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ROOTING HABITS OF LODGEPOLE PINE

by
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Note

This work was initiated by D. I. Crossley, formerly Senior Research Officer, Alberta District, Forestry Branch. Mr. Crossley supervised the project and, together with the author, prepared a comprehensive manuscript upon which this Technical Note is based.

Rooting Habits of Lodgepole Pine

(Project K.70)

by

K. W. Horton*

INTRODUCTION

One of the aims of the Alberta office of the Federal Forestry Branch is to obtain a knowledge of the silvical characteristics of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.). Information on this species' rooting habits in its native Canadian range was found to be lacking and, although some studies had been made in the U.S.A., they applied largely to seedling growth. Thus an investigation of an observational type into lodgepole pine's rooting habits was deemed necessary. It was undertaken in 1952 in natural stands, mainly at the Kananaskis Forest Experiment Station (lat. 51°N; long. 115°W) in the mountains of western Alberta.

It is generally considered that the initial rooting habit of trees is a function of heredity and is similar for a given species under all growing conditions. After the early stage of development the environment begins to take effect and the root form changes in reaction to the condition. Since forest soils vary exceedingly, a wide variability in the form of the root system can be expected. It is not enough to examine the roots of windfalls; these may have blown down because of some abnormality of root form. Planned root excavation, although very laborious and time-consuming, seems to be the only way to obtain accurate knowledge of rooting tendencies.

The study was conducted by this means to provide some information on the behaviour patterns of lodgepole pine rooting in accordance with age and site. It was hoped that this knowledge would prove useful in explaining stem development and in assessing susceptibility to windthrow. The latter requires immediate investigation since it is a primary consideration in pine cutting practices.

METHODS

Since the unearthing of whole tree root systems is a time-consuming task, the samples in this study were limited and carefully chosen. The basic variables of rooting are site and age; therefore samples were taken on significantly different sites and, since the progressive root development of single trees obviously could not be followed, trees of different ages on the same site were used.

On this basis a number of sites were selected for study using as a preliminary criterion the soil texture. Several coarse and fine-textured soils capable of producing marketable pine trees were included. Then, to facilitate ecological comparison, certain extremes of site, not necessarily productive, were selected, namely, peat soils with a high water table and dry, shallow soil over root-restricting bedrock.

On each soil, trees of different ages from the seedling or sapling stage to near-maturity were chosen for root excavation. It was decided that root competition between different trees would only complicate the study of rooting in

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relation to its environment; therefore only open-grown trees were selected. A full, vigorous and normally shaped crown (of class A or B in Taylor's (1939) classification) was required of these trees along with an apparently normal growth rate. There were a few planned exceptions to these qualifications.

The method of excavation was as follows: on an arbitrarily selected tangent of the bole, a vertical pit was dug to the depth of maximum root penetration. With the smaller trees the width of the pit was sufficient to include all of the roots appearing on a 6-foot-wide profile face. No attempt was made to enlarge the pit beyond this width when larger trees were being excavated. After the pit had been dug, the soil face adjacent to the central axis of the tree was smoothed off and the roots on that face were mapped. At the same time the physical features of the soil profile were mapped and described. Following this, the main vertical root system was excavated. The excavation commenced at the bottom of the pit and progressed upward until the main system was free, which procedure resulted in a minimum of breakage of the smaller roots. The root was then removed from the pit and drawn or photographed.

At the same time the system of surface laterals on the side of the tree opposite to the soil pit was unearthed. Using a trowel and ice picks, each main lateral was followed out from the stem until the complete system on that side of the tree was revealed.

The site of each root system described in this study has been evaluated. Site plays an important part in all forest growth and development and, while it is an integrated complex of all the features of a locality, an attempt can be made to evaluate it by selecting a few factors which are presumed to integrate the effect of most of the others. Such a system has been devised by Hills (1952) and evaluates topographic local climate or ecoclimate, soil moisture regime, material permeability or pore pattern, and the origin and petrography of the parent material into a "physiographic site classification". W.G.E. Brown has so classified the sites included in this study and the roots are grouped accordingly throughout this report.

Over 40 root systems were excavated in the course of the work at Kananaskis and more than 20 are considered either representative or of special interest so that they are included in this report. In addition, several roots (which are indicated by asterisks in the succeeding figures) from lodgepole stands in the Alberta foothills were examined as to vertical rooting only. The completed study thus provides information on the rooting habit of the species under certain specific yet ubiquitous soil conditions.

In the following presentation only the actual vertical root system of each tree and its corresponding soil profile are illustrated. The profile face diagrams showing the distribution of the various-sized roots in cross section have not, except in two demonstrative cases, been included since they are space-consuming and add little to the over-all picture. The same applies to the mapped lateral root systems.

DESCRIPTION OF SOIL TYPES AND ROOTS

Nine soil types have been recognized and grouped into three soil series, based on productivity, drainage and texture. Most of the soil types within a series do not have a uniform texture, and it has been necessary to describe some as medium-coarse (MC) or medium-fine (MF). In this report Soil Series I is considered to be the coarser soils and Soil Series II the finer soils.

(Symbols:— C = coarse, M = medium, F = fine, I = inter-banded, R = rock, P = peat)

Soil Series I—productive soils, more or less dry and coarse-textured.
  Soil Type C—sorted, excessively drained, medium sands and gravels.
  Soil Type MC—uniformly sorted, somewhat dry, fine sands, often loamy.
  Soil Type MC/F—as above over deeply-laid moist clay strata.

Soil Series II—productive soils, more or less fresh and fine-textured.
  Soil Type F/C—stratified, well drained clays and silty clays, one to three feet deep, overlying coarse gravel outwash.
  Soil Type I—stratified, inter-banded clays and fine sands, fresh but well drained.
  Soil Type MF—stratified, fresh soils of medium texture, mainly clays and loams.

Soil Series III—unproductive soils—wet peats, and shallow till over bedrock.
  Soil Type P/F—shallow sedge peat over saturated clay glei.
  Soil Type P—hangmoor sedge peat, saturated by telluric water.
  Soil Type M/R—unsorted, dry till, shallow over fractured shale bedrock.

In Figures 1, 2 and 3 the vertical root systems considered to be representative of each soil type are depicted, arranged in ascending order of age. Each tree root is numbered for individual reference and the soil profile details are included alongside. Pertinent points about individual soil types and specific rooting tendencies follow:

Soil Type C—Trees 9 and 11.

Dry, coarse-textured soils appear to restrict normal penetration and distort the taproot and sinkers. It is difficult to say whether this is a result of desiccation or straight physical resistance but it seems to be characteristic in "set" coarse materials. In the case of Tree 9, the high lime content in the coarse outwash horizon may well have emphasized the root convolutions.

Soil Type MC—Trees 2, 4, 5 and 7.

Somewhat dry, coarse to medium-textured conditions allow normal taproot growth at first. Twin tap variants may occur (e.g. Tree 4). Then, as the tree becomes older and its water requirements increase, a complex system of sinkers develops from the bases of the main lateral roots, resulting in a "heart-shaped" rooting form. This has occurred before 50 years of age as Tree 7 shows. Note the rapid initial penetration (Tree 2). The development of a fibrous mass of root endings in adolescence (Tree 5) suggests that adsorption is involved in the taproot's function.

Soil Type MC/F—Trees 3, 6 and 10.

Somewhat dry, coarse to medium-textured soil occurs here over a fine-textured, deeply-laid stratum. The rooting tendencies are similar to those in Soil Type MC but the presence of the fine layer within rooting depth appears to encourage deeper penetration. Tree 6 is comparable in age and taproot form to Tree 5 of Soil Type MC but probes appreciably deeper. The complicated development from taproot to heart-shaped form took place between 35 and 70 or 80 years. In Tree 10 the heart-shaped expression is evident and the deep penetration of a few roots to the fine material is pronounced. An interesting explanation is available for the exceptionally deep sinkers in this example.

