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Summary

Commercial nurseries often grow containerized conifer seedlings for extended periods to reach predetermined size and shoot:root ratio targets in order to enhance field survival. The consequences of this practice are addressed. White spruce (*Picea glauca* (Moench) Voss), red spruce (*Picea rubens* Sarg.) and eastern white pine (*Pinus strobus* L.) were grown in three hardwall container types and three mesh-covered soil plug types. Seedlings were grown either (a) for a short period designed to produce sufficient rooting in hardwall plugs to facilitate extraction and handling or (b) for an extended growing period, designed to produce large seedlings with low shoot:root ratios. At the end of four growing seasons, the field growth of smaller seedlings from short rearing regimes was consistently greater than field growth of seedlings from extended rearing regimes. Implications for nursery practice are discussed.

Key words: field growth, hardwall containers, mesh-covered plugs, seedling size, shoot:root ratio

Resumé

Les pépinières commerciales cultivent souvent en conteneurs des semis de résineux pendant de longues périodes pour atteindre des objectifs prédéterminés au chapitre de la taille et du rapport système racinaire/système foliacé (SR/SF) dans le but d'améliorer la survie sur le terrain. Les auteurs étudient les effets de cette pratique. Des jeunes plants d'épinette blanche (*Picea glauca* (Moench) Voss), d'épinette rouge (*Picea rubens* Sarg.) et de pin blanc (*Pinus strobus* L.) ont été cultivés dans trois sortes de conteneurs rigides et dans trois types de mottes entourées d'un filet. Ils ont été cultivés ou bien a) pendant une courte période afin de produire assez de racines dans les alvéoles rigides pour en faciliter l'extraction et la manutention, ou bien b) pendant une longue période pour produire des jeunes plants de bonne taille au faible rapport SR/SF. Après quatre saisons de végétation, la croissance en plein champ des plus petits semis élevés pendant une courte période a été régulièrement plus forte que celle des semis qui avaient été soumis à un élevage prolongé. Les auteurs discutent des répercussions de cette constatation sur les pratiques des pépinières.

Mots clés : conteneurs rigides, croissance en plein champ, mottes entourées d'un filet, rapport système racinaire/système foliacé, taille des semis

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INTRODUCTION

Incentives for developing conifer seedlings with enhanced competitive advantages have been provided by restrictions on planting-site preparation by fire and mechanical scarification (Newton et al. 1993) and reductions in or elimination of the use of chemical herbicides (Jobidon et al. 1998). Various studies have shown that larger seedlings have a growth advantage compared to smaller seedlings in plantations, especially when competing vegetation is vigorous (Dobbs 1976, Walker and Johnson 1980, van den Driessche 1982, Caulfield et al. 1987, Sutherland and Newsome 1988, Newton et al. 1993, South and Mason 1993). Many of these studies involved bareroot seedlings that were often grown at different densities in the nursery to produce various seedling sizes, or they were comparisons between bareroot and container-grown seedlings.

Studies comparing the field growth of container-reared seedlings have also demonstrated the advantages of large seedlings over small seedlings; containers with larger cavities were used to produce larger seedlings (McMinn 1982, Simpson 1991, Jobidon et al. 1998). McMinn (1982) suggested that the use of large container-grown seedlings, without planting-site preparation, may be a feasible alternative to planting small container stock on mechanically prepared sites. Container stock quality must be maintained if the performance expectations of larger seedlings are to be realized (McMinn 1982). A high root-growth capacity is especially important for large container-reared seedlings (Jobidon et al. 1998).

Timmis and Tanaka (1976) suggested that growing conifers in same-sized container cells at increasingly wider spacings produced seedlings with morphological characteristics, such as higher dry weight and sturdiness, that improve field performance. However, Salonius et al. (2000) have shown that, during the hardening of nursery-grown seedlings in container configurations at wide spacings, root growth within the confines of the soil plug is excessive enough to produce root densities that reduce subsequent root growth in the field.

Current nursery practice often relies on extended growing regimes in containers to attain predetermined size specifications and to affect a lowering of the shoot:root ratio. The cultural lowering of shoot:root ratios by extended rearing to produce "balanced" seedlings capable of resisting evapotranspiration stress after outplanting, although imperative for bareroot stock, has been shown to be less necessary or even counterproductive for container-reared conifers (Walker and Johnson 1980, McGilvray and Barnett 1982, Barnett and Brissette 1986, Bernier et al. 1995). Bernier et al. (1995) suggested that low shoot:root ratios for containerized conifer seedlings may indicate an overgrown root system with large suberized roots, tightly packed inside the container cavity. The negative effects on seedling growth of increasing root density within the confines of the container cavity, even before adequate root growth has occurred to bind the soil plug together, have been demonstrated (Salonius et al. 2000, Balisky et al. 1995, Endean and Carlson 1975).

