Nursery Growing Density and Container Volume Affect Nursery and Field Growth of Douglas-fir and Lodgepole Pine Seedlings

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Abstract—Douglas-fir and lodgepole pine were grown for a single growing season (24 - 28 weeks) in containers that varied in cell volume from 45 to 120 mL, and at nursery growing densities of 64 to 1111 seedlings per square meter (seedling growing space 9 to 156 cm^2). Seedlings grown in 45 mL containers were consistently smaller (shorter; smaller root collar diameter; less dry weight) than seedlings grown in larger (57 - 120 mL) containers. At greater nursery growing densities, seedlings were taller, with smaller root collar diameters, and with less root, stem, and foliage dry weight. Maximum crop biomass (1.4 kg per square meter) and maximum seedling basal area production (0.4 mm^2 basal area / cm^2 growing space) was reached at growing densities of approx. 600 seedlings per square meter. Field growth for 3 years (lodgepole pine) or 4 years (Douglas-fir) suggests that seedlings widely varying in size at planting, grew at similar relative growth rates thus preserving the size ranking of nursery treatments. Comparing the growth of treatments with the smallest and largest seedlings, suggests there is less than a single year time difference for stock to reach a similar size.

INTRODUCTION

The growing density at which forest tree nurseries grow planting stock has obvious and significant effects on both the cost of growing and the size of the stock. When planting stock is grown in containers, reductions in nursery growing density are usually accompanied by an increase in cell volumes, thus the effects of density and cell volume are often not considered separately. It is widely held that as the growing space avaliable to each plant increases (growing density decreases), larger plants will result. In the production of forest nursery stock, larger size is often equated with an increased morphological quality. It is very common for forest nurseries to grow seedlings and often cull crops to meet some morphological targets thought important by their customers. It is therefore clearly important for nursery managers to understand how both nursery growing density and cell volume affect the growth of their crops. This enables them to produce as many seedlings as possible exceeding the morphological cull levels at the lowest cost. It is equally important for reforestation foresters to know how the field performance potential of plant-ing stock is affected by its physical size (ie. morphological quality) at planting.

This paper thus has the dual objective of firstly examining how nursery growing density and cell volume affects the growth of planting stock in the

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nursery, and secondly examining how batches of stock of different sizes (due to the nursery treatments) grow in the field following planting (ie. their field performance potential).

METHODS

Douglas-fir

Stratified Douglas-fir seed (BC Ministry of Forests registered seedlot 1374) was sown into standard or modified seedling trays used in the production of container-grown forest planting stock. On April 10, 1989 one replicate of the 15 container volume - growing density treatments (Table 2) was sown, and one month later (May 9,1989) two additional replicates of the 15-treatments were also sown. The seedling trays were placed into a glasshouse at the Kalamalka Research Station with daylengths extended to 20 hours and temperature of 20C. Begining on May 1 (April 10th sown seedlings) and May 29 (May 9th sown seedlings), the seedlings were fertilized 2-3 times each week with 9-45-15 to provide N at 50 ppm. On May 26 (April 10th sown seedlings) and on June 21 (May 9th sown seedlings) the fertilizer was changed to 20-20-20 to provide N at 100 ppm. On June 29 the seedlings sown April 10 were moved out-of-doors under extended daylength (20 hours) and natural temperature conditions. From September 1 all seedlings were exposed to a natural photoperiod. Temperature in the greenhouse was maintained near 20C until Oct 11 when it was lowered to 15C during the days and 10C at night. On Nov 7 the greenhouse temperature was further lowered to 7C. Fertilization was changed to 9-45-15 on Sept 1 (outside) or Sept 6 (greenhouse) providing N at 50 ppm. In early-December, the seedlings out-of-doors were lifted to cold (-2C) storage, and between Jan 30 and Feb 28, 1990 the greenhouse grown seedlings were lifted to storage.

