NATURALLY DEVELOPED SEEDLING ROOTS OF FIVE WESTERN CONIFERS[1/]

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Abstract.--Two-year-old seedlings grown from seed outdoors in three southwestern Oregon soils were excavated to determine their root development. Roots of Douglas-fir, ponderosa pine, sugar pine, grand fir, and incense-cedar seedlings differed substantially in total extent, form, and balance in relation to tops. Information on the natural development of roots provides a benchmark for judging how much root development of nursery stock is altered.

INTRODUCTION

At time of outplanting and in their subsequent development, the roots of trees produced in nurseries differ appreciably from those of seedlings originating from seed on site (Sutton 1969). Some differences caused by nursery or planting practices may be unimportant to the seedlings' normal growth and development; others may be critically important. During this Symposium we hope to identify more precisely the key elements of root form that influence the performance of planting stock. Detailed information gained from seedlings grown undisturbed provides a benchmark for judging in what way and by how much nursery practices alter the natural form and development of roots.

Information on the natural root form of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], ponderosa pine (*Pinus ponderosa* Laws.), sugar pine (*Pinus lambertiana* Dougl.), grand fir [*Abies grandis* (Dougl.) Lindl.], and incense-cedar (*Libocedrus decurrens* Torr.) was gathered as part of a comprehensive study on juvenile development of these five species.[3/] This report covers only the root form and top-root ratio of 2-year-old seedlings that grew outdoors from seed. Such seedlings are the same age and broadly comparable in size to 2-0 bare-root nursery stock, the most commonly used class of stock in the Pacific Northwest.

METHODS

Seedlings were grown from local seed especially collected for study purposes within the South Umpqua drainage, Douglas County, Oregon. To obtain seed lots that were locally representative and genetically comparable, cones were collected from at least 10 trees of each species within a 10-mile radius of the South Umpqua Experimental Forest. The 10 source trees for each species represented two or more localities and were of average phenotype or better. Collections included seed from north and south slopes from an elevation range of 518 to 975 m (1,700 to 3,200 feet). Seed for all species but sugar pine was collected in the generally good seed year 1956; sugar pine was collected in 1958.

Sets of seedbeds were located on three contrasting soils in the Umpqua River drainage. The most accessible site was on a river terrace of pumice soil in the North Umpqua Valley within the community of Glide (T. 26 S., R. 3 W., NE1/4, NW1/4, sec. 19, Willamette meridian). This was a cleared area which still contained a scattering of live conifer roots from adjacent grand fir trees. The second site, on Gustin soil, was located in an older clearcut along Acker Ridge, a major landform between the South Umpqua River and a main tributary to the south, Jackson Creek (T. 30 S., R. 1 W., SE1/4, SE1/4, sec. 1, Willamette meridian). The third site was in a fresh clearcut on Dumont soil located north of the South Umpqua

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3/ Stein, William I. 1963. Comparative juvenile growth of five western conifers. 194 p., illus. Ph.D. thesis on file at Yale Univ., New Haven, Connecticut.

River (T. 29 S., R. 1 E., NW1/4, SW1/4, sec. 3, Willamette meridian). All five species are native in the three test localities.

Important characteristics of the specific sites and soils that affected root growth include the following:

Site characteristic	Glide	Location Gustin	Dumont
Elevation (m)	210	1 010	850
Aspect	Flat	West	Northeast
Slope	0	5-10	5-10
Soil series	Crater Lake[1/]	Gustin[2/]	Dumont[2/]
Kind of soil	Alluvial pumice	Gray-brown podzol	Reddish-brown latosol
Soil properties			
Texture-surface	Loamy sand	Loam	Clay loam
-lowest horizon	Silty clay loam	Weathered rhyolitic tuff	Weathered breccia
Total depth (cm)	180	100	160
Bulk density-surface (gm/cc)	.61	.90	.81
-maximum (gm/cc)	.67	1.20	1.21
Total pore space-surface (%)	77	66	69
-minimum (%)	75	55	54
Micropore space-minimum (%)	44	32	26

[1/] Alluvial pumice at Glide is probably identical to the Crater Lake series but lies outside the territory for which the Crater Lake series has been described and delineated (see Richlen 1973).

[2/] General profiles and many characteristics of Dumont and Gustin soil series are given in "Soil Survey of the South Umpqua Area, Oregon," (Richlen 1973).

