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Two-year field performance of lodgepole pine seedlings: Effects of container type, mycorrhizal fungal inoculants, and site preparation

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Abstract

Interior lodgepole pine (*Pinus contorta* var. *latifolia*) seedlings were grown in Styroblocks™, Copperblocks™, or AirBlocks™, and inoculated with *Rhizopogon rubescens* or *Hebeloma longicaudum,* or left as non-inoculated controls. Seedlings were planted into different rooting environments in two separate locations, encompassing two separate experiments. In experiment 1, seedlings were planted into fully rehabilitated landings (ripped with burn-pile debris and topsoil incorporated), ripped landings, and unprepared cutblocks in the spring. In experiment 2, seedlings were planted in a cutblock in manually screefed (i.e., boot screefed) planting sites or undisturbed forest floor planting sites in the summer. Seedlings in the fully rehabilitated landings were 21% taller, had 45% larger diameters, and were more vigorous than seedlings in landings that were simply ripped; seedlings planted in the unprepared cutblock were taller, but with a smaller diameter, than those on the rehabilitated landings. Seedlings in screefed microsites grew significantly larger (5%) than seedlings planted directly in the forest floor. After 2 years in the field, the sizes of spring-planted, non-inoculated seedlings, and seedlings inoculated with ectomycorrhizal fungi were not significantly different. Inoculated summer-planted seedlings were approximately 5% larger than non-inoculated control seedlings. Among the variables we manipulated, planting environment had the greatest influence on seedling growth.

KEYWORDS: *container type, Copperblock™, AirBlock™, Styroblock™, ectomycorrhizae, inoculation, lodgepole pine, landing rehabilitation, forest floor planting*

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Introduction

Reduced growth and survival after outplanting may be due to both biotic and abiotic factors (McKay 1997) including competition from herbaceous vegetation, poor planting microsite, or root system architecture (Balisky *et al.* 1995). Choices made during the production of seedlings in the nursery as well as during replanting can influence these factors. In this study, we examined two factors that can influence root system architecture: container type and inoculation with ectomycorrhizal fungi. Furthermore, we evaluated the impact of forest floor planting and landing rehabilitation on growth of lodgepole pine seedlings.

Three container types are in common use (i.e., Styroblock™, Copperblock™, and AirBlock™) for commercial production of seedlings in British Columbia. The standard Styroblock container is the most widely used and is an affordable means of seedling propagation. In Styroblocks, lateral roots grow until they reach the sides of the cavities and then grow downwards. This results in the root tips of many of the major lateral roots being located at the bottom of the root plug (Balisky *et al.* 1995). Concern that the resulting root system architecture would lead to toppling in pine stands regenerated from container-grown stock (Mason 1985; Burdett *et al*. 1986) has led to modifications of the standard styroblock-style container to allow for pruning of roots by chemicals (e.g., Copperblock) or air (e.g., AirBlock) (Burdett *et al.* 1986). Chemical root pruning is achieved by adding copper oxychloride or copper carbonate to the interior container walls. Lateral roots contact the container walls and cease growing, thus promoting the generation of new lateral roots (Arnold and Struve 1993), which creates a more dispersed fibrous root system (Lamhamedi *et al*. 2001). Air pruning of lateral roots occurs via a similar mechanism. Air-pruned or chemically pruned root tips are situated along the surface of the entire root plug, and can therefore access the substrate in any direction (Burdett 1990). This would allow a higher proportion of roots to grow in warmer, more nutrient-rich surface soils (Balisky *et al*. 1995).

Ample evidence indicates that copper or air root pruning influences the initial root form of planted container seedlings, but it is unclear whether this influences tree growth in the long term. The altered root system of copper-pruned trees appears to have minimal, if any, effect on the early establishment and above-ground growth of planted pine. Copper-treated lodgepole pine seedlings had the same (Burdett 1981; Clarke and Winter 1987), or slightly increased survival (Clarke and Winter 1986; Winter and Low 1990). With a few exceptions (e.g., Burdett 1981), no significant differences in height or root-collar diameter have been found between regular and copper-treated lodgepole pine seedlings 2–5 years after planting. Trials with *Pinus monticola*, *Pinus ponderosa,* and *Pseudotsuga menziesii* var. *glauca* also reported no significant above-ground growth responses (Wenny 1988). Although commonly inferred or suggested, scant evidence shows that trees originating as Copperblock seedlings are less susceptible to toppling than conventional Styroblock seedlings (Krasowski *et al*. 1996).

