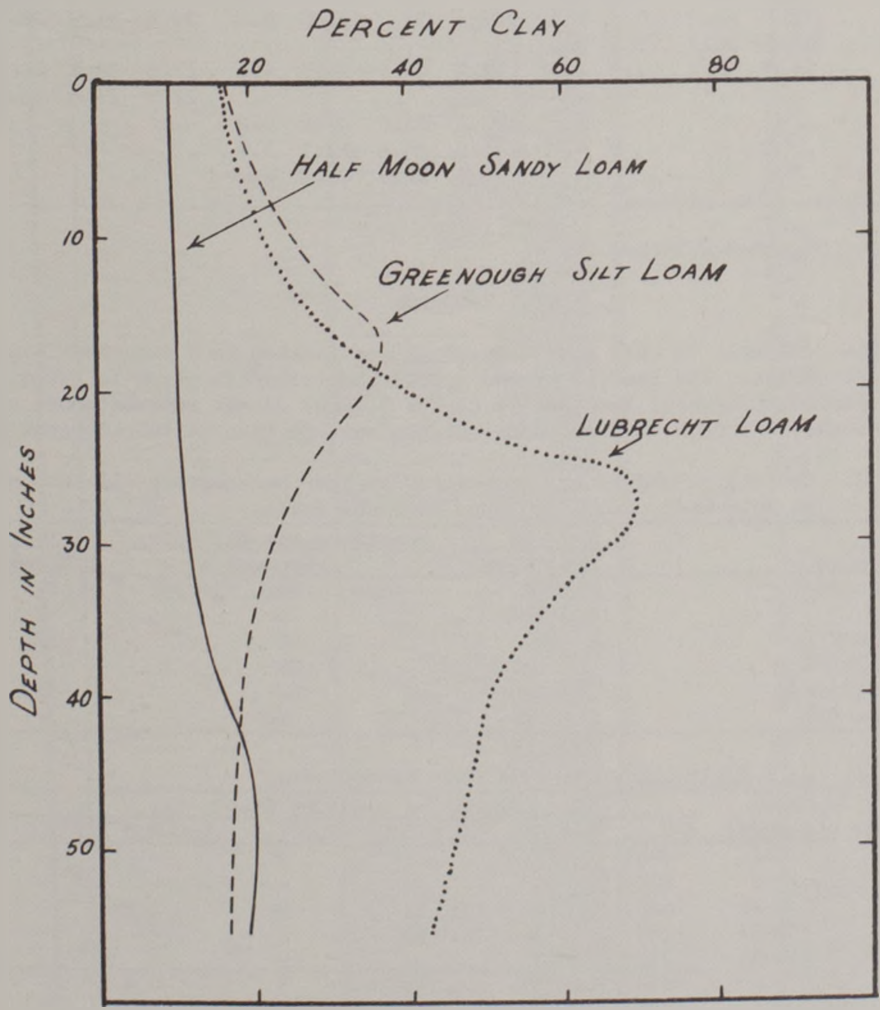

Fig. 1. Clay content of Half Moon, Greenough, and Lubrecht soils.

Table 1. Mechanical composition and pH of Half Moon, Greenough, and Lubrecht soils.

Horizon	Half Moon Percent of Sand	Silt	Clay	pH	Greenough Percent of Sand	Silt	Clay	pH	Lubrecht Percent of Sand	Silt	Clay	pH
A_1	61.4	28.8	9.8	6.2	29.1	53.7	17.2	5.8	37.9	44.9	17.2	6.2
A_2	67.5	22.0	10.5	6.5	26.1	52.9	21.0	6.0	41.3	34.8	23.9	6.4
B_2-A_2	71.1	18.2	10.7	6.5	22.3	54.7	23.0	6.3	39.6	31.9	28.5	6.4
B_{21}	67.6	20.2	12.2	6.5								
B_{22}	24.0	56.7	19.3	6.6	19.2	44.1	36.7	6.0	17.3	13.4	69.3	5.1
B_3									21.5	27.6	50.9	6.3
C					28.8	43.0	28.2	6.3				
D_{ca1}					41.3	45.6	13.1	7.8				
D_{ca2}					33.4	52.9	13.7	8.0				

organic layer was 2 inches thick.

Results

The soil well in Half Moon sandy loam was located in a ponderosa pine stand 75 years of age. The density of the ground vegetation is given in Table 2. Root distribution throughout the profile (Table 3, Fig. 2) was somewhat more uniform than in the Greenough soil and considerably more so than in the Lubrecht plot.