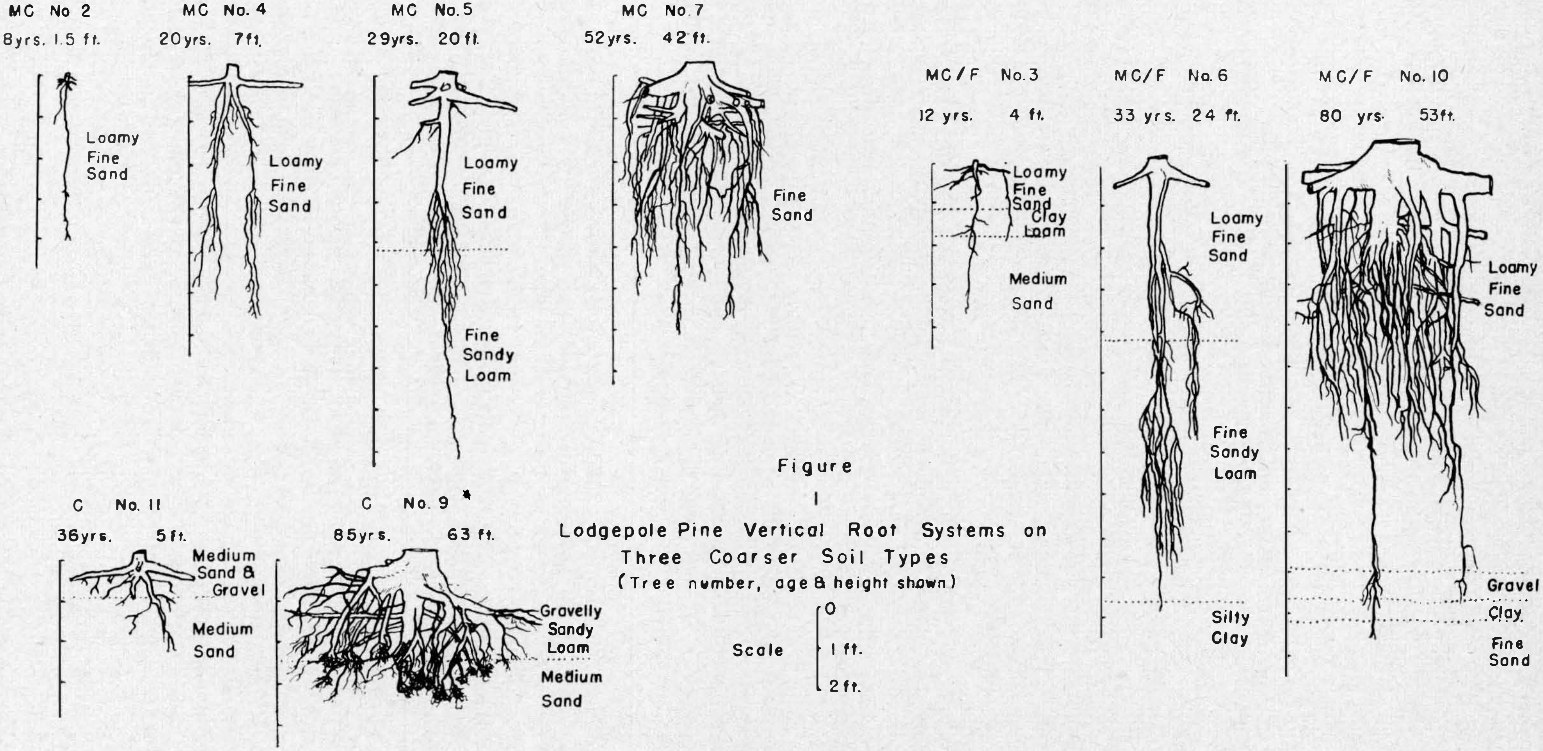

Figure 1

Lodgepole Pine Vertical Root Systems on Three Coarser Soil Types
(Tree number, age & height shown)

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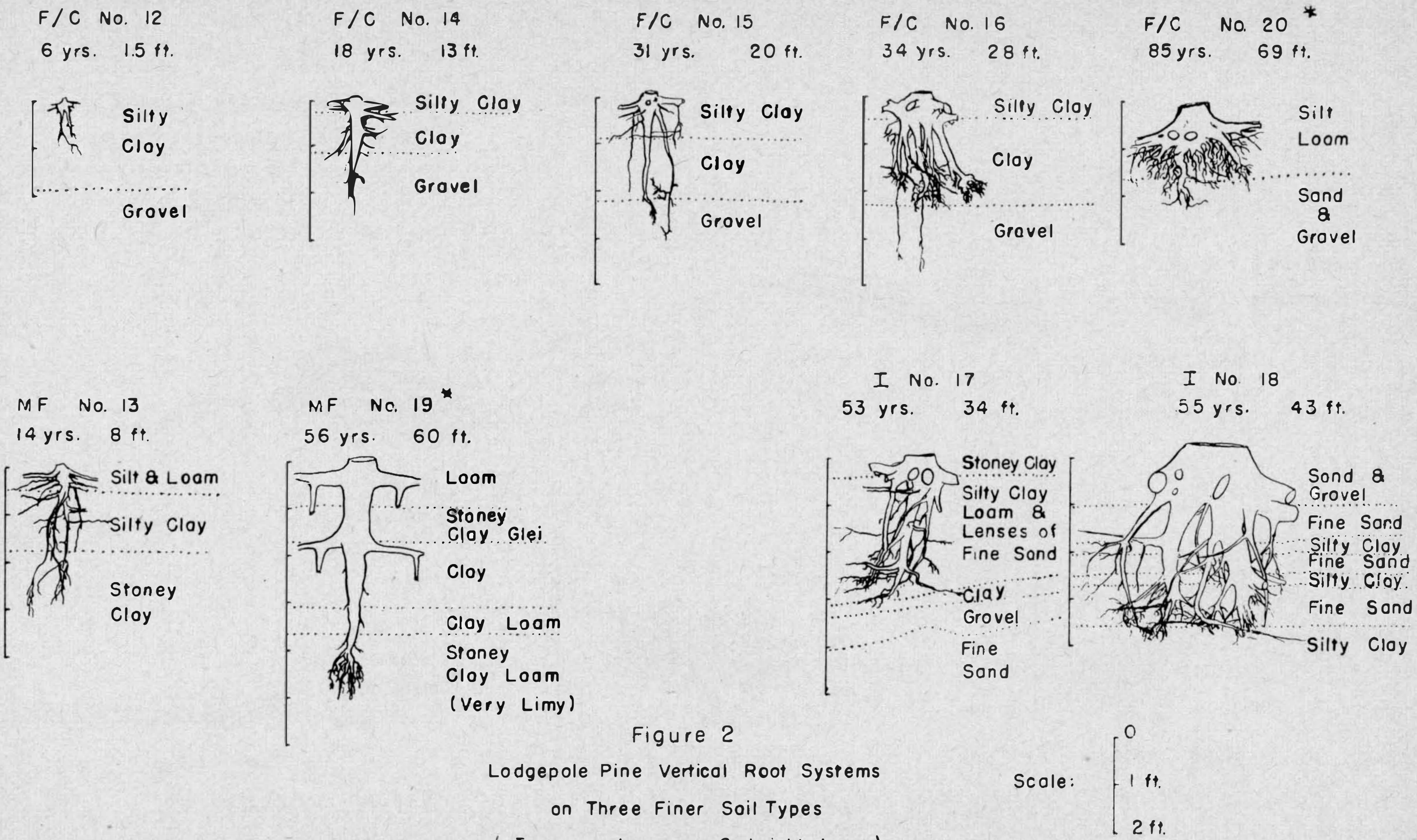


Figure 2

Lodgepole Pine Vertical Root Systems on Three Finer Soil Types

(Tree numbers age & height shown)

