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The Effects of Plantation Density on the Growth and Yield of Lodgepole Pine: 20-year Results

W.D. Johnstone
(emeritus scientist)
and
F.J. van Thienen (retired)
Ministry of Forests and Range
Kalamalka Forestry Centre
3401 Reservoir Road
Vernon, BC

Abstract

The effects of plantation density (espacement) on the growth and yield of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are reported 20 growing seasons after planting. Five densities (500, 1000, 1500, 2000, and 2500 trees per hectare) were established on plots in central British Columbia. Both individual-tree and per-hectare data were analyzed. With the exceptions of mean height, periodic height growth, and survival, espacement had a statistically significant effect on all of the characteristics examined. Although this report provides only short-term information on the effects of espacement, it does indicate the need to optimize individual-tree growth rates with levels of growing stock in order to maximize yield per unit area.

Introduction

Current forest management trends in British Columbia indicate a reduced reliance on natural regeneration and an increased commitment to planting lodgepole pine (*Pinus contorta*

Dougl. var. *latifolia* Engelm.). During the 10-year period between 1999 and 2008, over 940 million lodgepole pine seedlings were planted on Crown land in the Northern and Southern Forest Regions of British Columbia.¹ Despite this major commitment to plantation establishment and despite the fact that stand density has a major impact on the growth and yield of lodgepole pine, there is very little local, quantitative information available for identifying optimum plantation management regimes for the species. This report presents the effects, for the first 20 years after planting, of various espacements (planting densities) on the development of a lodgepole pine plantation in west-central British Columbia.

Methods

Site Description and Study Establishment

In this trial, B.C. Ministry of Forests and Range Experimental Project (EP) 964.06, 1+0 PSB 211 lodgepole pine seedlings (seedlot #13501) were planted on a level to east-facing site (54°10'N, 126°18'W), at an elevation of

¹ David Weaver, Silviculture Survey Specialist, B.C. Min. For. Range, For. Pract. Br., Victoria, B.C., pers. comm., Mar. 2010.

970 m, south of Crow Creek, at the edge of the Paul Fire, in the Nadina Forest District (Figure 1). This mesic SBSmc2/01 site (Meidinger et al. 1991) is on a Humo-Ferric Podzol that developed on an ablation till overlying a basal till blanket. The soil is moderately well drained with no root restriction within 75–100 cm of the surface. Before the site was clearcut in 1984, it was occupied by a stand of interior spruce (*Picea glauca* x *engelmannii*), lodgepole pine, and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.). The site was burned in the fall of 1985 with no damage to the organic or litter horizons. The trial was planted in May 1987, and because of concerns about a high meadow vole (*Microtus pennsylvanicus* [Ord]) population, the seedlings were protected with Vexar netting. In the spring of 1988, 1989, 1990, and 1991, mortality was replaced with transplants of the same age and seedlot from an on-site reserve plantation. In the summer of 1997, all the brush and natural ingress was manually removed from the plots.

Study Design

This trial uses a randomized complete-block design with three blocks. Treatments consist of five spacings: 500, 1000, 1500, 2000, and 2500 trees per hectare (tph). Therefore, the trial contains 15 plots, which vary in size because 144 trees (12 rows of 12 trees) were planted in each plot. The planting grid interval and the variable plot sizes for each spacing are shown in Table 1.

Tree Measurements and Compilation

At the time of planting, each tree was identified by a numbered tag. The inner 64 trees (8 rows of 8 trees) in each plot were “sample trees.” The remaining 80 trees occupied the outer

two rows of each plot as treatment surrounds. In the spring of 1992, before the growing season, the height and dbhob (diameter outside bark at 1.30 m) were measured on the sample trees. Before the growing season in the spring of 1997, the height and dbhob were measured on all 144 trees in each plot. In the fall of 2001 and of 2006, the height, dbhob, crown width, and height to live crown of all sample trees were measured. At each measurement, the condition of each sample tree was examined and the presence of any damage or defect was recorded.