Seeds were fall-sown individually by hand in rows placed 10 cm (4 inches) apart across the 1.2- x 2.4-m (4- x 8-foot) beds. Surface soil to about 10-cm (4-inch) depth was first loosened, raked free of debris, and smoothed. Seeds were then pressed into the soil and covered proportionate to their size, 3 to 19 mm (1/8 - 3/4 inch) deep. Within rows, pine seeds were spaced 10 cm (4 inches) apart, Douglas-fir seeds 5 cm (2 inches) apart, and grand fir and incense-cedar seeds 2.5 cm (1 inch) apart. Unequal spacings were used within rows to compensate for expected species differences in germination and survival. For the same reason, five rows of grand fir and incense-cedar seed were sown per bed and only four rows each of the other three species. The species were assigned at random to the 22 rows per seedbed. A wooden frame enclosed each seedbed and supported a protective hardware cloth cover from sowing through the first growing season. Seedbeds were weeded periodically.

Two years after sowing, all seedlings were excavated from two beds designated in advance at each location. Roots were washed out of the soil at Glide. In the two forest locations, they were dug out manually with shovel, axe, hoe, trowel, screw driver, and ice pick (fig. 1). Diligent efforts were made to recover the entire tap root and all large laterals. During manual excavation, many smaller roots and rootlets were not recovered from chunks of soil.

After excavation, length of top, tap root, and lateral roots was measured on 20 predesignated seedlings of each species except incense-cedar. Roots were pulled straight for measurement, and allowances for kinks or bends that did not straighten were included. Seedlings were dried overnight or longer at 105°C before determination of oven-dry weights. Both size and ratio data were subjected to analysis of variance; the data for tap root length and for length of main laterals were transformed to logarithms to overcome variance heterogeneity. Differences among species indicated by F Test were identified by use of Duncan's Multiple Range Test for pairwise multiple comparisons among means (Duncan 1955). The actual probability level for many of the differences was also determined. Data for incense-cedar are only indicative since too few samples of this species were available to permit full analysis.

TAP ROOT LENGTH

In 2 years from seed, seedling tap roots grew deeply into lower soil horizons and revealed important differences in species capability (table 1). Ponderosa pine grew the longest tap roots by a substantial margin in each of the three kinds of soil. A limited sample indicated that incense-cedar generally had the second greatest capability despite evidence that root rots cause more tip dieback and root proliferation in this species than others. Sugar pine had an intermediate amount of tap root development. Tap roots of Douglas-fir and grand fir grew about the same length, but substantially less than those of the other three species.

Table 1.--Average tap root length of 2-year-old seedlings grown outdoors in three soils

Species	Average tap root length in each soil		
	Crater Lake	Gustin	Dumont
	--- Centimeters ---		
Douglas-fir	63.2a[1]	46.5ab	58.0a
Grand fir	66.9a	44.3a	54.3a
Sugar pine	101.9b	57.3b	89.2b
Ponderosa pine	165.6c	92.8c	102.4c
Incense-cedar	126.5	79.3	90.3

[1]Means in each column not followed by a common letter differ significantly at the 5-percent level. All species are represented by 40 seedlings each except incense-cedar. Few incense-cedar seedlings were available, 7, 9, and 2 for Crater Lake, Gustin, and Dumont soils respectively, and their data were omitted from statistical comparisons.

Average tap root length differed substantially in the three soils, but ranking among species remained about the same. Tap roots were longest in the deepest and least dense soil and shortest in the shallowest and most dense soil.

The longest tap roots of ponderosa seedlings had penetrated through 180 cm of pumice soil at Glide and 16 cm into a buried clay layer. In Gustin soil, they penetrated 100 cm of soil and extended as much as 11 cm into weathered parent material. Their penetration was equally impressive in Dumont soil, 126 cm, but ponderosa tap roots had generally not yet grown completely through a non-uniformly deep C horizon.

LENGTH OF MAIN LATERALS

In 2 years, seedlings developed long lateral roots, and average length differed substantially among species. The average length of main laterals was calculated as the mean of the four longest laterals. Numerous seedlings had more than four long laterals.

Length of main laterals differed significantly among Douglas-fir, grand fir, sugar pine, and ponderosa pine when data from all localities were combined. Lengths also differed significantly among the four species at individual localities (table 2), except at Dumont between Douglas-fir and grand fir and between the two pines. Grand fir and Douglas-fir had the shortest laterals; those of sugar pine were intermediate; and those of ponderosa pine and incense-cedar were generally longest.