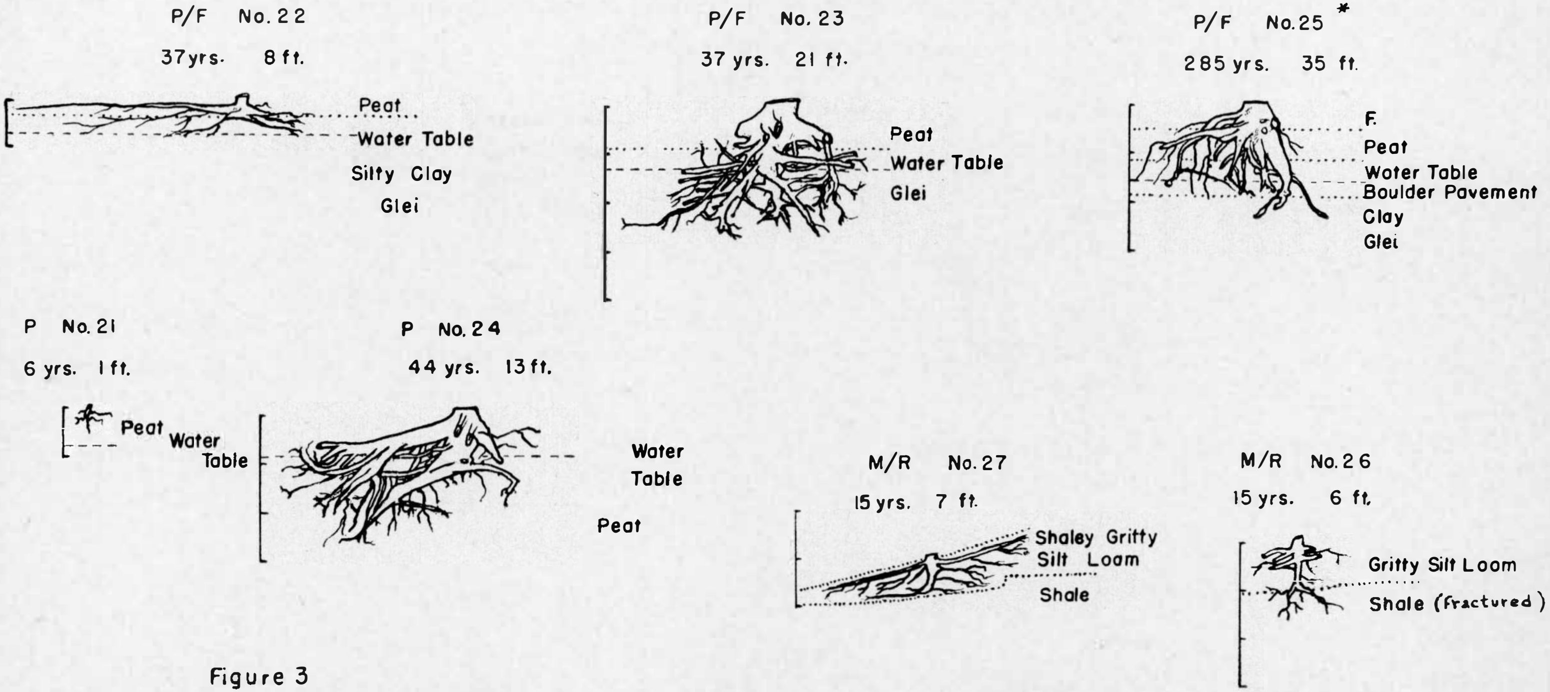


Figure 3
Lodgepole Pine Vertical Root Systems
on Three Unproductive Soil Types
(Tree Number Age & Height shown)

This tree (together with a similar case, Tree 8, not shown) was growing for most of its life on a xeric ridge. Though rooting was extensive, penetration ceased at about the five-foot level. Ten years before excavation the water table of the site was raised to about the nine-foot level by damming. Ring counts on the deep sinkers below the general rooting level indicated that they had developed *after* the raising of the water table—a good case for hydrotropism. It is noteworthy that many of the vertical roots of this tree followed down the decaying root channels of trees of a previous generation, which suggests that this, and not a tropism, is influential in the development of the heart-shaped form.

Soil Type F/C—Trees 12, 14, 15, 16 and 20.

Somewhat moist, fine-textured soil overlies a coarse layer. Initial good root development in the fine-textured upper soil horizon is followed by restriction and distortion of all vertical roots (as in Soil Type C) as the underlying coarse outwash is encountered, well before 20 years of age. Note the atrophied taps of Trees 14 and 15. As to the development of the heart-shaped form, Trees 15 and 16 afford an interesting contrast. They were growing within 25 yards of one another in apparently identical conditions, but, in spite of a similarity in age, Tree 15 had largely maintained the taproot form while Tree 16 had developed several major sinkers, producing the heart shape. This suggests a hereditary difference; it may tie in with growth rate since Tree 16 was considerably larger in both height and diameter. The two deep sinkers in Tree 16 that have penetrated into the gravel layer may have done so during a period of excessive moisture. Tree 20 was from a well-stocked stand in the lower foothills (at Strachan, Alberta). It shows that deep penetration is not essential for fair height growth. Its lateral roots appeared to have utilized fully the available site, being concentrated in the areas of least competition.

Soil Type MF—Trees 13 and 19.

Somewhat moist, medium to fine-textured soils; this type was the closest to a uniform fine material that was encountered in the study. Rooting development is expressed in the normal tap form with sparse lateral sinkers. The tendency, evident here, to maintain a strong tap is looked upon as a characteristic of lodgepole pine. Tree 19 had a secondary set of lateral roots in the finer stratum at the two-foot level and a few deep sinkers occurred from both sets, extending down to the same level as the central tap, with similar branching and clubbing in the excessively limy lowest horizon. This whole secondary system is likely a response to a perched water table, penetrated during a series of dry years; the site is abnormal in this respect. Tree 19, which is another sample from the lower foothills, also had the best aerial growth of any in the study.

Soil Type I—Trees 17 and 18.

Somewhat moist, inter-banded clays and sands constitute this soil which, in its condition of contrast, is considered to be quite productive. Tree 18 is the typical example here, showing distinctly the stratification or concentration of roots in the fine moist layers rather than in the coarse dry strata (Figure 6, of the profile face of this root system, particularly shows this). Note again the retention of a strong tap (apparently twinned in this case) and the development of a moderate number of branched sinkers. Tree 17 is a more irregular example of the condition. Root penetration ceased at the gravel stratum at three feet in this case; presumably the finer material above this level has sufficient effective depth to accommodate rooting requirements. There was a slight suggestion that roots avoided the lenses of the fine sand occurring in this heterogeneous horizon. Note the direction of dip of the vertical root system, i.e. down the slope of the lower strata, or in the direction of drainage.

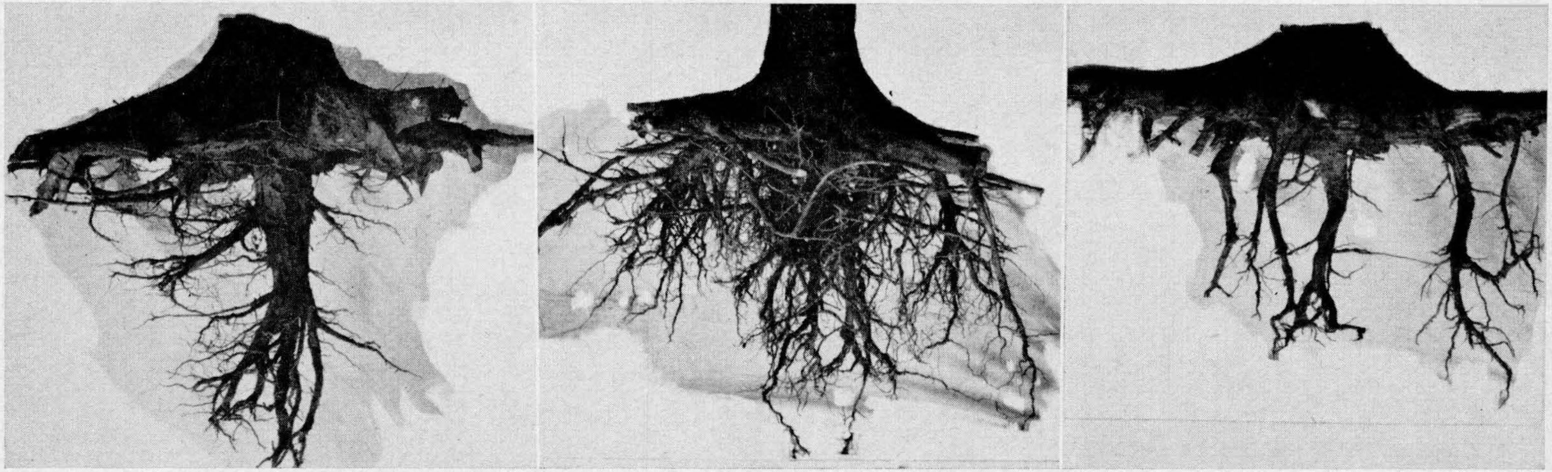


Plate 1. Roots from an 85-year-old lodgepole pine stand at Strachan, Alberta, showing the inherent variation in vertical root form to be found within a soil type (F/C).

Soil Type P/F—Trees 22, 23 and 25.

Shallow peat overlies saturated glei with the water table within 18 inches of the surface; for Trees 22 and 23 the soil water is telluric (hangmoor conditions) and for Tree 25 it is stagnant (a half-bog). Rooting is definitely restricted by the excess water, the tap bending rather than penetrating the water table. Where the water table was highest (e.g. Tree 22), the vertical rooting was shallowest. The fluctuation of the water table appears to allow some vertical root development but the result (submerged at the time of excavation) is convoluted, club-like appendages, often dead and quite inactive. Tree 25 provides an interesting point on root development in relation to stem growth. A stem analysis showed that the tree grew normally for the first 15 years and then was drastically retarded to the present (285 years). Presumably, initial rooting, in muck, was unimpeded; then the doubly restricting boulder pavement and water table was reached, causing the roots to club-up. In contrast, neighbouring spruce and fir, with shallow, plate-like root systems, grew at moderate rates throughout their lives.

