NINE-YEAR RESULTS OF A BLACK SPRUCE AND WHITE SPRUCE PAPERPOT PLANTING TRIAL IN BOREAL ONTARIO

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ABSTRACT

Results are reported from a comparative planting trial with black spruce *(Picea mariana* [Mill.] B.S.P.) and white spruce *(P. glauca* [Moench] Voss) FH308 Japanese paperpot and 3+0 bare-root stock, established in 1974 on a moderately fertile mixedwood cutover in north central Ontario. The trial was part of a larger, semi-operational planting within which 2400 trees, in 16 random plots, were identified for periodic measurement. In both species, spring-planted paperpot stock had lower mortality than either spring- or summer-planted bare-root stock or summer-planted paperpot stock. In black spruce, higher initial growth rates enabled paperpot seedlings to attain the same size as bare-root seedlings three to five years after outplanting. Planting season had no significant effect on the growth of black spruce paperpots, but spring-planted bare-root stock was superior to summer-planted bare-root stock. In white spruce, bare-root stock generally maintained its superiority over paperpot stock; in neither stock type did planting date have a significant effect on tree size. For both species, the benefits of containerization, in terms of higher growth rates, had largely disappeared within three years of outplanting. Relative growth rate was found to be a useful adjunct to absolute growth values in interpreting biological response but, as the sole basis for evaluating plantation performance, it can be difficult to interpret.

RÉSUMÉ

Ce rapport fait état des résultats obtenus dans une plantation comparative établie en 1974 à l'aide de plants d'épinettes noires *(Picea mariana* [Mill.] B.S.P.) et d'épinettes blanches *(P. glauca* [Moench] Voss) en récipients (pots en papier du Japon FH308) et à racines nues 3+0 dans un parterre de coupe rase modérément fertile du centre-nord de l'Ontario précédemment occupé par des peuplements mixtes. Cette plantation expérimentale faisait partie d'un vaste plan semi-opérationnel en vertu duquel 2 400 arbres, répartis dans 16 parcelles aléatoires, avaient été désignés pour être mesurés périodiquement. Quelle que soit l'essence, les plants en récipients mis en terre au printemps avaient un taux de mortalité plus faible que le matériel à racines nues planté au printemps ou à l'été ou que les semis en récipients mis en place à l'été. L'épinette noire ayant un taux de croissance initial plus élevé, les semis en récipients de cette essence ont pu atteindre la même taille que les plants à racines nues, de 3 à 5 ans après leur transplantation. L'époque de plantation n'avait aucun effet significatif sur le développement des plants d'épinettes noires en récipients, mais le matériel à racines nues mis en place au printemps a donné de meilleurs résultats que celui mis en terre à l'été. Les plants d'épinettes blanches à racines nues ont, dans l'ensemble, continué de progresser plus rapidement que les semis en récipients; l'époque de plantation n'a eu aucun effet significatif sur la grosseur de l'arbre, quel que soit le type de matériel mis en terre. Les avantages de la mise en terre de plants en récipients, qui ont une croissance plus rapide, s'estompent en grande partie moins de 3 ans après la transplantation. Les autres ont découvert que le taux de croissance relatif, associé aux données sur la croissance absolue, facilitait l'interprétation de la réaction biologique, mais qu'à lui seul il pouvait difficilement servir à évaluer la performance d'une plantation.

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Cover photo: Dog River experimental site at time of planting.

INTRODUCTION

A few years before the Ontario Ministry of Natural Resources (OMNR) adopted the Japanese paperpot system in its container planting program, the Canadian Forestry Service (CFS) initiated a series of planting trials with this container. The first of these trials, comparing the performance of FH308 paperpots and 3+0 bare-root stock, was established in 1974 near Thunder Bay, Ontario. Black spruce (*Picea mariana* [Mill.] B.S.P.) and white spruce (*P. glauca* [Moench] Voss) were planted in late May and late July on a recent cutover underlain by loess deposits. This report documents the first nine years' performance in this planting trial (1974-1982).

Most of the published work comparing field performance of containerized and bare-root planting stock has used absolute size or incremental growth as the principal criterion for comparing productivity (cf. Tinus et al. 1974, Scarratt 1982). However, because of the initial size advantage of bare-root stock in relation to container stock, some foresters have questioned the validity of comparisons based on these parameters. In response to this criticism, Vyse (1982) advocated the use of relative growth rate (RGR) as a measure of performance that would avoid such direct comparisons and would quantify tree performance on the basis of the relationship between initial and final plant size.

The concept of RGR was first proposed by Blackman (1919) in Britain for use in agricultural research, and is analogous to the rate of interest earned on a savings account (Hunt 1978). If plant size is equated with money accumulated in an account over a period of time, it will be seen that, as the period of growth (investment period) increases, the influence of RGR (interest rate) on final plant size (money accumulated) increases and the influence of initial plant size (money deposited) decreases. Final plant size, therefore, depends upon initial size, RGR, and the time over which it grows (Blackman 1919). Hunt (1978) offers the opinion that RGR provides a more informative comparison of relative performance than absolute size at the end of a specific period of time. However, the growing conditions on a forest cutover are generally harsher than those on agricultural sites. Consequently, the forest manager needs to be concerned with both RGR and absolute growth rate when considering a regeneration treatment. Forest outplants not only must grow fast in relation to their initial size but must also be vigorous enough, in absolute terms, to overcome weed competition within a reasonably short period after planting.

In this report both absolute size and RGR are used to compare growth performance of paperpot and bare-root outplants over nine growing seasons.

METHODS

Layout of Experiment

Semi-operational plantings of black spruce and white spruce paperpot stock were carried out in the Dog River Management Unit, northwest of Thunder Bay, Ontario in the spring and summer of 1974. The plantings were performed by operational tree-planting crews. At time of planting 16 assessment plots were established at random throughout the planted areas, eight each in the black spruce and white spruce areas. Within species, four assessment plots were established in areas planted from 27 to 31 May inclusive, and a further four plots were established in areas planted on 24 and 25 July. Each plot consisted of two subplots, one containing the regular paperpot stock, the other planted with bare-root stock. Subplots comprised 12 rows of 25 trees each, of which the center portion (five rows by 15 trees) was reserved for periodic measurement and evaluation.

