GROWTH, NUTRITION AND ROOT DEVELOPMENT OF ONTARIO TUBELINGS, PLUGS AND 3+0 BARE-ROOT BLACK SPRUCE

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Abstract.--Young stands established with Ontario tubelings, plugs and 3+0 bare root black spruce *(Picea mariana* [Mill.] B.S.P.) were examined and their growth, nutrition, and root development were compared. Mean height and current annual height increments of bare-root stock significantly exceeded those of tubelings and plugs. Although all stand types were moderately deficient in nitrogen and phosphorus, growth differences were associated with original tree size, root development and overhead competition.

Résumé.--On a examiné des peuplements juvéniles d'épinette noire *(Picea mariana* [Mill.] B.S.P.) établis au moyen de semis en tubes Ontario, en cartouches et 3+0 à racines nues et on a comparé leur croissance, leur nutrition et le développement de leurs racines. La hauteur moyenne et la vitesse de croissance en hauteur annuelle des semis à racines nues étaient considérablement supérieures à celles des semis en tubes ou en cartouches. Même s'il y avait une carence modérée d'azote et de phosphore dans tous les trois types de peuplement, les différences de croissance étaient liées à la taille originale de chaque arbre, au développement de ses racines et à la concurrence du couvert.

INTRODUCTION

From its inception in 1957 and through various developmental phases in the 1960s, the Ontario tubeling program flourished, but has since waned. From the outset (McLean 1959) the small split cylindrical polystrene tube was regarded as a means of supplementing the province's bare-root production program, as well as supplying stock on short notice, for example, for planting areas destroyed by fire. Besides the biological advantages of minimal root disturbance at planting and extension of the planting season, considerable opportunity for mechanization was envisaged. The prospects of these advantages gave such impetus to the tubeling program that research into the biological implications of the system lagged behind.

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The problems associated with the performance of tubed seedlings are now known to most of us and have been reviewed by Scarratt (1974). Most notable among the problems are frost heaving, low survival and slow subsequent growth of surviving trees.

In northern Ontario, fifth year survival of black spruce *(Picea mariana* [Mill.] B.S.P.) tubeling plantations established between 1966 and 1968 ranged from approximately 30% to 37% with an average height of 25 cm (MacKinnon 1974). In sharp contrast, mean survival and height of black spruce bare-root stock for the same period were 61% and 69 cm, respectively. These inconsistencies are as yet unexplained, but it is abundantly clear that if container stock is to assume a prominent role in light of its intended purpose, it must compare favorably with established regeneration techniques (i.e., in Ontario, bare-root planting) (Reese 1974).

In this study, growth performance of Ontario black spruce tubelings, plug and bare-root stock was examined with reference to root development, nutrition, and competition. It must be emphasized, however, that these results and the performance of current containerized conifer and bare-root stock may not be directly comparable. Nevertheless, the results do provide a measure of growth differences between stock types that are presumably due to differences in stock size at the time of planting.

STUDY DESCRIPTION

Study Location and Stand History

The plantation area is located north of Reivonen Lake approximately 150 km northwest of Thunder Bay, Ontario in the Dog River working circle of the Great Lakes Forest Products Co. Ltd. In 1968, harvesting operations removed high cordage of black spruce, white spruce *(Picea glauca* [Moench] Voss), balsam fir *(Abies balsamea* [L.] Mill.) and jack pine *(Pinus banksiana* Lamb.), leaving a considerable poplar *(Populus* spp.) overstory.

The area was subsequently scarified with shark-finned barrels and chains, and in May, 1970 bare-root spring-lifted 3W 3+0 black spruce stock was planted in the northern portions of the cutover. The bare-root stock arrived at the planting site packed in sphagnum moss in veneer crates. Trees were graded stock with an average height of 25 cm. The remaining area was planted in 1971 with black spruce seedlings raised in Ontario tubes. At the time of planting, these tubelings were overwintered, 15-month-old seedlings approximately 6–8 cm high. Approximately half of the tubelings were planted as plugs, i.e., without the tube. In total, 130,000 bare-root seedlings and 113,000 plugs and tubelings were planted at approximate densities of 2,710 and 4,500 trees per ha, respectively.

Field Methods

Within each of the tubeling and plug plantations two plots were located so as to provide two levels of overstory competition. For comparative purposes, a single plot was located within the 3+0 bare-root plantation immediately adjacent to areas planted to tubelings and plugs. The plantation could have been classified as "free to grow", but it had an average height for which only mature residual poplar offered a moderate form of overhead competition. The bare-root plantation was 11 years old and the tubeling and plug plantations were 10 years old when assessed. Although this disparity does not permit direct growth comparisons on the basis of age, unformity of site and treatment is an overriding advantage in this study.

