EFFECTS OF REMOVAL OF THE PAPERPOT CONTAINER ON GROWTH AND DEVELOPMENT OF BLACK SPRUCE SEEDLINGS ON A DRAINED PEATLAND CLEARCUT IN NORTHEASTERN ONTARIO

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ABSTRACT

This report discusses the results of a study of 60 black spruce (*Picea mariana* [Mill.] B.S.P.) paperpot seedlings, of which half were planted with the paper container removed. Planting was done on a drained clearcut in northeastern Ontario at two distances from a drainage ditch. Seedling growth and root development were studied.

Results indicated that the paper container was still present 4 years after planting and few roots had penetrated the paper wall. Seedlings planted without the paper had better height and diameter growth, more roots and greater root area; root systems were also less asymmetrical and root spiraling was less common. Adventitious roots were more abundant in seedlings planted in their paper containers, but adventitious rooting had no positive effect on growth.

RÉSUMÉ

Le présent rapport examine les résultats d'une étude portant sur 60 semis d'épinette noire (*Picea mariana* [Mill.] B.S.P.) cultivés en paperpot (récipients de papier) dont la moitié a été plantés sans récipient. Les semis ont été plantés dans une parterre de coup à blanc drainé du nord-est de l'Ontario à deux distances différentes du fossé de drainage. La croissance des semis et leur développement racinaire ont été étudiés.

Les résultats révèlent que les récipients de papier étaient toujours là 4 ans après la plantation et que peu de racines avaient réussi à en traverser les parois. Les semis plantés sans récipient avaient une meilleure croissance en hauteur et en diamètre et des racines plus nombreuses et plus étendues; les systèmes racinaires étaient également moins asymétriques et moins fréquemment enroulés en spirale. Les semis plantés avec leurs récipients de papier avaient des racines adventives plus nombreuses, ce qui n'avait aucun effet positif sur la croissance.

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Cover photo:

Paperpot seedlings with paper container left on (left, top and bottom) and with the container removed (right, top and bottom). Seedlings were planted in spring 1987 and excavated in fall 1990. (N = north, numbers = root quadrants)

INTRODUCTION

In Ontario, 230,308 ha were harvested in fiscal 1988/1989 under both even- and uneven-aged management (Anon. 1991). During the same year, planting nursery stock was the regeneration method chosen for 70,319 ha (30.5% of the harvested areas). Of the planted areas, 60% were planted with containerized seedlings (Anon. 1990).

The total production of nursery stock in Ontario in 1988/1989 was 171.6 million seedlings, 52% of which were containerized coniferous seedlings (Anon. 1990). The principal species produced was black spruce (*Picea mariana* [Mill.] B.S.P.), with 73.5 million seedlings (both bareroot and containerized).

Until a few years ago, the majority of containerized seedlings in Ontario were grown in Japanese paperpot containers. Today, the paperpot system is becoming less common in most districts, although about 45% of all container seedlings were still in paperpots in 1990. For black spruce seedlings grown in containers in Ontario in 1990, the proportion of paperpots is the same.

When planting rooted seedlings, irrespective of their stock type, there will always be some root deformation and restriction of root development in the field compared with natural seedlings grown *in situ*. Different kinds of root deformation, such as spiraling, kinking, asymmetric distribution and restriction of growth, have been reported in many studies both in Europe (Spitzenberg 1908, Wibeck 1923, Jansson 1971, Bergman and Häggström 1976, Huuri 1978) and in North America (Van Eerden and Arnott 1974, Carlson and Nairn 1977, Hellum 1978).

Many of the deformation problems reported for container stock are created in the nursery, and depend on the size, shape and material of the container (Scarratt 1972, Lindström 1978, Hultén 1983). Other problems occur as a result of the manner in which the seedlings are planted and in what form (Wibeck 1923, Brown and Carvell 1961, Sutton 1969, Walters 1978).

For the majority of containerized seedlings used today, the seedling will be removed from the container to form a plug for planting. For paperpots, this is not the case: the container is planted together with the seedling on the assumption that the paper will soon deteriorate and let the roots penetrate it freely. However, the paper wall has been found to be much more resistant than expected, especially where soil temperatures are low. Under such conditions, the remaining paper wall seems to restrict the passage of lateral roots, causing spiraling, kinking and poor development of root systems, which may give rise to secondary effects such as reduced growth and poor stability (Bergman and Häggström 1976, Sundquist 1988, Lindström 1990). Problems with root deformation seem to be more severe with pines (*Pinus* spp.) than with spruces (*Picea* spp.), as the latter seem able to overcome the problem to some extent by developing adventitious roots (Filipsson 1982).

The rooting problems connected with the use of paperpots have resulted in decreased use of this system. Paperpots in Sweden accounted for 59% of the container market in 1981, but are no longer used. "Ecopots" are the successors to the original paperpot, as their paper is easily stripped off before planting; they comprised 13% of the container market in 1989. The use of paperpots is also decreasing in Finland, and in the northern parts of the country, the Finns require removal of the paper before outplanting. As mentioned earlier, the use of paperpots has decreased significantly in Ontario over the past 5 years, but still accounts for 75% of all containers planted in the largest regions.

An obvious question arises: What would be the effect on root deformation, growth, stability and other problems of paperpot seedlings if the paper was removed before planting? Some field trials have been conducted in which paper was removed from paperpot-grown seedlings, but very few results comparing seedlings with and without paper are available. In a study of black spruce paperpot seedlings with the paper removed before planting, Jeglum (1991b) found that the spruce were performing slightly better 3 years after outplanting both in survival and shoot growth than seedlings with the paper left on.

The work described in the present report studied the growth, distribution and deformation of roots, as well as shoot growth and performance, in black spruce paperpot seedlings planted on a drained wetland area that had undergone prescribed burning. For half the seedlings, the paper was removed before outplanting. Seedlings were studied at two distances (2 and 6 m) from the ditch.

The objectives of the study were to determine whether removal of the paper before outplanting would influence root development (or morphology) of the seedlings, whether any such influence was related to a seedling's distance from a drainage ditch, and whether survival and growth of outplants were affected thereby.

MATERIALS AND METHODS

The Study Area

The study area is in the Northern Clay Section of the Boreal Forest Region (Rowe 1972) of northeastern

Ontario, 30 km east of Cochrane (49°03'N, 80°40'W). It consists of both upland mineral soils and peatlands on deep lacustrine clays, with organic-matter depths ranging between 30 and 110 cm. The area is part of a cutover in the Wally Creek Area Forest Drainage Project (Rosen 1986, Jeglum 1991a), and was drained in June 1985. The ditch spacing in the area is 15 m (Fig. 1). The area was classified as mainly Operational Group 11 (OG11) with some minor OG9 components (Jones et al. 1983); black spruce forest had been conventionally harvested by the tree-length method in the winter of 1984/1985, and this was followed by a prescribed burn in May 1985.

Experimental Design and Sampling

In mid-June 1987, the area was planted with black spruce seedlings that had been grown in a greenhouse in Japanese FH–408 Paperpots. For further details of seedling production, see Jeglum (1991b). The planting was done in a regular grid at 1.5- x 1.5-m spacing, in rectangular blocks oriented in a transect crossing several ditches (Fig. 1). At the time of outplanting, the paper was removed from 50% of the paperpot seedlings. The sample in this study consisted of 60 seedlings, 30 with their paper intact and 30 with paper removed. Seedlings were sampled at two distances from the ditch (2 and 6 m) in order to study the influence of drainage on root development.

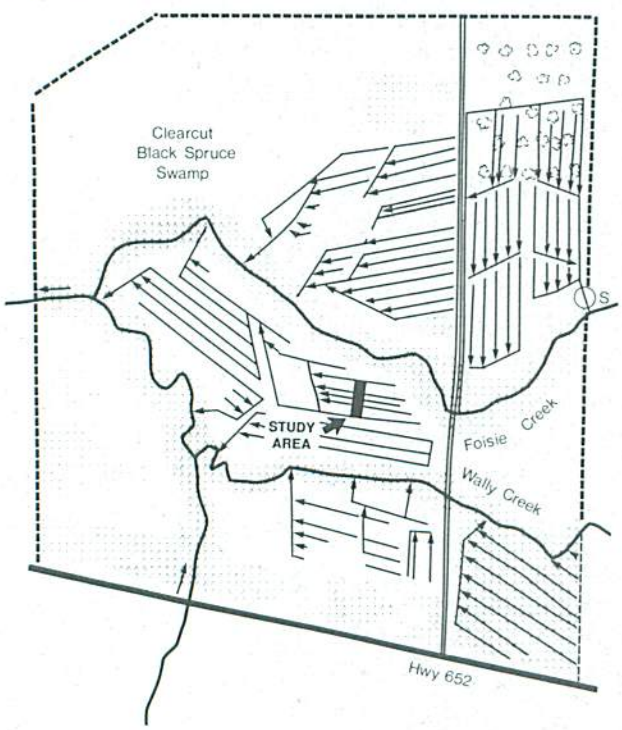

Figure 1. The location of the study area and its drainage system (15-m ditch spacing).