From each treatment 150 seedlings (50 per replicate) were outplanted in the field at Miriam Creek April 23-25, 1990. The outplanting site is in the Interior Cedar Hemlock - Shuswap Moist Warm (ICH-mw2) biogeo-climatic sub-zone (Lloyd et al 1990) at an elevation of 800 m. The site is sloped (5-15%) with a sandy loam soil and had been clearcut logged in 1988 with the logging debris piled and burnt the same year. The height and stem diameter at root collar of all seedlings were measured at lifting. In addition, the root, foliage and stem dry weights of 45 seedlings from each treatment were measured at lifting. At planting in April 1990 and at the end of the first growing season (Oct 12-13,1990), the height of each planted seedling was measured. Stem diameter at the root collar was not measured at planting, nor at the end of the first growing season. The second (1991), third (1992), and fourth (1993) growing season heights and stem diameters at root collar were measured for all surviving seedlings.

Lodgepole Pine

Stratified Lodgepole pine (BCMoF registered seedlot 3130) was sown May 7-10,1990 into the 15 container volume and spacing treatments. There were three replications of each treatment consisting of two to four seedling trays. The seedling trays were placed out-of-doors at the Kalamalka Research Station, Vernon BC (50N) and the first germinates were observed by May 22nd. Fertilization began June 11 with 9-45-15 being applied at a concentration to provide 75 ppm N. Fertilization was applied two to three times each week. One June 25 the fertilizer was changed to 20-19-18 and applied to provide 50 ppm N. Trace elements were applied as STEM at 5 ppm. On August 8, due to cool wet weather the seedlings were transferred to a glass house where the natural daylength was extended to 16-hours with high pressure sodium lights (minimum PPFD 200 umol/m 2 /s) and temperatures were maintained between 15 and 30°C. Seedlings were grown under glasshouse conditions until November 7, where after they received natural daylengths. Fertilization was terminated on November 13, and on December 14 the glasshouse

Table1. Analyses of variance.

Douglas-fir

Sources	df	Height MS	F	P	RCD MS	F	P	Root Weight MS	F	P	Stem Weight MS	F	P	Foliage Weight MS	F	P
Volume	4	12853.6	27.4	.0001	370.7	16.9	.0001	10.3	10.0	.0001	3.2	43.1	.0001	8.3	30.8	.0001
Density(V)	10	4906.3	10.5	.0001	59.0	2.7	.0177	3.7	3.6	.0029	0.06	0.8	.6060	0.5	1.8	.1084
Rep(VD)	30	468.8	-	-	22.0	-	-	1.0	-	-	0.07	-	-	0.3	-	-

Lodgepole Pine

Sources	df	Height MS	F	P	RCD MS	F	P	Root Weight MS	F	P	Stem Weight MS	F	P	Foliage Weight MS	F	P
Volume	4	2947.8	27.6	.0001	353.3	135.3	.0001	8.4	47.3	.0001	2.8	34.6	.0001	31.4	98.2	.0001
Density(V)	10	1384.4	13.0	.0001	65.1	24.9	.0001	3.3	18.6	.0001	0.4	5.6	.0001	11.4	35.8	.0001
Rep(VD)	30	106.7	-	-	2.6	-	-	0.2	-	-	0.08	-	-	0.3	-	-

Table 2. Container cell volume (cm 3), growing density (seedlings/m 2) and height (cm), root collar diameter (mm), root dry weight (mg), stem dry weight (mg), and foliage dry weight (mg) of 1+0 Douglas-fir seedlings at lifting.(mean +/- sd) (n= 332 to 1187 for height and RCD and n= 45 for dry weights).