Kinghorn (1978) suggested that root shaping and deformation commence as soon as any roots extend to the bounds of the container. Martinsson (1986) stated that no container system can satisfy the demand for growing space for roots and, therefore, the longer seedlings have been grown within the confines of container cavities the worse will be the resulting root deformation. Barnett and Brissette (1986) came to similar conclusions regarding duration in containers.

Our early work with a multitude of hardwall container seedling stock types (unpublished) showed correlations between field performance and either nursery root weight or shoot:root ratio to be very poor while correlations between field performance and shoot volume, shoot weight and stem diameter were high. These observations were consistent with the finding that current photosynthate production is the primary energy source for the new root growth that is essential for good field performance (Philipson 1987, van den Driessche 1987). The effects of container-induced root deformities on plantation stability (Lindgren and Orlander 1978, Burdett et al. 1986) and planted seedling growth rates compared to naturally regenerated seedlings (Halter et al. 1993) have received attention. However, there has not been a study specifically directed towards a comparison of the field performance of early planted seedlings with seedlings planted after extended rearing in the same container system.

The study presented here reports the field performance of three conifer species grown in three hardwall and three mesh-covered plug container types. The field growth performance of early planted seedlings is compared with the performance of seedlings that were exposed to prolonged nursery rearing designed to lower shoot:root ratio and increase seedling size.

MATERIALS AND METHODS

Three conifer species were included in these experiments: white spruce (*Picea glauca* [Moench] Voss), red spruce (*Picea rubens* Sarg.), and white pine (*Pinus strobus* L.). Seedlings were grown in three sizes of hardwall multipots and three sizes of JIFFYâ mesh-covered plugs (Table 1).

Hardwall cavities were filled with a moist peat:vermiculite (2:1) mix. They were seeded and then a thin layer of limestone grit was applied over the seed. Unexpanded JIFFY plugs (fine peat) were seeded and covered with a thin layer of paper tissue, over which a thin layer of limestone grit was applied to hold the seed in place.

Longer rearing time was allowed for formats with larger soil plugs (Table 1). A comparison summer crop, seeded May 2, was grown in IPL 45-90 and Jiffy 96 only. All three species were seeded on each date. Immediately after seeding, regular mist irrigation was applied with a fertilizer solution (forestry starter) at ten parts per million (ppm) nitrogen for the 20-day germination period. Supplemental light was supplied for 2 hours each night to prevent bud formation in response to short daylength. The greenhouse was maintained at 25°C during the germination period.

When germination of the winter crops was complete, seedlings were thinned to one per soil plug or cavity and they were moved into a greenhouse that was operated at a day temperature of 22°C and a night temperature of 18°C. During the first 2 weeks following the germination period, forestry starter solution was applied at 20 ppm nitrogen. Irrigation with this solution was carried out at least three times weekly, sufficient to produce both soil saturation and drip from the bottom of the soil plug. This irrigation regime ensured that nutrient concentrations would be the same in the soil plugs of all container types.

Table 1. Sizes and seeding dates of multi-pot and mesh-covered soil plugs

Container	Top Diameter (mm)	Soil Volume (cm^3)	Seeding Date
STYROPLUG 415D	42	170	4/1
IPL 45-90	38	90	7/2
ROPAK 1-67	32	57	14/3
JIFFY 70	45	90	4/1
JIFFY 98	38	78	7/2
JIFFY 140	32	50	14/3

Forestry grower solution at 50 ppm nitrogen was applied from 5 weeks after seeding until the crops were heavily leached to lower soil nutrient levels. After leaching, the seedlings were irrigated with water for a week to slow growth rates at the start of the hardening period (June 12–19). Following this week of water application, forestry finisher solution was applied at 35 ppm nitrogen, starting June 20. All winter-reared crops were moved out of doors on June 27 to assist in the transition to less succulent growth during hardening. That portion of the winter crop not submitted to extended rearing, was field planted in mid-July over a period of 2 days. That portion of the winter crop that was subjected to extended rearing remained in the outside growing area until frost hardiness to –15°C was determined. These seedlings were frozen for overwinter storage at the end of October, as is standard practice.

The summer crops, which were reared under the same nutrient, irrigation, and temperature conditions, had supplemental night lighting withdrawn as leaching commenced on August 23. These crops, after setting bud, received forestry finisher solution and extended greenhouse culture during hardening (Columbo et al. 1989). They were frozen for winter storage after frost hardiness to –15°C was determined.

The winter crop of JIFFY plugs held in the nursery for extended rearing developed many root connections between adjacent soil plugs; this was also the case for JIFFYs reared as a summer crop as a result of extended root growth after bud set. These root connections had to be cut in order to separate the seedlings from each other. No cutting was required for the JIFFY winter crops that were outplanted in July as these plugs had very few fine root connections. Two cutting treatments were compared for the winter-reared crops held in the nursery for extended growing. Early root cutting was done September 5 to allow healing of severed roots during the autumn hardening period. The late root cutting was done October 28, just before the seedlings were placed in freezer storage; this treatment did not allow for any repair of severed roots. The root cutting for summer-reared JIFFY 96 was conducted December 12, just before the seedlings were frozen.