All assessment plots were circular and varied in size to permit an adequate number of sample trees for reliable estimates of plantation growth parameters. Sample plot statistics are presented in Table 1. Within each plot, all trees were tagged, numbered and measured for total height, diameter at breast height, length of live crown, and crown width. Once tallied, all bare-root and plug trees were harvested and transported to the laboratory for aging to ensure that the sample trees did not include natural trees. The root systems of two trees per plot were excavated and described according to their configuration and extent.

Ten trees from each sample plot were randomly selected across the range of heights and further measured for annual height increments from 1974 to 1980. The 1980 foliage of these same trees was sampled from the upper third of the crown and subsequently dried, ground, and analyzed for concentrations of N, P, K, Ca and Mg using standard laboratory procedures.

Site Conditions of Study Plots

All sample plots were located in close proximity to one another. Examination of the soil in each plot indicated little variation in profile development, texture, and soil moisture conditions. Common to each profile was evidence of past disturbance by logging and scarification. The LFH layers varied in thickness from 5 to 8 cm and were underlain by an intermittent and faint A_e horizon. The Bfl and Bf2 horizons were easily observed as well as pockets or strata of charcoal which were possibly inverted on the profile during the scarification process. The presence of charcoal suggests the likelihood that the original stand originated after fire.

Textural analysis of each profile indicated that the soil is predominantly silt loam with pH ranging from 4.7 to 5.6. The C horizon was composed of unsorted, sandy gravels. The profile showed no mottling, and this suggests that the site is well drained. The site is moderately fresh and the size of stumps from the previous stand indicated that the site had a moderately high timber production potential.

The most commonly occurring species in the ground vegetation were blueberry *(Vaccinium angustifolium* Ait.), honeysuckle *(Diervilla lonicera* L.), prickly rose *(Rosa acicu-*

Table 1. Stand description of sample plots. Numbers within parentheses refer to the number of stems recorded in each sample plot.

Stand type	Competition level	Plot area (ha)	Density (stems/ha): Planted black spruce	Poplar	Other conifer	Total
Tubeling	light	0.045	2,000 (90)	867 (39)	489 (22)	3,356
Tubeling	heavy	0.023	1,870 (67)	9,130 (210)	956 (22)	11,956
Plug	light	0.040	1,925 (77)	100 (4)	75 (3)	2,100
Plug	heavy	0.038	2,667 (100)	6,373 (239)	187 (7)	9,227
3+0 Bare-root	moderate	0.035	2,429 (85)	1,629 (57)	571 (20)	4,629

laris Lindl.), mountain maple *(Ater spicatum* Lam.), feather moss *(Pleurozium schreberi* BSG. Mitt.), Labrador tea *(Ledum groenlandicum* (Oeder), and other lower vegetation commonly found in a mixedwood forest association.

RESULTS

Height Growth

In this comparative study and in others like it, height growth is commonly utilized to assess the relative performance of various forms of planting stock. Each mention of statistical significance relates to the 5% level of probability.

In Figure 1, the progression of mean height of the five stand types is presented from 1973 through to 1980. Clearly, the difference between the 3+0 bare-root plantation and the tubeling and plug plantations remains significant regardless of the competition level. The removal of the tube at the time of planting had little early effect on height growth of plug stock in relation to tubeling stock. It was only by 1975 that a pattern of superiority emerged as plug stock under light competition achieved greater height than the other plug and tubeling sample plots. This growth advantage was consistent up to 1980, at which time plug trees under light competition attained the performance standard suggested by Mullin (1978). Over all, tubelings and plugs growing under light competition achieved 5% and 33% greater height, respectively, than when under heavy competition.

Although tubeling and plug stock achieved Mullin's growth standard 10 years after planting, this does not compare favorably with the performance of 3+0 bare-root stock, which achieved the growth standard (extrapolated back in time) five years after planting. This early achievement by 1974 and 50% over-achievement in 1980 substantiates the competitive growth advantage of 3+0 bare-root stock over Ontario black spruce tubelings and plugs. Tubelings grown under light and heavy competition and plug stock under heavy competition attained similar heights by 1980, but this was nearly 30% below the minimum acceptable performance standard for 3+0 bare-root black spruce stock. In 1980, mean height of 3+0 bare-root stock significantly exceeded the mean height of tubelings and plugs (competition levels combined) by 104% and 69%, respectively.

Current Annual Height Increment

Current annual height growth from 1974 through to 1980 for tubeling, plug and bare-root stock is presented in Figure 2. Several trends are readily apparent. First, mean annual height growth of the bare-root stock was greater than that of the tubeling or plug plantations, regardless of competition level. This difference is significant from 1974 to 1976, after which the height growth difference between the bare-root and the plug plantations under light competition was not significant. Specifically, the mean height increment of the bare-root plantation exceeded that of tubelings and plugs (competition levels combined) by 85.4% and 40.0%, respectively.