Soil Type P—Trees 21 and 24.

Wet peat; lodgepole pine is capable of rooting in this medium but the vertical system is strongly distorted, a bent tap with many clubbed branches. Tree 24 probably developed its comparatively large root proportions owing to its position on a decayed stump which raised it above the high water table.

Soil Type M/R—Trees 26 and 27.

A dry, shallow soil over limestone bedrock shows the effect of an impenetrable obstacle on lodgepole pine vertical rooting. The taproot is maintained, merely being deflected along the surface of the rock. Note in Tree 27 the occurrence of a series of parallel laterals from the tap at all levels. These are all on the up-slope side of the tree and the suggestion is that they have developed as extra supports for the tree in this precarious rooting condition.

ROOT MORPHOLOGY

The Vertical Root System

Root Form—Initial rooting habit is controlled by heredity, being similar for a species under all growing conditions (Toumey 1929, Weaver and Clements 1938, etc.). In the early seedling stage all forest trees have a strongly positive geotropic radicle which later may persist as a taproot, become suppressed or die back (Aldrich-Blake 1929). As seedlings grow older the general tendency of the form in the majority of species is to change in accordance with the environment. This tendency will increase with age but the degree of flexibility varies widely with species, some being quite plastic and others relatively invariable. This helps to explain why some species can survive for a time under almost any conditions while others have very exact requirements. Thus in a species with a wide ecological amplitude the normal rooting habit may be difficult to define. As Luncz (1931) put it, the root system of a species will probably show greater variation in different soils than different species in the same soil.

Lodgepole pine appears to be in this category. Preston (1941), working in Colorado, found the vertical development of its root system markedly affected by soil condition. The taproot was normally strongly developed except when mechanical obstructions were met, in which case vertical sinkers usually evolved from the lateral roots. Sometimes sinkers occurred when the taproot was undisturbed. On this last point Aldrich-Blake states that whenever conditions

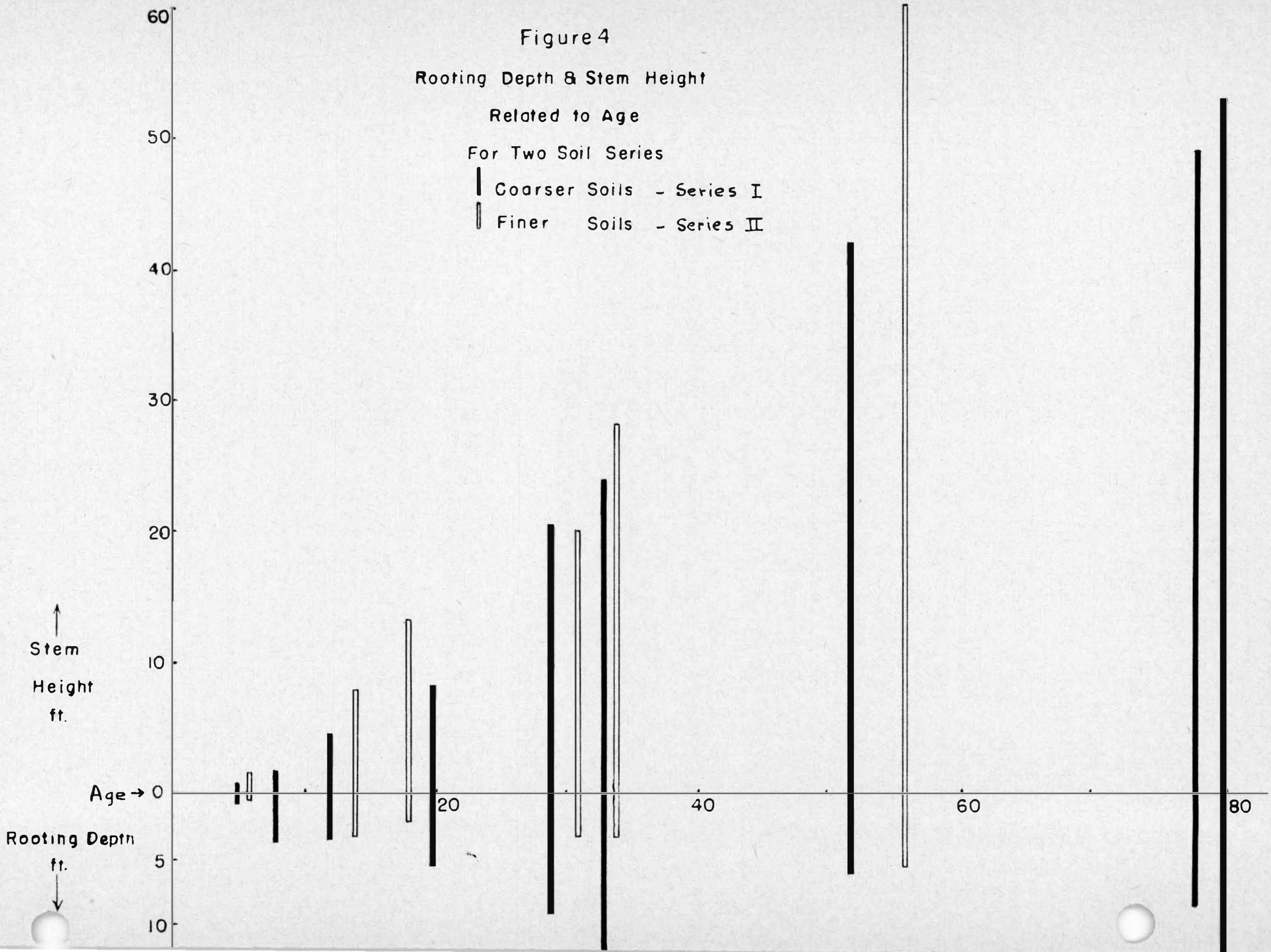


Figure 4

Rooting Depth & Stem Height

Related to Age

For Two Soil Series

are right for deep rooting, all species will develop sinkers from the laterals at varying distances from the bole, with the centre-most forming the vertical root system (which in this case is usually termed 'heart-shaped').

These observations by other investigators agree closely with the information found in this study. Within each soil type there is a general trend from the simple taproot form in the juvenile stages to the complex heart-shaped expression later (between 30 and 60 years). The sample on which this generalization is based is small; to provide a check on the trend, two heart-shaped root systems were selected (Trees 8 and 10 in Soil Type MC/F) and all the sinkers as well as the tap were sectioned at the one-foot level. Resulting age counts are presented in Table 1.

TABLE 1

Ages of Roots at One Foot Below the Root Collar

Root No.	Tree Age (years)	Tap Age (years)	No. of Sinkers Sampled	Ages of Sinkers (years)									
8	78	72	8	66	58	55	55	54	51	50	48		
10	80	75	10	67	62	62	61	61	57	57	52	32	31

It is apparent from the above table that the sinkers developed quite independently after the taproot.

Thus there is evidence of an inherent tendency in lodgepole pine to develop the heart-shaped root form after the initial taproot form. Exceptions to this are quite common, however. Plate 1 illustrates the variability that can occur, comparing the roots of three dominant pines from an 85-year-old, fully-stocked stand. Another example can be seen in comparing Trees 15 and 16 (Figure 2) which are of similar age on identical conditions a few yards apart, yet are very different in root form.

Other studies have shown that sinkers often grow along old root channels. Laitakari (1929), working on Scots pine, and Cheyney (1932), on jack pine, suggest that the presence of these channels (rather than a tropism or inherent tendency) causes the development of sinkers. As well as the above authors, Day (1941), with red pine, and Preston (1941), with lodgepole pine, found that exceptionally deep roots followed old channels. This is exemplified in the present study in Tree 10 (Figure 1), but this was the only case encountered where the tendency was marked. Therefore it may be said that sinkers can and do develop without any apparent external influence.

Despite the variability in lodgepole pine rooting habit, shown here and in studies by Preston (1941) and Yeatman (1955), and despite the complexity involving the development of the heart-shaped form, there is one common trait—the prevailing taproot. It may bend horizontally when it hits obstructions (e.g. Soil Type M/R), it may die back when it encounters water (Soil Types P/F and P), or it may be completely obscured by a surrounding mass of sinkers, but it prevails, apparently in all conditions. The taproot form may therefore be looked upon as the normal for lodgepole pine, subject to variations especially in sinker development.