The sample therefore consisted of four groups of 15 seedlings, as follows: WP-2 m = with paper at 2 m from the ditch, WP-6 m = with paper at 6 m from the ditch, WOP-2 m = without paper at 2 m from the ditch, and WOP-6 m = without paper at 6 m from the ditch. Only seedlings classified as healthy and of good quality 1 year after planting, with vitality ratings >3 (on a scale of 1–5, with 5 best) in spring 1988 were chosen for excavation. For further details of the vitality ratings and other variables, see Appendix 1.

Seedlings were assessed for height at the time of planting (spring 1987) and for height, root-collar diameter and vitality in spring 1988 and 1989 and in fall 1989. The mean height in spring 1987 and the mean diameter and vitality in spring 1988 for the different groups are given in Table 1.

Excavations and Field Measurements

In September 1990, all seedlings in the sample were measured and then excavated; their root systems were harvested within a radius of 30 cm from the stem. The following shoot measurements were taken:

HEIGHT90 = height from the ground surface to the tip of the bud (mm),

DIAM90 = diameter at 5 cm above the ground (mm),

HEINC90 = Height increment in 1990, the length of the previous year's shoot (mm).

The original surface at the time of planting was determined by identifying the level of the ash that originated from the prescribed burning. The depth of planting could then be determined after finding the top of the container plug. For seedlings with the paper still present, this presented no difficulty. For seedlings with the paper removed, a careful excavation was conducted along the stem until the first quartz pellets were found; these originated in the seed cover used in the nursery, and determined the location of the top of the plug. Two measurements were then taken:

DISURF = distance (mm) between the original and the present surface, which gave an estimate of the degree to which vegetation and mosses had grown up along the stem,

DIPLUG = distance (mm) from the original surface to the top of the plug, which gave an estimate of the depth of planting.

Before excavating the seedling, the following observations were made (details are provided in Appendix 1):

SEEDBED = dominent seedbed material (24 classes),

SLASH = branches, twigs and leaves around the seedling (% cover in a 30-cm-radius circle),

EXPOSURE = degree of exposure to sun and wind (0–5),

MINERAL = mineral soil around the seedling (% cover in a 30-cm-radius circle),

VIFA90 = vitality of the seedling in fall 1990 using the same basis as the earlier vitality assessment (1–5),

NEWLEAD = whether a new branch took over as the leader in 1990,

COMP = the degree of competition, classified in three categories (1–3, with 3 representing the highest degree of competition),

SOIL = classification of the soil in which the seedling was planted (1–5, where 1 represents *Sphagnum* mosses and 5 means >90% mineral soil),

MICRO90 = the microtopography of the seedling's location (1–5, where 1 is very low and 5 is very high).

After all measurements and notes had been taken, the seedling's shoots were cut off, numbered and placed in a paper bag. A pin was then inserted in the stump of the seedling to mark the direction of the ditch and the entire root system was carefully excavated within a radius of 30 cm. Each root system was numbered and placed in a separate bag. Tops and roots were both stored in a cold room at 3°C for subsequent examination.

Root and Shoot Measurements

Each seedling's shoots were cleaned and all needles were removed. The needles were then dried in an oven at 70°C for 24 hours and weighed. The variable NEEDWEI was used for the oven-dry weight of needles (g) for each seedling.

Each root system was carefully cleaned to remove all mineral and organic soil material. The root system was then mounted upside down on a specially made table, which was marked with four quadrants and three circles (5-, 10- and 25-cm radii) (Fig. 2). By dividing the roots into four quadrants, an estimate could be made of the degree of asymmetry of root distribution. Measuring roots at different distances from the stem gave an estimate of root growth and its distribution.

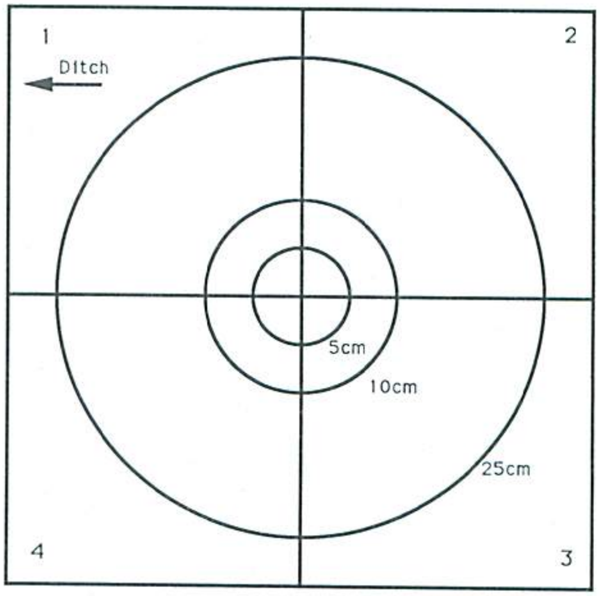

Figure 2. Root measuring table, with four quadrants and three circles, on which roots were mounted to determine their distribution and degree of asymmetry.

To evaluate the origin of roots, the measurements were divided into three groups (Fig. 3): above = roots growing from the top of the plug, above the paper; through = roots growing through the paper; and below = roots growing from the bottom of the plug, below the paper. For seedlings with the paper removed, these three locations were estimated, but since the shape of the root system was still very much influenced by the earlier paper wall, there was generally no problem in determining these locations (Fig. 3). Photographs of each root system were taken both from above and from the side, with the directions of the ditch and of map north marked.

Table 1. Mean height in 1987 and mean diameter and vitality in 1988 for seedlings with and without paper and for seedlings planted at 2 and 6 m from a ditch.

	With paper			Without paper			All seedlings	
	$\bar{x}$	2 m	6 m	$\bar{x}$	2 m	6 m	2 m	6 m
Height 1987 (cm)	17.7	16.9	18.6	17.0	16.1	17.8	16.5	18.2
Root-collar diameter 1988 (mm)	3.4	2.9	3.8	3.6	3.6	3.6	3.3	3.7
Vitality[a] 1988 (1–5)	4.5	4.8	4.3	4.6	4.6	4.5	4.7	4.4

[a] 1 = worst, 5 = best

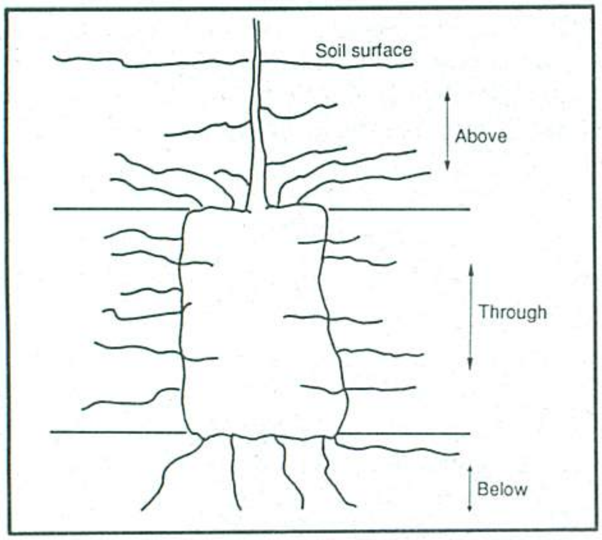

Figure 3. The three locations from which roots originated: above, through and below the paper.

Root area (RA)

In each of the four quadrants, the diameter of each root >1 mm in diameter was measured with a caliper accurate to 0.01 mm. A root's diameter was measured at three different radii from the stem (5, 10 and 25 cm) in each quadrant. The root diameter measurements were separated according to where in the root system each root originated. The area (mm^2) of each root was then calculated from the following formula:

$$RA = \pi * (\text{root diameter})^2 / 4$$

Number of roots (NR)

All roots, irrespective of size, were counted in the same way as for root area. Where roots divided, each of the divisions was counted if it crossed one of the three radii. For example, if one root at 5 cm had split into four roots at 25 cm, the number of roots was counted as one at 5 cm and four at 25 cm.

Adventitious roots (ADVR)

If roots grew from above the plug or above the root collar, they were characterized as adventitious roots. Each root was split longitudinally in order to locate the true root collar, which sometimes meant that if the seed had been placed deep in the container, adventitious roots had already started to develop in the container in the nursery. The following variables were used to characterize a seedling's adventitious rooting:

NADVR = number of adventitious roots at a 5-cm radius from the stem,

RAADVR = root area of adventitious roots >1 mm in diameter at 5 cm from the stem,

ADVRNEW = number of adventitious roots at 5 cm from the stem after splitting the root longitudinally.