					Dry Weight (mg)		
Experiment	Cell volume (cm3)	Density (per m2)	Height (cm)	RCD (mm)	Root Wt.	Stem Wt.	Foliage Wt.
Douglas-fir	45	278	9.6 (2.3)	2.22 (0.49)	549 (180)	192 (79)	434 (121)
	45	625	12.2 (6.9)	2.21 (0.48)	525 (209)	235 (114)	467 (166)
	45	1111	15.4 (4.0)	1.98 (0.44)	345 (178)	239 (93)	479 (144)
	57	256	13.9 (4.2)	2.97 (0.63)	1002 (299)	408 (176)	789 (288)
	57	494	16.1 (4.4)	2.66 (0.50)	688 (263)	386 (153)	731 (201)
	57	1008	18.8 (4.4)	2.24 (0.53)	353 (124)	350 (209)	554 (154)
	65	213	15.5 (5.2)	2.95 (0.72)	1091 (416)	497 (185)	928 (284)
	65	434	18.0 (4.0)	2.85 (0.52)	860 (334)	546 (180)	911 (226)
	65	816	19.0 (4.6)	2.34 (0.50)	538 (258)	460 (143)	694 (211)
	102	149	15.9 (4.2)	3.50 (0.67)	1439 (352)	635 (211)	1186 (426)
	102	287	19.7 (4.6)	3.37 (0.68)	1019 (311)	676 (209)	1151 (343)
	102	568	22.5 (5.0)	2.90 (0.61)	730 (398)	589 (265)	964 (356)
	120	64	14.1 (3.0)	3.31 (0.69)	1432 (553)	456 (165)	877 (300)
	120	156	15.5 (3.6)	3.08 (0.65)	1198 (480)	529 (208)	1036 (312)
	120	625	19.9 (5.9)	2.81 (0.67)	826 (362)	521 (219)	976 (407)

temperature was lowered to +2C. Seedlings were measured (height, stem diameter at root collar, shoot dry weight, root dry weight) and lifted to cold (-2C) storage January 8-17, 1991.

Outplanting of the seedlings was done May 21-23, 1991. The outplanting site is in the Interior Cedar Hemlock - Shuswap Moist Warm (ICH-mw2) biogeo-climatic sub-zone (Lloyd et al 1990) at an elevation of 1100m. The site is flat with a sandy-loam soil and had been clearcut logged in 1989 and mechanically site prepared in 1990. On June 14,1991 (aprox. three weeks following planting) the heights and stem diameters at root collar of the planted trees were measured (normally these measurements are taken at the time of planting, however due to funding and staff limits the measurements were delayed). Heights and stem diameters at root collar after the first (1991), second (1992), and third (1993) growing seasons were measured for surviving seedlings.

DATA ANALYSIS

The height and stem diameter at root collar of all seedlings were measured and subject to ANOVA with factors of Cellvolume, Density (Cellvolume), and Rep (Cellvolume Density). The root, foliage and stem dry weights of 45 seedlings from each treatment