Rooting Extent—While the sample is small, it does give some idea of the trends of taproot penetration as they differ in the various soils. Figure 4 shows the taproot depths and corresponding stem heights according to age in certain soils. The indications are that taproot extension in all soils increases with age up to 30 or 40 years, and then decreases; thus maximum taproot growth is reached long before maximum stem height is attained.

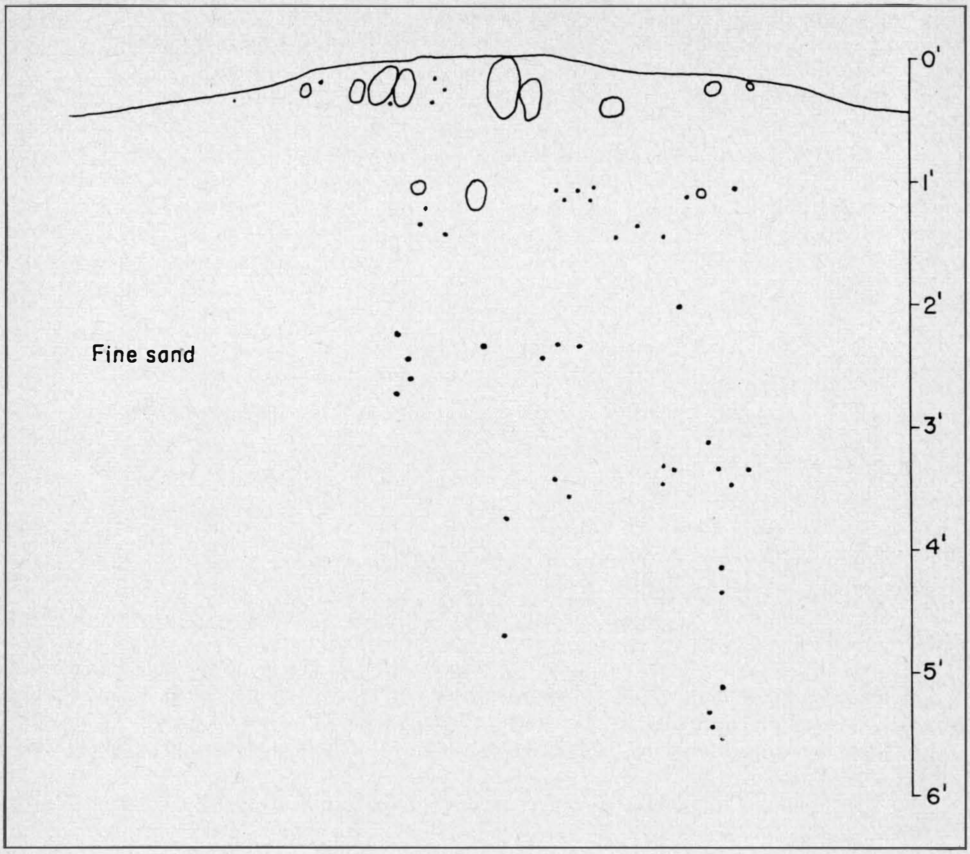


FIGURE 5. Tree No. 7, Soil Type MC. Cross-sectional profile of the root system on a six-foot face beneath the bole, showing the random distribution of roots at all levels in a uniform soil.

Total taproot penetration is distinctly greater in the coarse-to-moderate soil types MC and MC/F, and is greatest in the latter, suggesting an attractive influence on the part of the deep layer of finer and, accordingly, moister material. Least penetration occurred on the wet sites, the implication of which will be discussed later under "moisture effects". The relatively shallow rooting in Soil Type F/C may be explained by the uninviting gravel horizon lying below the fine-textured medium. Yet the height growth on this condition is similar or slightly superior to that on the coarser soils (Figure 1), where rooting is much deeper—a fact which suggests that more effective rooting is possible in finer material. This point is reconsidered later in the section on productivity.

The Lateral Root System

Distribution—The vertical distribution of the lateral roots in the soil is usually assessed cross-sectionally, on a profile face exposed along a tangent to the bole. This was done for most sample trees in this study but the data have not been presented individually since they add little to the information gleaned from the vertical root system. Rather, two profiles have been selected to exemplify the method and its results (Figures 5 and 6).

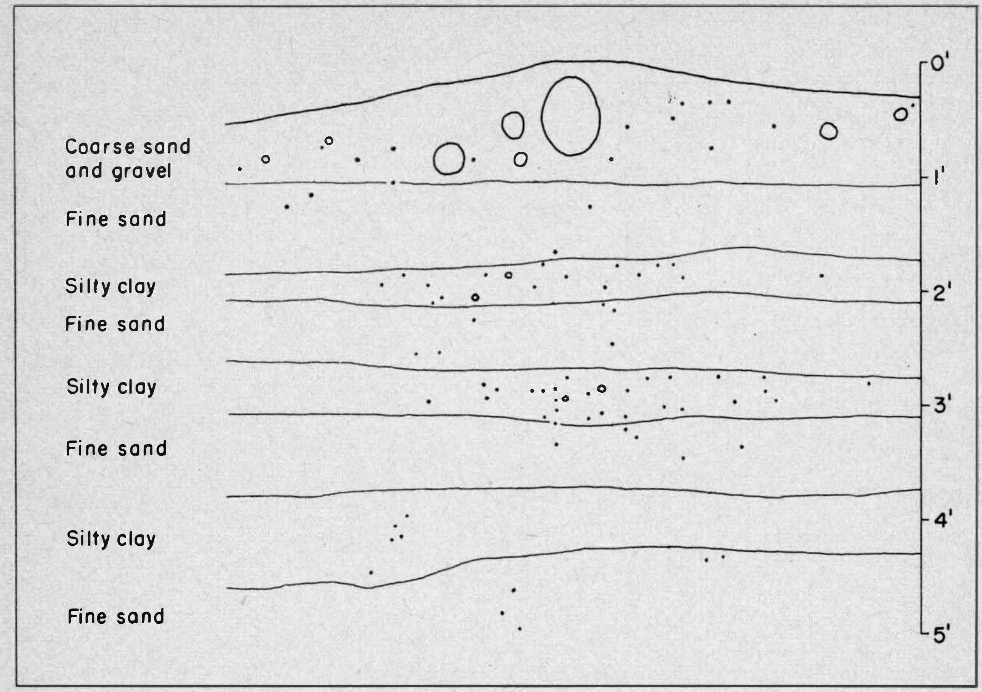


FIGURE 6. Tree No. 18, Soil Type I. Cross-sectional profile of the root system on a six-foot face beneath the bole, showing the concentration of roots in the fine-textured strata rather than the coarse.

It is generally recognized that the majority of tree root laterals are normally concentrated in the top few inches of soil. Gail and Long (1935) found that in lodgepole pine seedlings, the surface laterals occur about one inch below the surface, deeper laterals being few in number and short. Preston (1941) states that the main laterals of lodgepole pine remain in the upper three inches of soil and constitute the greatest percentage of lateral growth. The present study corroborates this trend for pine of all ages growing on all the sites encountered. In the unearthing of the surface lateral system it was rarely necessary to dig below four inches, although an occasional root was found which, towards its extremity, suddenly turned downwards. A limited number of deeper laterals will often occur, as Figures 1 to 5 show. To summarize, in any given tree there is a general decrease in both number of roots and cross-sectional root area with increasing depth.