Conifer seedlings in nurseries frequently become mycorrhizal with fungi introduced from the air or present in the potting substrate. It is sometimes possible to control which ectomycorrhizal fungi colonize the seedlings by inoculating the substrate with commercially available slurries of spores or mycelium during seedling growth. When inoculated with some strains of ectomycorrhizal fungi, seedlings can grow significantly more in the nursery than seedlings colonized with typical nursery fungi; inoculation with other strains can suppress growth rates (Ruehle 1982; Browning and Whitney 1992; Berch and Roth 1993; Walker and Kane 1997; Parladé *et al*. 2001). Growth response in the field depends on the fungus and the planting site (e.g., Browning and Whitney 1992), but growth stimulation can be enduring, especially on harsh sites, under drought conditions, or with tree species that are not native to an area (LoBuglio and Wilcox 1988; Marx *et al*. 1988; Garbaye and Churin 1997). In other cases, any growth stimulation in the nursery disappears with time. This may be because, if planted on a recently logged site, seedlings gradually become colonized with ectomycorrhizal fungi native to that site (Hagerman *et al*. 1999; Jones *et al*. 2002a) and inoculated fungi tend to disappear from the root system with time. Thus, the benefits of nursery inoculation for newly logged, productive sites are still uncertain.

For operational timber harvesting, haul roads, skid trails, and landings typically need to be built. Landing construction and subsequent machine traffic compact soil, which negatively affects infiltration rates, soil structure, and water movement (Miller *et al*. 1996). Soil compaction tends to reduce seedling root growth and root system development. Growth can be retarded for many years, reducing root/shoot ratios and shoot nutrient mineral status (Greacen and Sands 1980; Conlin and van den Driessche 1996).

This study builds on that of Jones *et al*. (2002b), which examined the growth of lodgepole pine seedlings 2 growing seasons after production in AirBlocks, Copperblocks, and Styroblocks. That earlier work concluded that, as long as planting stock was healthy, seedling growth was more influenced by planting site than by container type. In the two studies presented here, we expand the investigation to study the interactions between mycorrhizal fungal inoculum, container type, and site preparation treatments on the field growth performance of interior lodgepole pine seedlings. This study was designed to test the effects of inoculation with ectomycorrhizal fungi, so we compared non-inoculated with inoculated seedlings. We did not investigate differences between non-mycorrhizal and mycorrhizal seedlings. That would not have been either useful or practical because pine invariably becomes mycorrhizal during production in nurseries. Instead, we tested whether inoculation with a specific ectomycorrhizal fungus influenced seedling growth. In one study, we compared two methods of landing rehabilitation with the adjacent cutblock, while in the second study we compared manual screefing with forest floor planting.

Methods

Field Trials

Two independent field trials, one with spring-planted and one with summer-planted stock, were used to compare the growth performance of 1-year-old (1+0) interior lodgepole pine (*Pinus contorta* var. *latifolia*) grown in new Styroblocks (PSB 410, 80 ml; Beaver Plastics Ltd., Edmonton, Alta.), Copperblocks (PCT 410, 80 ml; Beaver Plastics Ltd.), or AirBlocks (PAB 410, 80 ml; BCC Silviculture Technology, Landskrona, Sweden). Randomly selected blocks of each stock type were either inoculated with one of two fungal inocula: a spore slurry of *Rhizopogon rubescens* (Mycorrhizal Applications, Grants Pass, Oreg.), or a mycelial slurry of *Hebeloma longicaudum* (Mikro-Tek, Timmins, Ont.), or left non-inoculated. All seedlings, except the spring-planted seedlings grown in AirBlocks, met the minimum height (7 cm) and diameter (2.5 mm) specifications for commercially planted pine seedlings of that stock type in British Columbia.

For experiment 1, spring-planted stock was either inoculated once with *Hebeloma longicaudum* (hereafter called "*Hebeloma*") (July 28, 1999) or twice with *Rhizopogon rubescens* (hereafter called "*Rhizopogon*") (July 16 and October 5, 1999). The spring-planted stock (seedlots 10828 and 32720) was grown at Pacific Regeneration Technologies (PRT), Vernon, British Columbia, sown in the spring of 1999, lifted in December 1999, frozen stored at –2°C, and planted out during the first week of June 2000. These seedlings were planted in the Interior Douglas-fir biogeoclimatic zone (IDF), Cascade dry cool variant (dk2), site series 03, on the Thompson Plateau near Falkland, British Columbia (50°27.17N, 119°38.33W, 1244 m). The silty clay loam contained 20% coarse fragments with an overlaying moder humus layer. This site had been logged in February 1999, and operationally raw-planted the following spring. Experimental seedlings were planted at three replicate sites, each consisting of a landing and a portion of the adjacent cutblock. Each site encompassed three rooting environments: two landing rehabilitation treatments and an unprepared cutblock. Landings were ripped to 50 cm in October 1999 with burn-pile debris (burned slash) and recovered topsoil (scalped during landing construction) incorporated into half of each landing (Figure 1).