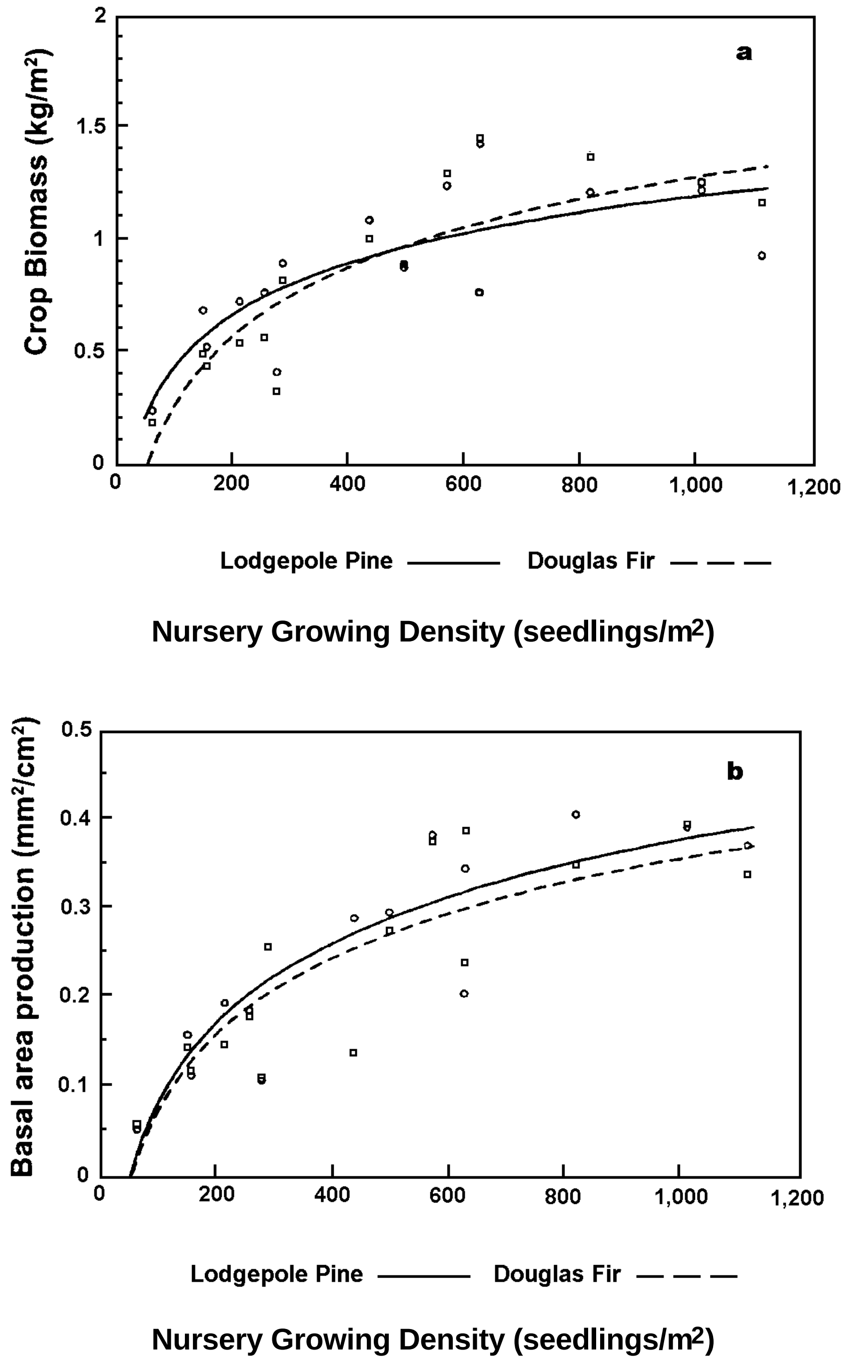

Figure 1. Effect of nursery growing density on (a) crop biomass and (b) stem basal area production of Douglas-fir and Lodgepole pine

Table 3. Container cell volume (cm^3), growing density (seedlings/m^2) and height (cm), root collar diameter (mm),root dry weight (mg), stem dry weight (mg), and foliage dry weight (mg) of 1+0 Lodgepole Pine seedlings at lifting. (mean +/- sd) (n=330 to 1014 for height and RCD and 45 for dry weights).

					Dry Weight (mg)		
Experiment	Cell volume (cm3)	Density (per m2)	Height (cm)	RCD (mm)	Root Wt.	StemWt.	Foliage Wt.
Lodgepole pine	45	278	7.8 (2.0)	2.20 (0.33)	432 (82)	249 (75)	786 (199)
	45	625	9.9 (2.8)	2.04 (0.36)	274 (95)	216 (92)	682 (172)
	45	1111	12.3 (3.1)	2.07 (0.45)	205 (89)	190 (88)	455 (217)
	57	256	11.5 (3.6)	3.02 (0.51)	726 (225)	550 (210)	1697 (469)
	57	494	12.8 (4.1)	2.76 (0.59)	390 (132)	347 (125)	1040 (336)
	57	1008	13.8 (4.5)	2.23 (0.56)	236 (149)	295 (151)	691 (306)
	65	213	11.5 (3.5)	3.39 (0.54)	741 (218)	596 (203)	2048 (543)
	65	434	13.3 (3.8)	2.91 (0.55)	537 (207)	465 (216)	1499 (459)
	65	816	13.5 (4.5)	2.52 (0.57)	320 (152)	337 (172)	835 (375)
	102	149	12.5 (3.5)	3.65 (0.49)	1260 (335)	730 (254)	2574 (595)
	102	287	13.0 (3.9)	3.37 (0.64)	770 (322)	597 (251)	1743 (517)
	102	568	14.4 (4.0)	2.93 (0.62)	451 (197)	504 (212)	1232 (493)
	120	64	9.5 (3.0)	3.15 (0.58)	1158 (408)	500 (201)	1940 (559)
	120	156	11.2 (3.3)	3.00 (0.56)	911 (286)	493 (177)	1923 (447)
	120	625	12.5 (4.5)	2.65 (0.66)	597 (356)	440 (202)	1252 (532)