The results presented in this report were based only upon data from the sample trees in each plot. Furthermore, sample trees that were unlikely to become future crop trees because of dead or broken tops, or because of severe leans, were also excluded from the analyses. Percent live crown was determined for each tree by dividing the length of live crown by its total height and multiplying by 100%. Mean-tree and per-hectare stand values of each plot were calculated for each measurement period. Mean-tree periodic increments (p.i.) are based on the measured growth of the sample trees alive at the end of each measurement interval. Individual-tree volumes are inside-bark volumes calculated from Kozak’s taper functions (Kozak 1997). Per-hectare values are net values (i.e., exclude mortality and noncrop trees) and were determined for each plot by multiplying the mean value of

the sample trees (volume/tree or basal area/tree) times the treatment level times the number of living sample trees as a decimal fraction of 64. Data from the three blocks were combined to produce the summary data shown in the figures.

Analyses

Analysis of variance was used to determine the effects of the treatments on mean-tree and per-hectare stand values. All analyses were limited to the observations made following 20 growing seasons. Before analysis, percentage data for percent live crown and survival were converted with an inverse sine transformation [i.e., $z = \sin^{-1}(\sqrt{p})$]. All analyses were performed using SAS statistical procedures (SAS Institute Inc. 1990).

Results

The effects of spacing after 20 years on the various growth and yield characteristics examined are summarized in Table 2. Except for mean height and periodic height growth during the last five years, spacing had a statistically significant ($p \leq 0.05$) effect on all of the individual-tree values examined. In general, the significance of differences in pairwise treatment comparisons increased directly as differences in available growing space increased. Spacing also had a significant effect on all of

TABLE 1 Treatment plot specifications

Treatment number	Treatment (trees/ha)	Intertree distance (m)	Plot edge (m)	Plot size (ha)
1	500	4.47	49.17	0.2420
2	1000	3.16	34.76	0.1210
3	1500	2.58	28.38	0.0807
4	2000	2.24	24.64	0.0605
5	2500	2.00	22.00	0.0484