Root area index (RAI) and root number index (RNI)

The asymmetrical distribution of roots was quantified by counting the numbers of roots and measuring the root area of all roots >1 mm in diameter in each of four quadrants. A root number index (RNI) and a root area index (RAI) were developed: RNI is the number of roots in the quadrant with the greatest number of roots (NRdom) divided by total number of roots in the seedling (NRtot); RAI is calculated similarly, and is the root area in the quadrant with the highest root area (RAdom) divided by the total root area (RAtot). For an evenly distributed root system, RNI and RAI should both be 0.25, and higher RNI and RAI indices indicate more asymmetrical root systems. Seedlings were also divided into three classes on the basis of RNI and RAI ratings, and the frequency of seedlings in each group was determined.

Spiraling roots (SPIR)

The roots of seedlings grown in containers have a tendency to spiral. When spiraling occurs, the root is not growing towards the periphery, but instead follows the paper wall in a circular manner and starts to twist. The number of spiraling roots was noted and the degree of spiraling measured. A root spiraling index (RSPIND) that takes into account root area and the degree of spiraling was developed as follows (Fig. 4):

NRSP = the number of spiraling roots,

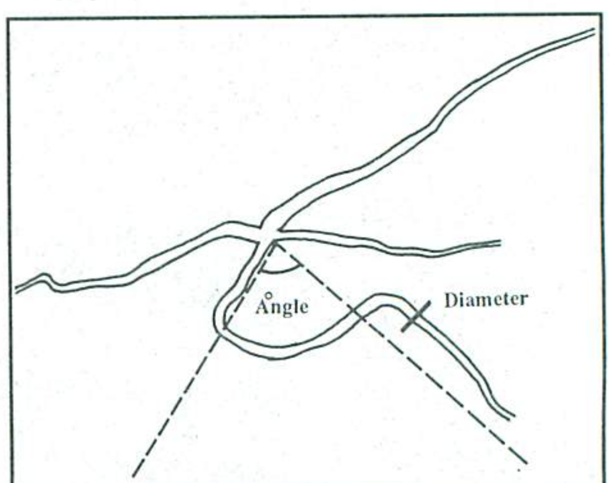

Figure 4. The degree of spiraling and root diameter were used to calculate a root spiraling index (RSPIND).

RSPIND = root spiraling index = [Σ(RA*DEG)]/RAtot, where: RA = root area at 5 cm from the stem for each spiraling root >1 mm in diameter, DEG = the angle between where the root starts and where it turns towards the periphery of the container (Fig. 4), and RAtot = the total root area at 5 cm from the stem for all roots >1 mm in diameter.

Statistical analyses were carried out using the Statistical Analysis System (Anon. 1985) software. Stepwise linear regression analysis was used with mixed models (i.e., those containing both continuous and discrete variables) to express growth and root variables as functions of site, seedling and treatment factors.

RESULTS

Means for heights and diameters of seedlings with and without paper at different distances from the ditch are shown in Figures 5 and 6 and in Tables 2 through 7.

Height Growth

The average height of seedlings in spring 1987, at the time of outplanting, was 0.7 cm greater for seedlings with paper (WP) than seedlings without (WOP) (Table 1). In fall 1990, this relationship had reversed, with WOP seedlings 6.7 cm taller on average than WP seedlings (Fig. 5, Table 2).

The 4-year height increment from spring 1987 to fall 1990 was significantly greater in WOP seedlings (48.1 cm) than in WP seedlings (40.7 cm). This was confirmed by a significant difference in relative height increment over the same period. Height growth was greater each year in WOP seedlings and the difference increased with time; the largest difference occurred in 1990 (Fig. 5, Table 2).

Seedlings planted 6 m from the ditch were significantly taller (18.2 cm) in spring 1987 than those planted closer to the ditch (16.5 cm). Four seasons later (fall 1990), after significantly greater height growth (47.7 cm) for seedlings closer to the ditch than for those further away, the relationship was reversed (Table 3). Height growth was greater every season for seedlings growing closer to the ditch, but the difference (7.1 cm) was only significant in 1987. Relative height increment was significantly higher for seedlings close to the ditch (2.94) than for seedlings further away (2.32) (Table 3).

Seedlings without paper and planted close to a ditch (WOP–2 m) had the largest height increments (51.0 cm) and were also the tallest in fall 1990 (67.0 cm), whereas in spring 1987 they were the shortest (16.1 cm) (Fig. 5, Table 4). Seedlings with paper intact and planted farther from the ditch (WP–6 m) had the smallest height increment (36.5 cm) and were also shortest in fall 1990 (55.0 cm), whereas at the time of planting they were the tallest (18.6 cm). For the other two groups, WP seedlings close to the ditch (WP–2 m) and WOP seedlings farther from the ditch (WOP–6m), the differences in height growth were small and not significant (Fig. 5, Table 4).

Using stepwise linear regression for height increment as a function of site, treatment and seedling variables gave the following equation:

$$HEINCR = 35.985 + 3.754\ STOCKTYP - 9.075\ DISTDI + 10.504\ COMP + 0.313\ NEEDWEI$$
$$(R^2 = 0.520, F = 14.33)$$

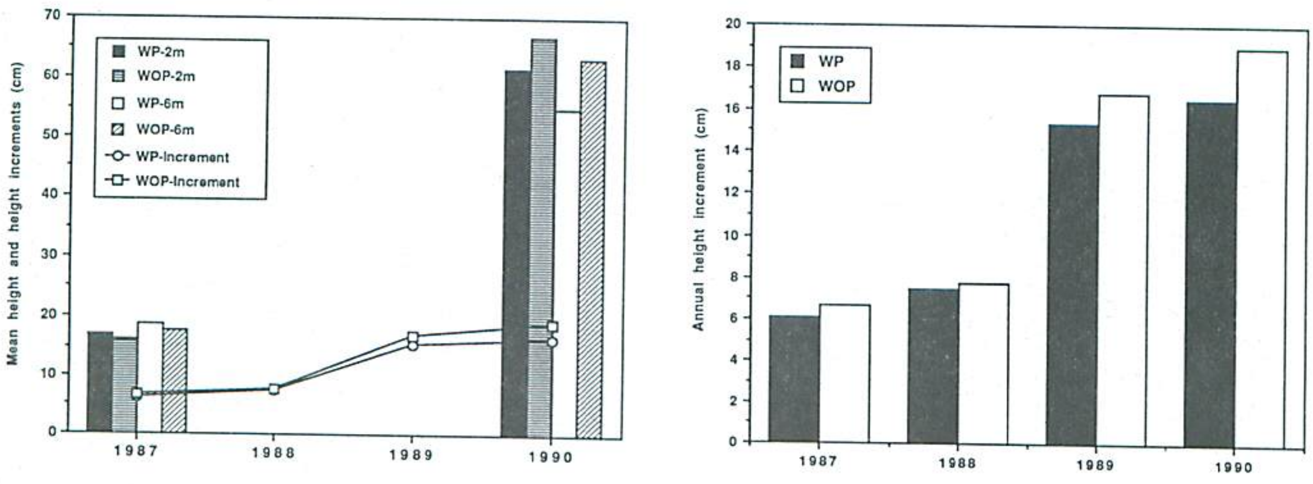

Figure 5. Mean height and mean annual height increments (from 1987 to 1990) for seedlings with (WP) and without (WOP) paper, planted 2 and 6 m from a ditch.

Table 2. Mean heights in spring 1987 and fall 1990 and mean height increments for black spruce paperpot seedlings planted with and without the paper container in spring 1987. (Sample size = 29 seedlings for both types.)

	With paper		Without paper			
	x̄	s	x̄	s	F	P
Height (cm)						
1987	17.7	3.33	17.0	2.56	0.95	0.333
1990	58.4	10.53	65.1	9.05	7.04	0.010
Height increment (cm)						
1990–1987	40.7	9.09	48.1	8.80	11.46	0.001
1990	16.5	3.68	19.0	5.65	4.13	0.047
1989	15.3	4.51	16.8	5.18	1.55	0.219
1988	7.5	4.26	7.8	3.87	0.10	0.749
1987	6.1	2.63	6.7	1.74	0.95	0.335
Relative[a]	2.36	0.62	2.90	0.68	13.21	0.001

[a] Relative height increment = height increment (1990–1987)/height (1987)

Table 3. Mean heights in spring 1987 and fall 1990 and mean height increments for black spruce paperpot seedlings planted at 2 and 6 m from a ditch in spring 1987 (with and without paper combined, sample size = 29 for each distance).