were subject to ANOVA with the same design.

The height and stem diameter of surviving field planted seedlings measured at planting and after each growing season were used to calculate for each seedling a stem volume estimate (vol= 1/3 * basal area * height). The mean annual stem volume relative growth rates (RGR) of each seedling for each growing season was calculated as:

RGR= Ln(vol+1yr) - Ln(vol)

All field data were subject to ANOVA using the factors Cellvolume , Density (Cellvolume) and Rep (Cellvolume Density).

NURSERY RESULTS

Douglas-fir

Both nursery growing density and container volume affected the height, root collar diameter and root dry weight of Douglas-fir seedlings (Table 1). However, only container volume affected stem and foliage dry weights. The design of the experiment does not allow statistical evaluation of interactions between nursery growing density and container volume. However, examination of the data (Table 2) suggests that irrespective of nursery growing density, seedlings grown in the 45 mL containers were consistently smallest. Likewise, seedlings grown in the 102 mL containers were generally the largest. Seedlings grown at greater nursery densities were taller, and had smaller root collar diameters and root dry weights. On a crop basis, total crop biomass increased with nursery growing density reaching a maximum of 1.4 kg dry weight/m ^{2} at a growing density of 600 seedlings/m ^{2} (Figure 1-a). Similarly, seedling stem basal area reached a maximum of 0.4 mm ^{2}/cm ^{2} of growing space at a nursery density of 600 seedlings/m ^{2} (Figure 1-b).

Lodgepole Pine

Both nursery growing density and container volume affected the height and root collar diameter as well as the root, stem and foliage dry weights of Lodgepole pine seedlings (Table 1). Seedlings grown in 45 mL containers were consistently smallest, while seedlings grown in 102 or 120 mL containers were generally largest (Table 3). Seedlings grown at greater nursery densities were taller, and had smaller root collar diameters, as well as smaller root, stem and foliage dry weights. On a crop basis, both total crop biomass and seedling stem basal area increased reaching maximums of 1.4 kg/m ^{2} and 0.4 mm ^{2} /cm ^{2}, respectively, at a nursery density of 600 seedlings/m ^{2} (Figure 1-b).

FIELD RESULTS

Douglas-fir

In the four growing seasons following planting, seedling height and root collar diameter increased (Figures 2-a, and 2-b). Although the stem volume increased substantially, the stem volume ranking of seedlings from the various treatments did not change over the four years (Figure 2-c) because for each year the annual mean relative growth rate for large and small seedlings were not different. The annual mean relative growth rates (the slope of Figure 2-c) were 1.03 and 1.04 $cm^3/cm^3/yr$ for the third and fourth growing seasons, respectively.

Lodgepole Pine

Over the three growing seasons following planting the seedling height and root collar diameter increased (Figures 3-a, and 3-b). However as the annual mean stem volume relative growth rates of large and small seedlings were not different, the stem volume ranking over the three years did not change (Figure 3-c). The annual mean relative growth rates (the slope of Figure 3-c) were 0.98, 1.65 and 1.92 $cm^3/cm^3/yr$ for the first, second and third growing seasons.