Second, the effect of competition on current annual increment of tubelings was not significant although height growth was

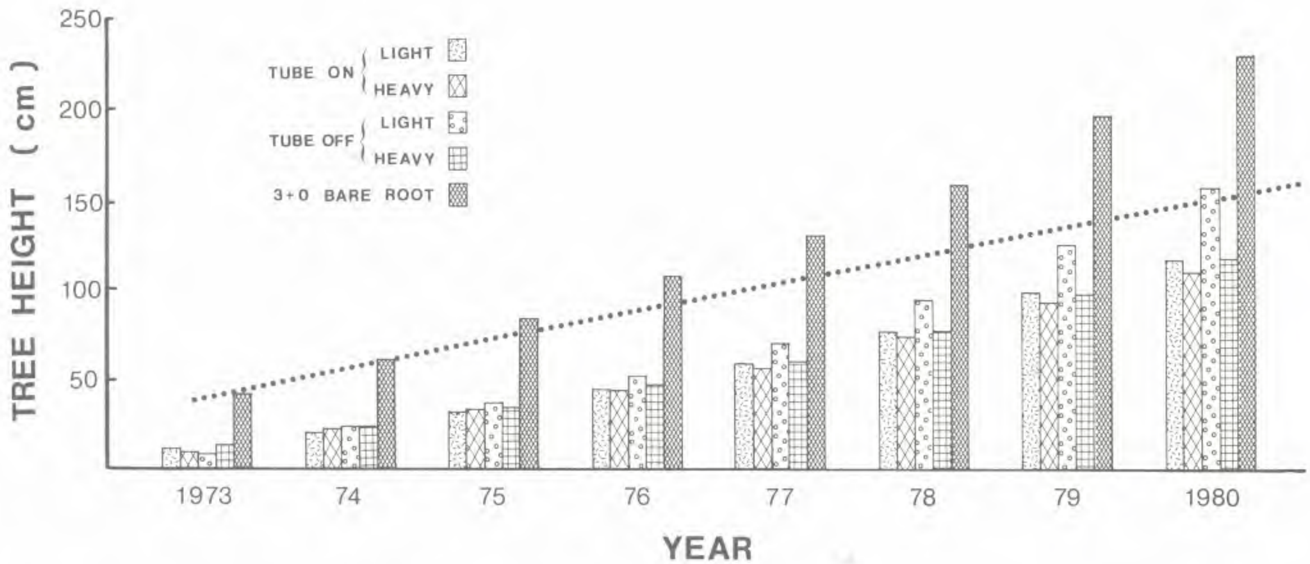

Figure 1. Average tree heights (1974-1980) for black spruce tubeling and plug stock under light and heavy competition, and 3+0 bare-root stock. Dotted line represents "minimum performance standard" (Mullin 1978) for 3+0 bare-root black spruce.