Site

The experimental area, about 160 km northwest of Thunder Bay (48°N, 89°W), is within the Upper English River Section (B.11) of the Boreal Forest Region (Rowe 1972) and the Savanne Site District of Lake Nipigon Site Region 3W (Hills 1959). It is situated in the Height of Land Climatic Region (Chapman and Thomas 1968). The average length of growing season is 162 days (mean daily temperature above 5.6°C), the mean date of the last spring frost is 15 June and the mean date of the first autumn frost is 2 September. Mean annual precipitation is 76.2 cm, half of which is received between 1 May and 30 September.

The surficial geology of the area comprises loess deposits over a fluvial outwash plain. A fine sand capping gives the area a gently rolling topography with slopes of up to 5%. The rapidly draining soils correspond to a moderately fresh to fresh moisture regime (Anon. 1985). Organic horizons are about 8 cm thick and tree rooting is evident to a depth of about 90 cm.

Prior to harvesting, the forest cover consisted of at least 75% small-diameter jack pine (*Pinus banksiana* Lamb.) in association with trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). The area was clear cut in 1971-1972 with chainsaws and wheeled skidders. It was scarified with sharkfin barrels, tractor pads, and spiked anchor chains in the summer of 1973. This exposed mineral soil in shallow furrows approximately 2 m apart.

The planting site remained fairly open for the first growing season, but subsequent regrowth of vegetation was quite rapid. In 1979 planted trees were manually released from competing vegetation, principally trembling aspen, although naturally regenerated jack pine was not removed at this time. By 1982, eight years after planting, jack pine, trembling aspen, and pin cherry (*Prunus pensylvanica* L. f.) had again become abundant throughout the experimental areas and were competing strongly with many planted trees (Fig. 1). Shrubs, including wild red raspberry (*Rubus idaeus* Michx.), alder (*Alnus* spp.), and rose (*Rosa* spp.), were also abundant. Herbaceous plants, including grasses, were common in more open areas.

Figure 1. Hardwood competition on experimental area after nine growing seasons.

Planting Stock

Container stock (FH308 Japanese paperpots) was grown at the Great Lakes Forestry Centre (GLFC) in Sault Ste. Marie, Ontario (47°N, 84°W). May-planted stock was started in the greenhouse in May 1973 and was moved outside later that same summer to overwinter under a snow cover. The July-planted trees were started in the greenhouse in late January 1974 and were moved outside in late May.

Bare-root seedling stock (3+0) was provided by the Thunder Bay Forest Station (OMNR) (48°N, 89°W). May-planted stock was fall lifted and overwintered in frozen storage, while July-planted stock was spring lifted and placed in cool storage for a short period prior to shipping. The July-planted bare-root stock was lifted before it had completed its final growing season in the seedbed and therefore may be termed 'rising 3+0' stock.

Random samples of planting stock (minimum 50 trees) were taken on each planting date for morphological characterization. Shoot and root dry weight (72 hr @ 70°C), root-collar diameter, and shoot lengths are summarized in Table 1.

Table 1. Morphological characteristics of paperpot and bare-root stock at time of planting.[a]

Species/stock type	Time of planting	n	Shoot length (cm)	Root-collar diameter (mm)	Total dry weight (g)	Shoot:root ratio
Black spruce						
paperpot	May	142	13.4	1.6	0.5	5.4
bare-root	May	52	25.3	4.0	3.9	1.5
paperpot	July	100	11.5	1.1	0.2	9.5
bare-root	July	50	24.4	3.8	3.2	3.0
White spruce						
paperpot	May	128	7.6	1.6	0.5	3.6
bare-root	May	50	22.7	5.7	6.5	3.0
paperpot	July	100	9.0	1.4	0.4	6.5
bare-root	July	50	22.6	4.8	5.1	3.6

[a] based on laboratory measurement of random sample taken at time of planting

ASSESSMENT AND MEASUREMENT

Survival and Absolute Growth Parameters

Each tree was assessed for survival status and morphological condition 1, 2, 3, 5, and 9 years after planting. The condition classes were vigorous, healthy, mediocre, and moribund (Scarratt 1974). Total height was measured at time of planting and, together with current annual height increment, after 2, 3, 5, and 9 growing seasons. At the final assessment (1982, after nine growing seasons) only two replicates per treatment were measured.

Shoot biomass was determined at the end of the first, second, third, fourth and ninth growing seasons after planting. Randomly selected shoot samples, from 19 to 41 trees per treatment, were taken from the nonreserved rows within each subplot. Sample trees were sheared at the root collar and returned to the laboratory for dry weight determination (seven days at 70°C for final sample).

For the 1982 sample only, inside-bark stem volumes were determined by stem analysis prior to oven drying, for each of the nine years. Trees were measured for total height (root collar to base of terminal bud) and then were sectioned into 0.5-m lengths. An Addo-X ring measuring device was used to measure annual growth. Volumes were calculated according to Smalian and right-circular cone volume formulae.

Relative Growth Rate (RGR)

Mean RGRs for height and stem volume, based on individual trees, and for shoot biomass, based on plot means, were calculated according to the formula for mean RGR given by Hunt (1978):

$$R(T_2-T_1) = \frac{\log_e W_2 - \log_e W_1}{T_2-T_1}$$

in which R is mean relative growth rate and W_2 and W_1 represent plant size at time 1 (T_1) and time 2 (T_2), respectively. RGR is expressed as the increase in plant material per unit of plant material per unit of time (i.e., relative increase in size per unit of time).

Data Analysis

Unplanned tests for goodness of fit (*G*-statistic) were used to analyze mortality data (Sokal and Rohlf 1981). Growth data (excluding RGR) were compared by one-way ANOVA, and significant differences were identified by means of Tukey's multiple comparison test (Steel and Torrie 1960).