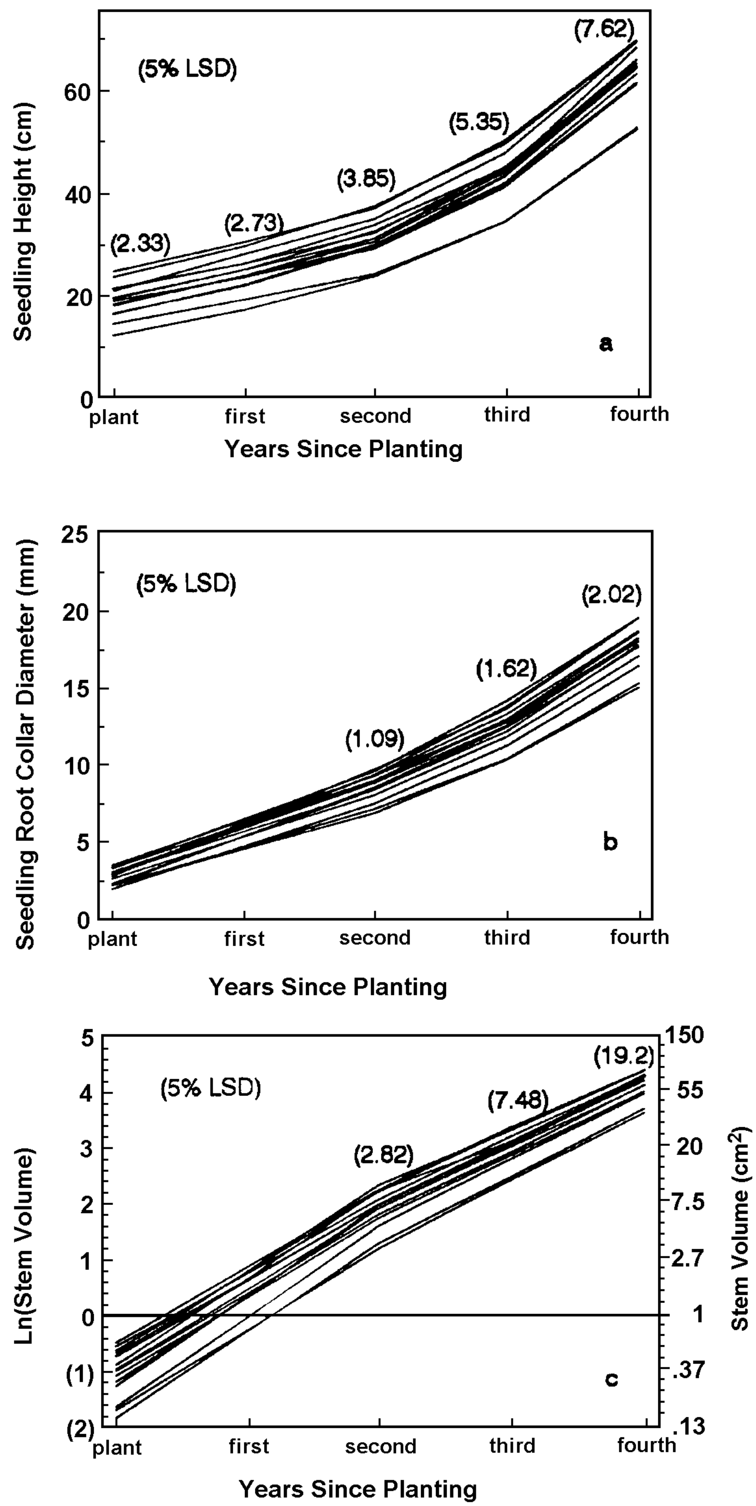

Figure 2. Field height (a), root collar diameter (b) and stem volume (c) of Douglas-fir seedlings