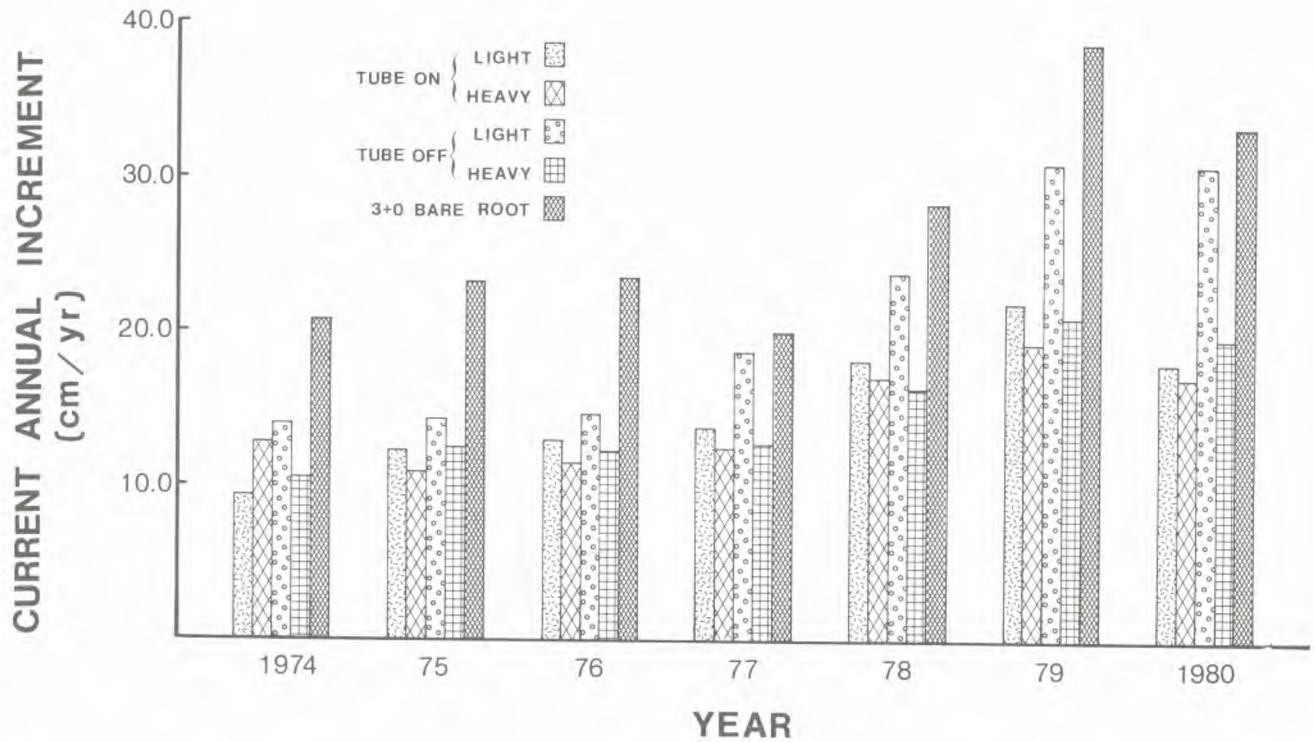

Figure 2. Current annual height increments (1974-1980) of black spruce tubeling and plug stock under light and heavy competition, and 3+0 bare-root stock.

Table 2. Stem diameters and crown dimensions of trees from sample plots of tubelings, plugs, and 3+0 bare-root black spruce.

Stand type	Competition level	DBH (cm)	Proportion of sample trees achieving DBH (%)	Crown dimensions Length (cm)	Crown length / Total height (%)	Width (cm)
Tubeling	light	0.71	52	93	80	59
Tubeling	heavy	0.62	19	88	80	70
Plug	light	0.66	36	92	59	65
Plug	heavy	0.52	21	110	94	70
3+0 Bare-root	moderate	1.62	90	192	83	107

marginally better (9.3%) under light competition than under heavy competition. The difference in mean annual height increment between plugs under light and heavy competition was 39%. The difference in rate of growth increased from 1977 until 1980, at which time plug trees growing under light competition achieved 57% greater height growth than plug trees under heavy competition.

Stem Diameter and Crown Dimensions

Differences in performance of the five stand types are further evidenced by diameters at breast height (Table 2). DBH was greatest for bare-root stock, followed by plugs and tubelings under light competition, and finally by tubelings and plugs under heavy competition.

Crown dimensions are also presented in Table 2. For plug seedlings grown under light competition, crown lengths averaged approximately 59% of their total height whereas the crowns of trees of the other stand types represented a greater percentage of their respective mean heights. When crown widths were considered in relation to crown length, the crowns of bare-root trees and of tubelings and plugs under light competition were cylindrical, and were shorter and stockier for tubelings and plugs under heavy competition.

Root Development

Poor root form of planted trees has been of major interest for many years and is often considered a limiting factor in the potential development of plantations (Van Eerden and Kinghorn 1978). Root deformities caused by planting were expected to lessen with the advent of containerization but planting failures have, nevertheless, continued to occur. For black spruce tubeling plantations, slow growth is often associated with, among other deficiencies, poor root development. Frost heaving is a principal factor leading to deformities of root systems particularly in Ontario tubelings (Fraser and Wahl 1969, Anon. 1971). The obvious implication of severe root deformity is that the tree may not recover to reach maturity, let alone grow as well as bare-root trees. Figures 3 and 4 portray an extreme example of abnormal root system development. Root systems excavated in the present study came from trees which were fully established and had presumably achieved an adequate root system. Prior to excavation, there was no visible evidence of root deformation and trees exhibited reasonably good growth; hence it was expected that the root systems of these trees would be well developed.

Such was the case for the tubeling trees excavated. Figures 5 and 6 clearly portray the radiating development of the root system. The trees were well anchored and possessed omni-directional stability. It is notable that root egress from the bottom of the tube was virtually nil and that circumstances causing the tilt in the tube possibly led to the creation of conditions suitable for adventitious root development from the stem.

A somewhat similar, but less extensive, radiating root configuration was typical of plug seedlings (Fig. 7 and 8). In this example, two tiers of roots are obvious; the upper or major tier was adventitious in origin and the lower or minor tier of roots

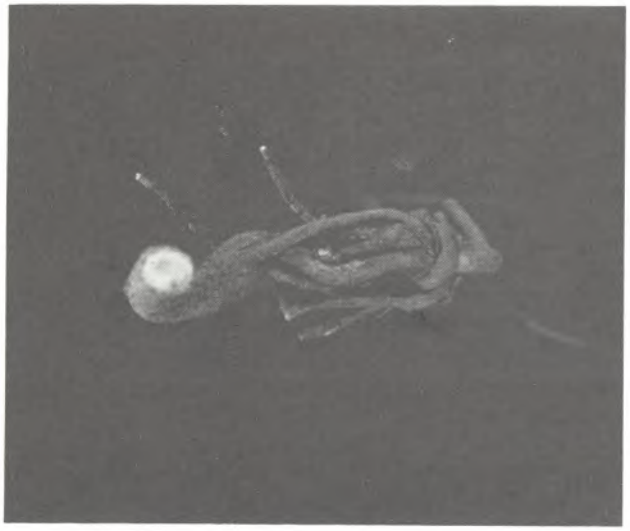

Figure 3. Top view of root deformation caused by frost heaving in a black spruce tubeling as it appeared 10 years after planting.