RESULTS AND DISCUSSION

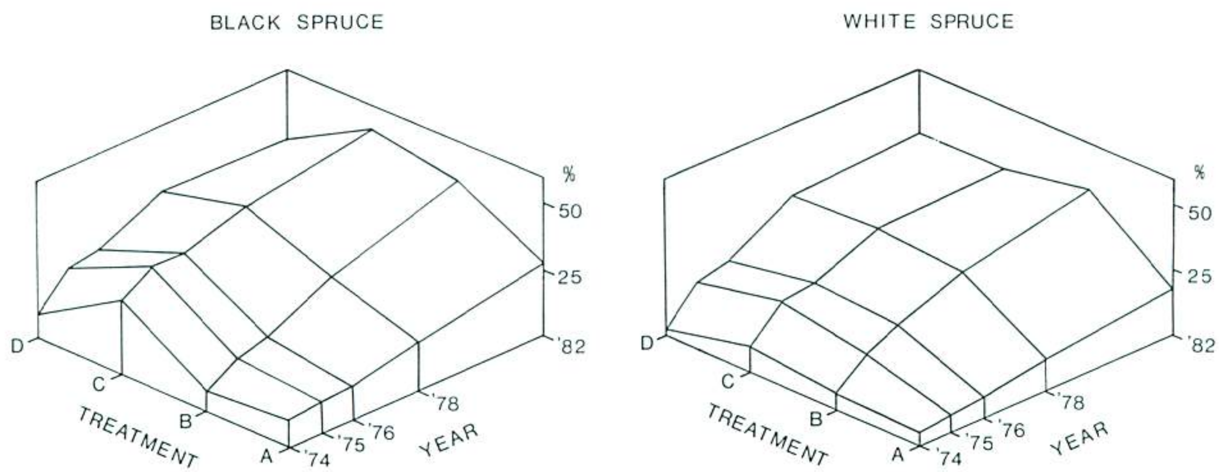
Survival and Condition

After nine growing seasons, spring (i.e., May)-planted paperpots of both species had significantly lower mortality than spring-planted bare-root and summer (i.e., July)-planted paperpots (Fig. 2). In black spruce, spring-planted bare-root and summer-planted paperpots both had more than 40% mortality. Mortality also exceeded 40% in the spring planting of white spruce bare-root stock. These results are in general agreement with the findings of related studies in boreal Ontario, discussed by Wood and Dominy (1985). However, paperpot black spruce had higher mortality than bare-root stock in the summer planting, whereas the opposite was usually the case in previous studies. It is evident from Figure 2 that this discrepancy originated with an especially high first-year mortality in the summer-planted paperpot stock. Reasons for this higher mortality are not hard to deduce. Not only were these seedlings rather small for their age (Table 1) but also their susceptibility to moisture stress would have been exacerbated by their high shoot:root ratio. Mortality rates after the first growing season were not out of line with those observed in other treatments. A second area of deviation involved white spruce paperpot stock. Previous results of white spruce plantings in boreal Ontario showed that mortality of spring-planted bare-root stock is usually equivalent to or lower than that of paperpot stock (Wood and Dominy 1985). However, in this trial, spring-planted paperpots had the lowest mortality of any treatment.

In neither species was there a consistent relationship between seedling morphological condition after planting and planting treatment. Seedling condition varied greatly both within and between treatments at the end of the first growing season, but the amount of variability decreased as the study progressed. At the same time, the overall condition of surviving seedlings tended to improve. Hence, the percentage of healthy black spruce seedlings in the various treatments ranged from 12% to 50% in 1974 whereas, by 1982, the range was 85% to 87% (i.e., improved condition and less variability). White spruce showed a comparable response. We have noted similar trends in other outplantings of black spruce and white spruce in northern Ontario. It is evident that the condition of outplants does not remain static after planting and that, as a plantation ages, the average condition of survivors tends to improve. At the same time, differences due to stock type, etc., tend to diminish.

Height Growth

Black spruce: At time of planting, the black spruce bare-root stock was substantially taller than the younger paperpot stock. However, mean RGR (shoot height) for the period 1974 to 1978 was higher in the paperpots (Table 2), and this enabled the heights of paperpot seedlings to equal or surpass those of bare-root trees within five years of planting. Thus, by 1978 paperpot seedlings had outgrown bare-root stock in the July-planted plots although their height did not differ significantly from that of bare-root seedlings (73 cm versus 83 cm) in the May plantings (Fig. 3).



	Black Spruce				White Spruce			
	May-planted		July-planted		May-planted		July-planted	
Year	PP (A)	BR (B)	PP (C)	BR (D)	PP (A)	BR (B)	PP (C)	BR (D)
1974	b	b	a	b	ab	ab	a	b
1975	c	bc	a	b	b	a	a	a
1976	c	bc	a	b	b	a	a	a
1978	c	b	a	ab	b	a	a	a
1982	c	ab	a	bc	b	a	a	a

PP=paperpot, BR=bare-root
For convenience, treatments are identified by the letters A, B, C, D, on the figures.

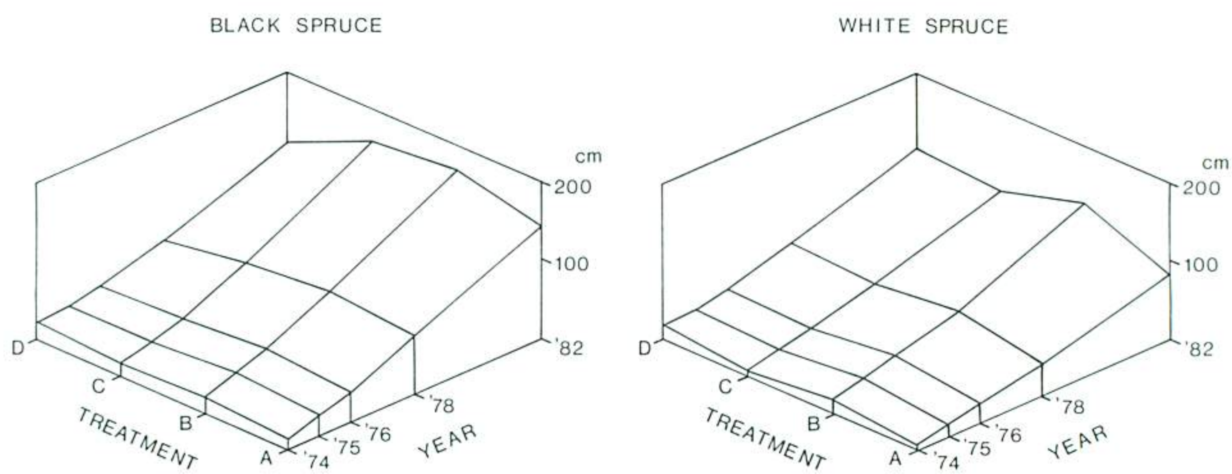
Figure 2. Progression of seedling mortality (%) over nine growing seasons. (Within years and species, treatments with the same letters do not differ significantly at P = 0.05.)