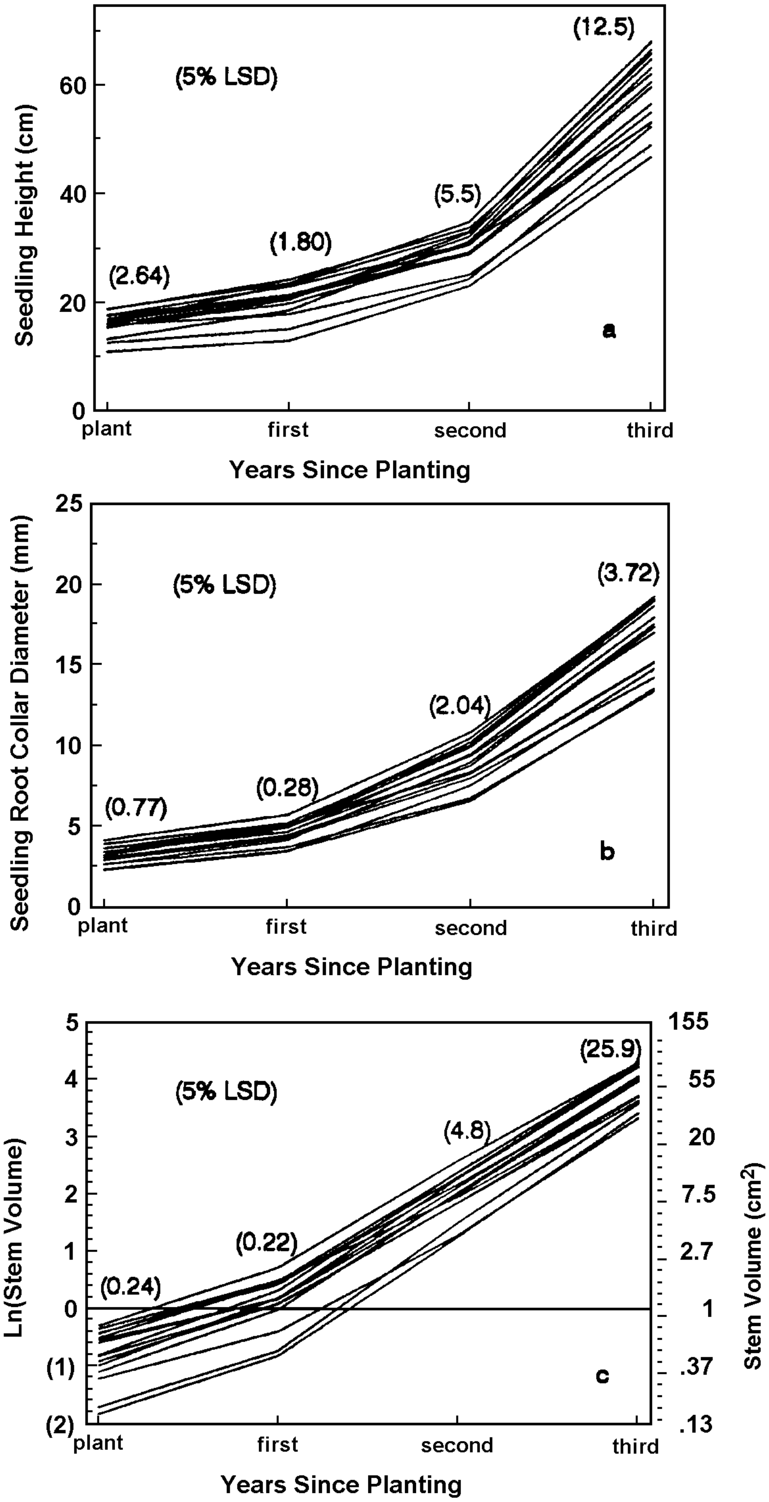

Figure 3. Field height (a), root collar diameter (b) and stem volume (c) of Lodgepole pine seedlings.