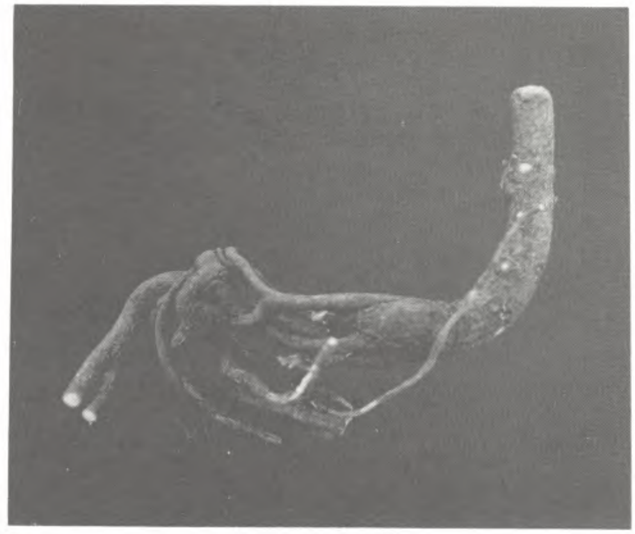

Figure 4. Side view of same root system as in Figure 3 showing extent of deformation.

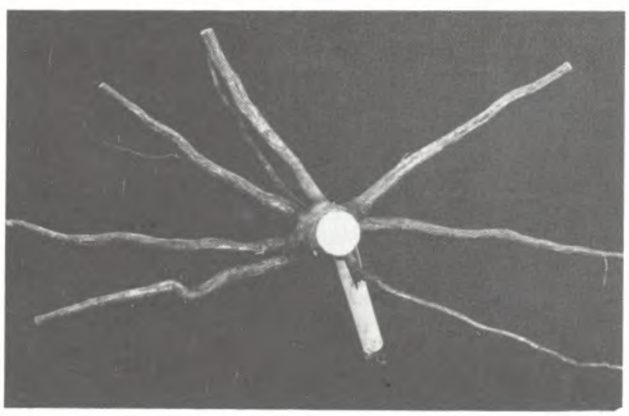

Figure 5. Top view of the root development of a black spruce tubeling 10 years after planting.

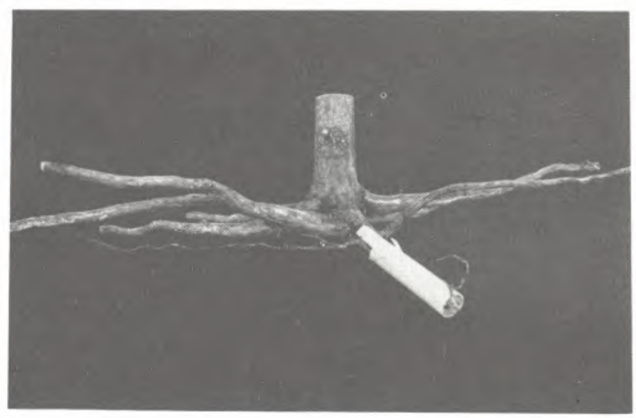

Figure 6. Side view of same root system as in Figure 5 exhibiting plate-like root form typical of black spruce. All roots emanating from above tube are adventitious roots.

was the original compact root system that had developed in the tube. Although the removal of the tube prior to planting allowed freedom of growth for the original root system, the new system was comprised entirely of adventitious roots.

The root system of a 3+0 bare-root tree, though larger, exhibits some similarities to the root system of a tubeling or plug tree (Fig. 9 and 10). The seedling root system developed a radiating root pattern, as well as a major tier of adventitious roots above an original root mass which was of low vitality.