For experiment 2, summer-planted stock was either inoculated with *Hebeloma* on June 1, 2000, or with *Rhizopogon* on April 28, 2000, and June 19, 2000. The summer-planted stock (seedlot 39505) was grown at PRT Red Rock, Prince George, British Columbia, sown in February 2000, hot lifted on July 24, 2000, and planted out on July 25, 2000. These seedlings were planted in three replicate plots within a 156-ha cutblock in the Graham River area west of Hudson's Hope, British Columbia (56°19.17N, 122°30.41W, 1324 m). The cutblock was located in the Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic zone, Bullmoose moist very cold variant (mv2), site series 01, and was logged in the winter of

FIGURE 1. Landing rehabilitation. Burn-pile debris and recovered topsoil incorporated via ripping (left) or landing simply ripped (right).

1999/2000. The sandy loam was overlain with a mor humus layer. The block was operationally raw-planted because the duff (horizons above the A horizon) was easily boot screefed to expose the mineral soil. Each replicate plot consisted of two different rooting environments: planting spots were either manually screefed during planting to remove the forest floor and expose the mineral soil, or were left undisturbed with only coarse woody debris removed from the planting spot.

Growth Performance

Field growth performance of seedlings was assessed at the end of each of the first 2 growing seasons (2000 and 2001). Twenty seedlings of each treatment (container × inoculation treatment × rooting environment) from each plot were randomly selected for measurement in 2000, with these same seedlings measured again in 2001. Seedling height was measured from the ground level to the tip of the terminal bud; seedling diameter was measured at ground level. Seedling height and diameter increments were calculated as the change in height and diameter between the end of the first growing season (2000) and the end of the second growing season (2001). Seedlings were also assessed for vigour at the end of the second season, with seedlings assigned a number from 0 to 3 based on their growth, survival, and form (0-dead; 1-poor, stunted; 2-average, healthy; 3-robust, hearty).

We analyzed all data using the general linear model multivariate analysis of variance, with the separation of significant means based on an honestly significant difference using Tukey's *W* or multiple comparison *t*-tests where appropriate (SAS version 8.0, Cary, N.C., and SPSS Version 10.0, SPSS Science, Chicago, Ill.). All differences reported as significant produced *p* values of less than 0.05 in the analysis of variance. Although all data were analyzed for each factor (site, rooting environment, container type, and inoculum treatment), the experiment was not designed to test site effects (i.e., site was not a replicated factor). Results from the two experiments were analyzed separately. The two seedlots (10828 and 32720) used for experiment 1 were combined for the analysis because initial stock quality assessments (root growth capacity, viability testing, drought stress tolerance, and total non-structural carbohydrate content) revealed no significant differences between seedlots for any variable (data not shown here). All results reported here represent means derived from pooled data consisting of an equal number of samples from each seedlot.

Results

Experiment 1: Spring-planted Seedlings

Size at Planting

Before planting, a random sample of seedlings ($n = 30$) from each nursery treatment was evaluated for both height and diameter. Initial seedling height ($p < 0.0001$) and diameter ($p = 0.004$) were affected by container type. AirBlock seedlings were significantly shorter than seedlings grown in the other container types and Copperblock seedlings were more than 1 cm taller than seedlings produced in Styroblocks (Figure 2). Note that AirBlock stock received the same irrigation regime as the other block types but, because of its hard plastic design with side slits, the substrate in this type of container dries out more rapidly (Figure 3). This might explain the reduced size of the AirBlock seedlings. Fungal inoculation did not affect height ($p = 0.1$) or diameter ($p = 0.8$) in the nursery. Approximately 45% of non-inoculated control seedling root tips became colonized with ectomycorrhizal fungi while in the nursery (data not shown here); this may explain the lack of inoculation effect.