	Distance from ditch					
	2 m		6 m			
	x̄	s	x̄	s	F	P
Height (cm)						
spring 1987	16.5	3.04	18.2	2.68	4.85	0.032
fall 1990	64.2	10.58	59.3	9.57	3.77	0.057
Height increment (cm)						
1990–1987	47.7	8.88	41.1	9.36	8.96	0.004
1990	18.3	5.04	17.3	4.75	0.78	0.381
1989	17.1	4.91	15.0	4.67	3.04	0.087
1988	7.7	4.21	7.6	3.91	0.02	0.898
1987	7.1	1.58	5.7	2.55	7.12	0.010
Relative[a]	2.94	0.60	2.32	0.65	17.78	0.000

[a] Relative height increment = height increment (1990–1987)/height (1987)

Height increment (HEINCR) was positively correlated with competition (COMP), needle dry weight (NEEDWEI) and type of seedling (STOCKTYP) but negatively correlated with distance to ditch (DISTDI). This means that height increment was greatest for seedlings that were planted without paper, close to the ditch and with high competition and needle mass in 1990. Height increment was not correlated with root variables, although these variables were included in the regressions.

Diameter Growth

Diameter growth was slightly greater (6.8 mm) for WOP seedlings than for WP seedlings (6.4 mm), but since WOP seedlings were already larger in 1988, the relative diameter growth was less than for WP seedlings. However, no differences were significant (Fig. 6, Table 5).

The average diameter for seedlings 2 m from the ditch (3.3 mm) was significantly smaller in spring 1988 than that of seedlings planted at 6 m distance (3.7 mm) (Table 6). However, both diameter increment and relative diameter increment were greater for seedlings close to the ditch and, therefore, the differences in diameter between seedlings at 2 and 6 m in fall 1990 were very small.

Seedlings without paper and close to the ditch (WOP–2 m) had the greatest actual diameter growth (6.9 mm) and the largest diameter in fall 1990 (10.6 mm) (Fig. 6, Table 7). This was more apparent in the 1990 diameter growth (3.6 mm). The relative diameter increment, however, was greatest in WP seedlings close to the ditch (WP–2 m), since these had a smaller mean diameter (2.9 mm) in spring 1988.

Stepwise linear regression was conducted for diameter increment as a function of site, treatment and seedling variables, and produced the following equation:

$$DIAMINC = 3.205 + 0.110\,NEEDWEI - 0.048\,RAADVR + 0.632\,EXPOSURE + 0.027\,NRT + 0.044\,NRB \quad (R^2 = 0.691, F = 23.30)$$

Table 4. Mean heights in spring 1987 and fall 1990 and mean height increments for black spruce paperpot seedlings planted with or without paper at 2 and 6 m from a ditch in spring 1987. Numbers in the same row followed by different letters are significantly different at the P = 0.05 level.

	With paper				Without paper			
	2 m (n = 15)		6 m (n = 14)		2 m (n = 14)		6 m (n = 15)	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Height (cm)								
spring 1987	16.9ab	3.7	18.6a	2.7	16.1b	2.2	17.8ab	2.7
fall 1990	61.6ab	10.7	55.0b	9.6	67.0a	10.1	63.3a	7.9
Height increment (cm)								
1990–1987	44.7b	7.7	36.5c	8.7	51.0a	9.1	45.5ab	7.9
1990	16.0b	3.1	17.2b	4.3	20.9a	5.6	17.3b	5.3
1989	17.1a	5.0	13.4b	3.1	17.2a	5.0	16.5ab	5.5
1988	8.2a	4.4	6.7a	4.1	7.2a	4.1	8.4a	3.7
1987	7.3a	1.7	4.9b	3.0	7.0a	1.5	6.4ab	1.9
Relative[a]	2.7b	0.5	2.0c	0.5	3.2a	0.6	2.6b	0.6

[a] Relative height increment = height increment (1990–1987)/height (1987)

Diameter growth (DIAMINC) is positively correlated with the weight of the needles (NEEDWEI), with the numbers of roots through (NRT) and below (NRB) the paper, and with an exposed microsite (EXPOSURE), but negatively correlated with the area of adventitious roots (RAADVR). This equation explains almost 70% of the variability in diameter increment. Diameter increment was better correlated with root variables than was height increment.

Root Growth

Numbers of roots (NR) and root area (RA) for WP and WOP seedlings at different levels in the root system and at different distances from the stem are shown in Figure 7 and Tables 8–9.

Seedlings planted with the paper removed (WOP) had 40% more roots and 10% higher root area than WP seedlings after four growing seasons (Table 8). These differences were most pronounced at the level where the paper is (WP) or was (WOP); here, WOP seedlings had 58% of their roots and 40% of their root area, significantly higher values than for WP seedlings. In seedlings planted with paper, only 16% of the roots had been able to penetrate the paper wall, comprising 13% of the root area (Fig. 7, Table 8).

Seedlings with paper had 49% of their roots and 42% of their root area below the paper, compared with 25% and 23%, respectively, for WOP seedlings. Seedlings with paper had less roots (35%) above the paper, but most of their root area (45%). Seedlings without paper had only 17% of their roots originating above the original level of the paper, whereas the root area at this position was 37% (Fig. 7, Table 8).

If planted farther from the ditch (6 m), WP seedlings had an average of 30% more roots and 65% greater root area. Distance to ditch had its most significant effect on the proportion of roots growing above the paper. For WOP seedlings, distance to ditch seemed to have no clear effect on root growth (Table 8).

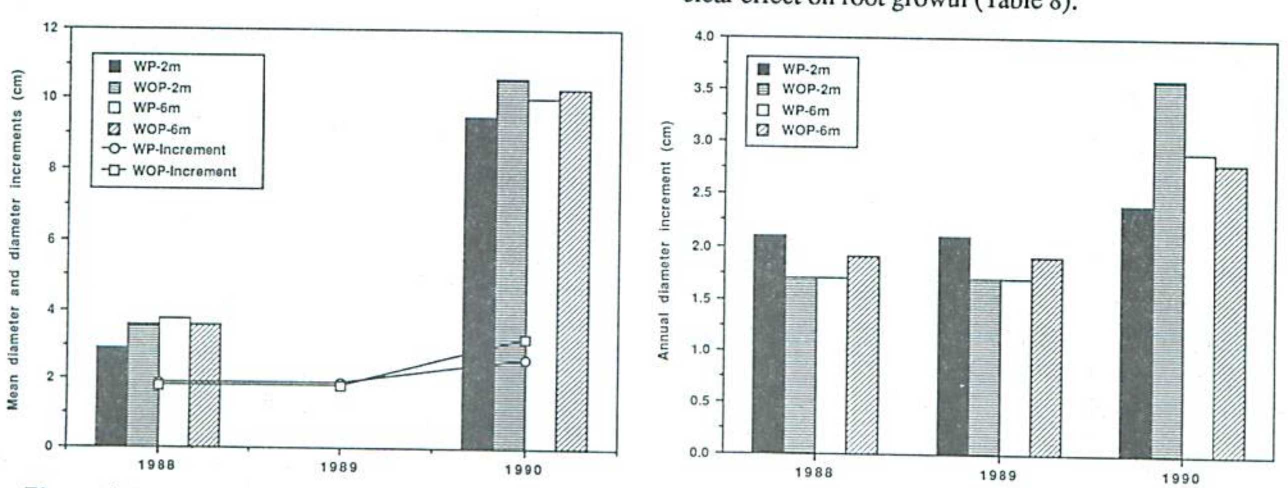

Figure 6. Mean diameter and mean annual diameter increments (1987–1990) for seedlings with (WP) and without (WOP) paper, planted at 2 and 6 m from a ditch.

Table 5. Mean diameters in spring 1988 and fall 1990 and mean diameter increments for black spruce paperpot seedlings planted with and without the paper container in spring 1987. Sample size = 29 for each type of seedling.

	With paper		Without paper			
	x̄	s	x̄	s	F	P
Diameter (mm)						
spring 1988	3.4	0.94	3.6	0.62	1.98	0.165
fall 1990	9.8	1.79	10.4	2.58	1.23	0.273
Diameter increment (mm)						
1990–1988	6.4	1.94	6.8	2.93	0.42	0.520
1990	2.6	1.57	3.2	1.39	2.03	0.160
1989[a]	1.9	0.89	1.8	0.84	0.14	0.705
Relative[b]	2.1	0.95	1.9	0.71	0.70	0.406

[a] Diameter increment 1989 is based on two seasons of diameter growth (i.e., [1989+1988]/2).

[b] Relative diameter increment = diameter increment (1990–1988)/diameter (spring 1988).

Table 6. Mean diameters in spring 1988 and fall 1990 and mean diameter increments for black spruce paperpot seedlings planted at 2 and 6 m from a ditch in spring 1987. Results include both seedlings with and without paper. Sample size = 29 for both types of seedlings.

	Distance from ditch					
	2 m		6 m			
	x̄	s	x̄	s	F	P
Diameter (mm)						
spring 1988	3.3	0.75	3.7	0.81	4.45	0.040
fall 1990	10.0	2.26	10.1	2.23	0.03	0.862
Diameter increment (mm)						
1990–1988	6.8	2.12	6.4	2.28	0.28	0.598
1990	3.0	1.68	2.8	1.31	0.13	0.723
1989[a]	1.9	0.89	1.8	0.84	0.14	0.705
Relative[b]	2.2	0.94	1.8	0.70	2.66	0.109

[a] Diameter increment 1989 is based on two seasons of diameter growth (i.e., [1989+1988]/2).