A quantitative assessment of the excavated root systems revealed that plug trees, on the average, possessed nearly twice as many major lateral roots as tubelings, i.e., 8.5 vs 4.3, and that the number of major lateral roots for plug trees and bare-root

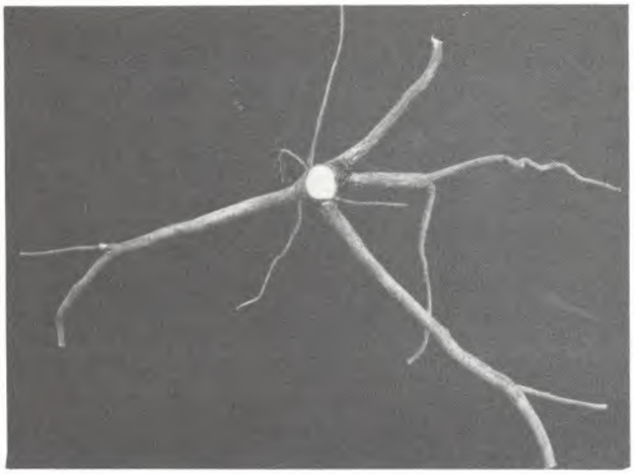

Figure 7. Top view of the root system of a black spruce plug 10 years after planting.

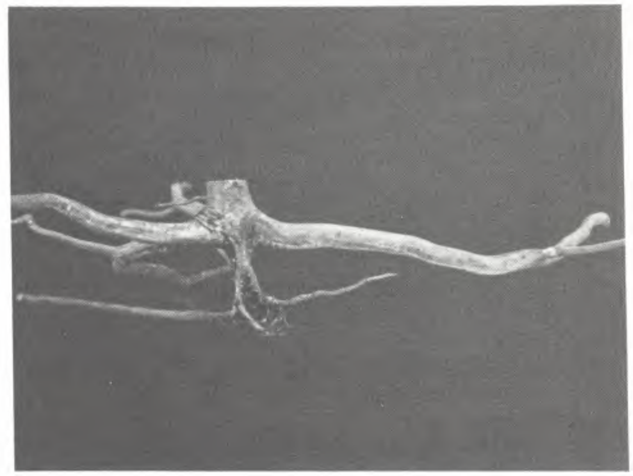

Figure 8. Side view of same root system as in Figure 7 exhibiting a major tier of adventitious roots and a lower tier of original roots.

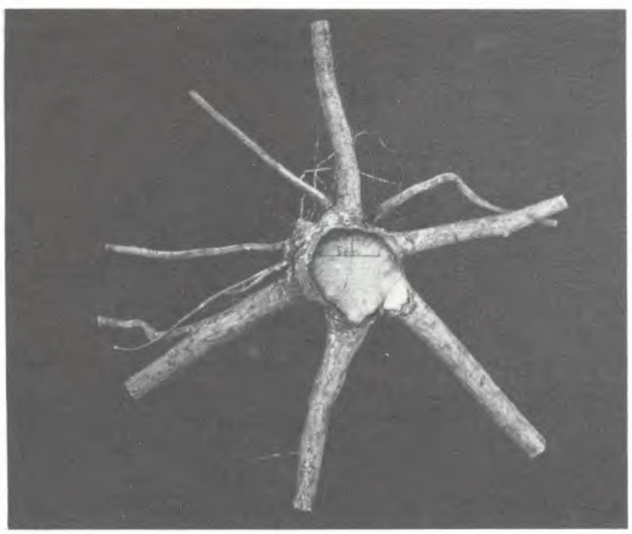

Figure 9. Top view of the root system of a 3+0 bare-root black spruce 11 years after planting.

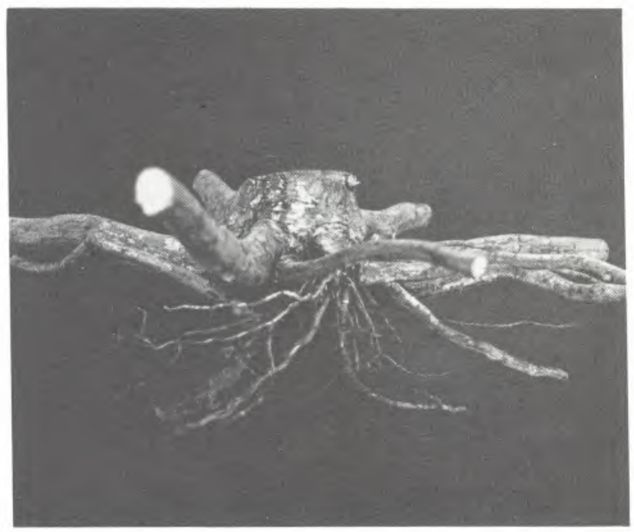

Figure 10. Side view of same root system as in Figure 9, exhibiting plate-like form. All roots are adventitious except for the remnant of the original root system.

trees was comparable. Root lengths varied considerably, but it was noteworthy that the average tubeling root was 1.35 m long, whereas the roots of plug trees average 1.24 m. The average root length of bare-root trees was 1.85 m and occasionally roots up to 3 m long were measured.