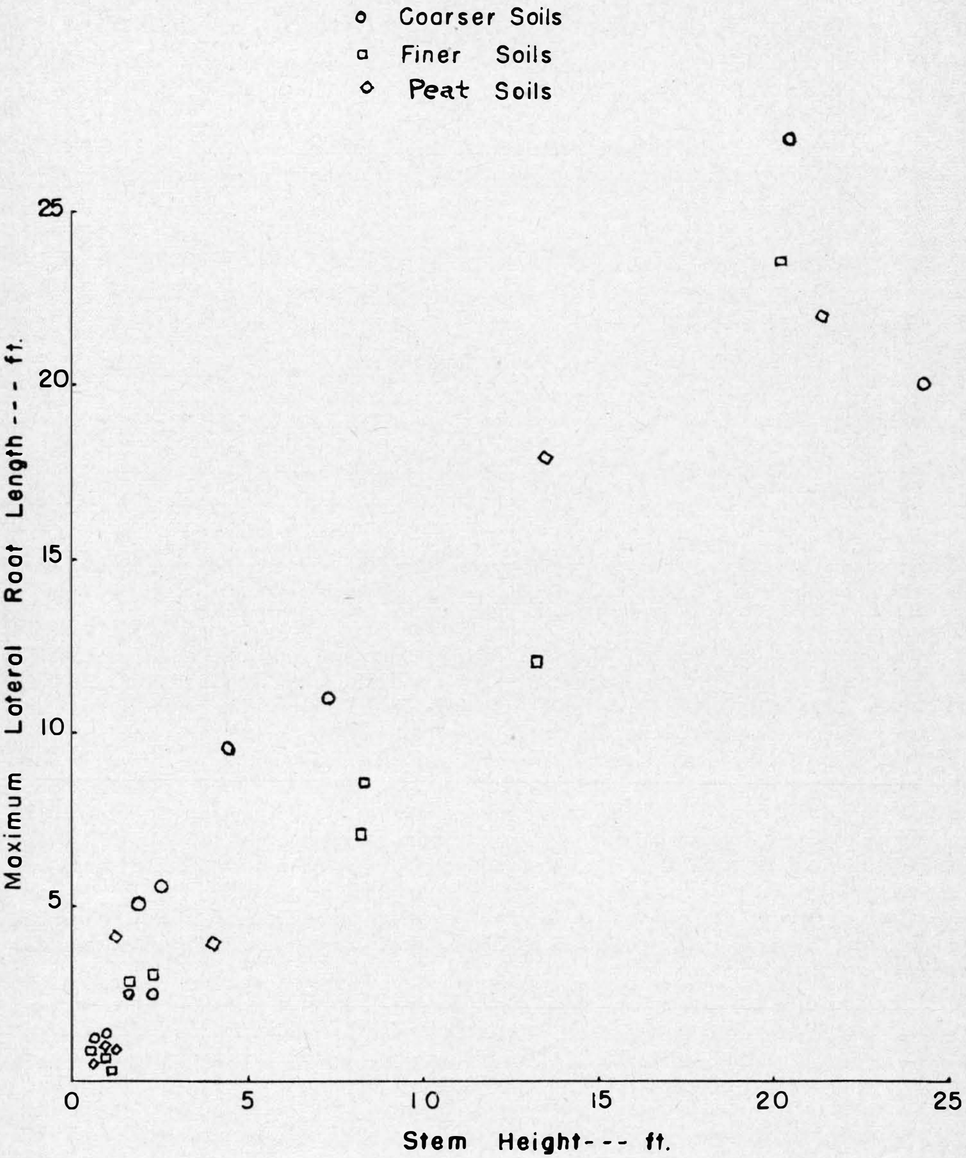
Rooting Extent—The fact that most lateral roots occur near the surface means that the lateral root system is much less influenced by the soil than the vertical system, which is normally subject to a variety of horizontal changes in texture and moisture. Among the various productive soil types of the present study there were no conclusive differences in lateral rooting extent. However, the unproductive soils supported much less extensive lateral rooting than the productive.

Length of the laterals increases with age of the tree on all soils, slowing to a negligible rate after about 50 years. Moreover, according to the data in Figure 7 there is a good relationship between maximum lateral root length and stem height. For the 20 years on all sites the two are practically similar, so that height could be used as a rough indicator of lateral root extent.

Figure 7

Maximum Lateral Root Extension

Related to Tree Height



The above discussion deals with open-grown trees, conditions where competition as a factor affecting root growth has been eliminated. Tree 20 was the only stand-grown tree to have its complete lateral root system exposed. Here, the roots showed a decided inclination to invade areas relatively free of root competition from neighbouring trees. Preston (1941) noted a similar tendency for lodgepole pine in Colorado. Of course, in a fully-stocked condition all of the available rooting space is presumably utilized so that a complex interweaving network of roots occurs. Plate 2 illustrates this situation clearly.

Occasionally laterals were noticed travelling directly under the stems of other trees some distance away. Preston (1941) also found this tendency and attributed it to a seeking-out of an area free of competition immediately surrounding the alien stem, where no secondary branching occurs.

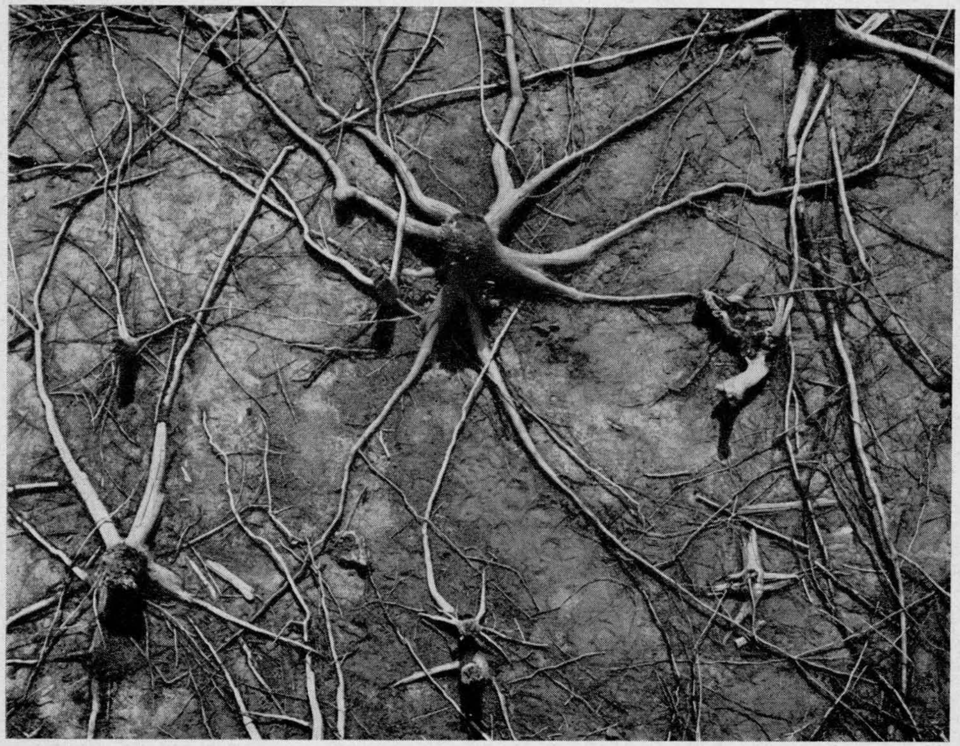


PLATE 2. Interwoven lateral root systems of a fully stocked 70-year-old lodgepole pine stand at Kananaskis, Alberta.

The Total Root System

The combined vertical and lateral rooting extent of most trees examined is shown in Figure 8, arranged to compare the effects of site and age. It indicates that in each soil type the total rooting extent reaches a maximum at about 35 years and then decreases. This suggests, considering that height growth continues to increase long afterwards, that rooting becomes more intensive as maturity approaches. Several of the oldest trees with the largest diameter had considerably less extensive root systems than some younger trees. They did, however, have a much more profuse or intensely-branched habit. This conforms with the findings of Vater (1927), Laitakari (1929) and others. As Laitakari put it, a young [Scots] pine explores a large area and, when older, it covers the exploited area more thoroughly.

Natural root grafts between trees in stand conditions were occasionally found in these examinations. According to Weaver and Kramer (1932), root intergrowth is a common phenomenon in many forest trees. It usually occurs within a few feet of the bole and is more abundant in fine-textured soils than in coarse owing to greater compression in the former.