Plantation Growth

Copperblock seedlings remained larger than both Styroblock (by 10% for height and 13% for diameter) and AirBlock seedlings (by 15% for height and 16% for diameter) after 2 seasons of growth in the field ($p < 0.001$ for container effects for each year). The difference in height appeared to be a retention of the differences found in the nursery because seedling height increment did not differ among container treatments. However, the diameter increment was significantly affected by container type ($p < 0.001$). Copperblock seedlings increased in diameter more than AirBlock seedlings, with the lowest rate of increase seen in Styroblock seedlings. Container type did not significantly affect seedling vigour ($p = 0.5$) after 2 years' growth (mean vigour: AirBlock 2.17 ± 0.03; Copperblock 2.20 ± 0.03; Styroblock 2.15 ± 0.03). Type of fungal inoculation resulted in no detectable difference in seedling height after the first season ($p = 0.2$); however, after the second season, *Hebeloma*-inoculated seedlings were taller than the *Rhizopogon*-inoculated seedlings (by 4%, $p = 0.04$; Figure 3), but not significantly taller than the non-inoculated controls. Diameter did not differ between inoculated and non-inoculated seedlings after the first ($p = 0.3$, overall mean 3.82 mm ± 0.02) or second season ($p = 0.3$, overall mean 6.85 mm ± 0.06).

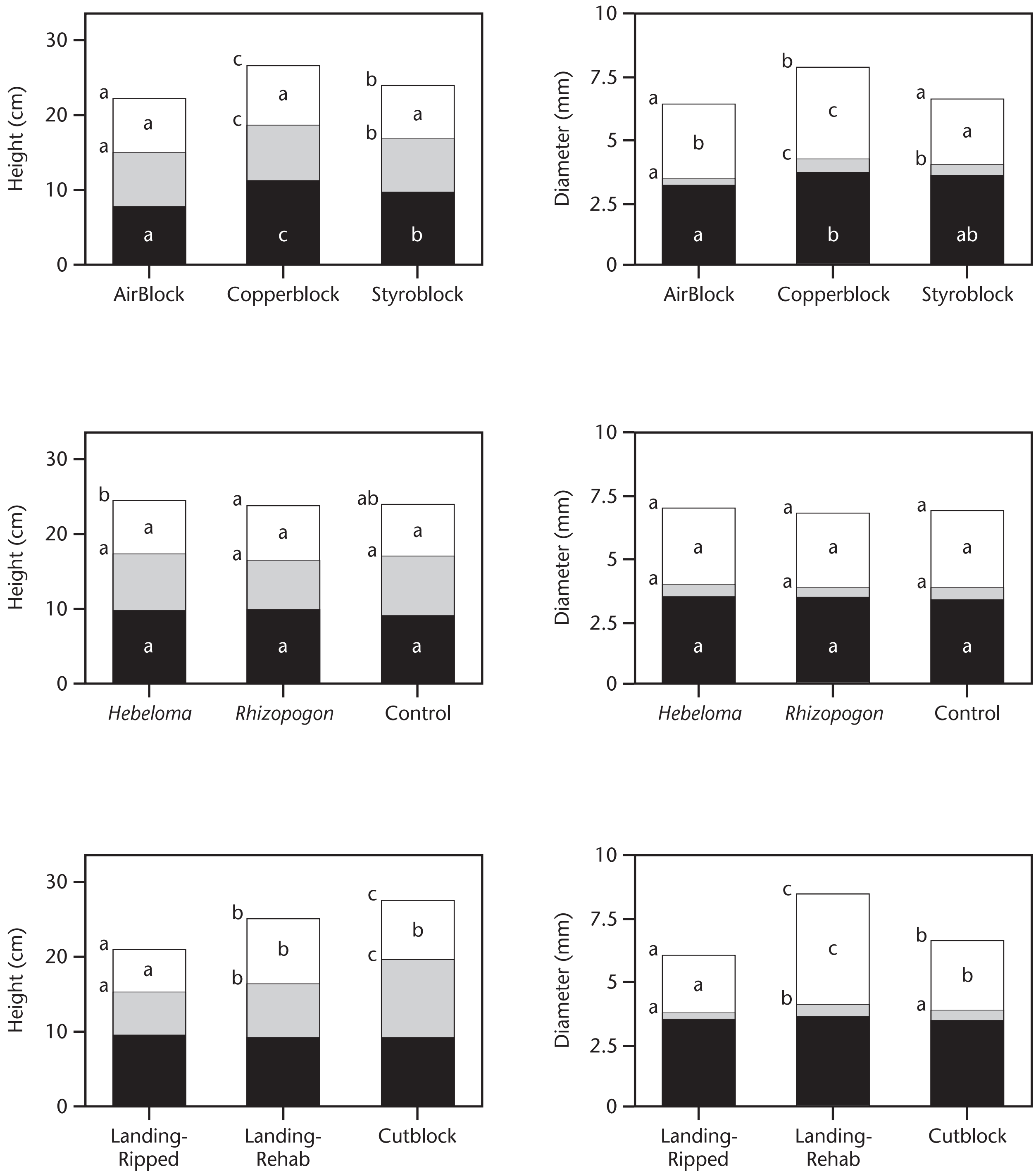

FIGURE 2. Heights and diameters of spring-planted seedlings at planting (black bars), after 1 season's (2000; stippled bars) and 2 seasons' (2001; white bars) growth in the field. Bars associated with different letters indicate a significant difference among treatments within each year, according to Tukey's *W*, $\alpha = 0.05$. Letters located within bars refer to growth increment at the nursery or over the second growing season; letters beside bars refer to cumulative growth after 1 or 2 field seasons. Overall mean values are shown; $n = 30$ (measurements at planting) or 180 (field measurements).