It would appear that, regardless of stock type, it is characteristic of black spruce to develop an entirely new root system. Apart from the original root system the ages of adventitious roots were less than the age of the tree from seed. Root ages for tubelings, plugs, and bare-root stock ranged from 3 to 8 years, 3 to 7 years, and 5 to 9 years, respectively.

Tree Nutrition

Nutrient maxima in tree foliage generally occur during the period from late summer

Table 3. Early spring nutrient concentrations of foliage from upper crowns of three sizes of black spruce tubelings, plugs, bare-root and natural trees.

Stand Type	Competition	Tree size	Height range (m)		Nutrient concentrations (%)				
					N	P	K	Ca	Mg
Tubeling	Light	S	0.44-0.99		1.014	0.119	0.473	0.408	0.088
		M	1.00-1.56		0.890	0.139	0.511	0.369	0.095
		L	1.57-2.12		0.833	0.120	0.417	0.273	0.075
				$\overline{X}$	0.912	0.126	0.467	0.350	0.086
Tubeling	Heavy	S	0.55-0.91		1.081	0.122	0.497	0.443	0.093
		M	0.92-1.29		0.980	0.136	0.462	0.318	0.090
		L	1.30-1.65		1.040	0.133	0.466	0.309	0.089
				$\overline{X}$	1.034	0.130	0.475	0.357	0.091
Plug	Light	S	1.28-1.50		1.050	0.129	0.361	0.563	0.077
		M	1.51-1.67		0.887	0.100	0.305	0.454	0.080
		L	1.68-2.37		0.937	0.106	0.387	0.332	0.063
				$\overline{X}$	0.958	0.112	0.351	0.450	0.073
Plug	Heavy	S	0.52-0.89		0.873	0.134	0.552	0.419	0.109
		M	0.90-1.27		0.940	0.126	0.481	0.381	0.105
		L	1.28-1.65		0.973	0.131	0.447	0.387	0.099
				$\overline{X}$	0.929	0.130	0.493	0.396	0.104
3+0 Bare-root	Moderate	S	1.67-2.19		0.887	0.103	0.449	0.450	0.078
		M	2.20-2.75		0.917	0.119	0.501	0.300	0.062
		L	2.76-3.24		1.070	0.108	0.521	0.495	0.077
				$\overline{X}$	0.958	0.110	0.490	0.415	0.072
Natural		S	0.98-3.02		0.903	0.120	0.503	0.423	0.088
		M	3.03-3.56		0.910	0.099	0.377	0.350	0.081
		L	3.57-4.10		0.880	0.101	0.408	0.315	0.081
				$\overline{X}$	0.898	0.106	0.438	0.362	0.083

to late fall, which is often the recommended time for sampling (Lowry 1970, Morrison 1974). For purposes of estimating relative nutrition, sampling can be carried out at other times and, if necessary, seasonal adjustment curves can be employed to allow for differences (Lowry and Avard 1969). In this study, sampling was carried out during early May, a period of relative nutrient stability (Salonius 1977).

Foliar nutrient concentrations are presented in Table 3 for the small, medium, and large trees from the five main stand types.

In general, nutrient concentrations revealed little consistent information which might be related to stand type, competition level, or size of tree. Nitrogen, phosphorus, and, in general, magnesium fall within the range of moderate deficiency (Swan 1970). The concentrations of potassium and calcium, however, were within the ranges of sufficiency and luxurious consumption, respectively (Swan 1970). It is of interest to note that, with few exceptions, the mean concentrations of N, P and K for natural trees were less than those for the planted trees. Concentrations of Ca and Mg were comparable.

DISCUSSION

Growth Performance

Although initially conceived to supplement the existing reforestation program, product ion of containerized trees in Ontario has expanded for economic as much as for biological reasons. With this expansion it has been asked (Barnett 1974) whether or not containers can do a better job than bare-root stock. The future direction of the container stock program hinges on this simple but important question. The results from recent field trials, e.g., Arnott (1974), Gutzwiler and Winjum (1974), Johnson (1974), Hite (1974) and Walker and Johnson (1974), leave one with the impression that this question cannot be answered categorically but depends largely on circumstances of site quality, site preparation, species, cultural treatment, time of planting, tending, etc. With exceptions, container stock does not generally outperform bare-root stock under similar conditions.

Despite the one year difference in plantation age between the bare-root and the tubeling/plug plantations, the results of the present study do not lend support to the hypothesis that--at least for black spruce--Ontario tubelings and plugs grow as well as 3+0 bare-root stock. Eleven years after planting, mean height of bare-root stock was 104% and 69% greater than mean heights of 10-year-old plantations of tubelings and plugs (competition levels combined), respectively. Because the height differences are substantial, it is unlikely that they are due wholly to the difference in plantation age, but are in fact an expression of the inherent growth potential of bare-root tubelings and plugs.