Table 2. Density of understory vegetation on four one-quarter mil acre quadrats on Half Moon, Greenough, and Lubrecht soils.

Species	Specimens per Mil Acre: Half Moon	Greenough	Lubrecht
Oregon grape	30	20	11
Rose	5	5	2
Snowberry	85	60	52
Kinnikinnik	–	39	–
Serviceberry	–	–	3
Douglas fir	–	1	–

Table 3. Root distribution in Half Moon sandy loam.

Horizon	Depth (inches)	Number of Roots by Size: < 0.1	0.1–0.3	0.3–0.5	0.5–1.0	1.0–2.0	> 2.0
A_1	0–2	479	32	1	–	–	–
A_2	2–5	574	21	3	–	–	–
B_2-A_2	5–22	1638	151	32	9	2	–
B_{21}	22–43	1140	62	10	–	–	–
B_{22}	43–48+	211	8	–	–	–	–
		4042	274	46	9	2	–
	(feet) 0–1	1678	123	15	2	1	–
	1–2	1132	86	22	7	1	–
	2–3	633	33	4	–	–	–
	3–4	599	32	5	–	–	–
		4042	274	46	9	2	–

Total number of roots was intermediate between the two other areas — 4,373 as compared to 4,993 and 4,032 for the Greenough and Lubrecht soils (Tables 3, 4, and 5). The number of roots over 0.1 inch in size was almost twice that of the

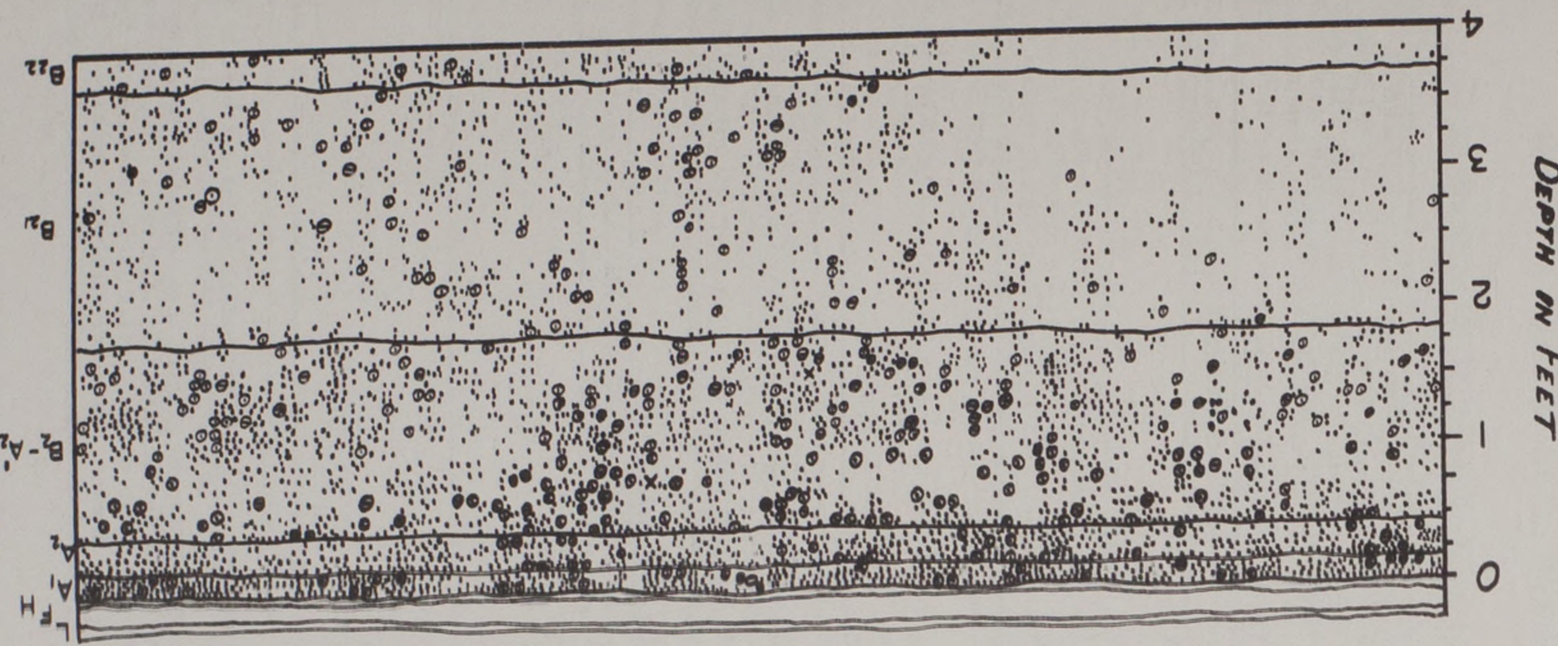

Fig. 2. Root distribution in Half Moon sandy loam. The following symbols indicate root size: up to 0.1 inch - •; 0.1 - 0.3 inch - ⊙; 0.3 to 0.5 inch - ◉; 0.5 to 1.0 inch - ●; 1.0 to 2.0 inch - x.

