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Growth and root morphology of planted and naturally-regenerated Douglas fir and Lodgepole pine

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Summary — Root system morphology and growth of Douglas fir (*Pseudotsuga menziesii* var *glauca* (Beissn) Franco) and Lodgepole pine (*Pinus contorta* var *latifolia* Engelm) saplings transplanted from containers to the field in 1979 were compared with naturally-regenerated saplings of the same species and age. Naturally-regenerated saplings of both species were significantly taller than planted trees, had greater leader growth in the previous year and height/diameter ratios, and smaller taproot diameters 10 cm below groundline. Naturally-regenerated saplings also had up to 2.3-fold the number of lateral roots compared with planted saplings. Seventy to 79% of all primary lateral roots of naturally-regenerated saplings occurred within the top 10 cm of the soil surface, compared with 30–42% for the planted trees. The depth of the first structural lateral root associated with naturally-regenerated saplings was also significantly less than that of planted saplings. The shape of the container in which seedlings were raised in the nursery was clearly evident when root system architecture of planted saplings was examined. Many container-initiated seedling root systems exhibited conical shaping with little lateral root egress. A variety of root deformities which included constriction, coiling and kinkiness were detected in planted, but not naturally-regenerated saplings. These results are discussed in relation to potential difficulties arising from artificial forest regeneration with pine and Douglas fir.

Pseudotsuga menziesii **var** ***glauca*** **(Beissn) Franco /** ***Pinus contorta*** **var** ***latifolia*** **Engelm / containerization / natural regeneration / root morphology**

Résumé — Croissance et morphologie des systèmes racinaires de douglas et de pins de Murray élevés en conteneurs. *La morphologie du système racinaire et la croissance de plants de douglas* (Pseudotsuga menziesii *var* glauca *(Beissn) Franco) et de pin de Murray* (Pinus contorta *var* latifolia *Engelm) éduqués en conteneurs et installés sur le terrain en 1979 ont été comparées avec celles de semis naturels de même essence et de même âge. Les semis naturels sont significative-*

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ment plus grands et ont une dernière pousse plus importante. Le diamètre du pivot mesuré à 10 cm sous le niveau du sol est plus petit; ils possèdent 2,3 fois plus de racines latérales que les plants élevés en conteneurs; 70 à 79% de leurs racines principales se développent dans les 10 premiers centimètres du sol, contre 30 à 42% pour les plants élevés en conteneurs. La profondeur d'apparition des premières racines latérales est également plus faible. Chez les plants élevés en conteneurs, la forme de ce conteneur reste visible lors de l'examen de l'architecture du système racinaire. Un certain nombre de déformations (resserrements, enroulements, nœuds) visibles chez les plants produits en conteneurs sont absents chez les semis naturels. Ces résultats sont discutés en relation avec les problèmes susceptibles de se produire dans le cas de régénération artificielle des pins et du douglas.

sapin de douglas / pin Lodgepole / semis / morphologie des systèmes racinaires / régénération naturelle / conteneurs

INTRODUCTION

Root system morphology can influence growth and stability of trees (Bergman and Haggstrom, 1976; Lindstrom, 1990). The structure that a natural root system will ultimately possess is determined in large part by the environment in which early stages of root development occur (McQuilkin, 1935; Preston, 1942; Eis, 1974). Seedling production in containers may have negative effects on root structure due to vertical shaping (Kinghorn, 1978), and can result in trees which possess deformed root systems.

Currently, > 200 million seedlings are planted annually in British Columbia, most of which are raised in containers. Studies of sapling performance within the first decade after outplanting often conclude that the effects of containerization on root morphology are not serious enough to cause future instability and/or growth reduction of trees (Van Eerden and Kinghorn, 1978; Preisig *et al,* 1979; Carlson *et al,* 1980). However, Lindstrom (1990) demonstrated that root deformation and poor sapling stability may result 7–8 yr after outplanting if containerized Scots pine (*P sylvestris* L) is used as planting stock.