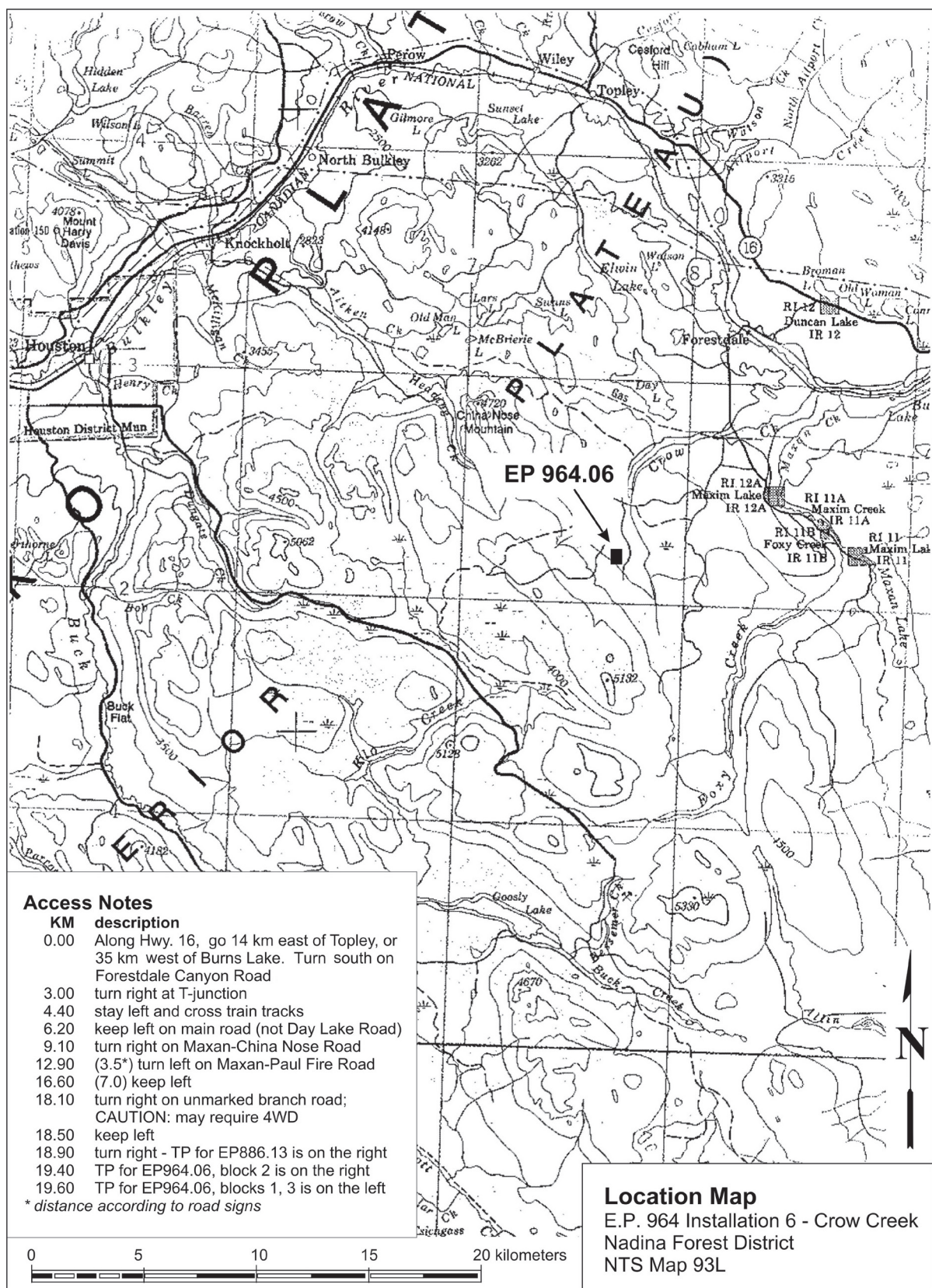


FIGURE 1 Location map and access notes for E.P. 964.06.

TABLE 2 Probability (*p* values)^a that the treatments **did not** affect the individual-tree and stand characteristics 20 years after planting

Characteristic	ANOVA results ^a	Pairwise treatment comparisons									
		1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5
<i>Individual tree</i>											
Mean % live crown (20 yr)	<0.001	0.013	0.004	0.002	<0.001	1.000	1.000	0.144	1.000	0.773	1.000
Mean crown width (20 yr)	<0.001	0.394	0.004	0.003	<0.001	0.106	0.060	0.003	1.000	0.281	0.512
Arithmetic mean dbhob (20 yr)	<0.001	0.005	<0.001	<0.001	<0.001	0.312	0.014	<0.001	0.618	0.005	0.080
Mean dbhob p.i. ^b (15–20 yr)	<0.001	<0.001	<0.001	<0.001	<0.001	0.034	<0.001	<0.001	0.134	0.020	1.000
Mean height (20 yr)	0.395	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.801
Mean height p.i. (15–20 yr)	0.221	1.000	0.923	1.000	1.000	1.000	1.000	1.000	0.555	1.000	1.000
Mean total volume/tree (20 yr)	<0.001	0.005	<0.001	<0.001	<0.001	0.739	0.098	0.002	1.000	0.026	0.172
Mean height/dbhob ratio (20 yr)	<0.001	0.002	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	0.002	<0.001	0.037
<i>Per hectare</i>											
% survival (20 yr)	0.797	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Basal area/ha (20 yr)	<0.001	0.233	0.007	0.001	0.001	0.351	0.027	0.038	1.000	1.000	1.000
Basal area p.i. (15–20 yr)	<0.001	0.081	0.002	<0.001	<0.001	0.215	0.026	0.018	1.000	1.000	1.000
Total volume/ha (20 yr)	0.003	0.845	0.048	0.006	0.013	0.943	0.080	0.212	1.000	1.000	1.000
Total volume/ha p.i. (15–20 yr)	0.002	0.618	0.035	0.004	0.008	0.914	0.068	0.146	1.000	1.000	1.000

a Analyses of variance (ANOVA) based on 4 and 8 degrees of freedom. Pairwise comparisons based on Bonferroni *t* tests

b p.i. = net periodic increment

the per-hectare values examined except for percent survival. Generally, differences between treatments effects increased as the levels of growing stock increased.

Individual-tree Values

Crown Development

Espacement had a pronounced effect on crown development after 20 years in this study (Figures 2 and 3). Percent live crown and crown width increased with available growing space. Although statistically significant, differences in percent live crown were small (ranging from 89.8% for the 500-tph spacing to 70.8% for the 2500-tph spacing). On the other hand, the crown widths in the 500-tph plots were 58.8% wider than those in the 2500-tph plots.