Mean RGRs of paperpot and bare-root trees were similar, within each planting date, over the subsequent four-year period (1979-1982) (Table 2). As a result, July-planted paperpots were able to maintain their superiority right up to the 1982 assessment. In the May planting, however, the small difference in height (i.e., 73 cm versus 83 cm) was amplified to the point at which, by 1982, the bare-root trees were again significantly taller than the paperpot stock. This serves to illustrate the fact that, in plants with the same RGR, small differences in initial plant size may become progressively larger with time (Sweet and Wareing 1966).

Table 2. Mean RGR for height (cm cm^{-1} yr^{-1}).

	Black spruce				White spruce			
	May-planted		July-planted		May-planted		July-planted	
Period	PP	BR	PP	BR	PP	BR	PP	BR
1974–1978	0.36	0.30	0.31	0.20	0.36	0.24	0.35	0.20
1979–1982	0.19	0.18	0.20	0.19	0.18	0.17	0.21	0.22

PP = paperpot, BR = bare-root



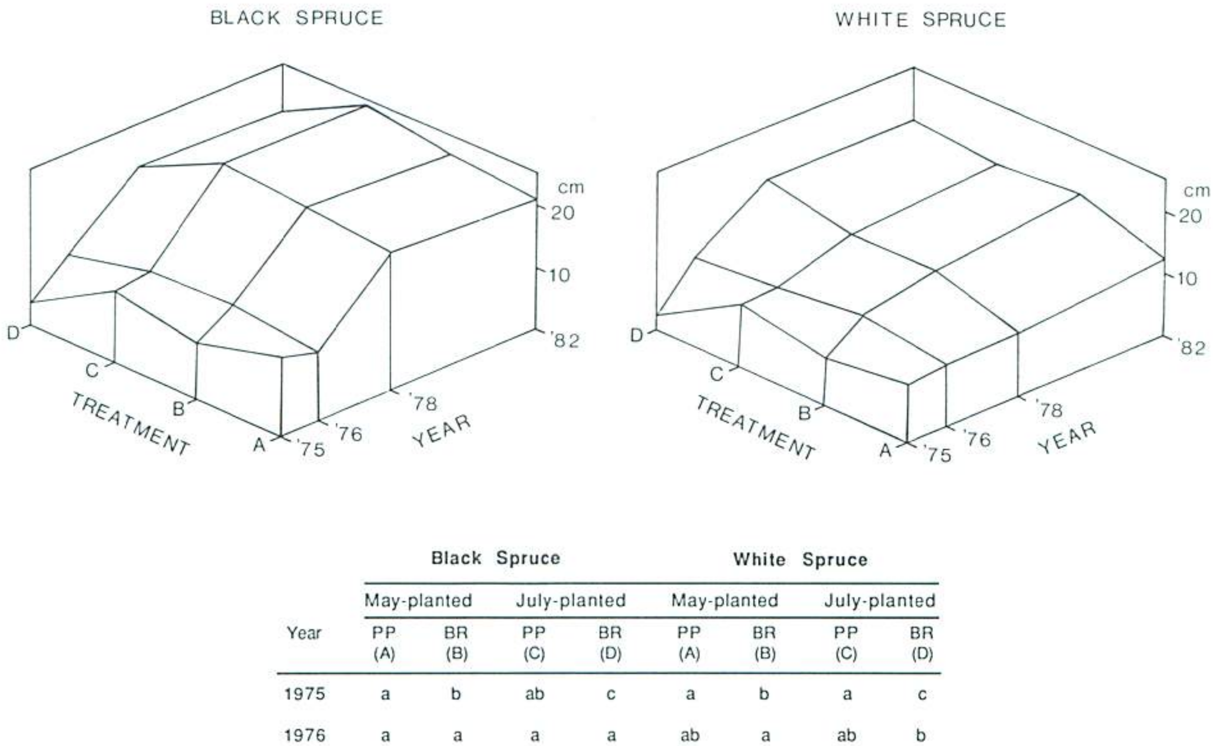
	Black Spruce				White Spruce			
	May-planted		July-planted		May-planted		July-planted	
Year	PP (A)	BR (B)	PP (C)	BR (D)	PP (A)	BR (B)	PP (C)	BR (D)
1975	b	a	bc	c	c	a	c	b
1976	b	a	bc	c	b	a	b	b
1978	a	a	a	b	b	a	ab	ab
1982	b	a	ab	c	b	a	b	ab

PP=paperpot, BR=bare-root
For convenience, treatments are identified by the letters A, B, C, D, on the figures.

Figure 3. Progression of mean total height (cm) over nine growing seasons. (Within years and species, treatments with the same letters do not differ significantly at P = 0.05).

Different responses to planting date were observed within stock types. In paperpots, RGRs for May- and July-planted seedlings were quite similar over the nine-year study period and, since initial heights were also similar, trees were still of equivalent height in 1982 (Fig. 3). In contrast, the RGR of May-planted bare-root stock was slightly higher, during the period 1974 to 1978, than that of the same stock type planted in July. In consequence, trees from the spring planting were significantly (52%) taller than their summer-planted counterparts from 1975 to 1982.

