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RELATIONSHIP OF SHOOT-ROOT RATIO TO SURVIVAL AND GROWTH OF OUTPLANTED DOUGLAS-FIR AND PONDEROSA PINE SEEDLINGS

by

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ABSTRACT

Two-year-old Douglas-fir and ponderosa pine seedlings with three top heights, and with either large or small roots, were planted in a burned-over area in north-central Washington to evaluate the relationship of shoot-root ratio to first-year survival and shoot growth. Survival of fir seedlings with large roots was 22 to 26 percent higher than survival of seedlings with small roots, and pine survival was increased 5 to 15 percent. Shoot growth (increase in shoot mass) of large-rooted fir and pine seedlings was as much as 2.1 and 4.8 times, respectively, that of small-rooted seedlings. Height growth of both fir and pine seedlings with large roots was 1.2 to 1.7 times that of seedlings with small roots.

KEYWORDS: Root development (-shoot growth, seedling survival, Douglas-fir, *Pseudotsuga menziesii*, ponderosa pine, *Pinus ponderosa*.

Shoot-root ratio is an important factor in survival of planted conifer seedlings, because shoot and root sizes directly affect water loss and uptake and hence the internal water stress of seedlings after outplanting. Hermann (1964), in a test with Coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), found that survival of seedlings with small roots was significantly lower than survival of seedlings with large roots, regardless of size of top. Also, Carlson (1972) found that the survival of jack pine (*Pinus banksiana* Lamb.) seedlings with low shoot-root ratios was higher than survival of seedlings with relatively high ratios. Edgren,^{1/} discussing factors in regeneration success of coastal Douglas-fir, regards a top-to-root ratio of 2:1 as acceptable for dry sites and possibly 4:1 for wet sites. However, information is limited concerning the relationship of shoot-root ratios to survival in most species and in varieties of a given species. This report describes the relationship of shoot-root ratio and height of top to survival and growth of Rocky Mountain Douglas-fir (var. *glauca*) and ponderosa pine (*Pinus ponderosa* Laws.) seedlings on a dry site.

METHODS

Seedlings were planted on two sites differing somewhat in dryness, in the Brennegan Creek watershed, a tributary of the Entiat River in north-central Washington. Elevation ranged from 900 to 1150 m (3,000 to 3,800 ft). Exposure varied from east to southwest and slope, from 20 to 40 percent. Average annual precipitation at 900 m is 55.9 cm (22 in) per year, and mean annual temperature is 6.8 °C (44.3 °F). Summers normally are hot and dry, with only about 13 percent of the precipitation occurring from June to September (fig. 1).

Figure 1.--Mean monthly precipitation and temperature at 880 meters (2,900 ft) in a watershed adjacent to the planted area show relatively high precipitation and low air temperature during 1975 compared with previous average values. The rainfall during August 1975 occurred during a 2-day period, thoroughly wetting the soil in the seedling root zone.

^{1/} Edgren, J. 1975. Factors in regeneration success. Talk presented to U.S. Forest Service R-6 Silvicultural Workshops. [On file at U.S. For. Serv. For. Sci. Lab., Corvallis, Oreg.]

Soils are coarse and relatively deep, developing in coarse ash or pumice over granite bedrock and are classified as Stormy or Rampart sandy loams (Iritani 1965). Vegetation, after a severe forest fire in 1970, consisted mostly of artificially seeded orchardgrass (*Dactylis glomerata* L.) and scattered snowbrush ceanothus (*Ceanothus velutinus* Dougl.).

Two-year-old fir and pine seedlings, grown at nurseries at Wind River, Washington, and Bend, Oregon, from locally collected seed, were graded to obtain three arbitrarily selected top height classes. Height classes were:

<u>Fir</u>	<u>Pine</u>
7-11 cm (2.8-4.3 in)	7-11 cm (2.8-4.3 in)
14-18 cm (5.5-7.1 in)	12-16 cm (4.7-6.3 in)
21-25 cm (8.3-9.8 in)	17-21 cm (6.7-8.3 in)

Height of top was measured from the root collar to the tip of the terminal bud. Each height class was then graded to obtain seedlings with large and small root systems (fig. 2).

Figure 2.--Height and root classes of Douglas-fir and ponderosa pine seedlings used in the experiment. In each height class, seedlings on the right represent good root development; those on the left, poor development.

Twenty-five seedlings of each height and root class were used to characterize shoot-root ratios and stem diameters. Stem diameters were measured just below the root collar. Seedlings then were cut at the root collar, shaken to remove excess water, and the shoot and root weighed, oven-dried, and reweighed to obtain fresh and dry weights. Top heights of the firs ranged from 7 to 25 cm (2.8 to 9.8 in), shoot-to-root ratio (ovendry basis) from 0.8 to 1.8, stem diameter from 2.9 to 6.1 mm (0.11 to 0.24 in), and seedling weight (ovendry basis) from 1.0 to 6.0 g (table 1). In the pines, top height ranged from 7 to 21 cm (2.8 to 8.3 in), shoot-to-root ratio from 1.5 to 2.7, stem diameter from 4.4 to 8.2 mm (0.17 to 0.32 in), and seedling dry weight from 2.9 to 10.5 g (table 2). In both species, shoot-root ratios on a fresh-weight basis were similar to those determined on a dry-weight basis.