The level of competition had a more pronounced effect on the mean annual height growth of tubelings than of plug trees. From 1974 to 1980 the difference in mean annual height increment between light and heavy competition was 39.8% and 9.3% for tubelings and plug trees, respectively. This substantiates the results of Scarratt (1974), which suggest that tubeling stock is suitable for a narrower range of less competitive sites than bare-root stock. This is further borne out when it is considered that in this study, bare-root stock under moderate competition exhibited an overall mean growth rate (1974-1980) 85.4% and 40.0% greater than that of tubelings and plug trees, respectively. In 1980, plug trees grew comparatively well, i.e., 30.8 cm vs 33.3 cm for bare-root trees, but in all probability, basic differences in total height between stand types will be maintained. This conjecture is supported by the observation of Armson (1975) that small and large black spruce trees at the time of planting remain small and large after the tenth growing season. Scarratt (1974) also noted that performance of container stock is very dependent on tree size and that many early failures can be related directly to this factor. Small trees with small crowns presumably are unable to compete vigorously with other vegetation and gain prominence, but instead become suppressed and grow relative to their size or die.

Root Development

Rapid root growth into the surrounding soil to tap needed supplies of moisture and nutrients is critical for survival of planted trees. Any factor or combination of factors that inhibits early rapid root growth can, at the outset, condition future growth. Although the root system of bare-root stock is often deformed by planting, water absorption can take place at a reduced rate until new root growth occurs. Apart from water and nutrients supplied from within the tube, there are similar delays in absorption of these elements by tubelings, but the presence of the rigid walled container is an added obstacle to the outward growth of roots (McClain 1978) and delays access to moisture and nutrients even further. Observations made in 1972, one year after the tubelings and plugs were planted operationally (Anon. 1971), revealed that those tubelings not heaved by frost were easily pulled from the ground and that plug seedlings could be removed from the soil only by breaking roots. The tube had obviously prevented early normal root growth necessary for anchorage and rapid future growth.

Adventitious root development is an important silvical characteristic of black spruce and is an obvious feature in the development of its root system (McClain 1978). While early rapid root growth was noted to be critical for survival it is the development of a new root system that eventually meets the requirements for anchorage and absorption. With some exceptions, the original roots, regardless of stock type, cease to function as a major component of the root system (e.g., Fig. 10), a fact which is substantiated by the ranges in root ages noted for tubelings, plugs, and 3+0 bare-root stock. Since no single major root was found to be as old as the tree, root system development for at least 10 years after planting is indeed a dynamic process in black spruce.

The conditions which prevailed at the time of adventitious root development can only be assumed, but deep planting or planting on a slant may have caused soil and organic debris to surround the stem, providing the suitably moist conditions for adventitious root development. The frequency of adventitious roots in black spruce suggests the need for this characteristic to be expressed if tree growth is to proceed normally. Unfortunately, silvical characteristics of species are often neglected in the development of containers.

Nutrition

The lack of any clear relationship between nutrient concentration and stand type indicates that, if nutritional differences between bare-root stock and tubelings were present at the time of planting, they have since subsided. Deficiency levels noted for nitrogen, phosphorus and, in general, magnesium, are not unlike values recorded for black spruce stands elsewhere (van Nostrand and Bhure 1973). Despite moderate nutrient deficiencies, however, growth (Fig. 2) was not significantly affected except where heavy competition was present, in which case interacting factors were probably responsible for reduced growth.

SUMMARY AND CONCLUSIONS

The results of the present study were obtained from sample plots located in operationally planted plantations of Ontario tubelings, plugs and 3+0 bare-root black spruce. Although the bare-root plantation was one year older than the tubeling and plug plantations its growth advantage after 11 years was clearly indicated. It was attributed principally to the original tree size and the respective ability of each stock type to develop its root system and crown under a given level of overhead competition. Interestingly, the height growth of plug trees after 10 years was similar to the height growth of bare-root stock after 11 years. Examination of the nutritional status of each stock type clearly indicated deficiencies in some nutrient elements, notably nitrogen, but this was not reflected in suppressed growth or in the coloration of tree foliage.

While the present study is based on regeneration methods of diminishing use, the results are important because they direct our attention to the silvics, stock type (bare-root, containers) and growth of various species in relation to environment. These are significant components of a successful regeneration system and should be considered in the design and choice of future regeneration systems. Specifically:

1. Production of black spruce as bare-root, tubeling and plug stock creates planting stock with inherent morphological and physiological differences. These differences precondition stock to achieve a given level of performance under similar environments. It appears that older, larger and heavier stock will outperform younger, smaller, lighter tubeling and plug stock.

2. It is an inherent characteristic of black spruce to produce adventitious roots. This process is critical to secure establishment and, therefore, must not be impeded. Slower growth of black spruce tubelings can be related to the fact that the tube restricts the early natural form of root development of the species.

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