In terms of absolute growth (i.e., height increment) black spruce paperpots grew significantly faster than the corresponding bare-root stock in the second growing season (Fig. 4, 1975 assessment). By the third growing season, however, height increments were the same for all stock types, a feature that persisted into the ninth season. Although the difference was generally not significant, height increment was consistently lowest in the 'rising 3+0' stock (i.e., July-planted bare-root) during this period (Fig. 4).



	Black Spruce				White Spruce			
	May-planted		July-planted		May-planted		July-planted	
Year	PP (A)	BR (B)	PP (C)	BR (D)	PP (A)	BR (B)	PP (C)	BR (D)
1975	a	b	ab	c	a	b	a	c
1976	a	a	a	a	ab	a	ab	b
1978	ab	ab	a	b	b	ab	ab	a
1982	a	a	a	a	a	a	a	a

PP=paperpot, BR=bare-root

For convenience, treatments are identified by the letters A, B, C, D, on the figures.

Figure 4. Progression of mean current annual height increment (cm) over nine growing seasons. (Within years and species, treatments with the same letters do not differ significantly at $P = 0.05$).

<u>White spruce</u>: Although mean shoot RGR was higher for paperpot than for bare-root trees during the 1974-1978 period in both May and July plantings (Table 2), the net response differed for the two plantings. In the May planting a higher RGR was insufficient to allow the paperpot seedlings to make up for the initial difference in shoot height, and the bare-root trees remained significantly taller throughout the nine-year study period (Fig. 3). In contrast, the July-planted paperpots achieved the same total height as the bare-root trees by the third growing season, and remained equivalent in height up to the final assessment. Because mean RGR for the 1979-1982 period was similar within planting dates (Table 2), relative height differences between stock types remained fairly constant during this final period, even though the absolute differences increased (Table 3).

Table 3. White spruce: differences between paperpot and bare-root seedling shoot heights.

	Spring planting		Summer planting	
	Absolute difference (cm)	Relative difference[a] (%)	Absolute difference (cm)	Relative difference[a] (%)
1975	11.9	56.1	3.7	81.5
1976	13.6	64.4	2.8	90.1
1978	19.3	67.3	4.8	90.8
1982	44.9	64.6	8.5	91.8

[a] paperpot seedling height as a percentage of bare-root seedling height

Within stock types, trees from both plantings were equivalent in height and absolute growth rate (height increment) five and nine years after planting, despite higher RGR values in the summer-planted trees during the period 1979-1982 (Table 2). This illustrates the importance of examining absolute as well as relative growth rates before attributing response differences to treatments.

Biomass

<u>Black spruce</u>: The May-planted bare-root trees remained significantly heavier than the paperpot trees for the first four years after planting (Table 4). This is consistent with our observation that, although containerized seedlings may quickly achieve the same height as bare-root stock, they generally remain distinguishable by their more slender form and less

Table 4. Progression of shoot (foliage + stem) biomass over nine growing seasons (g)[a].

Species/ stock type	Time of planting	Year of measurement 1974	1975	1976	1977	1982
		n=25	n=25	n=25	n=40	n=20
Black spruce						
paperpot	May	1.0 c	4.6 b	10.1 b	29.3 b	575.4 ab
bare-root	May	6.7 a	8.2 a	18.7 a	47.1 a	726.2 a
paperpot	July	0.8 c	2.9 b	4.2 c	13.4 c	693.4 a
bare-root	July	3.4 b	4.2 b	6.4 bc	13.1 c	302.0 b
White spruce						
paperpot	May	0.7 b	2.7 b	5.7 b	11.6 bc	164.8 b
bare-root	May	5.7 a	8.4 a	25.0 a	44.8 a	347.3 ab
paperpot	July	0.5 b	1.8 b	5.3 b	7.2 c	313.7 b
bare-root	July	5.2 a	6.8 a	9.1 b	20.7 b	404.5 a

[a] Within years and species, means followed by the same letters do not differ significantly at P = 0.05.

bushy habit (Fig. 5). By the ninth growing season, however, it was difficult to distinguish between spring-planted stock types, and differences in shoot biomass were no longer significant. July-planted paperpots, in contrast, despite their small size at time of planting, achieved the same shoot biomass as bare-root stock after only two growing seasons (Table 4, 1975). By 1982, they were significantly heavier than the bare-root trees, although this is probably more a reflection of the unsatisfactory nature of summer-planted 'rising 3+0' bare-root stock than of exceptional performance by the paperpot stock.

Figure 5. Black spruce paperpot (left) and bare-root (right) trees, three years after outplanting, illustrating differences in shoot form.

Initially (1975), the paperpot stock had a substantially higher mean RGR than the bare-root trees (Table 5), many of which exhibited typical early check symptoms (Sutton and Tinus 1983). The magnitude of the difference in early growth rates attests, perhaps, to the benefits of ball-planting in avoiding post-planting growth check. After 1975, however, paperpot RGRs declined rapidly, for both May- and July-planted seedlings, despite a temporary surge of growth in 1977. This decline in paperpot RGRs indicates that the advantages of containerization, in terms of better growth, lasted for no more than two or three years after planting.

Table 5. Mean RGR for shoot biomass (g g^{-1} yr^{-1}).

	Black spruce				White spruce			
	May-planted		July-planted		May-planted		July-planted	
Period	PP	BR	PP	BR	PP	BR	PP	BR
1975	1.52	0.20	1.26	0.22	1.30	0.38	1.27	0.28
1976	0.78	0.83	0.37	0.43	0.77	1.10	1.07	0.28
1977	1.08	0.92	1.17	0.71	0.70	0.58	0.30	0.83
1974-1977	1.13	0.65	0.93	0.45	0.92	0.69	0.88	0.46
1978-1982	0.60	0.55	0.79	0.63	0.53	0.41	0.76	0.59

PP = paperpot, BR = bare-root

Over all, mean paperpot RGRs for the period 1974-1977 were about double those of their bare-root counterparts; this led to a substantial reduction in bare-root:paperpot shoot biomass ratios over the course of the study in both early and late plantings (Table 6). From 1978 to 1982 mean RGRs were somewhat similar within planting dates, although paperpot RGRs still maintained a slight advantage (Table 5).