FIGURE 3. AirBlock container.

Similarly, fungal inoculation did not affect seedling vigour ($p = 0.8$), as all seedlings exhibited a vigour assessment of 2+ (*Hebeloma,* 2.14 ± 0.03; *Rhizopogon,* 2.20 ± 0.03; control, 2.19 ± 0.03).

Planting in different rooting environments resulted in substantial differences in seedling height and diameter ($p < 0.001$; Figure 2). After 2 growing seasons in the field, seedlings planted in cutblocks were 10% (2.4 cm) taller than seedlings planted on the landings with burn-pile debris and topsoil incorporated, and 25% (6.8 cm) taller than seedlings planted on landings that were simply ripped. Interestingly, stem diameters of seedlings growing on the fully rehabilitated landings were at least 29% larger than other seedlings. Seedlings planted in the fully rehabilitated portion of the landings exhibited a 51% increase in height and 108% increase in diameter over the second growing season, while seedlings planted in the portion of the landing that was only ripped increased in height by 35% and diameter by 58%, and seedlings planted in the unprepared cutblock increased in height by 41% and diameter by 74%. Seedlings planted into the fully rehabilitated portion of the landings exhibited significantly more vigour than seedlings planted in either the adjacent unprepared cutblocks or ripped landings ($p = 0.001$; Figure 4).

Experiment 2: Summer-planted Seedlings

Size at Planting

No effects of container type were found for summer-planted seedlings for seedling height ($p = 0.5$) or diameter ($p = 0.4$; Figure 5) at time of planting. Fungal inoculation significantly affected seedling height ($p = 0.002$), but not diameter ($p = 0.1$). Inoculated seedlings were up to 2.5 cm or 17% taller than non-inoculated control seedlings at lifting. As with the spring-planted stock, summer-planted non-inoculated control seedlings became colonized by ectomycorrhizal fungi while in the nursery, with approximately 50% of control seedling root tips being colonized with ectomycorrhizal fungi (data not shown here). Thus inoculum effects may be attributed to the species of ectomycorrhizal fungus present rather than to mycorrhizal colonization per se.

Plantation Growth

Although we noted no differences in height with respect to container type at planting, Copperblock and Styroblock seedlings were taller than AirBlock seedlings by the end of year 1 (by 3.1 cm or 21%; $p < 0.001$ for Copperblock; Figure 5). Copperblock seedlings were still taller at the end of year 2, but the differences were reduced (2.1 cm or 10% taller than AirBlock; $p < 0.001$). Reduced differences were because both AirBlock and Styroblock seedlings exhibited a greater increase in height over the second growing season ($p = 0.001$). Copperblock seedlings had larger diameters than both other block types after the first season ($p < 0.001$), with Styroblock seedlings in turn larger than AirBlock seedlings (Figure 5), but the differences were small. At the end of the second season, Copperblock seedlings again had marginally larger diameters ($p = 0.02$) than the AirBlock seedlings, with Styroblock seedlings intermediate in size. Over the 2001 growing season, diameter increment was not significantly affected by container type ($p = 0.3$).

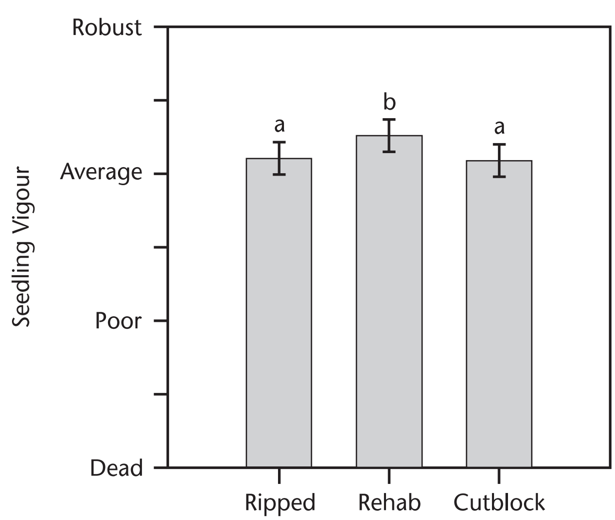

FIGURE 4. Vigour assessment of spring-planted seedlings after 2 seasons' (2001) growth in the field. Different bars associated with different letters indicate a significant difference within each year, according to Tukey's *W*, $\alpha = 0.05$; mean values are shown ± 1 SE, $n = 180$.