There were a total of 40 seedlings for each treatment available for destructive sampling and 40 seedlings available for outplanting. The data for summer-reared crops were obtained from 20 seedlings for destructive measurements and 20 seedlings for outplanting. The height and root collar diameter of each seedling were measured just before winter-reared crops were to be early planted (July) or just before winter crops from extended rearing or summer crops were frozen for winter storage. Soil was washed from the roots, then all shoots and all roots from individual treatments were oven dried in a pooled sample. The frozen seedlings were thawed for 48 hours at 20°C and planted directly from freezer boxes the following May. Measurements of height and root collar diameter, both at the end of the rearing period and after several years of growth in the field, allowed comparisons of seedling volume, which was calculated by multiplication of root collar diameter (rcd) squared times height (ht); this product (rcd^2.ht) has been found to correlate well with seedling shoot weight (Kira and Shidei 1967, Ruehle 1982, Methven 1983, Wagner et al. 1989). Pooled oven-dry shoot and root weights, determined at the end of nursery rearing, allowed shoot:root ratios to be calculated.

Seedlings were field planted in a former bareroot nursery in five-tree rows running north-south in tilled strips running east-west. Population numbers were randomly assigned to the five-tree rows at the outset, such that there were eight rows for each (four planted 1994, four planted 1995) of the winter-reared treatments and four rows for each of the summer-reared treatments. After early planting of winter-reared crops in July 1994 was complete, the remaining rows were unoccupied until seedlings that had been stored frozen were planted in May 1995. The five-tree rows were 38 cm apart and the seedlings within the rows were 25 cm apart.

Field measurements were carried out in August 1997. At this time, the winter crops planted in July 1994 had been growing in the field for four seasons. Their counterparts, which had been exposed to extended nursery rearing and then frozen overwinter, had been in the field for three growing seasons, as had the summer-reared crops which had also been stored frozen before outplanting in May of 1995.

RESULTS

Hardwall

White spruce seedling volumes for the three hardwall container types, at the time of planting and after several growing seasons in the field, are shown in Fig. 1. Winter-crop seedlings that were planted from frozen storage in May 1995 were larger, with reduced shoot:root ratios, than their counterparts were when planted early in July 1994 (Table 2). This advantage in plant size was lost when final field measurements were done in August 1997. The loss of this advantage in plant size was similar for each of the three hardwall container types (Fig. 1). The field performance of the white spruce summer crop reared in IPL 45-90 containers, (frozen December 12, 1994) was intermediate between the early planted and extended- reared winter crops; these seedlings resided in the container cavities for a considerably shorter period than the extended-reared winter crop. The planted shoot:root ratios of both summer-reared and extended-reared winter crop seedlings from IPL 45-90 containers were lower than that of the winter-crop seedlings when planted early in July 1994 (Table 2).

This field-response pattern was repeated for red spruce from the three hardwall container types (Fig. 2), where early planted seedlings were larger in August 1997 than seedlings that had been held in the nursery to gain size and reduce shoot:root ratios before planting in May 1995 (Table 2). Although the field growth of summer-reared red spruce from IPL 45-90 containers was intermediate in volume between early planted and extended-reared crops in August 1997, the mean shoot:root ratio of these summer-crop seedlings at planting was the same as that for the extended-reared winter crop and much lower than that of the red spruce winter-crop seedlings that were planted in July 1994 (Table 2).