[b] Relative diameter increment = diameter increment (1990–1988)/diameter (spring 1988).

Root area was measured only for roots with a root diameter >1 mm and therefore was less than the total root area. If roots with a diameter <1 mm were given an estimated diameter of 0.5 mm, the difference in root area between WOP and WP seedlings doubled, with the largest increase where roots arose at the level of the paper (Table 9).

Considering the total number of roots, independent of their level in the root system, WOP seedlings had 53.9 roots at 5 cm from the stem, significantly more than the 38.1 roots for WP seedlings (Table 8). The proportions of roots decreased to about 65% at 10 cm and 25 to 30% at 25 cm from the stem, but the difference of 40% more roots for WOP seedlings (14.1) compared with WP seedlings (9.9), remained (Table 8).

At 25 cm from the stem, root area had decreased to between 20 and 25% of the root area at 5 cm but WOP seedlings still had 18% greater root area than WP seedlings (Table 8).

Adventitious Roots

Numbers and root areas for adventitious roots are shown in Figures 8–10 and Tables 10–12.

Seedlings with paper (WP) had 20% of their roots adventitious compared with 10% for WOP seedlings, a difference that was significant (Fig. 8, Table 10). Almost half (48%) of WP seedlings had more than 20% adventitious roots, compared with 14% for WOP seedlings (Table 10).

Although the number of adventitious roots was larger for WP seedlings, the opposite was true for root area. Both root area and relative root area were greater for WOP seedlings, indicating that WOP seedlings had fewer but thicker adventitious roots (Fig. 8, Table 10). About 30% of the total root area was contributed by adventitious roots, irrespective of whether the seedlings had paper or not (Table 10).

Seedlings planted deeper than 25 mm below the surface had more adventitious roots and greater adventitious root areas than seedlings planted more superficially (Fig. 9, Table 11).

Adventitious roots accounted for 20% of the roots and 42% of the root area in seedlings planted more deeply than 25 mm, which was significantly higher than for the more superficially planted seedlings (Fig. 9, Table 11). All deeply planted seedlings had adventitious roots, whereas 21% of the superficially planted seedlings had no adventitious roots (Table 11).

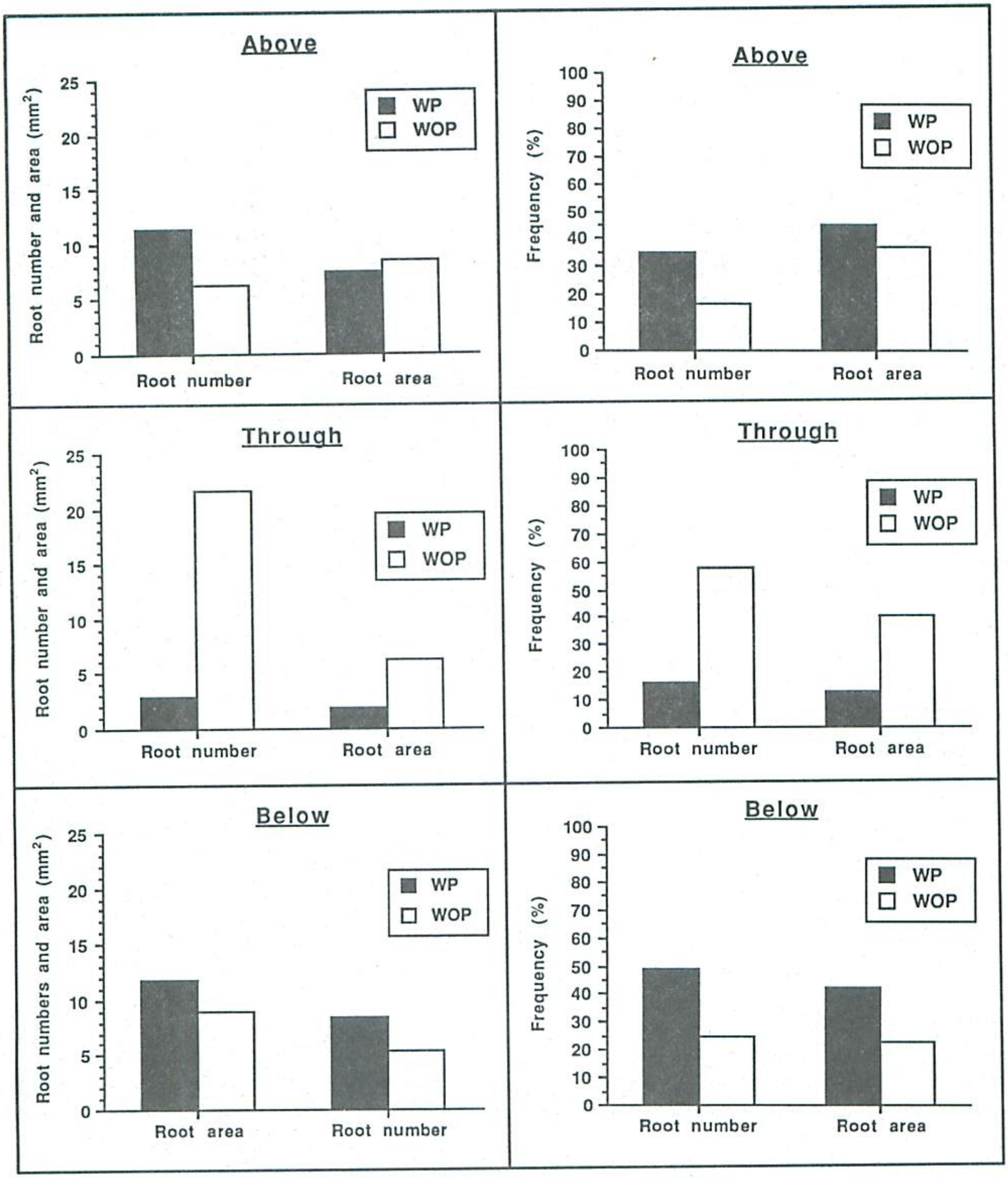

Figure 7. Mean number of roots and mean root area (in mm², for roots with a diameter >1 mm) at different levels with respect to the location of the paper (above, through and below) for seedlings with (WP) and without paper (WOP). To the right, the proportions for both parameters are listed for the different levels.

Seedlings without paper that lacked adventitious roots had greater height (52.8 cm) and diameter (9.0 mm) increments than WOP seedlings with adventitious roots (Fig. 10, Table 12). For seedlings with paper, there was no clear tendency for growth differences in relation to adventitious rooting. Increment differences related to adventitious rooting were not significant.

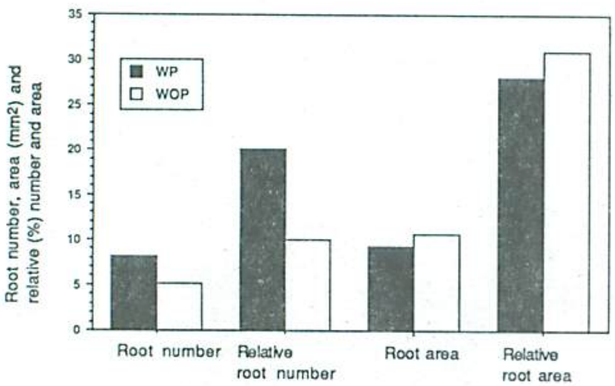

Figure 8. Mean number of roots, root area (for roots with diameter > 1 mm) and relative frequency of adventitious roots at 5 cm from the stem for seedlings planted with (WP) and without (WOP) paper.

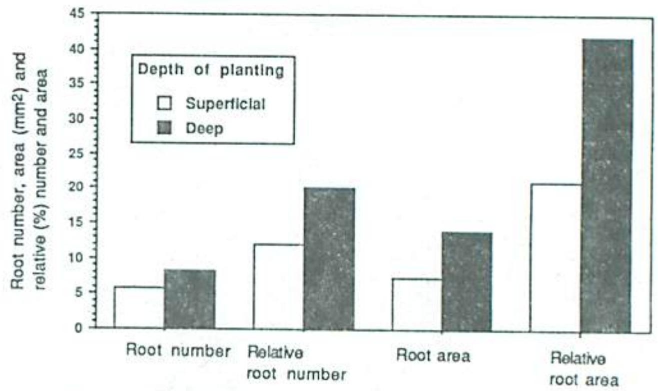

Figure 9. Mean number, root area (for roots with diameter >1 mm) and relative frequency of adventitious roots at 5 cm from the stem for seedlings (WP and WOP combined) planted at different depths (≤25 and >25 mm).

Table 7. Mean diameters in spring 1988 and fall 1990 and mean diameter increments for black spruce paperpot seedlings planted with or without paper at 2 and 6 m from a ditch in spring 1987. Numbers in the same row followed by different letters are significantly different at the P = 0.05 level.