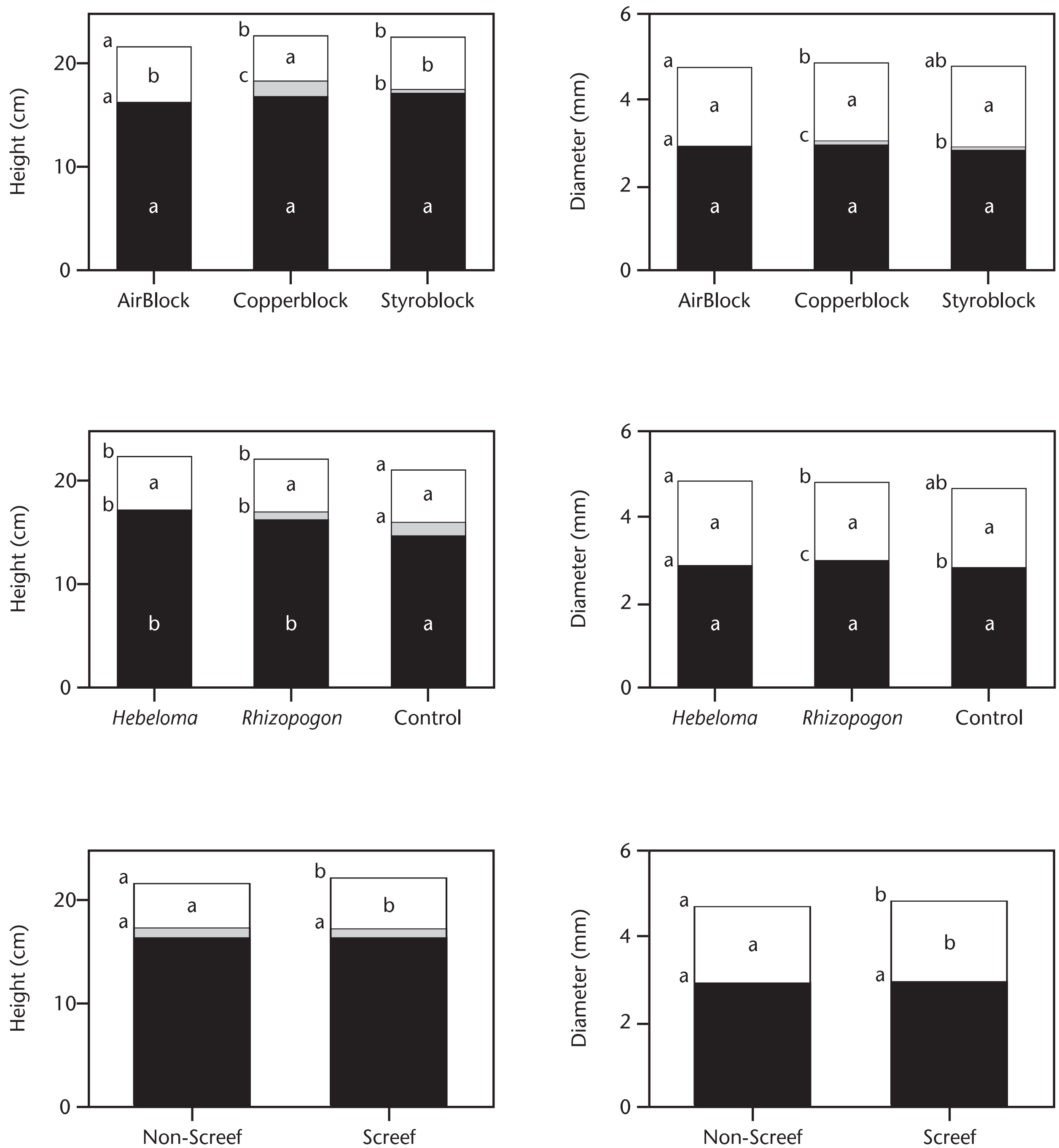

FIGURE 5. Heights and diameters of summer-planted seedlings at planting (black bars), after 1 season's (2000; stippled bars) and 2 seasons' (2001; white bars) growth in the field. Bars associated with different letters indicate a significant difference among treatments within each year, according to Tukey's *W*, $\alpha = 0.05$. Letters located within bars refer to growth increment at the nursery or over the second growing season; letters beside bars refer to cumulative growth after 1 or 2 field seasons. Overall mean values are shown; $n = 30$ (measurements at planting) or 180 (field measurements).