In comparing spring- and summer-planted paperpots it is necessary to bear in mind the differences in size and physiological condition of the seedlings at time of planting. May-planted paperpots had a slightly higher RGR than their July-planted counterparts in 1975 and 1976. It is not surprising, then, that these May-planted seedlings, whose dry weight was roughly double that of July-planted seedlings when outplanted (Table 1), had significantly more shoot biomass in 1976 and 1977. However, the May-planted paperpots had the lowest mean RGR in 1977 and during the period 1978-1982 (Table 5). As a result, by 1982, after nine growing seasons, differences in shoot biomass were no longer significant. This is a good example of how, over an extended period, a small superiority in RGR can cancel out the benefits of an initial size advantage.

Table 6. Bare-root:paperpot shoot biomass ratios.

Species	Time of planting	Year		
		1974	1977	1982
Black spruce	May	6.7	1.6	1.3
	July	4.1	1.0	0.4
White spruce	May	7.9	3.9	2.1
	July	10.0	2.9	1.3

After the initial period of post-planting growth check, early (1976-1977) RGRs in bare-root stock were also highest for May-planted trees (Table 5). The July-planted trees were already at a disadvantage because of their somewhat lower mass at planting (Table 1) and, as a result of their lower RGR, they fell further behind in terms of shoot biomass as the study progressed (Tables 4 and 5). A small superiority in RGR between 1978 and 1982 failed to change the situation. In contrast with the paperpot results, biomass differences remained significant throughout the trial, the May-planted trees being more than double the weight of those planted in July after nine growing seasons (1982).

White spruce: As was the case with black spruce, May-planted white spruce bare-root trees remained significantly heavier than paperpot trees for the first four years after planting (Table 4). By 1982 the differences between stock types were no longer significant, although the bare-root stock still had about double the biomass of the container stock. The lack of significance is probably explained by the great variability in individual tree biomass within treatments, particularly in the later years. This applies to trees planted in July also, although in this instance 1982 differences in shoot biomass between stock types were much smaller than in the spring-planted trees. Again, paperpot trees were distinguishable from bare-root trees for several years by their more slender form and less bushy habit. While the distinction tended to persist in open-grown trees, it was commonly obscured in trees subject to heavy competition from vegetation.

In general, paperpots had higher mean RGRs than bare-root trees throughout the study (Table 5), with the result that there was a substantial reduction in bare-root:paperpot shoot biomass ratios over the nine years (Table 6). As in black spruce, RGR differences between stock types were greatest in 1975, at the end of the second growing season, when paperpot RGRs peaked and bare-root stock still showed symptoms of post-planting growth check.

In paperpots, summer-planted trees were almost twice as heavy as spring-planted trees by 1982 (Table 4) although, because of large within-treatment variability, this difference was not significant. Much of the variation can be attributed to differences in microsite, particularly to the effects of vegetation competition upon small container stock. Spring- and summer-planted bare-root trees also had equivalent shoot biomass after nine growing seasons.

Stem Volume

Black spruce: May-planted bare-root stock had about eight times more stem volume than paperpot seedlings at the end of the first growing season (Tables 7 and 8). However, because of a higher RGR in the latter (Table 9), this advantage had been reduced to 1.7 times by 1978 (Table 8). Thereafter, the mean RGR was similar for both stock types and, as a result, the relative volume difference (not significant) remained constant up to the final measurement.

Results of the July planting were quite different. The stem volume of the July-planted bare-root stock at the end of the first growing season was less than half that of its spring-planted counterpart, and only 3.7 times greater than that of the contemporary paperpot stock (Tables 7 and 8). The lower early RGR of bare-root stock (Table 9) enabled the paperpot seedlings to catch up to the bare-root trees by the end of the third year after planting (Table 7). From 1978 to 1982, RGR levels were similar in the two stock types (Table 9), with the result that stem volume ratios of summer-planted bare-root and paperpot stock remained steady at 0.4 to 0.3 during this period (Table 8). However, in absolute terms the paperpots were significantly superior to the bare-root stock by 1982 (Table 7).

Both spring- and summer-planted paperpots had similar RGRs over the nine growing seasons (Table 9) and, since the trees were approximately equal in volume in 1974, there were no statistical differences in volume nine years later. In bare-root stock, however, spring-planted trees were significantly greater in volume than their summer-planted counterparts and, perhaps aided by higher RGRs from 1975 to 1977 (Table 9), remained so throughout the nine years (Table 7).

White spruce: May- and July-planted bare-root stock, respectively, had seven and ten times more initial stem volume after one growing season than the corresponding paperpot seedlings (Tables 7 and 8). However, mean RGRs for paperpots were consistently higher than those for bare-root trees in both plantings (Table 9), with the result that the relative differences between stock types were reduced substantially over the nine-year period (Table 8). Notwithstanding this reduced differential, stem volume of spring-planted bare-root stock was still significantly superior to that of paperpot stock for the entire nine years. Only summer-planted paperpots were able to achieve stem volume equal to that of bare-root stock by 1982.

Table 7. Progression of stem volumes (cm^3) over nine growing seasons[a] (n = 20)

Species/ stock type	Time of planting	Year of measurement 1974	1975	1977	1978	1979	1980	1981	1982
Black spruce									
paperpot	May	0.2 b	0.4 b	7.1 b	22.7 ab	48.8 ab	92.7 a	149.0 ab	237.7 ab
bare-root	May	1.3 a	2.9 a	16.4 a	38.2 a	77.2 a	135.6 a	224.2 a	351.8 a
paperpot	July	0.1 b	0.4 b	6.7 b	22.6 ab	53.2 ab	110.2 ab	213.2 a	365.4 a
bare-root	July	0.5 b	0.7 b	3.0 b	8.7 b	18.3 b	34.9 b	65.5 b	116.0 b
White spruce									
paperpot	May	0.2 b	0.4 b	2.7 b	5.9 b	11.6 b	19.6 b	34.2 b	54.3 b
bare-root	May	1.0 a	3.0 a	13.9 a	26.4 a	41.2 a	63.3 a	104.3 a	163.0 a
paperpot	July	0.1 b	0.3 b	2.6 b	8.1 b	20.6 ab	42.2 ab	78.4 ab	129.8 ab
bare-root	July	0.9 a	1.4 ab	9.2 ab	19.6 a	35.0 a	62.0 a	107.8 a	170.6 a

[a] Within years and species, means followed by the same letters do not differ significantly at P = 0.05.