DISCUSSION

The results reported here for Douglas-fir and Lodgepole pine are similar to those reported earlier for interior spruce (Simpson 1991). At greater nursery growing densities, seedlings were taller, with smaller root collar diameters and with less root, stem and foliage dry weight. As might be expected, seedlings grown in the smallest (45 mL) containers were consistently smaller. However, the second largest container (102 mL) generally produced larger seedlings than the largest (120 mL) containers. It is unclear if some aspect of container design such as drainage or construction material prevented the seedlings in the largest containers from achieving the greatest growth. Under the cultural conditions used to grow these seedlings, a maximum crop biomass of about 1.4 kg/m 2 was produced. This maximum limit although less than the 9 kg/m^2 reported by Hulten (1989) for Scots pine or 3 kg/m^2 reported by Simpson (1991) for interior spruce occurred at a nursery growing density of about 600 seedlings/m^2 as was seen in the earlier studies. At densities less than 600 seedlings/m^2, although larger seedlings result, the growing area is not fully occupied. At densities greater than 600 seedlings/m^2, as the growing space is fully occupied, the total maximum biomass is now distributed amongst more plants resulting in smaller individuals.

Growing density and cell volume have been shown here to have fairly similar and predictable effects on the nursery growth of both Douglas-fir and Lodgepole pine. For practical purposes, nursery managers need to know the maximum crop biomass (or stem basal area production) which can be reliably produced with normal cultural conditions for their nursery. With this information in hand, and knowing the morphological targets for their crops (plant weight or root collar diameter), they can then determine an appropriate growing density. With the multitude of container types and configurations commercially available, choosing a container system consistent with a nursery's biological potential becomes somewhat easier.

Although studies relating morphological quality (size) and field performance potential often show inconsistent correlations (Mexal and Landis 1990 and Puttonen 1989, for example), plant size targets and individual tree culling thresholds remain a feature of planting stock production. It is widely believed by purchasers of planting stock that larger trees are of better quality and should therefore result in better field performance. The results reported here support this idea. The field data for both species (Figures 2 and 3) clearly show that smaller trees at planting remain smaller after 3 (Lodgepole pine) or 4 (Douglas-fir) years growth on forest sites.

When the growth of the smallest (15.4 cm height, 1.98 mm RCD) and largest (19.7 cm height, 3.37 mm RCD) batches of Douglas-fir are considered, after 4 growing seasons the mean absolute size difference between batches is perhaps 20 cm in height, 5 mm in RCD and 40 cm^3 for stem volume. This size difference may have some importance for field situations where vegetation competition exists. However, it is important to note that this size difference between treatments reflects a difference in time of perhaps one growing season for the smaller batch to reach the size of the larger (Figure 4). If the added cost of producing larger planting stock can be justified by a one year growth advantage is a matter for purchasers of nursery stock to determine.

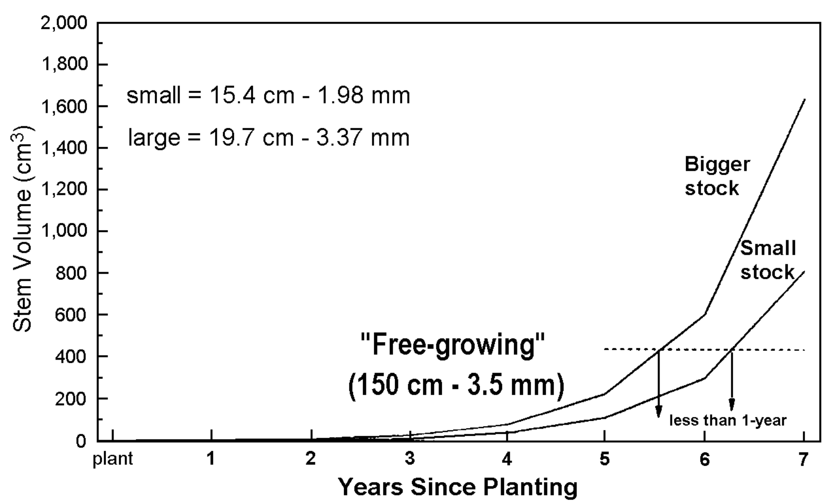

Figure 4. Actual (yrs 1-4) and estimated (yrs 4-7) stem volume growth of small and large Douglas-fir planting stock showing a less then one year time advantage for planting larger planting stock reaching "free-growing" size.

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