Diameter

In this trial, the expected general trend of the largest trees at the widest spacing continues to develop. Over the last 20 years, espacement has had a direct effect on periodic diameter growth. This response is undoubtedly related to the size and persistence of crowns, which increased directly with available growing space. This has resulted in large differences in mean diameter (Figure 4) and, assuming the trends in periodic growth continue, these differences are likely to continue to widen for the foreseeable future.

Height

Unlike diameter, espacement did not have a significant effect on either height growth or on mean height after 20 years (Table 2 and Figure 5).

Individual-tree Volume

Because of the larger stem diameters, and despite the lack of a clear height response, individual-tree total volumes increased directly with increased spacing (Figure 6). Although future observations of bole form will be required to determine how much of this additional volume is recoverable, the height/diameter ratios (slenderness coefficients) in Figure 7 suggest the extent to which stand density affects stem geometry.

Stand Values

Survival and Damage

Sample-tree survival 20 years after planting was very high at 98.6%, and the mortality that did occur was not related to espacement. The most frequently observed defects were

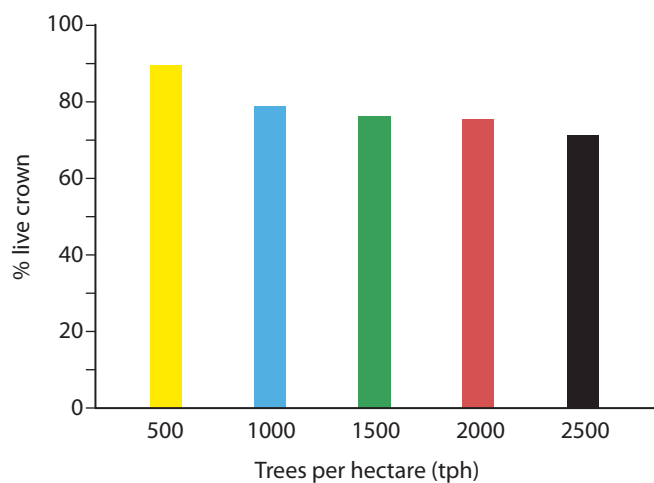


FIGURE 2 Percent live crown of lodgepole pine 20 years following planting.

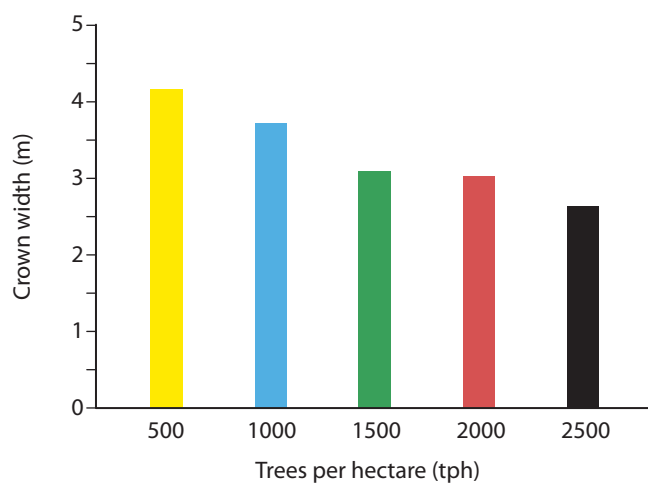


FIGURE 3 Crown width of lodgepole pine 20 years following planting.

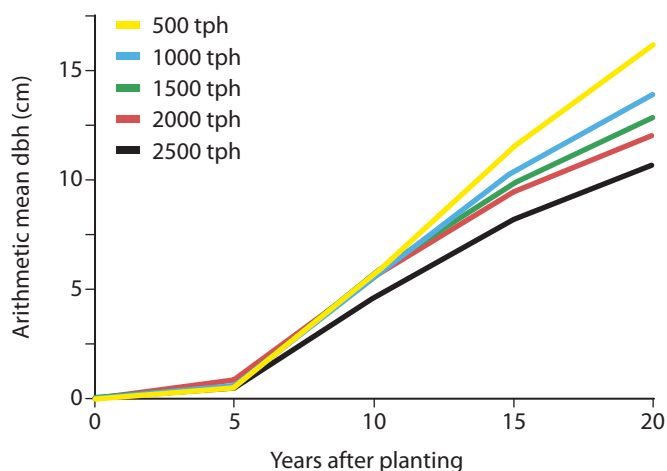


FIGURE 4 Diameter development of lodgepole pine following planting.