The objective of this study was to determine if differences in growth and root system morphology could be detected between container-reared and naturally-regenerated Douglas fir (*Pseudotsuga menziesii* var *glauca* (Beissn) Franco) and Lodgepole pine (*Pinus contorta* var *latifolia* Engelm) saplings after 11 yr of field performance in southeastern British Columbia.

MATERIALS AND METHODS

Study area

The study area, located ≈ 75 km west of Golden, British Columbia (51°N 117°W) has an interior continental climate characterized by cool wet winters and warm dry summers. The area was consumed by a 25 000 hectare fire in 1971, and was planted in 1979 with Douglas fir and Lodgepole pine. Planting was facilitated by using seedlings that were grown in plug-styroblocks (PSBs) (1800 cm^2) for 6 months. Each PSB contained 192 seedling cavities (2 cm diameter x 11 cm deep) filled with a standard peat-based seedling growth medium (Van Eerden and Gates, 1990). Seedlings were grown for 6 months in PSBs, after which they were lifted and cold-stored at *ca* –3 °C until spring. Mean seedling shoot height at the time of planting was 15 cm.

Trees were sampled from 4 sites within the study area. These were: 1) an 18-ha Lodgepole pine plantation; 2) a 21-ha Douglas fir plantation; 3) a stand of 12-yr-old naturally-regenerated Lodgepole pine; and 4) a stand of 12-yr-old naturally-regenerated Douglas fir. Selected stands of natural conifers were of the same seed provenance as were the plantations, and were also approximately the same size as the respective plantations. The Lodgepole pine plantation was situated on a northwest aspect 1277 m above sea level and had a gentle slope. The soil was podzolic, possibly due to an acidic B horizon, with a silty loam texture, a coarse fragment content of 25–30%, and a rooting depth of 22 cm. The C horizon was calcareous and occurred at a depth of 30 cm. The Douglas fir plantation was situated on a southwest aspect 1 000 m above sea level and also had a gentle slope. Soil characteristics were similar to those of the Lodgepole pine plantation except that the rooting depth was 30 cm and the C horizon occurred at a depth of 40 cm. The closest stands of naturally-regenerated Douglas-fir and Lodgepole pine saplings of similar age and that were growing at sites with topographical, edaphic and microsite conditions identical to those of the plantations were within 12.5 km of planted saplings.

Sampling method and sapling analysis

Four 1-ha plots were delineated at each of the selected plantations and natural stands based on similarities in sapling density (*ca* 1 800 stems per ha) and microsite characteristics (*eg* aspect and slope). Saplings were selected (5–9 per plot) until 35 planted and 20 naturally-regenerated representatives of each conifer species were secured. Saplings were manually excavated to a depth of 35 cm and to a radius of 35 cm from the stem. Sapling shoot growth was assessed by measuring stem height and the length of the previous year's leader. If trees possessed multiple leaders, then the mean length of the individual leaders was used. Roots were separated from shoots and several root system measurements were made: root collar diameter, the presence of a tap root and its diameter 10 cm below groundline, depth of the first structural lateral root which was characterized by thick, corky bark (McMinn, 1963) and a relatively large diameter (Eis, 1974), the number of lateral roots and their location in the soil profile.

An ocular scale was devised to quantify the occurrence of 5 types of root system deformation. Root constriction was a measure of lateral root egress from the stem base and was assessed using a scale of 0–4. A value of 0 was assigned when lateral roots spread horizontally from the stem base (in any direction) and 4 was assigned if the root system was dense and constricted and showed no horizontal egress. Symmetry was a measure of the location of egressed lateral roots. The circumference surrounding the stem base was separated into 4 quadrants of equal area and the occurrence of lateral roots in each quadrant was measured: 0 was assigned if there was no root egression, 1 was assigned if lateral roots were located in a single quadrant and 4 was assigned if roots egressed in all 4 quadrants surrounding the stem base. Coiling was a measure of the degree to which lateral roots encircled the stem base; 0 was assigned if no encircling was detected and 9 was assigned if the stem base was encircled by all lateral roots. An intermediate value of 4.5 indicated that 50% of the lateral roots encircled the stem base. Kinkiness was a measure of the number of 90° bends that a root made within a length of 5 cm. The scale ranged from 0, which indicated that there were no 90° bends, to 9, which indicated that 3 or more bends occurred within a 5-cm length. An intermediate value of 3 was used to describe a root system that had 1 90° bend within a 5-cm length, and a value of 6 corresponded to a root system with 2 such bends. A fractional value such as 4.5 was used to indicate that 1.5 90° bends were detected, *ie* 1 90° bend and 1 45° bend. Finally, the degree to which root systems had maintained the shape of the container from nursery culture was visually estimated. A value of 0 was assigned when no indication of containerization was apparent, and 9 was assigned when the root system had completely maintained the conical shape of the PSB cavity.