Table 1--Seedling characteristics, survival, and growth of 2-0 Douglas-fir seedlings

Top size and root development	Shoot: root ratio ^{1/}		Stem diameter ^{1/}	Seedling weight ^{1/}		Survival	Height growth ^{2/}	Shoot growth ^{3/}
	Ovendry weight	Fresh weight		Dry	Fresh			
	----- Grams -----		----- Millimeters -----	----- Grams -----		----- Percent -----		
Small (7-11 cm):								
Large roots	0.8	0.7	3.8	1.9	7.1	82.5	27.2	80.5
Small roots	1.4	1.5	2.9	1.0	2.8	56.5	17.8	51.5
Medium (14-18 cm):								
Large roots	1.0	1.0	4.4	3.8	13.2	78.5	21.4	64.3
Small roots	1.5	1.6	3.5	1.6	5.3	56.5	17.8	49.6
Large (21-25 cm):								
Large roots	1.3	1.2	6.1	6.0	20.6	80.0	17.1	52.3
Small roots	1.8	1.8	4.3	3.1	9.7	58.4	11.2	25.5

^{1/} Each value is based on 25 measurements.

^{2/} $\frac{\text{final height} - \text{initial height}}{\text{initial height}} \times 100$.

^{3/} $\frac{\text{total weight of new shoot growth}}{\text{total weight of shoot-weight of new shoot growth}} \times 100$.

Table 2--Seedling characteristics, survival, and growth of 2-0 ponderosa pine seedlings

Top size and root development	Shoot: root ratio ^{1/}		Stem diameter ^{1/}	Seedling weight ^{1/}		Survival	Height growth ^{2/}	Shoot growth ^{3/}
	Ovendry weight	Fresh weight		Dry	Fresh			
	----- Grams -----		----- Millimeters -----	----- Grams -----		----- Percent -----		
Small (7-11 cm):								
Large roots	1.7	1.7	5.4	4.8	16.9	99.5	27.8	79.9
Small roots	2.1	2.3	4.4	2.9	10.3	94.0	19.1	16.8
Medium (12-16 cm):								
Large roots	1.5	1.4	8.2	10.5	34.7	98.5	20.7	35.4
Small roots	2.3	2.5	4.6	3.5	12.1	91.0	13.2	15.4
Large (17-21 cm):								
Large roots	2.1	2.0	7.3	9.1	30.9	97.5	18.1	39.8
Small roots	2.7	3.0	5.5	5.2	17.6	82.0	10.8	11.4

^{1/} Each value is based on 25 measurements.

^{2/} $\frac{\text{final height} - \text{initial height}}{\text{initial height}} \times 100$.

^{3/} $\frac{\text{total weight of new shoot growth}}{\text{total weight of shoot-weight of new shoot growth}} \times 100$.

In mid-May, 600 seedlings of each species were planted on each of the two sites, a total of 1,200 seedlings of each species. Seedlings were planted in a randomized block design with split plots (paired rows) within blocks. Blocks were replicated four times per species at each site, with 25 seedlings of each top and root class per replication. Each pair of rows consisted of a particular top size, with one row containing seedlings with good roots and the adjacent row, seedlings with poor roots. Planting spots were scalped free of vegetation, and the seedlings were hand planted with a hoedag. Soil moisture tension measured just before planting was 0.1 to 0.2 bar.

After planting, heights of seedlings were measured from ground surface to the tip of the terminal bud. A survival count was made in mid-October, 5 months after planting, and heights were remeasured. Seedlings were classified as dead only if all needles were brown and dry. Seedlings from one block of each species were dug up for determination of the total amount, by weight, of new shoot growth.

RESULTS

Except for height growth of the firs, survival and height growth of the two species were similar for the two planting sites; consequently, data from the two sites are combined in tables 1 and 2. Significance of differences was determined by analysis of variance. Survival of fir seedlings for all height and root classes ranged from 56.5 to 82.5 percent, with no significant effect of top height on survival within root classes. Survival of pine was higher, ranging from 82 to 99.5 percent, with survival of small seedlings slightly but not significantly higher than that of medium and large seedlings. The most conclusive result was that in both fir and pine of all height classes, survival of seedlings with large roots was significantly higher (1-percent level) than survival of those with small roots. In fir, the increase in survival ranged from 21.6 to 26 percent, and in pine, 5.5 to 15.5 percent, with no significant differences between top sizes.