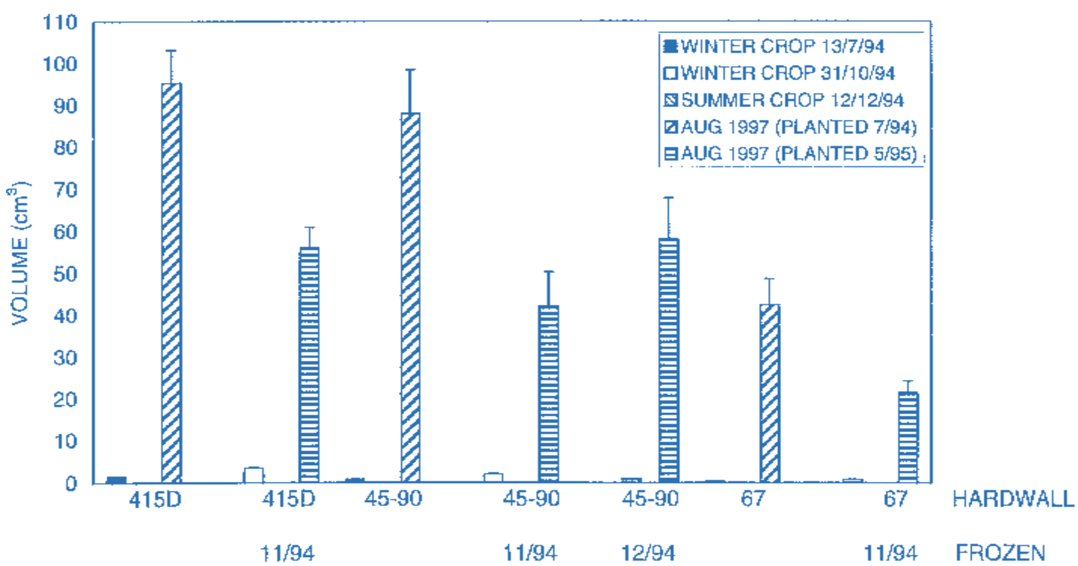

Figure 1. Mean volumes (± SE) of early planted and extended-reared white spruce seedlings grown in hardwall containers, at planting and after several field seasons.

Table 2. Sizes and seeding dates of multi-pot and mesh-covered soil plugs

				White spruce			Red spruce			White pine		
Container	Crop	Roots cut	Planted	Height (cm)	RCD (mm)	S/R	Height (cm)	RCD (mm)	S/R	Height (cm)	RCD (mm)	S/R
415D	Winter	-	7/94	20.1"0.54	2.6"0.07	5.03	23.7"0.73	2.3"0.08	4.77	9.9"0.41	2.6"0.06	3.17
415D	Winter	-	5/95	23.5"1.13	3.6"0.10	2.84	34.2"0.84	3.0"0.10	2.85	10.9"0.66	2.9"0.10	1.73
70	Winter	-	7/94	15.4"0.54	1.9"0.07	7.37	20.8"0.47	1.8"0.06	7.27	9.4"0.47	2.2"0.06	5.56
70	Winter	9/94	5/95	19.2"0.87	3.1"0.10	4.38	27.3"0.66	2.5"0.08	5.10	10.3"0.56	2.9"0.10	3.39
70	Winter	10/94	5/95	19.1"0.85	3.0"0.11	4.35	32.3"0.98	2.8"0.11	5.29	10.6"0.47	2.6"0.10	3.48
45-90	Winter	-	7/94	17.9"0.50	1.9"0.07	4.98	18.5"0.61	1.6"0.07	5.00	9.4"0.30	1.7"0.04	4.13
45-90	Winter	-	5/95	21.1"0.82	2.9"0.10	3.31	28.3"0.90	2.3"0.09	3.68	10.2"0.38	2.3"0.07	1.72
45-90	Summer	-	5/95	21.5"0.70	2.0"0.07	4.17	22.2"0.57	1.7"0.08	3.68	8.4"0.37	1.5"0.10	2.00
96	Winter	-	7/94	18.1"0.82	2.0"0.06	10.83	20.4"0.48	1.8"0.06	9.35	9.5"0.37	2.3"0.06	7.30
96	Winter	9/94	5/95	18.9"0.83	2.6"0.12	6.88	29.7"1.01	2.4"0.08	8.99	10.4"0.55	2.3"0.06	5.92
96	Winter	10/94	5/95	19.6"0.77	2.8"0.11	6.26	29.7"1.03	2.4"0.09	9.25	9.6".033	2.3"0.07	6.29
96	Summer	12/94	5/95	22.2"0.97	2.0"0.11	9.88	21.4"0.88	1.9"0.08	5.60	7.2"0.27	1.4"0.08	7.58
67	Winter	-	7/94	12.3"0.31	1.5"0.05	4.64	13.5"0.34	1.3"0.04	5.15	8.1"0.20	1.7"0.06	3.95
67	Winter	-	5/95	14.3"0.78	2.1"0.08	2.74	23.5"0.57	1.7"0.06	3.54	9.6"0.36	1.9"0.06	1.59
140	Winter	-	7/94	15.2"0.53	1.5"0.06	10.69	13.7"0.44	1.2"0.05	8.50	8.0"0.20	1.7"0.05	6.78
140	Winter	9/94	5/95	17.1"0.92	2.4"0.09	5.98	22.1"0.68	1.7"0.06	7.82	9.3"0.39	2.1"0.07	4.29
140	Winter	10/94	5/95	17.0"0.83	2.4"0.08	6.68	20.0"0.97	1.6"0.09	6.26	8.8"0.32	1.9"0.07	5.21