Statistical analysis

Data for each conifer species were analyzed separately using ANOVA. Homogeneity of variance tests were significant for Douglas fir height and previous year's leader growth and for the % of Lodgepole pine lateral roots within 10 cm of groundline; ANOVA was conducted on transformed data (log for Douglas fir and arcsine for Lodgepole pine) for these growth variables. Ocular rating means for naturally-regenerated saplings were equal to zero when the degree of root constriction, coiling, kinkiness, and container-shaping was analyzed. Therefore, confidence intervals were constructed to determine if planted sapling means were significantly different from zero.

RESULTS

Naturally-regenerated saplings of both species had significantly greater height growth, height/diameter ratios, previous year's leader growth, and lateral root number compared with planted saplings (table I). Root collar diameter at groundline was greater for planted Lodgepole pine compared with naturally-regenerated saplings, but not for planted Douglas fir. Taproot diameter 10 cm below the soil surface was significantly greater in planted saplings of both conifer species (*eg* Lodgepole pine differed by a factor of 2). Lateral roots of naturally-regenerated saplings were also more elevated in the soil profile than those of planted saplings as indicated by the depth of the first structural lateral root and the proportion of lateral roots within 10 cm

Table I. Shoot and root characteristics of 12-yr old Douglas fir and Lodgepole pine saplings (means ± standard error).

Characteristic	*Douglas fir*		*Lodgepole pine*	
	Naturally-regenerated	*Planted*	*Naturally-regenerated*	*Planted*
Height (m)	3.6 ± 0.13 *	1.9 ± 0.05	3.4 ± 0.08 *	2.5 ± 0.06
Previous year's leader growth (m)	0.6 ± 0.06 *	0.2 ± 0.02	0.62 ± 0.04 *	0.27 ± 0.02
Root collar diam at groundline (mm)	65 ± 2.9	60 ± 2.4	60 ± 1.7 *	70 ± 1.6
Height/root collar diameter ratio	56 ± 1.7 *	33 ± 1.0	56 ± 1.3 *	35 ± 1.0
Taproot diam 10 cm below groundline (mm)	48 ± 3.4 *	77 ± 2.6	43 ± 1.9 *	90 ± 2.5
Depth of the first structural lateral root (cm)	3.6 ± 0.22 *	5.7 ± 0.31	2.0 ± 0.28 *	6.0 ± 0.33
No of lateral roots	13.5 ± 1.18 *	8.5 ± 0.61	15.1 ± 0.95 *	6.4 ± 0.42
% of lateral roots within 10 cm of groundline	70 ± 4.6 *	30 ± 2.6	79 ± 2.3 *	42 ± 4.5
% of saplings with a taproot > 10 cm long	85	70	95	63

Asterisks indicate statistically significant differences between naturally-regenerated (i = 20) and planted saplings ($N = 35$) ($P < 0.001$).

of the soil surface (table I). More natural saplings of both species had a well-defined taproot (> 10 cm long) in comparison with planted saplings.

Planted saplings displayed a range of root deformities *ie* constriction, coiling, and kinkiness (Halter *et al,* 1993) that were not observed in natural saplings (table II). In many cases, the shape of the PSB cavity in which seedlings were originally reared was clearly evident in the root system architecture of planted saplings. Natural Lodgepole pine saplings showed a significantly greater degree of root system symmetry than did planted saplings. This difference was not significant in Douglas fir saplings.