Table 8. Bare-root:paperpot stem volume ratios.

Species	Time of planting	1974	1975	1976	1977	1978	1979	1980	1981	1982
		Year								
Black spruce	May	8.1	7.4	4.0	2.3	1.7	1.6	1.5	1.5	1.5
	July	3.7	2.0	0.8	0.4	0.4	0.3	0.3	0.3	0.3
White spruce	May	7.0	6.8	5.8	5.2	4.4	3.6	3.2	3.0	3.0
	July	9.7	4.9	3.7	3.5	2.4	1.7	1.5	1.4	1.3

Table 9. Mean stem volume RGR ($cm^3\ cm^{-3}\ yr^{-1}$).

	Black spruce				White spruce			
	May-planted		July-planted		May-planted		July-planted	
Period	PP	BR	PP	BR	PP	BR	PP	BR
1975	0.96	0.78	1.00	0.45	1.02	0.87	1.23	0.44
1976	1.27	0.97	1.21	0.60	0.87	0.69	1.04	0.89
1977	1.18	0.82	1.54	0.67	0.74	0.74	0.76	0.74
1978	1.35	0.82	1.31	1.06	0.78	0.62	1.09	0.76
1979	0.71	0.81	0.94	0.85	0.71	0.41	0.99	0.66
1980	0.59	0.60	0.75	0.59	0.62	0.37	0.67	0.54
1981	0.58	0.55	0.69	0.68	0.77	0.62	0.73	0.54
1982	0.48	0.48	0.54	0.55	0.46	0.40	0.51	0.45

PP = paperpot, BR = bare-root

In general, summer-planted paperpots had a slightly higher mean volume RGR than spring-planted paperpots throughout the study (Table 9). Despite the initial superiority of spring-planted seedlings, this led to a progressive divergence in treatment means after 1977 and, although the difference was not significant, by the final measurement July-planted trees had more than double the stem volume (Table 7). Bare-root volume RGR was also highest in summer-planted trees, although in this case the mean stem volumes of trees in the two plantings were equivalent after nine growing seasons.

GENERAL DISCUSSION

In a strict experimental sense, but subject to qualifications that will be discussed later, FH308 paperpot seedlings appear generally to have performed at least as well as 3+0 bare-root stock on this moderately difficult site. Over all, with black spruce, substantially higher paperpot RGRs during the first few years after planting enabled the paperpot stock to equal the size of bare-root stock for most growth parameters measured within three to five growing seasons. This confirms previous findings (Scarratt 1982) that the advantages of containerization, in terms of increased growth rates, largely disappear after about three growing seasons. Both stock types had similar relative growth rates from 1978 to 1982, and by the ninth growing season paperpot trees were either equivalent to bare-root trees in biomass and stem volume (for spring planting) or superior to them (for summer planting). The superiority of summer-planted paperpots may be partly a reflection of the use of smaller 'rising 3+0' seedlings rather than full 3+0 material. However, to put the performance of summer-planted paperpots into perspective, it will be noted that by 1982 they also had caught up to the spring-planted bare-root stock (all parameters).

With black spruce paperpots, planting season had no significant effect upon any of the parameters measured, both May- and July-planted trees having generally similar performance over the nine growing seasons. This is in agreement with findings by Scarratt (1974) and Wood and Dominy (1985) that, subject to seedling physiological quality and local site conditions, containerized spruce seedlings can be planted up to the end of July in northern Ontario without adverse effects on their field performance. Although this gives approximately a 12-week safe planting window, it does not mean that other factors related to season of planting can be ignored. For example, with paperpot stock it is highly desirable that overwintered seedlings be planted early in spring to take advantage of the new root flush, and to avoid damage or loss of actively growing roots.

In contrast to paperpots, spring-planted black spruce bare-root trees had a higher RGR than July-planted trees during the first few years after planting (1974-1978) and were significantly larger after nine growing seasons. Much of the difference can probably be attributed to the use of 'rising 3+0' stock for the summer planting. Although the smaller initial size of this stock will have put it at a disadvantage in comparison with the spring-planted material, lifting and planting of bare-root stock during periods of active growth, as in the case of 'rising' stock, are known to induce physiological shock in seedlings from which they may be slow to recover (McClain 1975).

In white spruce, because of a greater disparity between the initial size of paperpot and bare-root stock, treatment responses were not always as clear cut as in black spruce. Hence, despite the fact that paperpots had higher RGRs in most parameters, bare-root stock tended to maintain its superiority up to the final assessment.

White spruce exhibited greater consistency than black spruce in its response to planting date. In neither stock type did planting date have any significant effect upon tree size (all parameters) after nine growing seasons.

One of the principal biological arguments for container planting has been that, because seedlings are planted with an undisturbed and undamaged root system, they will experience less severe planting shock than bare-root stock, and should be in a better position to grow without delay after planting. As a corollary, it has been argued that containerized seedlings should be able to match the early performance of bare-root stock on comparable sites, even though they are typically smaller at time of planting. Early stock type comparisons, such as the one reported here, were designed to test this hypothesis, and provided the background for later research aimed at defining site-specific container stock standards (cf. Scarratt 1982).

Although the literature documents many instances in which containerized seedlings have performed as well as or better than bare-root stock (e.g., Dobbs 1976, Halland et al. 1981, Walker 1981, Krause 1982, Scarratt 1982, Alm 1983), it is evident that no general case can be made. Many factors interact to influence the result, *viz:* the absolute and relative sizes of the different stock types at time of planting; major morphological deficiencies (e.g., high shoot: root ratio, root damage, bud damage); the physiological condition of planting stock (e.g., drought tolerance, root growth capacity, nutrient status); site constraints, especially in relation, initially, to soil temperature and soil moisture, and later to the ability of trees to keep ahead of competing vegetation.