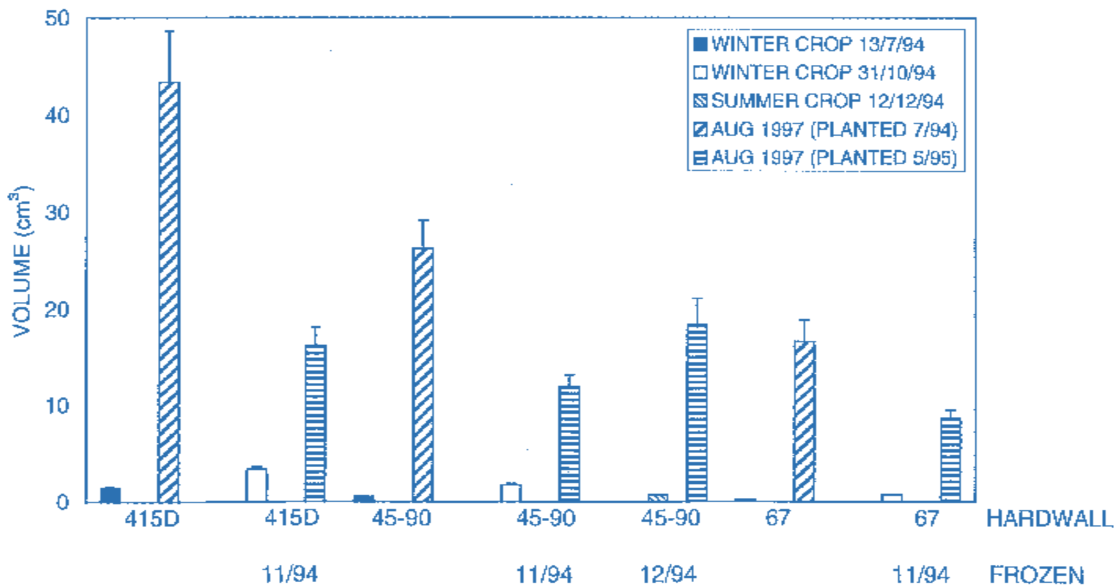

Figure 2. Mean volumes (± SE) of early planted and extended-reared red spruce seedlings grown in hardwall containers, at planting and after several field seasons.

The results for the white pine crops reared in the three hardwall container types (Fig. 3) show the superior field performance of the early planted winter crops in comparison with their extended-reared counterparts. The field performance of the summer-reared white pine was poorer than that of the extended winter crop even though its shoot:root ratio at planting was intermediate between that of the extended-reared and the early planted winter crops (Table 2).

Jiffy

The graphic presentation of results from the JIFFY (mesh-covered plug) rearing system is more complex because there were two groups of seedlings from the extended-reared winter crops. One of these groups had bridging roots between adjacent plugs cut early (September 5, 1994) while the other group had root connections cut just before they were frozen for winter storage (October 28, 1994).

Field performance of white spruce crops reared in each of the three JIFFY formats for extended periods was markedly inferior to their early planted counterparts (Fig. 4). The volumes of extended-reared winter-crop white spruce at outplanting in May 1995 were generally double those of their July 1994 planted counterparts at the end of their nursery residence, and the volume accumulation of these extended-reared crops was less than half that achieved by the early planted groups after several field growing seasons. The summer-reared white spruce crop from JIFFY 96 had a shoot:root ratio that was intermediate between the ratio for extended-reared seedlings that were late cut and the ratio for early planted winter crops at the time of planting (Table 2). For winter-crop white spruce JIFFYs that were extended