Height growth was similar in fir and pine, ranging from about 11 to 27 percent for all height classes. Percent height growth increased with decrease in top height in both fir and pine, except in the case of small and medium fir seedlings with small roots; but differences were not significant. In both fir and pine, height growth of seedlings with large roots was 1.2 to 1.7 times the height growth of seedlings with small roots (significant at 5-percent level); there were no significant differences between top sizes.

The total amount of new shoot growth was greater in fir seedlings than in pine, with an average for all height classes and root classes of 54 percent for fir, compared with 33 percent for pine. In both fir and pine, the greatest amount of shoot growth occurred in small seedlings with large roots, and the least in large seedlings with small roots. Although a definite trend was indicated, the effect of top height on shoot growth was not significant. Shoot growth of fir seedlings with large roots was 1.3 to 2.1 times that of seedlings with small roots. In pine, shoot growth of large-rooted seedlings was 2.3 to 4.8 times that of small-rooted seedlings. In both species, differences were significant at the 5-percent level.

DISCUSSION

The increased survival of seedlings with low shoot-root ratios over those with higher ratios emphasizes the desirability of planting seedlings with large root systems. Weather during 1975 was not typical--cooler and moister than most years (fig. 1)--which apparently accounts for the relatively high survival found in most classes of seedlings. During a preliminary test in 1974, a warm, dry year, survival of both fir and pine seedlings was considerably lower than during 1975. However, the increase in survival as a result of low shoot-root ratio, for both fir and pine, was similar for both years.

The higher survival of the pine seedlings than the fir and the smaller beneficial effect of low shoot-root ratio suggest that shoot-to-root balance is less important in the pine than in the fir, possibly because of the inherently greater drought resistance of ponderosa pine.

Survival was not significantly influenced by seedling height in the present test; however, some workers have reported a relationship between top size and survival. Hermann (1964) found that the survival of Douglas-fir seedlings with large tops (38.1-50.8 cm; 15-20 in) was significantly lower than survival of those with smaller tops; in our study, the largest fir seedlings used were considerably smaller, with a top size of 21-25 cm (8.3-9.8 in). Smith and Walters (1965), also working with Douglas-fir, found that in the 2 years after planting, mortality was greater in very short and very tall seedlings. We have observed, in greenhouse plantings of Douglas-fir seedlings, that the smallest seedlings often exhibit very small amounts of shoot growth, indicating low vigor. However, such seedlings usually were smaller than those we used. Another consideration is that, in some studies, survival probably was influenced by variation in shoot-root ratio as well as top size, whereas this factor was controlled in our study.

Our results indicate that, in the range of seedling heights tested, proper balance between shoot and root systems probably is more important than top height alone. For example, we found that large seedlings with large roots survived better than small and medium seedlings with small roots. However, it should be noted that large seedlings often lack large enough root systems for good shoot-root balance, whereas good balance is frequently found in smaller seedlings.

Low shoot-root ratios also were associated with greater height growth and particularly with a greater amount of new shoot growth, which reflects greater vigor and subsequent growth potential in these seedlings. Part of the increase in amount of new shoot growth of fir seedlings with large roots was a direct result of the greater number of lateral shoots and buds initially present in such seedlings compared to seedlings with small roots (fig. 2). Such differences were not apparent in the pine seedlings, which typically have few lateral buds.

Prompt root growth often is mentioned as a key factor in survival of newly planted seedlings. When we dug up our seedlings at the end of the first growing season, any new root growth typically consisted of short roots with no significant root extension beyond the original root mass. Consequently, during the first year, seedlings must rely entirely on soil moisture in the

immediate vicinity of the initial root system. Although we did not measure root growth, we did note that only seedlings with large initial root systems showed considerable amounts of new root growth, and seedlings with small roots produced very little or no new growth. Thus on dry sites, seedlings with low shoot-root ratios survive well because (1) desiccation and increase in moisture stress immediately after planting are minimized, and (2) subsequently internal water stress is low enough to permit some root growth, which further increases the absorptive capacity of the root system. The beneficial effects of increased root growth are somewhat offset by the increased shoot growth, but the net effect obviously is beneficial, as evidenced by the increased survival.

Because we used only one lifting and planting date we do not know the influence of date of lifting or length of storage. However, these factors are known to have a considerable effect on root growth and survival (Lavender 1964).

Since survival can be increased by planting seedlings with low shoot-root ratios, it would be desirable for nurseries to give greater emphasis to shoot-root ratio in growing and grading seedlings. In practice, visual grading may be satisfactory. After undersized or damaged seedlings and those with obviously poor root systems are discarded, remaining seedlings could be separated into two root sizes. This would permit planting the seedlings with the largest roots on the droughty sites and retaining average stock for more moderate sites.

We also emphasize the need to grade seedlings by shoot-root ratio in field tests designed to evaluate seedling response to environmental factors, because it is obvious that differences in shoot-root ratio could minimize or mask influence of other treatments.

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