Table 2.--Average length of main lateral roots on 2-year-old seedlings grown outdoors in three soils

Species	Average length of main lateral roots in each soil[1]		
	Crater Lake	Gustin	Dumont
	---- Centimeters ----		
Douglas-fir	43.4b[2]	19.4b	18.5a
Grand fir	31.3a	14.3a	15.3a
Sugar pine	69.1c	25.8c	35.0b
Ponderosa pine	106.9d	40.6d	46.8b
Incense-cedar	130.3	43.2	33.0

[1]The average length is the mean of the four longest laterals found on each seedling.

[2]Refer to footnote 1, table 1.

Some lateral roots were surprisingly long. Exceptional seedlings in Crater Lake soil had feeder roots in an area more than 4 meters across. An incense-cedar had the broadest lateral root spread of any seedling excavated, 4.5 meters (fig. 2).

TOP-ROOT RATIO

Roots of naturally developed seedlings are many times longer than seedling tops. Among the species studied, tap roots averaged from 2.2 to 8.3 times (ratios .45 and .12) longer than tops at the end of the second season (table 3). Incense-cedars had the lowest differentials between top and root lengths, and sugar pine was next lowest in two of the soils. In an analysis combining localities, top-root length ratio for sugar pine seedlings was significantly less than for grand fir but not for Douglas-fir or ponderosa pine. Nor did the top-root ratio for Douglas-fir differ from that for ponderosa pine or grand fir. There were significant soil-species interactions, however; for individual soils (localities) not the same species combinations differed significantly in top-root length ratios.

Table 3.--Average top-root ratio in length and dry weight of 2-year-old seedlings grown outdoors in three soils

Species	Average top-root ratio in each soil		
	Crater Lake	Gustin	Dumont
	------ Length ------		
Douglas-fir	.19ab[1/]	.18ab	.21a
Grand fir	.12a	.15a	.19a
Sugar pine	.28b	.22b	.19a
Ponderosa pine	.18a	.16a	.17a
Incense-cedar	.45	.36	.25
	---- Dry weight ----		
Douglas-fir	1.33a	1.71a	1.58a
Grand fir	1.13a	1.45a	1.60a
Sugar pine	1.33a	1.60a	1.46a
Ponderosa pine	1.27a	2.05a	1.71a
Incense-cedar	1.83	2.22	1.77

[1/] Refer to footnote 1, table 1.

The observed top-root ratios include the effects of spring frosts which slightly damaged year-old Douglas-fir and grand fir tops at Dumont, moderately damaged these species at Glide, and severely damaged Douglas-fir, grand fir, and sugar pine seedlings at Gustin. The late May frost at the latter location even lightly damaged ponderosa pine and incense-cedar seedlings. It is most likely the frost damage only slightly accentuated the top to root ratios.

For each species, the average top dry weight of 2-year-old seedlings exceeded their root dry weight (table 3). Only in two instances, however, was the top-root weight ratio as high as 2--for incense-cedar and ponderosa pine at Gustin. Analysis of data for these three localities combined indicated the probability was about 4 out of 5 that dry weight ratios differed among species. The probability was 93 percent that ratios for ponderosa pine and Douglas-fir differed from those for sugar pine and grand fir.

Top-root ratios differed significantly among soils--root weights more nearly equalled top weights in Crater Lake soil than in the heavier-textured Gustin and Dumont soils.

ROOTING PATTERN

Although individual seedlings varied greatly, root systems of each species developed rather distinctively. Rooting patterns were best observed when washing roots from Crater Lake soil but were also evident in Gustin and Dumont soils. At the latter locations, however, root distribution was much more affected by old root channels, solid objects, and variations in soil density.

The tawny brown root systems of grand fir had the least extensive development (fig. 3). Seedlings generally had a few main laterals that paralleled the soil surface at moderate depths or trended gently downward. Lower soil layers were sparsely occupied; generally, only short laterals extended outward from a deep-growing rather straight tap root. There were instances, however, where laterals originating near the surface grew as deep as the tap root but had less side roots. Higher order branching of roots was common but such roots were still very short.