	With paper				Without paper			
	2 m (n = 15)		6 m (n = 14)		2 m (n = 14)		6 m (n = 15)	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Diameter (mm)								
spring 1988	2.9b	0.6	3.8a	1.1	3.6a	0.8	3.6a	0.5
fall 1990	9.5a	2.0	10.0a	1.6	10.6a	2.5	10.3a	7.9
Diameter increment (mm)								
1990–1988	6.6a	2.0	6.2a	1.9	6.9a	2.3	6.7a	2.6
1990	2.4b	1.8	2.9ab	1.2	3.6a	1.3	2.8ab	1.4
1989[a]	2.1a	1.0	1.7a	0.8	1.7a	0.8	1.9a	0.9
Relative[b]	2.4a	1.1	1.8b	0.7	2.0ab	0.7	1.9ab	0.7

[a] Diameter increment 1989 is based on two seasons of diameter growth (i.e., [1989+1988]/2).
[b] Relative diameter increment = diameter increment (1990–1988)/diameter (spring 1988).

Asymmetrical Root Distribution

The asymmetrical distribution of roots was expressed either as root area index (RAI) or root number index (RNI). These indices are ratios of values for the quadrant with the highest concentration of root area or number of roots and the total root area or number of roots (respectively) for each seedling; for a perfectly symmetrical root system, both values would be 0.25. The higher the ratio, the more roots are concentrated into one quadrant and the more asymmetrical the root system.

Seedlings were divided into three classes on the basis of RAI and RNI ratings, and the frequency of seedlings in each group was counted. The results of this analysis are presented in Figure 11 and Tables 13–14.

At 5 cm from the stem, RAI averaged from 0.54 to 0.59 for all types of seedlings; that is, 54 to 59% of the total root area was concentrated within one quadrant (25% of the soil surrounding the seedling). The highest RAI (0.59) was found for seedlings planted close to the ditch (Table 13). No difference was found between WP and WOP seedlings at 5 cm from the stem.

At 25 cm from the stem, RAI values were higher (from 0.64 to 0.73), indicating a less symmetrical root distribution farther from the stem. The highest RAI values were found in WP seedlings planted close to the ditch (Fig. 11, Table 13).

Table 8. Mean root areas for roots with diameter >1 mm and mean numbers of all roots at different levels of the root system and at different distances from the stem for seedlings with (WP) and without (WOP) paper. Numbers in the same column followed by different letters are significantly different (for WP versus WOP) at the P = 0.05 level.

Distance from stem	WP seedlings No. of roots	WP seedlings % R5[a]	WOP seedlings No. of roots	WOP seedlings % R5[a]
25 cm				
2 m from ditch	8.5	–	15.4	–
6 m from ditch	11.4	–	13.0	–
mean	9.9a	31%	14.1a	25%
10 cm				
2 m from ditch	22.9	–	36.4	–
6 m from ditch	29.9	–	37.2	–
mean	26.3a	65%	36.8a	67%
5 cm				
2 m from ditch	35.6	–	53.1	–
6 m from ditch	40.4	–	54.7	–
mean	38.1b	100%	53.9a	100%

Distance from stem	WP seedlings Area (mm²)	WP seedlings % R5[a]	WOP seedlings Area (mm²)	WOP seedlings % R5[a]
25 cm				
2 m from ditch	5.3	–	10.9	–
6 m from ditch	9.5	–	7.2	–
mean	7.3a	20%	8.6a	25%
10 cm				
2 m from ditch	13.6	–	21.4	–
6 m from ditch	22.4	–	18.7	–
mean	17.8a	50%	20.0a	46%
5 cm				
2 m from ditch	30.0	–	41.2	–
6 m from ditch	42.3	–	36.3	–
mean	35.1a	100%	38.7a	100%

Level in container[b]	Number of roots at 10 cm WP	% R5[a]	WOP	% R5[a]
Above				
2 m from ditch	8.1	–	5.4	–
6 m from ditch	14.9	–	6.9	–
mean	11.4a	35%	6.2a	17%
Through				
2 m from ditch	3.3	–	21.5	–
6 m from ditch	2.5	–	21.7	–
mean	2.9a	16%	21.6a	58%
Below				
2 m from ditch	11.4	–	9.6	–
6 m from ditch	12.5	–	8.2	–
mean	11.9a	49%	8.9a	25%

Level in container[b]	Root area (mm²) at 10 cm WP	% R5[a]	WOP	% R5[a]
Above				
2 m from ditch	5.3	–	8.5	–
6 m from ditch	9.8	–	8.4	–
mean	7.5a	45%	8.4a	37%
Through				
2 m from ditch	1.6	–	6.8	–
6 m from ditch	2.1	–	5.9	–
mean	1.8b	13%	6.3a	40%
Below				
2 m from ditch	6.7	–	6.2	–
6 m from ditch	10.5	–	4.7	–
mean	8.5a	42%	5.4a	23%

[a] % of the value for roots at 5 cm from the stem
[b] see Figure 3

More than half of the seedlings planted at 2 m from the ditch, versus one-third of the seedlings at 6 m from the ditch, had more than 70% of the total root area concentrated into one quadrant (Table 13). Almost half (46%) of WP seedlings had more than 70% of the total root area in one quadrant, whereas the same figure for WOP seedlings was only 37% (Table 13). No differences relating to RAI were significant.

The distribution of numbers of roots showed the same pattern as for root area, with RNI values between 0.42 and 0.46 at 5 cm from the stem (Table 14). The differences in RNI between WP and WOP seedlings at 5 cm from the stem and at different distances from the ditch were small and not significant.

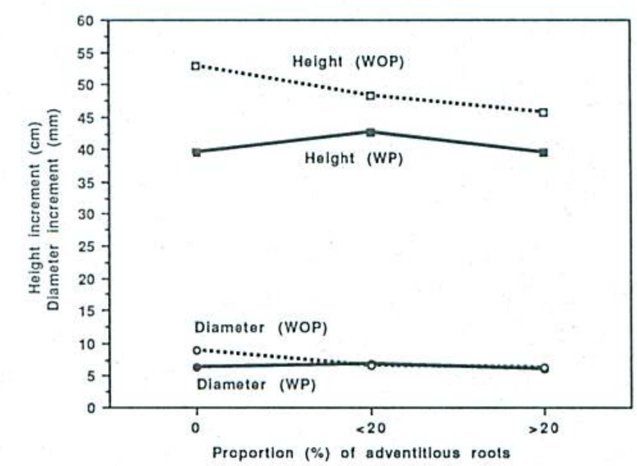

Figure 10. Mean height and diameter increments for seedlings with (WP) and without (WOP) paper and with different proportions (0, ≤20%, >20%) of adventitious roots.

Table 9. Root area for roots with diameter >1 mm and for all roots (including those <1 mm in diameter) for seedlings with and without paper. Roots <1 mm in diameter have been given an estimated root diameter of 0.5 mm.

Level in root system[a]	Root area (mm²)[b] WP	WOP
Roots with diameter < 1mm		
Above	7.5 (45%)	8.4 (37%)
Through	1.8 (13%)	6.3 (40%)
Below	8.5 (42%)	5.4 (23%)
Total	17.8	20.1
All roots		
Above	9.2 (42%)	9.2 (29%)
Through	2.2 (13%)	9.9 (47%)
Below	10.1 (45%)	6.8 (24%)
Total	21.5	25.9

[a] see Figure 3

[b] proportion (%) of total at that level in brackets

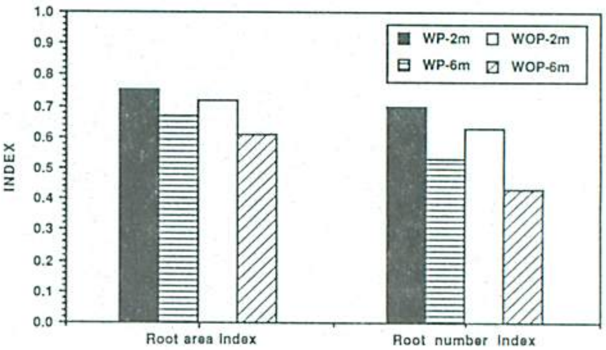

Figure 11. Mean root area index and mean root number index at 25 cm from the stem for seedlings with (WP) and without (WOP) paper at 2 and 6 m from a ditch. (For both parameters, values = 0.25 mean a perfectly symmetrical root system.)

At 25 cm from the stem, the differences in RNI were greater and seedlings planted close to the ditch (at 2 m) had a significantly higher RNI (0.67) than seedlings planted at 6 m (0.52), indicating a less symmetrical root distribution closer to the ditch (Table 14). This was the only significant difference in RNI at the P = 0.05 level.

Almost 80% of seedlings planted at 2 m from the ditch had more than 50% of their roots within one quadrant, whereas the same figure for seedlings at 6 m was 37% (Table 14).