DISCUSSION

Results from this study indicate that root development of naturally-regenerated Douglas fir and Lodgepole pine saplings differed markedly from that of planted saplings of the same species. Eleven years after outplanting, the root systems of 70 planted trees still exhibited manifestations of rearing in PSB cavities.

The bulbous taproot as indicated by the diameter 10 cm below groundline, the greater depth of the first structural lateral root, the lower number of lateral roots, and the preponderance of constricted, coiled, asymmetric, and/or bent root systems characteristic of container-reared saplings suggest that tree stability may be affected as shoot biomass and height increase. Lindstrom (1990) observed similar differences between naturally-regenerated and containerized Scots pine 7–8 yr after outplanting, and based on dynamometer tests, suggested that stability of some types of planted stock may be seriously compromised. Long (1978) also documented root deformation on Douglas fir and Lodgepole pine saplings which were initiated as container stock.

Surface roots of naturally established conifers are usually located within 15 cm of

Table II. Root deformations of 12-yr old Douglas fir and Lodgepole pine saplings (means ± standard errors).

Characteristic	*Douglas fir*		*Lodgepole pine*	
	Naturally-regenerated	*Planted*	*Naturally-regenerated*	*Planted*
Constriction	0*	1.7 ± 0.21	0*	3.1 ± 0.14
Root system symmetry	3 ± 0.16	2.6 ± 0.13	3.5* ± 0.10	1.5 ± 0.14
Coiling	0*	6.2 ± 0.36	0*	8.3 ± 0.16
Kinkiness	0*	5.6 ± 0.36	0*	7.8 ± 0.21
Container-shaped	0*	6.9 ± 0.40	0*	8.4 ± 0.21

Asterisks indicate statistically significant differences between naturally-regenerated ($n = 20$) and planted ($n = 35$) saplings ($P < 0.001$).

groundline (Cheyney, 1929; 1932; Gail and Long, 1935; McQuilkin, 1935; Day, 1945). However, due to cavity size and shape, roots of containerized seedlings are inadvertently trained to grow vertically, not horizontally. Therefore, laterals that ultimately develop would be predicted to occur at a greater depth than normal. This phenomenon was observed in our study with both species and has been noted by Long (1978).

The observation that more naturally-regenerated Douglas fir and Lodgepole pine saplings possessed a taproot than planted saplings also supports the work of Long (1978). However, it is less clear what the effect of containerization is on lateral root formation. Halter *et al* (1993) found that naturally-regenerated Lodgepole pine saplings had more lateral roots than planted saplings. Results from our current study support that finding (*ie* natural Lodgepole pine had more than double the number of lateral roots compared with planted saplings). Harrington *et al* (1989) also found that naturally-regenerated southern pines had more lateral roots than planted saplings (from bare root stock), but Long (1978) and Preisig *et al* (1979) reached the opposite conclusion with Douglas fir and Lodgepole pine. Several factors may contribute to these discrepant findings including nursery and site conditions, and seedling handling before outplanting, but one obvious difference between our studies (Halter *et al*, 1993) and those of Long (1978) and Preisig *et al* (1979) is the time since outplanting. Our saplings had been in the field for 11 yr while those examined in the latter 2 studies had been outplanted for only ≈ one-half that time. The difference in lateral root formation between planted and naturally-regenerated saplings may increase with time.

Previous researchers have suggested that no serious problems will result from use of containerized planting stock (Hagner, 1978; Huuri, 1978; Van Eerden and Kinghorn, 1978; Preisig *et al*, 1979; Carlson *et al*, 1980). However, we have detected a significant reduction in growth and an increase in root deformities associated with planted saplings. Surveys of this type should be expanded to include ecophysiological measurements and collection of data that relate to tree stability before conclusions can be reached with confidence. The value of survey data will increase as plantations age and we are able to better predict their performance at harvest. In addition, the influence of containers with recent design improvements should be assessed (Landis *et al*, 1990; Lindstrom, 1990) in long-term experiments with non-containerized, seeded in controls. The plantations described in this paper will be monitored within the next decade and the root system morphology will be re-assessed.