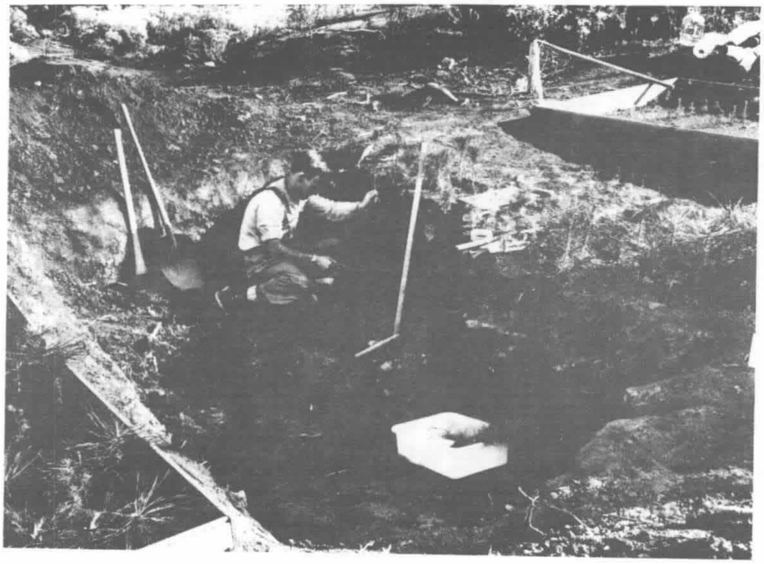


Figure 1 (left).--Manual excavation of seedlings from Dumont soil required painstaking digging with a variety of tools.

Figure 2 (right).--An incense-cedar growing in pumice soil had the broadest lateral root spread of any seedling excavated, 4.5 meters (Scale - 1 meter.)

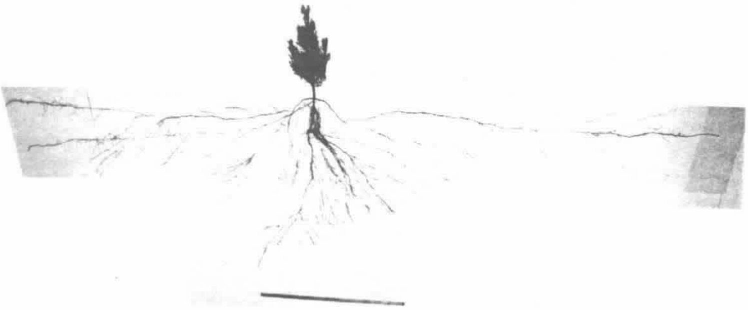


Figure 3 (bottom).--Representative 2-year-old grand fir seedlings excavated from pumice soil. (Successive depth lines are 30 cm apart.)

Typical Douglas-fir seedlings developed laterals that paralleled the soil surface, a tap root, and a number of laterals that originated in upper soil layers but trended downward at a 45° angle or less (fig. 4). Root systems varied greatly--from a long tap root with a limited number of short laterals to lack of a distinct tap root and exceedingly heavy lateral and higher order root development. Descending laterals often extended as deep, and sometimes deeper, than the tap root; but their tips were generally not as large as the tip of the tap root. Unbalanced development of descending laterals was common; often the tap root appeared impeded and growth of laterals seemed to compensate. Douglas-fir roots tended to be medium brown to brownish-black and had many prominent mycorrhizal short roots.

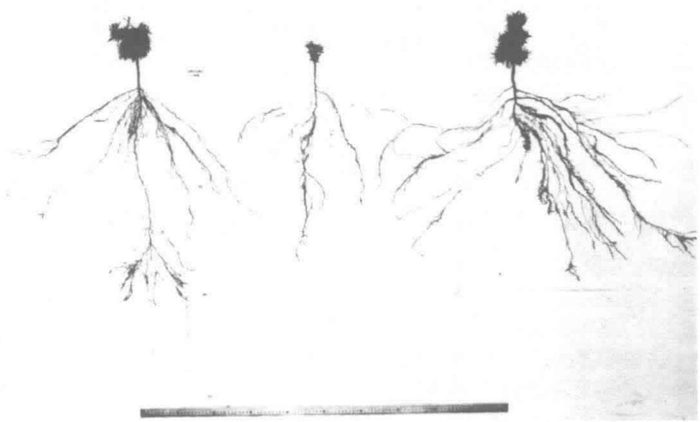
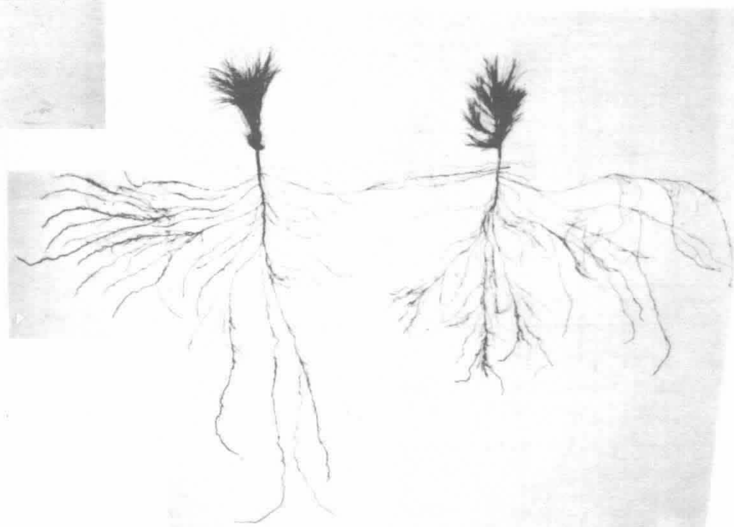