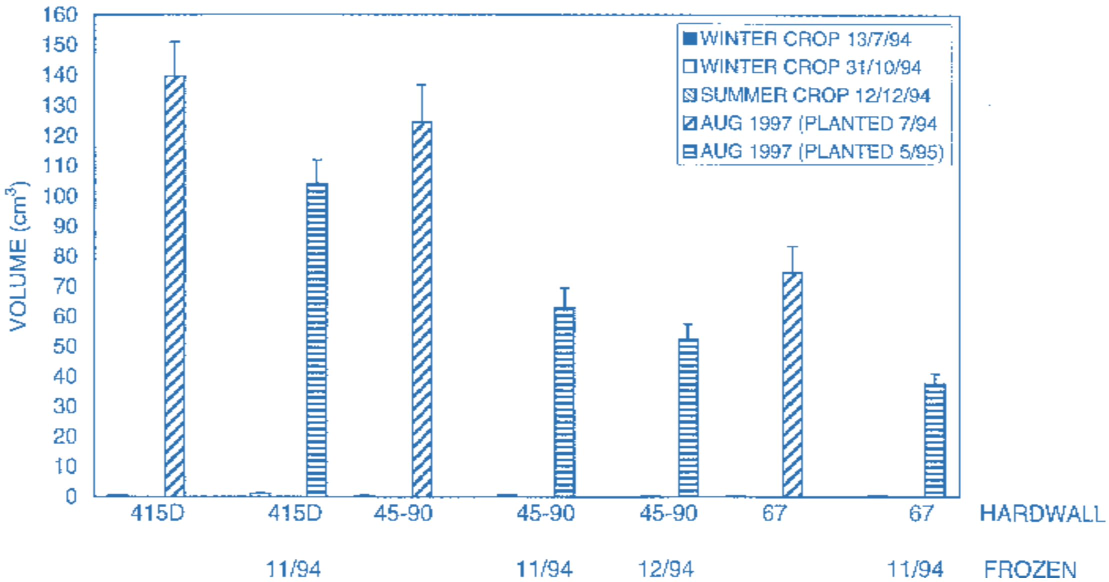

Figure 3. Mean volumes (± SE) of early planted and extended-reared white pine seedlings grown in hardwall containers, at planting and after several field seasons.

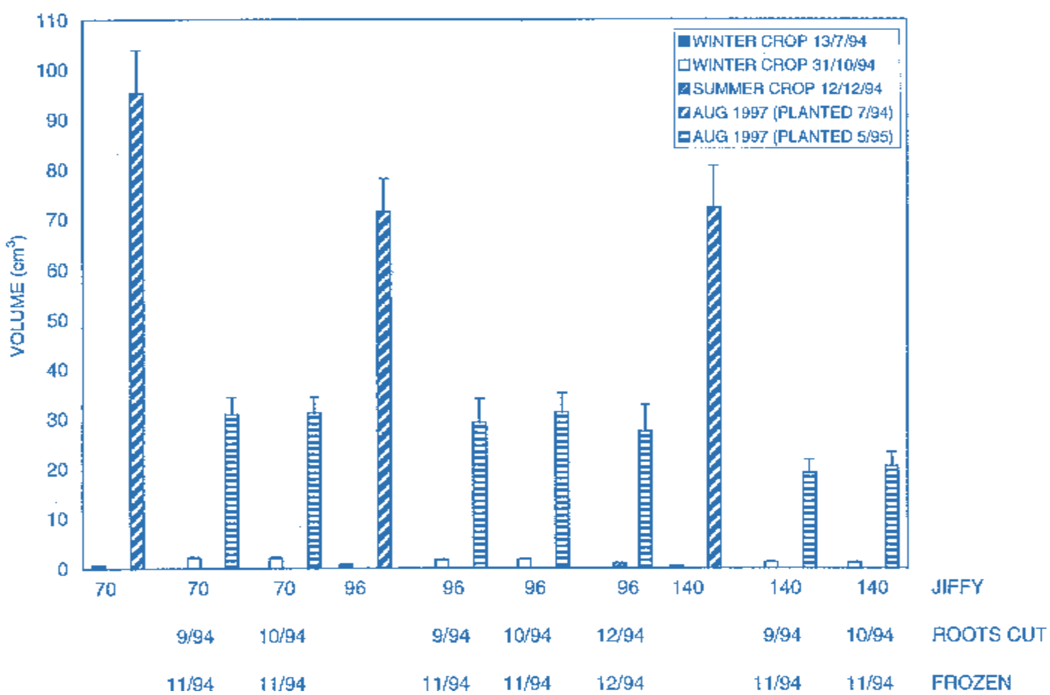

Figure 4. Mean volumes (± SE) of early planted and extended-reared (early and late root-cut) white spruce seedlings grown in JIFFY plugs, at planting and after several field seasons.

reared, there was little difference in field performance between seedlings subjected to September root cutting (9/94) and those whose root connections were severed in late October just before they were frozen for winter storage (10/94) (Fig. 4).

Red spruce seedling volumes for the three JIFFY types, at the time of planting and after several growth seasons in the field, are shown in Fig. 5. Although the volume of extended-reared seedlings was much higher than the volume of early planted winter-crop seedlings at the time of planting, the extended-reared seedlings were considerably smaller after several field growing seasons. The summer crop from JIFFY 96 had a lower shoot:root ratio than either the early cut, late cut, or July 1994 winter crops at the time of planting (Table 2). The field volume results for red spruce JIFFY seedlings whose roots were cut in September (9/94) or in late October (10/94) are not consistent; for JIFFY 70 and 140 sizes, late cutting resulted in better volume accumulation in the field; however, for JIFFY 96, early cutting resulted in better growth.

The volumes of seedlings when planted in the field and at final measurement in August 1997, for white pine reared in the three sizes of JIFFY, are shown in Fig. 6. The field volume accumulation of extended-reared crops was much lower compared with the volume growth of early planted winter crops. The performance of summer-reared seedlings in JIFFY 96 was intermediate between early and late root-cut treatments, as was the case for red spruce. The shoot:root ratio of the summer-reared seedlings was higher than either the late-cut winter crop or the July-planted winter crop at the time of field planting.

The reason for extended rearing in common nursery practice is to build larger seedlings with improved survival; mortality in this outplanting study was almost non-existant.