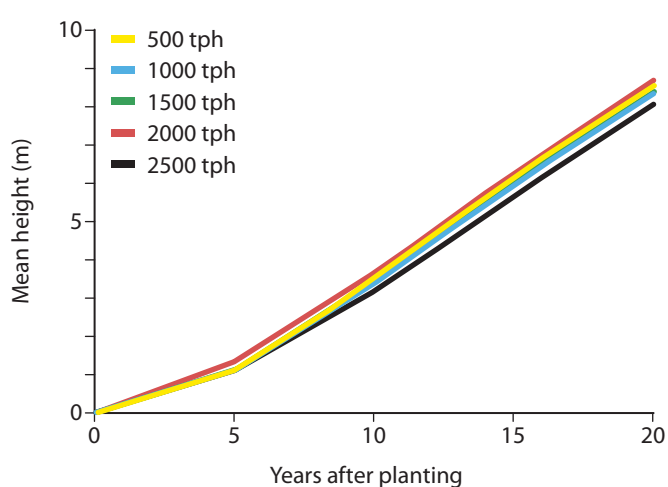


FIGURE 5 Height development of lodgepole pine following planting.

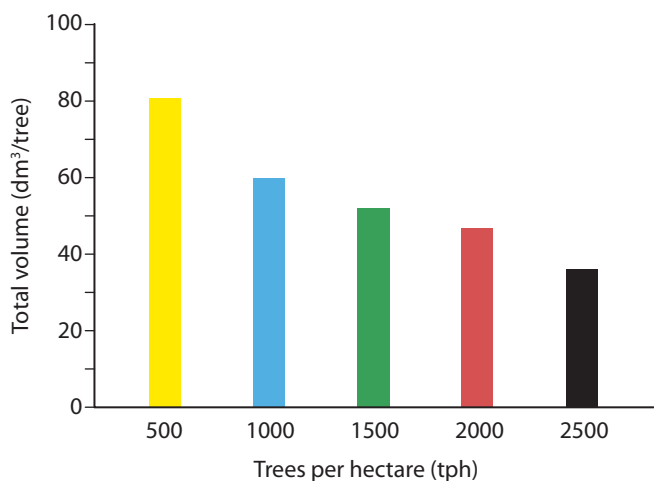


FIGURE 6 Individual-tree total volumes of pine 20 years following planting.

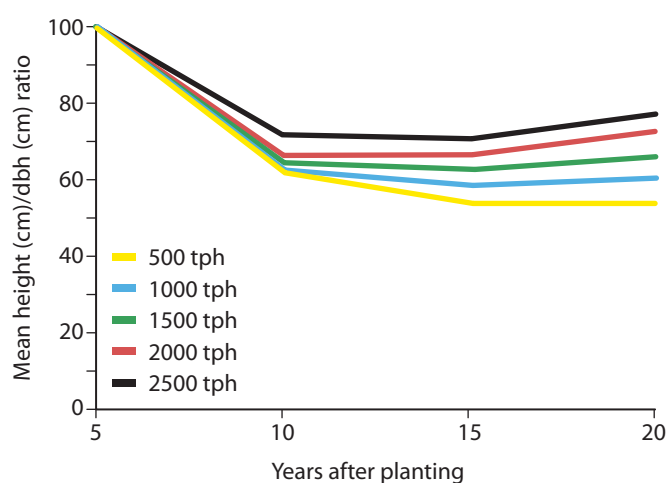


FIGURE 7 Height/dbh ratios of lodgepole pine following planting.

forks (32.6%), minor sweeps (15.8%), multiple tops (10.9%), and crooks (8.9%). In addition, western gall rust (*Endocronartium harknessii* [J.P. Moore] Y. Hiratsuka) was observed on 6.5% of the sample trees.

Basal Area and Stand Volume

Despite larger and faster growing trees at lower densities, both stand basal area (Figure 8) and stand total volume (Figure 9) increased with plantation density up to 2000 tph and then declined slightly. This was also true for the periodic increments in these characteristics during the last five years.