Figure 4.--Representative 2-year-old Douglas-fir seedlings excavated from pumice soil. The seedling on the righ has an atrophied tap root and extra long laterals. (Scale - 1 meter).

Figure 6 (below).--Representative 2-year-old ponderosa pine seedlings excavated from pumice soil. The seedling on the right lost its tap root at 16.5 cm and developed several deep-rooted replacements.



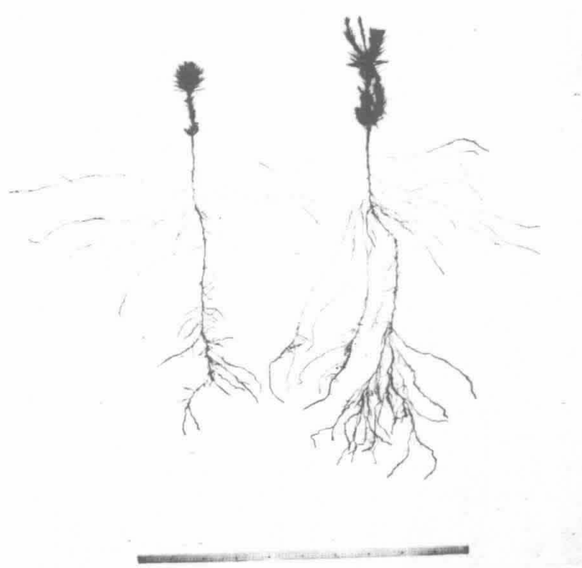


Figure 5.--Two-year-old sugar pines excavated from pumice soil. The one on the right has a well-developed group of deep laterals that occupied a cone of soil around the tap root.

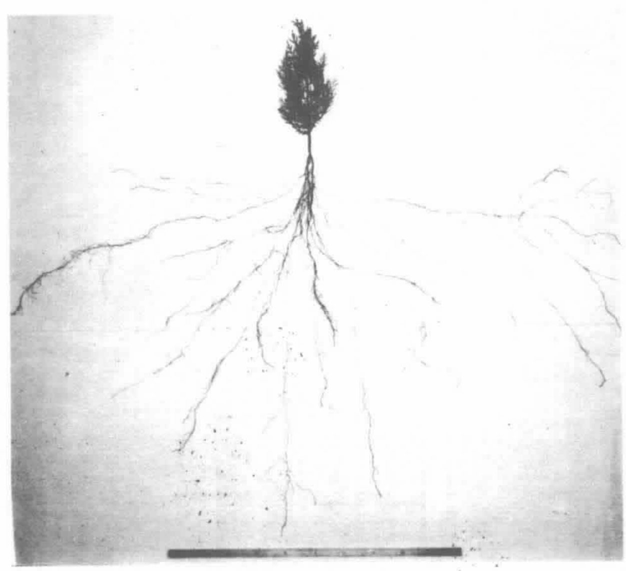


Figure 7.--An average size 2-year-old incense-cedar excavated from pumice soil. Multiple taɪ roots penetrated moderately deep and the root system branched extensively.