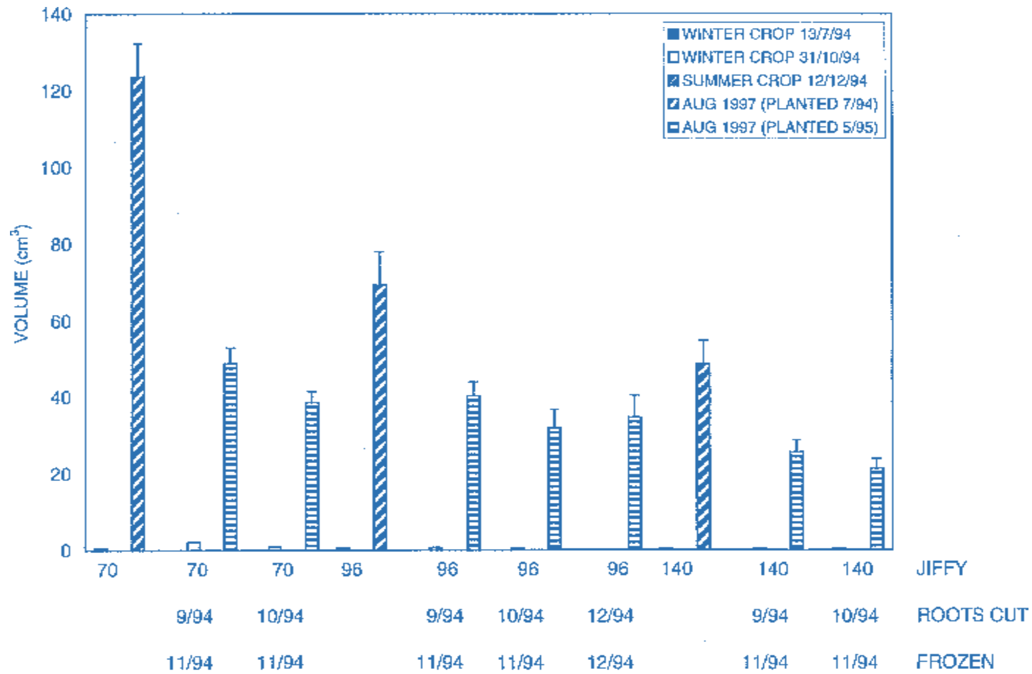

Figure 5. Mean volumes (± SE) of early planted and extended-reared (early and late root-cut) red spruce seedlings grown in JIFFY plugs, at planting and after several field seasons.

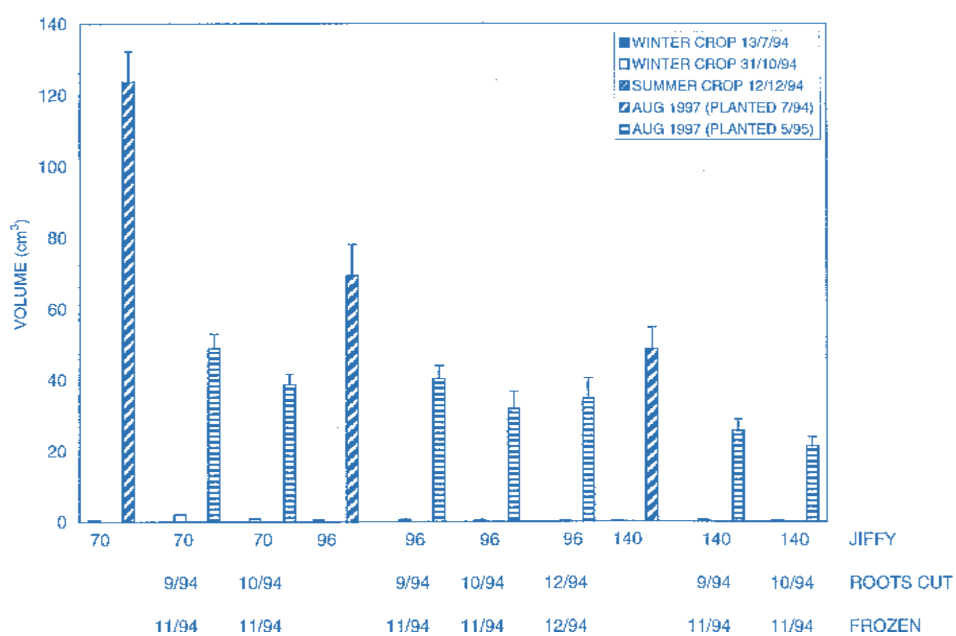

Figure 6. Mean volumes (± SE) of early planted and extended-reared (early and late root-cut) white pine seedlings grown in JIFFY plugs, at planting and after several field seasons.