The results reported here need to be put into perspective, for the stock grades employed in this experiment are no longer used today. Hence, the 3+0 bare-root seedlings were appreciably smaller than the transplant stock that is used in current spruce plantings and, in consequence, constituted a less stringent standard by which to compare paperpot performance. Similarly, the FH308 paperpot has been superseded by the larger-volume FH408 container, while current specifications for containerized spruce require substantially larger seedlings than those used here. These changes do not render the present results obsolete, for the experiment is representative of the situation in many young spruce plantations throughout northern Ontario. However, we must be objective in differentiating the biological results from the operational effectiveness of our treatments.

The fact that containerized seedlings were able to match the performance of bare-root trees many times their own weight on this site, although it confirms the superior early growth potential of container stock, tells us little about their regeneration "impact" (i.e., their effectiveness in meeting regeneration goals). Essential criteria in any evaluation of plantation performance are high survival, an acceptable growth rate, and freedom from competing vegetation. Although field performance standards are woefully lacking, Armson et al. (1980) have defined "free-to-grow" standards for the assessment of forest industry plantations established under Forest Management Agreements. For a 2+2 transplant plantation of an age similar to that used in the present experiment, supplementary height-age tables specify the following growth targets (freedom from competition assumed):

	Total height (cm)	Minimum current height increment (cm)
Black spruce	198.0	30.0
White spruce	150.0	24.0

Although 2+2 transplants constitute a fairly stringent basis for comparison, use of this standard confirms what was evident on the ground: that, in general, neither stock type was adequate for this moderately difficult site. Spring-planted bare-root trees came closest to meeting the standard in both black spruce (169 cm) and white spruce (127 cm); they were closely followed by summer-planted black spruce paperpots (159 cm), and trailed by summer-planted white spruce paperpots (96 cm). Height increments in bare-root stock of both species were, on average, 35% lower than the standard; in paperpots the deficit was 25% and 44% in black spruce and white spruce, respectively.

With more frequent weed control the trees might have performed better. Certainly, there would probably have been less variability among individual trees. However, experience with spruce on other sites in northern Ontario suggests that, even with adequate weed control, planting stock larger than that used in this experiment would have been necessary to achieve a vigorous, dominant stand within a reasonable time after planting on this site. Scarratt (1982) recommends a one-year-old seedling with a shoot height of 20 cm and a dry weight of 1.0 g as the minimum for containerized black spruce even on the easiest sites. For more fertile upland sites with heavy competition potential, even larger, older seedlings (up to 1.5 years) are recommended (ibid.). This reinforces the need for care in matching planting stock (type, morphology and physiology) to the particular conditions of the planting site, especially in relation to the potential for weed competition and probable weed control strategies.

Finally, a few comments are in order about the use of RGRs for comparing the performance of containerized and bare-root stock. The validity of using absolute growth rates has often been questioned on grounds of the large initial size differential between these stock types (the apple and the orange analogy). Vyse (1982) advocated the use of RGR as a means of circumventing this perceived problem, because "...it allows an investigator to assess the efficiency of growth in relation to size." However, although the argument has biological merit, we believe that reliance on RGR for evaluating stock type performance could result in misleading conclusions.

A high RGR is not an infallible indicator of superior performance, nor does it necessarily denote a better treatment (from an operational viewpoint). Small seedlings frequently have higher RGRs than larger ones but, if the initial size differential is too great, the former may never be able to catch up, in absolute terms, to the latter. This is given in the basic relationship: growth = initial size x RGR x growth period. In a related context, Sweet and Wareing

(1966) recognize this when they state that "...while the breeder could if required select for high RGR in seedlings, there is no guarantee [based] on current knowledge that this will give larger trees at rotation age." There is also a need for caution in interpreting relative growth rates when the values are similar. This is illustrated by two observations from the present study: (1) when initial plant size is similar, relatively small differences in RGR can lead to substantial differences in absolute size over a number of years; (2) when, on the other hand, RGRs are similar, a small initial size difference can be magnified over time, and can again lead to substantial differences in absolute size.

Notwithstanding these observations, RGR can be a valuable adjunct to absolute growth values in interpreting biological response, more particularly in experiments that compare stock of equivalent size and physiological status. It has to be recognized, however, that certain absolute growth parameters, such as shoot height, have important operational implications with respect to the success of a regeneration treatment (i.e., the regeneration "impact" of a treatment). An ability to stay ahead of competing vegetation is one such consideration, irrespective of the type of stock employed or its RGR.

CONCLUSIONS

1. On this moderately difficult site, black spruce containerized seedlings performed at least as well as much larger 3+0 bare-root stock during the first nine years after planting. In general, substantially higher paperpot RGRs during the first few years enabled paperpot seedlings to attain the same size as bare-root trees within three to five growing seasons. This confirms the superior early growth potential of container stock, although many other factors, both biological and environmental, interact to influence the final result.

2. In contrast to black spruce, white spruce container stock of the grade tested performed less well than 3+0 bare-root stock. Substantially larger container stock is probably required to provide a practicable alternative to bare-root material.

3. Within the context of May and July plantings, planting season does not appear to have any long-term significance for field performance of container stock. This confirms previous findings that, subject to seedling physiological quality and local site conditions, containerized spruce seedlings can be planted up to the end of July in northern Ontario without adverse effects on field performance.

4. The benefits of containerization, in terms of increased growth potential, largely disappear within about three years of outplanting. Therefore, if growth performance of container stock is to match that of bare-root stock on a given site, seedlings must be of a size that will allow this to occur within a similar time frame.

5. Larger planting stock, both paperpot and bare-root, than was used in this experiment is required to ensure that young plantations quickly grow free from competition even on sites, similar to the one described here, with only moderate competition potential.

6. As the sole basis for evaluating plantation performance, RGRs can be difficult to interpret, especially in an operational context. However, as an adjunct to absolute growth indices, RGR can provide valuable insights into the growth dynamics of a situation and help to interpret biological response.

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