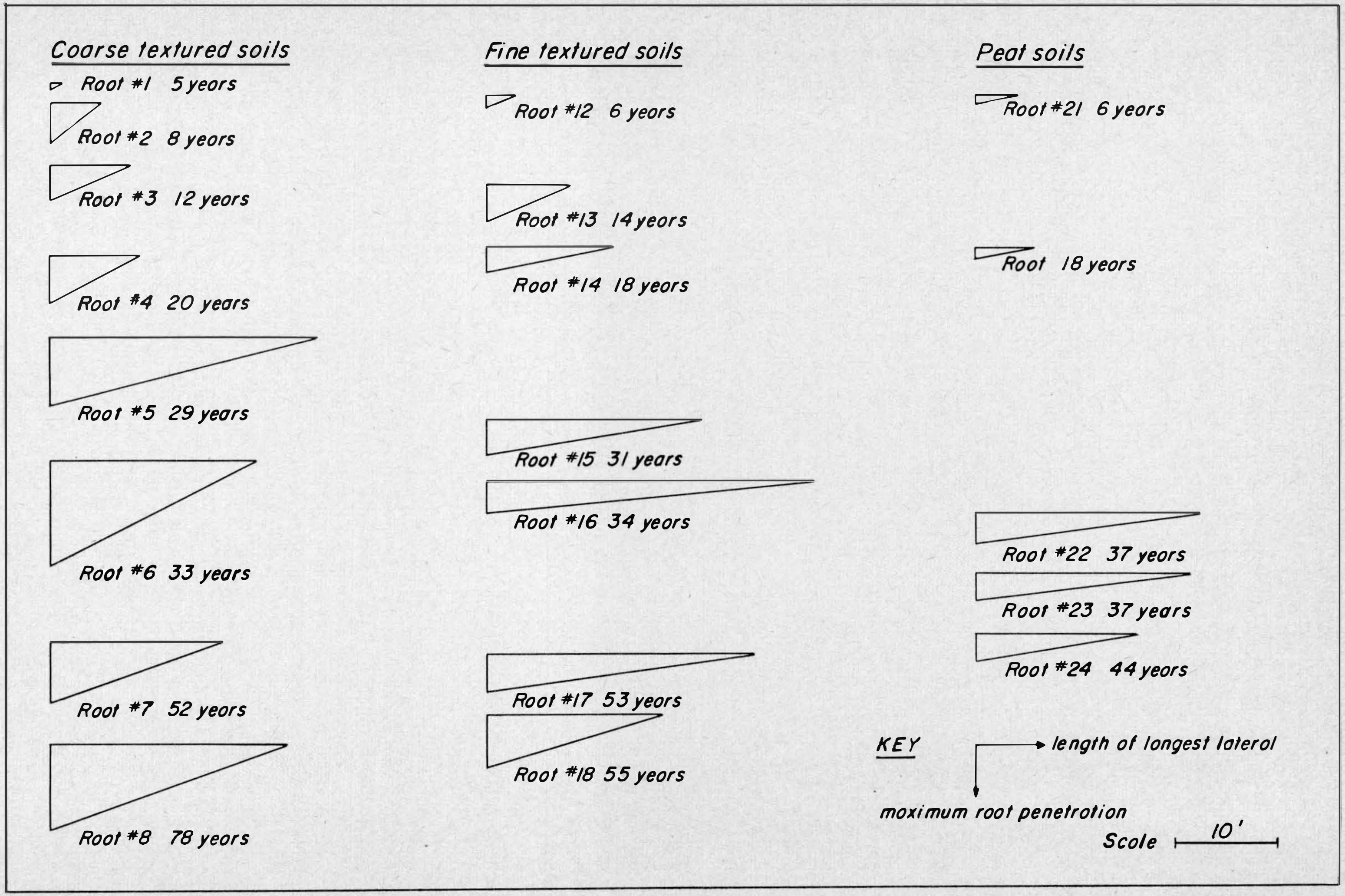


FIGURE 8. Relationship between maximum vertical root penetration and surface lateral extension by rooting media.

EFFECTS OF THE SOIL ON ROOTING

The implications of the foregoing facts and discussions on root morphology will be considered in connection with their causative agents. In this study the effect of tree competition has been controlled, and it was found that local climate was more or less similar in all samples. Thus, of the important factors of site influencing tree growth, only the soil remains. The component properties of the soil are dealt with below individually, i.e., physical texture, moisture and fertility.

It is difficult to isolate the effects of these three components. Obviously the finer silts and clays will have a greater moisture-holding capacity and fertility than the coarser materials, the sands and gravels. There is abundant evidence from the roots studied of a preference for the finer media. Tree 18 (see Figures 2 and 6) is a striking example of this, with its profusion of branching and resultant concentration of roots in the clay strata as opposed to the alternating sand strata. This finding concurs with those of Cheyney (1932), Sweet (1933), and Lutz *et al.* (1937). The point is also inferred by the roots in Soil Type F/C which show a marked inhibition of growth and a contorted form upon reaching the gravel layer underlying the clay. Furthermore, in Soil Type C, the coarsest soil involved, the root form is stunted and twisted from the first. It is not known whether the chief cause of these effects is physical soil texture, availability of moisture, or degree of fertility, but some light may be thrown on the question from the pertinent literature.

Texture

The physical resistance of the soil doubtless has some influence on the root form. Roots readily take advantage of channels in the soil—the path of least resistance—but, on the other hand, root growth up to a point at least can be inexorable, as witnessed in Soil Type M/R where an impenetrable obstruction merely deflected the taproot which proceeded to grow parallel with it. Yeatman (1955), in Britain, found a similar trend in lodgepole pine growing on upland heath soils with a hardpan at about one foot in depth, although some roots did penetrate the pan. According to Weaver and Crist (1922), an indurated layer in itself is no barrier to root penetration but a lack of available moisture therein is the cause.

Between these extremes of free and restricted rooting there is scope for great variation in rooting habit in relation to soil texture. It is reasonable to state from the evidence that the uniform fine sands permit a deep and relatively symmetrical root system whereas heterogeneous gravels result in a stunted tortured root form.

According to numerous workers, an extensive, sparsely branched and often deeply penetrating root system develops on coarse-textured soil while on fine materials a more compact, intensively branched effect occurs. Anderson and Cheyney (1934), in a controlled experiment with seedlings, went deeper into this question and showed that the length of the taproot increased decidedly from fine to coarser soil but that the opposite was true with the side roots. They propose that the taproot is not hydrotropic (being functional in anchorage), and therefore the greater resistance in finer soil would cause shorter taproots than in coarse soil, but the higher moisture content of fine soil would make the side roots larger in that texture. This description fits the observations of the present study well, if Soil Type MC and MC/F are looked upon as the coarser soils and F/C and MF as the finer.

The apparent anomaly involved in the coarsest soil, Type C, having suppressed vertical rooting, while the somewhat coarse Types MC and MC/F have the deepest rooting, might be explained by referring to the investigations of Cannon (1911), Weaver (1919), and Hayes and Stoeckeler (1935). They suggest that deep penetration is not the result of minimized resistance in coarse soil but of a following of filtering water. Preston (1941) concurs with this for lodgepole pine and agrees with the conclusion of Laitakari (1929) that the shallowest root systems are in coarse sandy soil (where percolation is too fast to influence rooting). This brings us to consideration of the effects on rooting of water in itself.

Moisture

The consensus is that the greater the available moisture the more intensive is the root system of a given species. This is a generalization and does not directly apply, particularly to lateral rooting of lodgepole pine. Excessive moisture seemed to cause sparse, branchless rooting of moderate length, and the effect was similar on the driest soil (Type M/R), which trend concurs with the findings of several workers (Weaver 1919, Laitakari 1929, and Day 1945).

The question of hydrotropism is involved in all these effects. Hooker (1915) stated that tree roots exhibit hydrotropism but will not penetrate a dry soil horizon to reach a moist one below it, and Preston (1941) found examples of this for lodgepole pine. There is evidence of hydrotropism in this study. The deep taproots (notably Trees 5 and 6) break up at a considerable depth into a fibrous root mass which suggests absorption as a function. The roots in Soil Type MC/F particularly seem to be attracted by the deep-lying, fine-textured stratum which holds more moisture than the overlying sand. But the clearest case for hydrotropism is Tree 10 (Figure 1), where some roots went 3 to 4 feet below the established rooting level of the tree to exploit an artificially raised water table.

In saturated soils, the lack of oxygen limits rooting (Weaver and Clements 1938, etc.). The experiments of Gail and Long (1935) with lodgepole pine seedlings showed that improved soil aeration resulted in more vigorous root and shoot development. Taproots of seedlings grown artificially in saturated soil were inhibited and many short stubby laterals appeared just below the water surface. This also occurs in older trees, as the roots in saturated peats studied here indicate (*see* Trees 23 and 24, Figure 3); much of the vertical rooting extension in these trees has resulted from the periodic lowering of the water table that occurs in hangmoors. A high incidence of dieback was evident in the roots which were under water at the time of excavation. In the case of an extremely high water table, such as in Tree 22, there is virtually no vertical root development, all roots bending horizontally. The stunted root and poor shoot development occurring in lodgepole pine on wet sites results in low productivity, but it is ecologically significant that, despite the extremely adverse condition, the species will live up to 285 years, as in Tree 25. This speaks well for the inherent vigour and adaptability of the species.