DISCUSSION

Extended nursery rearing, which is commonly practised to produce larger containerized conifer seedlings with lower shoot:root ratios for enhanced survival, has been shown to be consistently counterproductive to growth for three species of conifers in three hardwall and three mesh-covered plug container systems. This supports the conclusions of Bernier et al. (1995), who suggested that a low shoot:root ratio for container-reared seedlings can indicate an overly developed root system with large, unresponsive, suberized roots tightly packed inside the container cavity. Seedlings with such dense root systems in the containerized soil plug are often referred to as "rootbound." The results of the study presented here suggest that, if there is any relationship between the shoot:root ratio of container seedlings at planting and their subsequent field performance, that relationship appears to be negative; crops with higher shoot:root ratios grew best. Such a negative relationship between the shoot:root ratios of outplanted container seedlings and height growth in the field was also reported by McGilvray and Barnett (1982).

The shoot:root ratios of seedlings reared in JIFFY systems are always higher than those of seedlings reared in hardwall systems with similar plug sizes because of higher seedling density. Higher density or crowding of seedlings has been shown to produce higher shoot:root ratios for container-grown seedlings (Salonius et al. 2000, Simpson 1991, Timmis & Tanaka 1976); the mesh-covered plugs in the JIFFY systems have no space between adjacent soil plugs, but, in hardwall systems, there is always some distance between adjacent soil cavities.

Salonius et al. (2000) and Bernier et al. (1995) have referred to the importance of rapid root extension to seedling performance after outplanting. Based on the contention of Martinsson (1986) and the results of Balisky et al. (1995) and Barnett and Brissette (1986) regarding the effect of container residence time on root form, the poor field performance of the extended-reared seedlings in this study may be due to root deformation and the resultant decreased ability to rapidly extend new roots into the soil on the planting site for water and nutrient acquisition.

Rearing protocols for hardwall-container systems require sufficient root growth within the cavity to hold the soil plug together, however the work of Endean and Carlson (1975) has shown that increasing root density begins to restrict seedling growth very early during container rearing. Selby and Seaby (1982) demonstrated the short time during which primary lateral roots could be formed after seed germination; this short time suggests that primary lateral roots will usually be seriously deformed in most container systems. High correlations between increasing root density in walled container systems, and decreasing field root growth have been reported (Salonius et al. 2000). The reorientation of primary lateral roots from horizontal to vertical by cavity walls was identified by Kinghorn (1978) as one of the most important weaknesses in hardwall-container design. Seedlings reared in mesh-covered plugs have been shown to experience less root deformation than those in walled containers, even after prolonged rearing (Balisky et al. 1995). Root deformation can be eliminated entirely, if small seedling size is accepted at planting; seedlings in free-standing mesh-covered plugs like JIFFY can be planted any time after seeds have germinated because root-plug integrity is supplied by the mesh. Thus seedlings in these systems can be planted before any root deformation has occurred.

Although extended rearing produced growth disadvantages in both hardwall and mesh-covered plug rearing systems, there are differences in the effects of extended rearing on roots in the two systems. All roots produced in hardwall soil plugs are planted, although the root system of the extended-reared seedlings is more suberized, more densely packed, and less resilient than the roots of seedlings reared for shorter periods. In the JIFFY system, we have found an increasing number of active root tips of seedlings are found to have grown into the root plugs of adjacent seedlings as outplanting is delayed; these roots are lost during the cutting operation which is necessary to separate the individual cells from each other before planting. Burdett et al. (1986) speculated that pruning deformed container-grown primary lateral roots might allow these roots to resume their normal horizontal growth habit after outplanting. Bigras (1998) has demonstrated moderate field-growth increases, for extended-reared black spruce, as a result of moderate root pruning and small decreases in field growth as a result of heavy root damage by pruning. Studies have not been done to establish whether deformed lateral roots, pruned just below the root collar in the upper part of the soil plug, as they resume growth on the planting site from the pruned base, will function similarly to primary lateral roots that have not undergone confinement deformation. The results of comparisons of early root cutting, designed to allow a period of regrowth and repair, with cutting just before freezer storage, do not offer definitive guidance as to the best time to perform this operation.

Four months of extended nursery rearing with either hardwall or mesh-covered plug systems, designed to produce larger seedlings with lower shoot:root ratios, did not produce a field growth advantage and in fact this cultural practice was shown to be counterproductive in this study. Better field performance should be achieved with container seedlings whose root growth does not greatly exceed the capacity of the soil plug. This point would be reached when the roots of seedlings in hardwall containers bind the soil plug only sufficiently to facilitate extraction and handling without the soil falling off the roots. For mesh-covered soil-plug systems, this point would be reached before any significant root growth between adjacent soil plugs has occurred.

Vigorous seedlings, with juvenile responsive roots, that develop large stature and sturdiness in the field are more effective than seedlings that achieve large stature and sturdiness in the nursery during extended rearing within the confines of the container system.

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