Lubrecht plot and was over three times that of the Greenough area.

The Greenough silt loam plot was in a 51-year-old stand. This area was the only one in which kinnikinnik was present in the understory vegetation (Table 2). The total number of roots was the greatest of the three areas studied; also the only root over 2 inches in diameter found in the course of the study was mapped in this pit. There is a marked contrast in the number of roots less than 0.1 inch in size and those greater than 0.1 inch in size (Table 4).

Table 4. Root distribution in Greenough silt loam.

Horizon	Depth (inches)	Number of Roots by Size					
		<0.1	0.1-0.3	0.3-0.5	0.5-1.0	1.0-2.0	>2.0
A_1	0-1	402	11	-	-	-	-
A_2	1-4	753	22	2	-	-	1
B_2-A_2	4-11	1070	37	5	4	-	-
B_2	11-24	1597	7	-	-	-	-
C	24-33	453	1	-	-	-	-
D_{ca1}	33-42	593	4	-	-	-	-
D_{ca2}	42+	31	-	-	-	-	-
		4899	82	7	4	-	1
	(feet)						
	0-1	2203	67	6	4	-	1
	1-2	1539	10	1	-	-	-
	2-3	828	5	-	-	-	-
	3-4	329	-	-	-	-	-
		4899	82	7	4	-	1

The ponderosa pine stand on the Lubrecht loam site was 78 years of age. Table 2 shows the species density of the understory vegetation. As shown in Table 5, this area had the smallest number of roots; over one thousand fewer roots 0.1 inch in diameter or smaller than were present in the Greenough soil.

Table 5. Root distribution in Lubrecht loam.

Horizon	Depth (inches)	Number of Roots by Size					
		<0.1	0.1-0.3	0.3-0.5	0.5-1.0	1.0-2.0	>2.0
A_1	0-4	1013	41	1	-	-	-
A_2	4-11	1027	70	10	2	-	-
B_2-A_2	11-13	257	19	3	1	-	-
B_2	13-33	1436	29	4	1	-	-
B_3	33-48+	117	1	-	-	-	-
		3850	160	18	4	-	-
	(feet)						
	0-1	2062	113	11	2	-	-
	1-2	1249	38	7	2	-	-
	2-3	394	8	-	-	-	-
	3-4	145	1	-	-	-	-
		3850	160	18	4	-	-

The influence of texture and structure is evident in the patterns of root distribution. The Lubrecht subsoil is the poorest medium for root growth of the three soils since it is a poorly aerated plastic clay. The concentration of roots drops abruptly below a depth of about 18 inches in this soil. The Half Moon soil is fairly well aerated throughout the entire profile as is evidenced by the more uniform distribution of roots. However, the water supplying capacity of this soil is not as favorable as that of Greenough silt loam, consequently root concentrations are lower. The Greenough soil is the most favorable environment for root development as a result of good aeration and moisture availability.

The percentages of the total number of roots less than 0.1 inch in diameter in the upper foot of soil on the coarse, medium, and fine-textured soils were 42, 45, and 54 respectively; for the 0-2 foot depth the percentages were 70, 76, and 86. This concentration is primarily a result of better aeration and greater ease of root penetration than exists in the deeper soil layers.

The small number of roots over 0.3 inch in diameter is very noticeable (Tables 3, 4, 5, Fig. 2). The combined total in all soil wells was 91 roots of which 20 exceeded 0.5 inch in diameter.

Summary

The distribution of roots in ponderosa pine stands growing on a coarse, medium, and fine-textured soil was measured by the soil-well method.

Greatest numbers of roots were found in the medium-textured soil and the smallest number in the fine-textured soil — 4,993 and 4,032 respectively.

The concentration of roots decreased markedly in succeedingly deeper horizons. Over 70 percent of the roots were concentrated in the upper two feet of the soil.

Very few roots over 0.5 inch in diameter were present.

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