Seedlings inoculated with *Hebeloma* or *Rhizopogon* were taller at lifting and this height difference was retained in the field over 2 growing seasons ($p < 0.001$; Figure 5), as inoculated seedlings were approximately 5% taller (1.1 cm) at the end of the second season. Diameter differences were not significant at lifting, but became so over time ($p = 0.002$ for 2000 and $p = 0.005$ for 2001; Figure 5). After 2 field seasons, seedlings inoculated with *Hebeloma* were 4% larger in diameter than non-inoculated seedlings, whereas the diameters of *Rhizopogon* inoculated seedlings, although larger, were not honestly significantly different from non-inoculated control seedlings. Seedling height ($p = 0.9$) and diameter ($p = 0.3$) increments were not affected by the inoculation treatments. These small differences are probably due to insignificant size differences at planting because height ($p = 0.8$) and diameter ($p = 0.3$) increments were not significantly affected by inoculation.

Rooting environment did not affect either seedling height ($p = 0.3$) or seedling diameter ($p = 0.7$) over the first growing season but by the second growing season, seedlings planted in screefed microsites were slightly taller (5%, 0.7 cm; $p = 0.006$) and had marginally larger (2%, 0.1 mm) diameters ($p = 0.03$) than the undisturbed microsites. Seedlings planted on screefed microsites exhibited significantly greater height ($p = 0.02$) and diameter ($p = 0.02$) increments. Rooting environment did not affect seedling vigour ($p = 0.14$) (1.66 ± 0.02 and 1.69 ± 0.02 for screefed planting and forest floor planting, respectively).

Discussion

Landing Rehabilitation

In parts of the British Columbia Interior, landings occupy approximately 3% of the harvested portions of the operational forest (Bulmer and Curran 1999). Therefore if landings were successfully rehabilitated and returned to productive forest, the amount of land available for growing trees would increase significantly. Results here indicate that landing rehabilitation that incorporates recovered topsoil and burn-pile debris via mechanical ripping provides an adequate rooting environment for successful reforestation. In this experiment, seedlings planted in the fully rehabilitated landings actually grew better than those in the unprepared cutblocks. They had produced 62% more volume (based on $V = d^2h$) than seedlings planted in cutblocks after 2 growing seasons. Seedlings growing on the cutblocks had to compete with *Calamagrostis rubescens* (pinegrass); this may be why they were taller, but with smaller diameters, than those planted on the rehabilitated landings. For the most part, landings remained clear of competing vegetation over the 2 years of study. However, during the second year, pioneer species such as *Verbascum thapsus* (great mullein), *Taraxacum officinale* (common dandelion), *Plantago major* (common plantain), and *Cirsium arvense* (Canada thistle) began to spread over the landings.

Forest Floor Planting

On many sites, seedlings have customarily been planted in mechanically or manually screefed microsites. Planting seedlings directly in the undisturbed forest floor has been recently proposed to overcome the high costs and concerns about soil compaction associated with mechanical site preparation (Heinman 1998). Furthermore, mechanical site preparation is difficult on certain types of terrain. The forest floor may offer an ideal environment for root growth because it has low bulk density, good aeration, and available nutrients and water. Experiment 2, where seedlings were planted in forest floor or manually screefed planting sites, was located at a northern cool wet location (ESSFmv2). We expected screefing to stimulate growth at this location because exposing the mineral soil may increase soil temperature, decrease soil moisture content, and decrease competing vegetation (Balisky *et al.* 1995; Heinman 1998). Thus, it was surprising that seedlings planted in screefed microsites were only slightly larger than seedlings planted directly in the forest floor. Forest floor planting is recommended for sites with shallow soils or high risk of frost heaving, and these factors may have been important at our site (Balisky *et al.* 1995; Heinman 1998). Differences in seedling size may decrease over time, given that the screefed patches around each seedling were small. However, if differences persist as seen over the second growing season, seedlings planted in screefed patches may outperform forest floor planted seedlings. After only 2 seasons' growth following outplanting, it is too early to conclude whether one planting method has an advantage over the other at this site. Some sites might be more suitable than others for forest floor planting, and decisions should be made on a site-specific basis.

Container Type

Results provide no substantial evidence to support the use of one container type over any other in terms of growth in the nursery. Before planting, the Copperblock and Styroblock seedlings were larger than the AirBlock seedlings for spring-planted stock. This was likely due to inadequate irrigation for the AirBlock seedlings (all container types received the same amount of water). AirBlocks require more irrigation because they are made of hard plastic with many side-slits, which leads to the potting substrate becoming hotter and drier than in Styrofoam containers. Summer-planted AirBlock seedlings were supplied with additional irrigation and did not differ in size from seedlings grown in the other containers.