Fertility

The influence of soil fertility on rooting was demonstrated experimentally by Wahlenberg (1929) by stratifying highly fertile layers with almost sterile sand. Maximum seedling root development was found in and just below the fertile strata. Laitakari (1929) cites European investigators who arrived at the same conclusion. In the present study the roots of lodgepole pine appear to behave similarly—the soil conditions and rooting effects of Tree 18 (Figure 6) are much like Wahlenberg's—but, as has already been pointed out, the moisture variable confounds the issue.

Limy soils have been reported to cause root stunting in several species (Hilf 1927). In this study all of the root systems, with the exception of Tree 20 and those pictured in Plate 1, were from calcareous soil. There is no pronounced effect by the lime, although a high concentration of it in horizons under Tree 9 (Figure 1) and Tree 19 (Figure 2) may have had something to do with the sudden profuse and contorted root branching. Since a large proportion of the lodgepole pine in Alberta grows on calcareous soils, this matter warrants further investigation.

ROOT FUNCTION

This study provides some additional information on the controversial subject of vertical root function. Sterret (1920) and Cheyney (1932), describing vertical sinkers on jack pine, noted that they lacked fine root endings but terminated in short, finger-like processes indicating anchorage rather than absorption as their principal function. Toumey (1929) and Anderson and Cheyney (1934) support this functional concept but Weaver and Clements (1938), among others, oppose it, asserting that roots are active in absorption to their maximum depth. The suggestion put forth by Cannon (1911) and others, that deepest rooting results from the following of filtering water, adds weight to the latter view.

In the present investigation an interesting piece of evidence for the anchorage viewpoint was discovered. An even-aged stand of 80-year-old lodgepole pine growing on Soil Type MC/F had been thinned heavily in 1950. Four years later one of the dominant residuals (Tree A) was blown over, carrying with it the stump and root of a neighbour (Tree B). The windthrown Tree A had only a rudimentary taproot and no appreciable system of deep sinkers while the stump (Tree B) had both a strong tap and deep sinkers and, what is most significant, its laterals grew *over* those of Tree A. It looked as if Tree A did not become firmly anchored because it was able to depend on the over-riding laterals of the deeply rooted Tree B for anchorage. When Tree B was cut and its roots became so rotted that they lost their hold on the soil, Tree A lost its firm footing and was blown down by an extra-strong wind. Anchorage certainly seemed to be the main function of the root in this case.

On the other hand the fibrous root endings often encountered, together with various signs of hydrotropism on the part of the vertical roots, indicate that absorption does occur. Perhaps both anchorage and absorption are important functions of the vertical roots of lodgepole pine. In any case it is apparent that this species, either in its deep taproot or broad heart-root form, is relatively well anchored in an unimpeded soil.

PRODUCTIVITY

Generally, in productive soils height growth does not seem to be dependent on rooting depth. The comparatively shallow roots of Soil Type F/C support slightly better stem heights than the deep roots of Soil Type MC. The most important factor is rooting capacity rather than rooting extent: the fact that less than two feet of clay can produce equal stem growth to more than 10 feet of fine sand is surely significant. This implies that the rooting capacity of a given depth of fine-textured soil is greater than that of a similar depth of coarse-textured soil.

The sample on fine materials was neither large nor variable enough to confirm whether depth of the given soil medium affected height growth. However, the work of Smithers (1956) in the same area as Soil Type F/C indicated that as the fine (F) layer became shallower, the height growth of lodgepole pine decreased. This suggests that there is (for full stem growth) an effective rooting depth in the fine stratum; in lesser depths the root and stem development are retarded according to the decrease.

The most unproductive sites for lodgepole pine are those at the two extremes of the soil moisture scale, the very dry and the wet, both of which exhibit restricted rooting and hence slow stem growth. The fact that the species will grow at all on such adverse conditions as described here (and by Yeatman 1955 for upland heaths in Britain) indicates its great adaptability, which is largely attributed to its rooting habits.

APPLICATIONS

This study adds to the literature on rooting habits of trees and the physiological processes involved. Some of the evidence touches upon such fundamental points as hydrotropism and root function. Further investigations on diverse conditions and species are needed to obtain a proper knowledge of the relationships between soil properties and rooting, and between rooting and stem growth.

However, there are certain immediate practical applications of a study such as this. It has been shown that lodgepole pine rooting is adaptable to a very wide range of sites, but in extremely wet and very dry soils root restriction is such that poor stem growth results; also rooting and hence stem development is better in fine-textured soil than in coarse. This information may be useful whenever reforestation with lodgepole pine is planned. For example, the work of Yeatman (1955) shows it has already been usefully applied in Britain. There, the species is considered most suitable for pioneering afforestation on the very adverse conditions of upland heaths, because of its rooting adaptability and inherent hardiness.

In its native range the most important practical aspect of lodegpole pine's rooting habits is its effect on windthrow, a primary concern in forest management. The root systems examined suggest that this species is comparatively windfirm under normal rooting conditions. Its vertical root penetration is considerably greater than that of its common coniferous associates, spruce and fir, and toward maturity the broad, heart-shaped root form usually develops, adding stability. Only when the soil profile has some feature which restricts root penetration does the danger of windthrow become imminent.

Thus, when thinning or partial harvest cutting is contemplated, the danger of windthrow might be evaluated by a simple examination of the soil. If the texture within a foot or two of the surface is particularly coarse, if the bedrock is close to the surface, or if a high water table or hardpan exists, the rooting will be unstable and the cutting plans should be modified accordingly. Such conditions will usually be encountered on ridge tops, on gravelly alluvial flats, on the slopes where surface seepage occurs (hangmoor areas) and in poorly drained basins. Experience in a lodgepole pine cutting project in the Kananaskis area (Crossley 1955) has shown that, over a period of four years, up-rooting has been confined to heavily cut residual stands on soils where an inhibiting layer of gravel outwash approaches to within nine inches of the surface.

Similarly in clear-cutting practices, the cutting lines, particularly on the leeward side of the cut-over area, should avoid those sites which are susceptible to windthrow.

Anderson (1954), in a study of gale damage to forests in Scotland, pointed out that the firmer the rooting, the greater is the chance of stem breakage. Limited experience in this connection in Alberta suggests that stem breakage in residual lodgepole pine stands is usually confined to trees with heart-rot in the trunk. The narrow crown which characterizes even the dominant trees at harvestable age may well be a deterrent to this form of damage.

SUMMARY

In this study of rooting habits of lodgepole pine in Alberta, more than 40 root systems of varied ages and in diverse soils were excavated. The findings, outlined below, were considered in relation to the pertinent literature.

General root form. Lodgepole pine root forms vary widely with different soil conditions and between individuals in the same soil. The taproot is maintained, although it may be bent, stunted, atrophied at its extremity, or obscured by a surrounding mass of sinkers which descend vertically from the bases of the lateral roots. A system of sinkers usually develops before the polewood stage (40 years), resulting in a heart-shaped root form. This appears to be largely an inherent tendency but exceptions are frequent. The adaptability of this species' rooting habit explains its wide ecological amplitude.

Vertical rooting. This is restricted by very coarse-textured soil, by a high water table, and by an impermeable layer. In such conditions the roots become bent, convoluted, clubbed or dead. In the soils sampled, penetration was greater in somewhat coarse than in fine-textured media and was greatest in fine sands deeply underlain by clays. There is evidence that the vertical roots function significantly in both anchorage and absorption. Several examples of apparent hydrotropism were noted.

Lateral rooting. Most of the lateral roots are in the top few inches of soil. They will seek out areas free of root competition, but on a fully-stocked site the root systems of adjoining trees become inter-woven, and natural grafts may occur. In wet and very dry conditions both rooting extent and amount of branching are much less than on the more productive sites. For the first 20 to 25 years, maximum lateral root length was found to be about the same as stem height in the open-grown conditions sampled.

Root growth. In general, rooting is extensive at first, attaining maximum areal coverage by 30 years, well before maximum stem height growth is reached; then, nearing maturity, as tree growth requirements increase, rooting becomes much more intensive and complex.

Soil influence. Rooting is more concentrated in the finer-textured soils where both moisture and fertility are superior. Thus a given depth of silt or clay has a greater effective root capacity than a similar depth of sand. The coarse sands and gravels inhibit rooting altogether.

Productivity. The greater root capacity of the finer soils is reflected in superior stem height growth. Restriction of rooting, owing to a shallow effective soil or a high water table, results in correspondingly poor stem growth.

Windthrow. Lodgepole pine is considered to be a relatively wind-firm species on normal soils due to its deep vertical rooting and its tendency to form a broad, heart-shaped root system. On sites where vertical rooting is inhibited, however, the danger of windthrow is appreciable, and cutting practices should be planned accordingly.

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