Discussion and Conclusions

This study clearly demonstrates the extent to which espacement can affect the early growth and development of young lodgepole pine trees and stands. In general, the results agree with earlier research conducted in plantations by Johnstone and Pollack (1990) and by Coopersmith et al. (1997, 1998a, 1998b), and following juvenile spacing of fire-origin stands (Johnstone 1985; Johnstone and Cole

1988). On an individual-tree basis, spacing had a direct effect on the size and persistence of the tree crowns, and thus has had a direct effect on several bole characteristics, particularly diameter and volume. Length of crown retention at the widest spacings may become a concern in the future because previous studies (Ballard and Long 1988; Johnstone and Pollack 1990) have shown that branch (knot) size can become a problem in widely spaced, young lodgepole pine. The effect of spacing on height growth is less clear and less dramatic, and the trees in the widest spacings were neither the tallest nor the fastest growing. A comparison of the height/diameter ratios indicates that for a given diameter, trees at the wider spacings are substantially shorter than trees at the closer spacings. Also, because these ratios give an indication of susceptibility to snow and wind damage (Oliver and Larson 1990), the results suggest that the risk of damage from these factors will increase as espacement decreases. Spacing, because of its effect on diameter and even in the absence of a concomitant height effect, had a

direct, positive effect on bole volume at lower densities.

This study also demonstrates the need for forest managers to clearly identify and define their future timber management objectives. Despite larger and faster growing trees at the wider spacings, both stand basal area and stand total volume were inversely related to espacement level. This study is still too young to permit the identification of a spacing level that will optimize individual tree size while maximizing the yield of desired products on an area basis. This study does show how the choice of espacement level can affect the accumulation of volume, thereby shortening rotations. Espacement, therefore, may be a useful technique for addressing age-class imbalances in the timber supply.

This study has provided detailed, short-term information on the effects of espacement on the growth and development of young lodgepole pine plantations. Continued, periodic re-measurement and analysis of the study will verify and expand the conclusions reached to date.

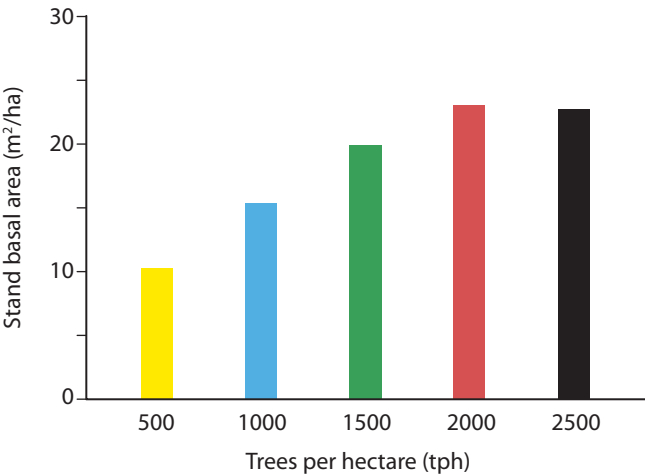


FIGURE 8 Stand basal area of lodgepole pine 20 years following planting.

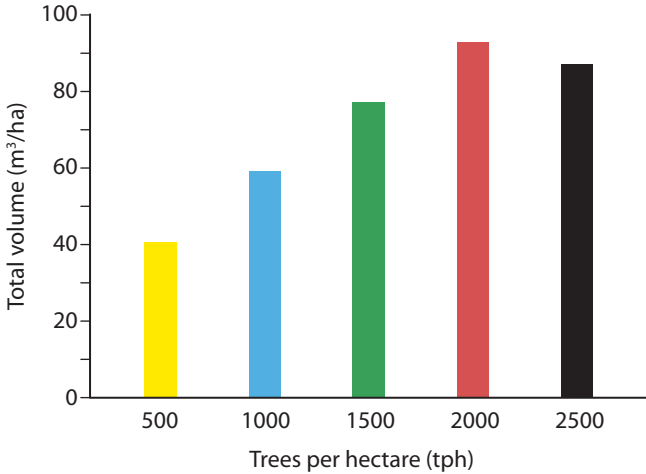


FIGURE 9 Stand total volume of lodgepole pine 20 years following planting.

Acknowledgements

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