Although growth in the nursery is important, the seedlings' performance in the field is more critical. Over the first 2 years, Copperblock spring-planted seedlings maintained the size advantages that had developed over Styroblock seedlings in the nursery. Although height increments did not differ among treatments, diameter increment was substantially higher in Copperblock seedlings. Differences were smaller among summer-planted seedlings, which is possibly due to adequate irrigation in the nursery of AirBlock stock.

We found that emergent roots of Copperblock pine seedlings tend to be more evenly distributed over the entire surface of the root plug and originate more from the upper portions of the root plug, when compared with Styroblock seedlings (data not shown here). Consequently, copper-pruned seedlings have the potential to develop roots that are better able to access available water and nutrients from upper soil horizons. Air-pruned seedlings did not perform as expected over the first 2 years. Air pruning has been shown to produce more fibrous root systems (Lamhamedi *et al.* 2001) and, therefore, can function as an alternative to copper root pruning (Jones *et al.* 2002b). It was expected that AirBlock stock would have similar field performance characteristics to the Copperblock stock. Therefore, it was surprising that AirBlock stock was smaller than the other stock types after both seasons in the field for either experiment. In experiment 1, this was due to size differences that developed in the nursery, but in experiment 2, the differences developed in the field. Absolute growth increment (height and diameter) of AirBlock seedlings was equal to or greater than that of Styroblock seedlings. Thus, differences in seedling height and diameter will likely be small over the long term. These plots will be measured in future years to determine if this difference in increment continues.

Fungal Inoculation

In spring-planted stock, no significant differences in seedling height or diameter, between inoculated and non-inoculated seedlings, were found at lifting. This is not unusual because seedlings grown in nurseries have nutrients and water supplied in excess (Stenstrom 1990; Villeneuve *et al.* 1991; Quoreshi and Timmer 2000), and thus growth stimulation from inoculation is not necessarily expected. Furthermore, pine seedlings almost always become mycorrhizal in the nursery, even without inoculation. Laboratory studies have illustrated the potential benefits of the inoculation of seedlings with specific ectomycorrhizal fungi, especially under stressful conditions. In the field, inoculation often increases survival or growth under drought conditions. For example, Browning and Whitney (1992) conclude that the growth and nutrition following outplanting of *Pinus banksiana* and *Picea mariana* can be improved through inoculation with ectomycorrhizal fungi in the nursery. MacFall and Slack (1991) report that inoculated container-grown *Pinus resinosa* seedlings were 28% taller than non-inoculated controls, and inoculation significantly increased survival following outplanting.

Inoculated summer-planted seedlings were considerably taller than non-inoculated seedlings at lifting and, although these differences were still evident after 2 years of field growth, growth increments did not differ between inoculated and non-inoculated seedlings. Further measurement will determine whether the slight increase in growth produced by inoculation justifies the additional expenditure of approximately 8% per seedling (inoculation increases average cost of a seedling from $0.25 to $0.27).

Management Implications

Landing Rehabilitation

Results indicate that landing rehabilitation—incorporating recovered topsoil and burn-pile debris via mechanical ripping—provides an adequate rooting environment for successful reforestation. In this trial, fully rehabilitated landings and undisturbed sites in the cutblocks had similar growth rates after 2 years. The extra expense associated with incorporating ash and burn-pile debris led to improved growth compared with simply ripping the landings. Because machinery costs are high, cost-effective soil rehabilitation will likely require innovative strategies for conserving topsoil during landing construction, and distributing topsoil during rehabilitation.

Forest Floor Planting

Decisions regarding forest floor planting must be site-specific. After 2 years of growth, seedlings planted in screefed planting spots were only slightly larger in height and diameter than seedlings planted directly in the forest floor; these differences are unlikely to increase further.

Container Type

In our experiments, we did not find sufficient evidence to support the universal use of one container type over another. The use of Copperblock stock may be warranted on sites with periods of water deficit; our results indicate Copperblock seedlings continued to have higher diameter increments than other container types for spring-planted stock at a drought-prone site (IDFdk2). Based on early growth results, these trials suggest no benefit to the use of AirBlock containers over Styroblock containers for the production of interior lodgepole pine, and it is too early to know whether they will influence future tree stability.

Fungal Inoculation

It is still not clear whether seedling inoculation with commercially available mycorrhiza in the nursery imparts an advantage after planting during normal forestry operations in Canada. The minor growth response observed in one of our experiments may not justify the extra cost of inoculating seedlings.

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