At 25 cm, 69% of WP seedlings had more than 50% of their roots concentrated into one quadrant versus 48% of the WOP seedlings (Table 14). The highest RNI value at 25 cm (0.70) was found for WP seedlings at 2 m from the ditch and the lowest value (0.43) was for WOP seedlings at 6 m (Fig. 11). The results indicate that root asymmetry is more pronounced farther from the seedling, especially for seedlings planted close to a ditch and with the paper left on.

Table 10. Mean numbers, root areas and relative numbers and relative root areas of adventitious roots for seedlings planted with and without paper. The numbers and frequency of seedlings are also reported for three classes each of relative root number and area.

	With paper[a]				Without paper[a]			
	N	%	$\bar{x}$	s	N	%	$\bar{x}$	s
Number of roots[b]								
mean	29	–	8.1 A	12.3	28	–	5.1 A	4.6
relative	29	–	0.20 A	0.18	28	–	0.10 B	0.09
relative number:								
= 0	4	14	–	–	3	11	–	–
≤0.2	11	38	–	–	21	75	–	–
>0.2	14	48	–	–	4	14		–
Root area (mm²)[c]								
mean	29	–	9.2 A	12.6	28	–	10.6 A	12.9
relative	29	–	0.28 A	0.29	28	–	0.31 A	0.24
relative area:								
= 0	11	38	–	–	7	25	–	–
≤0.4	8	28	–	–	10	36	–	–
>0.4	10	34	–	–	11	39	–	–

[a] Numbers on the same row followed by different letters are significantly diffenenc different at the P = 0.05 level.

[b] at 5 cm from the stem

[c] for roots with diameter > 1 mm

Table 11. Mean numbers, root areas, relative numbers and relative root areas of adventitious roots for seedlings planted at two depths (determined from the distance from the original surface to the top of the plug). The data are also presented in three classes of relative numbers and areas.

	Distance from original surface to top of plug							
	<0.25 cm				>0.25 cm			
	N	%	$\bar{x}$	s	N	%	$\bar{x}$	s
Number of roots								
mean	34	–	5.7 A	11.4	23	–	8.1 A	5.25
relative	34	–	0.12 B	0.14	23	–	0.20 A	0.16
relative number								
= 0	7	21	–	–	0	0	–	–
≤0.2	19	56	–	–	13	57	–	–
>0.2	8	23	–	–	10	43	–	–
Root area (mm^2)								
mean	34	–	7.2 A	11.2	23	–	13.8 A	13.8
relative	34	–	0.21 B	0.23	23	–	0.42 A	0.26
relative area:								
= 0	15	44	–	–	3	13	–	–
≤0.4	9	27	–	–	9	39	–	–
>0.4	10	29	–	–	11	48	–	–

[a] Numbers on the same row followed by different letters are significantly different at the P = 0.05 level.

Table 12. Mean height and diameter increments for seedlings planted with and without paper (in three classes each of relative frequency of adventitious roots and root areas).

	Height increment (cm)						Diameter increment (mm)			
	With paper			Without paper			With paper		Without paper	
	N	$\bar{x}$	s	N	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
relative number										
= 0	4	39.5	7.6	3	52.8	5.9	6.3	1.5	9.0	2.7
≤0.2	11	42.6	6.8	21	48.2	8.7	7.0	2.7	6.7	2.4
>0.2	14	39.6	11.2	4	45.7	12.5	6.0	1.3	6.3	2.2
relative area (mm^2)										
= 0	11	42.4	6.8	7	50.9	4.4	6.8	2.6	7.9	3.2
≤0.4	8	38.0	9.9	10	49.1	9.9	6.3	1.2	7.4	2.4
>0.4	10	41.0	10.9	11	46.1	10.1	6.1	1.7	5.8	1.5

Effect of North/south Aspect on Root Distribution

Another question examined in the present study was whether the different sides of a ditch (i.e., with different soil temperatures on northern and southern sides) affect the way the roots grow and/or the root distribution on the southern and northern sides of the seedling. Roots (number and area) were divided into two groups, each within half-circles pointing towards and away from the ditch, respectively. Seedlings planted on the southern and northern sides of ditches and at 2 and 6 m were treated separately (Table 15).

Although the results were neither consistent nor significant, there were some apparent trends. Close to the the ditch, the relative numbers of roots (NR) on the side nearest to the ditch were higher for seedlings planted on the northern side of the ditch, whereas seedlings on the southern side had more roots on the side away from the ditch. This means that there were more roots growing on the southern side of a seedling. Root area (RA), on the other hand, was higher on the northern side of a seedling, with no apparent differences between the two sides of the ditch (Table 15).

Table 13. Mean root area indices (RAI) at 5 and 25 cm from the stem and the distribution of seedlings in three RAI classes. Data are presented for seedlings in four classes: with and without paper and at 2 and 6 m from a ditch.

	Seedling class, at two distances from the stem							
	With paper		No paper		2 m		6 m	
	5 cm	25 cm	5 cm	25 cm	5 cm	25 cm	5 cm	25 cm
Sample size	29	26	28	24	29	25	28	25
Mean RAI	0.56	0.71	0.57	0.67	0.59	0.73	0.54	0.64
Proportion in RAI class:								
< 0.5	48%	12%	28%	17%	38%	12%	39%	16%
0.5–0.7	24%	42%	61%	46%	34%	36%	50%	52%
> 0.7	28%	46%	11%	37%	28%	52%	11%	32%
RAI at 2 m	0.75	–	0.72	–	–	–	–	–
RAI at 6 m	0.67	–	0.61	–	–	–	–	–

Table 14. Mean root number indices (NRI) at 5 and 25 cm from the stem and the distribution of seedlings in three NRI classes. Data are presented for seedlings in four classes: with and without paper and at 2 and 6 m from a ditch.

	Seedling class, at two distances from the stem							
	With paper		No paper		2 m		6 m	
	5 cm	25 cm	5 cm	25 cm	5 cm	25 cm	5 cm	25 cm
Sample size	29	29	29	27	29	29	29	27
Mean RNI	0.43	0.62	0.45	0.57	0.46	0.67a	0.42	0.52 b
Proportion in RNI class:								
<0.5	90%	31%	76%	52%	73%	21%	93%	63%
0.5–0.7	10%	48%	21%	33%	24%	52%	7%	30%
>0.7	0%	21%	3%	15%	3%	27%	0%	7%
RNI at 2 m	0.70	–	0.63	–	–	–	–	–
RNI at 6 m	0.53	–	0.43	–	–	–	–	–

The proportions of root area arising from spiraling roots were 43% of the total root area for WP seedlings versus 26% for WOP seedlings, a significant difference. The root spiraling index was 58 for WP seedlings compared with 39 for WOP seedlings (Table 16).

At 2 m from the ditch, 93% of all seedlings exhibited root spiraling compared with 82% at 6 m. Spiraling roots at both distances from the ditch represented about 10% of the total numbers of roots. Both the area of spiraling roots and the degree to which each root spiraled were higher close to the ditch; therefore, RSPIND was significantly higher for seedlings at 2 m from the ditch (59) than at 6 m (37), indicating that roots spiraled more in seedlings close to a ditch (Table 16).

At 6 m from the ditch, where the influence of the ditch should be less, both NR and RA were higher on the southern side of the seedling (Table 15).

Root Spiraling

The root spiraling index (RSPIND) was developed by multiplying the area of each spiraling root with the extent (angular degrees) of the spiral, summing these values for each seedling and dividing the sum by the total root area of the seedling. These values and the numbers and areas of spiraling roots are shown in Figure 12 and Tables 16–17.

Spiraling roots were found in all but one (97%) WP seedling, whereas the same figure for WOP seedlings was 80%. On average, WP seedlings had 3.7 spiraling roots per seedling versus 2.9 for WOP seedlings; this represents 12% of all roots per WP seedling, significantly higher than the 6% for WOP seedlings (Table 16).

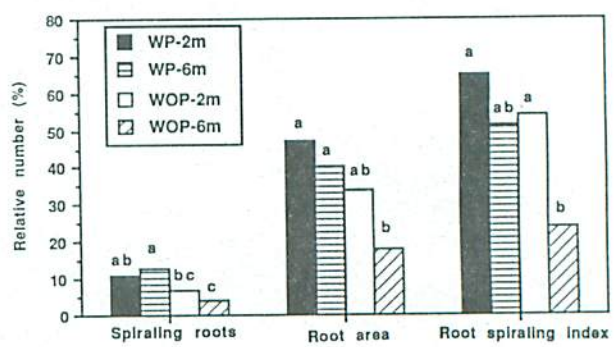

Figure 12. Relative numbers of spiraling roots, their relative root areas and the root spiraling index for seedlings with (WP) and without paper (WOP) planted at 2 and 6 m from a ditch. Bars labeled with different letters are significantly different at the P = 0.05 level.