Sugar pine generally developed a well-defined tap root and heavy laterals that paralleled the soil surface (fig. 5). Laterals near the surface were often longer than the tap root if rooting depth tended to be shallow; but if the tap root extended deeply, horizontal root development was less. Some large laterals tended to grow downward at a distance from the seedling stem. During the second season, laterals commonly originated on the lower tap root and occupied a cone of soil around the tip (fig. 5). Their tips were at nearly the same depth as the tip of the tap root. Sugar pine roots tended to be medium to dirty brown in color, not markedly different from Douglas-fir.

The tawny to reddish brown roots of ponderosa pine seedlings demonstrated impressive ability to occupy large volumes of soil. A deeply penetrating tap root was often flanked by two or more roots which originated from it in upper soil layers (fig. 6). At intervals, these vertical-growing roots would put out laterals which grew either horizontally or at an angle downward. Long horizontal or slightly downward growing laterals also developed 5 to 30 centimeters below the surface. Roots branched from main laterals horizontally, downward at different angles, and straight down. In Crater Lake soil, such vertical "sinker" roots often exceeded 1 meter in length and might number up to half dozen or more per single primary lateral. On both ponderosa pine and sugar pine, the main horizontal laterals tended to curve as they extended outward.

Incense-cedar seedlings also demonstrated impressive ability to occupy large volumes of soil, but their rooting pattern was more diverse and unpredictable than for ponderosa pine. Typically, incense-cedar had widespreading lateral roots and several downward-growing roots, any one of which might turn out to be deepest (fig. 7). Laterals and downward-growing roots branched and rebranched profusely with new roots generally angling away from the parent root at about a 45° angle. Thus, each main root tended to occupy an enlarging cone of soil as it grew outward. Some branches from horizontal laterals commonly grew upward to within 2 or 3 centimeters of the soil surface, a feature observed to some extent also on ponderosa pine. Larger roots of incense-cedar were purple-red in color; lengthy stretches of pinkish or yellow-white unsuberized roots were found behind off-white root tips.

Solid obstacles, differences in soil density, degree of competition, and damaging agents caused variation in the root form of many seedlings. It was evident that roots often grew along paths of least resistance, especially hollow or loosely filled old root channels. Since Crater Lake soil had greater depth, more uniformity, and less obstacles than the others, each species' typical pattern of root development was probably best expressed at Glide. Evidence that seedlings of all five species lost tap roots because of rots or other causes (Stein 1963) was common. Many seedlings withstood such mishaps without indicating by their top appearance that they had been damaged.

NATURALS VS. NURSERY STOCK

By the end of the second year, seedlings that developed on site were well-established and ready for fast growth. Their roots already occupied a surprising amount of territory. Differences in species capability were not unexpected but are still noteworthy because of their magnitude. Even more noteworthy, however, is the marked contrast in balance and form of natural seedlings and nursery stock.

Top to root length ratios are reversed in nursery stock when compared to seedlings of the same age that have developed in place. Whether grown in a container or grown bare-root and trimmed, at outplanting time the top length of nursery stock often equals or is longer than its root length, i.e., a ratio of 1:1 to 2:1 or more. Compare this with a generally 1:4 or greater top to root length differential natural seedlings have while becoming established! The contrast between the dry weight ratios is not as great; but at the end of their establishment period, dry weight ratios for natural seedlings ranged from about 1:1 to 2:1, whereas top-root weight ratios for nursery stock often exceed 2:1 at the beginning of its establishment period. Nursery stock has more top to sustain with a proportionately smaller, somewhat damaged, poorly distributed, and loosely anchored root system.

All five species developed long laterals a short distance below the soil surface. These laterals branched extensively to tap both surface and lower soil layers. They also provided a widespreading support system. Laterals of bare-root nursery stock are usually trimmed to the same length as the tap root, or are shaped in containers to parallel the tap root. Thus, when nursery stock is planted, its laterals all point downward. Some may grow on to compete with the original tap root. Renewal of horizontal growth requires development of new root tips either near the cut end of the lateral or higher up. Do such replacement roots provide the equivalent in absorbing and support capability to laterals that develop in place? It appears we don't know.

Container seedlings particularly, and to a lesser extent bare-root trees, have a dense, fibrous root mass clustered around the tap root in upper soil layers. Natural seedlings generally do not develop such a concentration of roots anywhere on their systems. Consequently, there is less need or occasion for roots of naturals to coalesce to maintain a functioning system.

It is evident there are some important differences in the form and balance of nursery stock and seedlings that develop in place. We must still learn, however, which of these differences are critically important to the tree's "normal" top and root development.

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