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REFERENCES

Bergman F, Haggstrom B (1976) Some important facts considering planting with rooted forest plants. *For Chron* 52, 266-273

Carlson WC, Preisig CL, Promnitz LC (1980) Comparative root system morphologies of seeded-in-place, bareroot, and container-cultured plug Sitka spruce seedlings after outplanting. *Can J For Res* 10, 250-256

Cheyney EG (1929) A study of the roots in a square yard of jack pine forest. *J For* 27, 546-549

Cheyney EG (1932) The roots of a jack pine tree. *J For* 30, 929-932

Day MW (1945) A comparison of the root systems of Jack pine and tamarack. *J For* 43, 41-42

Eis S (1974) Root system morphology of western hemlock, western red cedar, and Douglas fir. *Can J For Res* 4, 28-38

Gail FW, Long EM (1935) A study of site, root development, and transpiration in relation to the distribution of *Pinus contorta*. *Ecology* 16, 88-100

Hagner S (1978) Observations on the importance of root development in the planting of containerized tree seedlings. *In: Proceedings of the Root Form of Planted Trees Symposium* (Van Eerden E, Kinghorn JM, eds) British Columbia Ministry of Forests, Victoria, BC, Canada, 109-113

Halter MR, Chanway CP, Harper GJ (1993) Growth reduction and root deformation of containerized Lodgepole pine saplings 11 years after outplanting. *For Ecol Manage* 56, 131-146

Harrington CA, Brissette JC, Carlson WC (1989) Root system structure in planted and seeded Loblolly and Shortleaf pine. *For Sci* 35, 469-480

Huuri O (1978) Effect of various treatments at planting and of soft containers on the development of Scots pine (*Pinus silvestris* L). *In: Proceedings of the Root Form of Planted Trees Symposium* (Van Eerden E, Kinghorn JM, eds) Victoria, BC, Canada, 101-108

Kinghorn JM (1978) Minimizing potential root problems through container design. *In: Proceedings of the Root Form of Planted Trees Symposium* (Van Eerden E, Kinghorn JM, eds) British Columbia Ministry of Forests, Victoria, BC, Canada, 311-314

Landis TD, Tinus RW, McDonald SE, Barnett JP (1990) *The Container Tree Nursery Manual, Vol 2, Containers and Growing Media.* USDA For Serv Agric Handbook No 674, Washington, DC

Lindstrom A (1990) Stability in young stands of containerized pine (*Pinus sylvestris*). Swedish Univ Agric Sci, Internal Rep No 57-1990, Garpenberg, Sweden

Long JN (1978) Root system form and its relationship to growth in young planted conifers. *In: Proceedings of the Root Form of Planted Trees Symposium* (Van Eerden E, Kinghorn JM, eds) British Columbia Ministry of Forests, Victoria, BC, Canada, 56-64

McMinn RG (1963) Characteristics of Douglas fir root systems. *Can J Bot* 41, 105-122

McQuilkin WE (1935) Root development of pitch pine with some comparative observations on Shortleaf pine. *J Agric Res* 51, 983-1016

Preisig CL, Carlson WC, Promnitz LC (1979) Comparative root system morphologies of seeded-in-place, bareroot, and container-cultured plug Douglas fir seedlings after outplanting. *Can J For Res* 9, 399-405

Preston RJ (1942) The growth and development of the root system of juvenile Lodgepole pine. *Ecol Monogr* 12, 451-468

Van Eerden E, Kinghorn JM (eds) (1978) *Proceedings of the Root Form of Planted Trees Symposium.* British Columbia, Ministry of Forests, Victoria, BC, Canada

Van Eerden E, Gates JW (1990) Seedling production and processing: container. *In: Regenerating British Columbia's Forests* (Lavender DP, Parish R, Johnson CM, Montgomery G, Vyse A, Willis RA, Winston D, eds) Univ British Columbia Press, Vancouver, BC, Canada, 226-234