Seedlings without paper planted away from the ditch (WOP-6 m) had the fewest spiraling roots and the lowest root spiraling index of all groups (Fig. 12, Table 17). On average, WOP-6 m seedlings had 4% spiraling roots, which accounted for 18% of the root area, and a root spiraling index of 24. This was significantly lower than for seedlings at 2 m, either with or without paper. The highest root spiraling index (65) was found in seedlings with paper close to a ditch (Table 17).

Table 15. Relative numbers of roots and root areas in two semicircles around each seedling: one pointing towards the ditch (quadrants 1 and 4 in the text), and one facing away (quadrants 2 and 3 in the text). Data are presented for seedlings planted at 2 and 6 m from a ditch on both the southern and northern sides of the ditch.

	Relative root number			Relative root area		
	n	$\bar{x}$	s	n	$\bar{x}$	s
Southern side of ditch						
2 m from ditch						
facing away[a]	10	0.56	0.32	5	0.39	0.40
facing towards[b]	7	0.46	0.29	9	0.61	0.41
6 m from ditch						
facing away[a]	11	0.55	0.22	9	0.59	0.21
facing towards[b]	5	0.45	0.22	5	0.41	0.21
Northern side of ditch						
2 m from ditch						
facing away[b]	5	0.41	0.32	6	0.52	0.40
facing towards[a]	7	0.60	0.32	5	0.49	0.40
6 m from ditch						
facing away[b]	6	0.52	0.32	5	0.43	0.37
facing towards[a]	7	0.49	0.31	6	0.58	0.38

[a] on the southern side of the seedling
[b] on the northern side of the seedling

DISCUSSION

The results and the interpretations of this study refer to seedlings excavated four growing seasons after planting. The study deals only with seedlings planted on a peatland and that had high vitality both when planted and when excavated. With these caveats, black spruce paperpot seedlings had better aboveground growth and root development if the paper containers were removed from the seedlings at the time of planting. The positive effect of removing the paper was improved if seedlings were planted close to a ditch, which suggests an effect of drainage and/or site disturbance. Height growth was significantly greater for

Table 16. Mean number and relative number of roots, relative root area, average degree of root spiraling and root spiraling index of spiraling roots in seedlings planted with and without paper at two distances from a ditch. Numbers in a column followed by different letters are significantly different between treatments at the P = 0.05 level.

		Number of spiraling roots: Mean		Number of spiraling roots: Relative		Relative root area		Average degree of spiraling[b]		Root spiraling index	
	N	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Paper container											
Present	29	3.7a	2.5	0.12a	0.10	0.43a	0.29	132a	57	58a	43
Removed	28	2.9a	2.0	0.06b	0.04	0.26b	0.21	113a	70	39a	34
Present[a]	28	3.8a	2.4	0.12a	0.10	0.45a	0.28	137a	52	60a	42
Removed[a]	22	3.6a	1.5	0.07a	0.04	0.33a	0.18	144a	41	49a	30
Distance from ditch											
2 m	29	3.4a	2.3	0.09a	0.08	0.41a	0.27	139a	64	59a	39
6 m	28	3.2a	2.3	0.09a	0.09	0.29a	0.26	106a	61	37b	37
2 m[a]	27	3.6a	2.2	0.09a	0.08	0.44a	0.25	149a	54	64a	37
6 m[a]	23	3.9a	1.9	0.11a	0.09	0.35a	0.24	130a	38	45a	37

[a] Only seedlings with spiraling roots are included in this row.
[b] The degree of spiraling is illustrated in Figure 4.

WOP seedlings planted close to the ditch. Diameter increment was also higher for such seedlings. There are two obvious factors that affected the growth performance of the seedlings: First, removal of the paper increased the contact between roots and the surrounding soil, in this case peat, allowing existing roots to expand their area of uptake of water and nutrients and easier growth of new roots into the adjacent peat layers. Second, the positive effect of planting close to a ditch was probably a combination of reduced soil water (as a result of drainage) and disturbance of the microsite, creating a microclimate with higher soil temperature and better soil aeration.

Seedlings with both these factors combined also showed the best overall growth performance, whereas seedlings with none of these factors, farther from the ditch and with the paper still on, exhibited the least growth. Seedlings with the paper removed but planted farther from the ditch showed the same growth performance as those planted closer to the ditch but with the paper still on.

The difference in growth between seedlings with and without paper was not great during the first years after planting, but both diameter and height increments were significantly higher in the fourth year of growth (1990) for seedlings without paper and close to the ditch. This indicates that the paper in paperpots has no negative effect on the early growth of the seedling but that the differences in aboveground growth between WP and WOP seedlings may increase in the following years. A future study should be made to reveal if this trend of better growth with the paper removed lasts, and for how long.

Regression analyses showed that diameter increment was more likely to be correlated with root growth variables than was height increment, which was more correlated with other variables such as competition, type of seedling and distance to ditch. Under high competitive pressure, the seedlings seemed to develop a strategy that emphasized height growth in order to get above and ahead of the competition. Another explanation for the improved height growth could be that alder (*Alnus* spp.) shrubs comprised much of the competition, and alder may have fertilized the soil through nitrogen fixation.

After 4 years, the paper, or at least its non-cellulose, artificial-fiber elements, remained intact and very few roots managed to penetrate the paper wall. In WP seedlings, nearly all roots were forced to grow either above or below the paper wall, whereas most roots arose at a level where the paper had once been in WOP seedlings. The total number of roots was 40% higher in WOP seedlings; at the level where the paper is/was, the difference increased to 7.5 times more roots for WOP seedlings.

The difference in root area (for roots with diameter >1 mm) between WP and WOP seedlings was less than that for the number of roots (10% more root area in WOP seedlings), suggesting that WOP seedlings had more but finer roots. When small roots, with a root diameter <1 mm, were assigned an estimated root diameter of 0.5 mm, the difference in root area doubled.

The larger number of roots and the higher root area in WOP seedlings clearly indicated that the paper did not decompose as expected and instead prevented root penetration and impeded root growth and development.

Table 17. Mean numbers and relative numbers of roots, relative root areas, average degree of spiraling and root spiraling indices of spiraling roots in seedlings divided into four treatment subgroups. Treatment means followed by different letters are significantly different at the P = 0.05 level.

		Number of roots				Relative root area		Average degree of spiraling		Root spiraling index	
		Mean		Relative							
Subgroup[a]	N	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
WP–2 m	15	3.3a	2.7	0.11ab	0.10	0.47a	0.30	139a	.5	65a	43
WP–6 m	14	4.0a	2.4	0.13a	0.11	0.40a	0.28	124a	75	51ab	44
WOP–2 m	14	3.4a	2.0	0.07bc	0.05	0.34ab	0.22	138a	53	54a	36
WOP–6 m	14	2.4a	2.0	0.04c	0.04	0.18b	0.18	89a	78	24b	24
WP–2 m[b]	14	3.5a	2.6	0.12a	0.11	0.50a	0.28	149a	67	69a	40
WP–6 m[b]	14	4.0a	2.4	0.13a	0.11	0.40ab	0.28	124a	30	51ab	44
WOP–2 m[b]	13	3.6a	1.9	0.07a	0.04	0.37ab	0.20	148a	37	58ab	34
WOP–6 m[b]	9	3.7a	1.0	0.07a	0.03	0.29b	0.15	138a	48	37b	20

[a] Coding: WP = with paper, WOP = without paper, 2 m and 6 m = distance from the ditch

[b] Only seedlings with spiraling roots are included in this group.

Using number of roots and root area instead of dry mass of roots as measures of root growth was a practical method for obtaining root information. When excavating a root system, it is virtually impossible to harvest all roots, especially the fine roots that are most active in taking up water and nutrients and which presumably contribute most to seedling growth. It has been shown that root area at selected distances from the seedling stem can be used as a good estimate of the total root mass (Lindgren and Öhrlander 1977).

Distance to ditch did not seem to affect the numbers of roots or root area, though seedlings farther from the ditch developed more roots and higher root areas for roots coming out above the plug than did seedlings closer to the ditch. The reason for this may be that seedlings on less well-drained sites with higher water tables allocate more resources to root growth higher up in the root system, where more oxygen is available.

One might expect that WP seedlings, with fewer and thicker roots, had to reach farther for nutrient uptake and there split into more and thinner roots than in WOP seedlings, which could take up nutrients closer to the seedling. The total length of root growth was not studied, but number of roots and root area decreased to about the same degree within a range of 5 to 25 cm from the center of the stem in both WP and WOP seedlings. At 25 cm, numbers of roots were 25% of the numbers at 5 cm, and root area was down to 21% of the area closer to the stem. Nonetheless, the relative difference in numbers and area between WP and WOP seedlings remained constant. These findings contradict the idea that WP seedlings, at least within 25 cm of the stem, would have more of their root mass concentrated farther from the stem.

Do seedlings growing in a constraining container such as the paperpot develop more adventitious roots to compensate for the impeded root growth caused by the paper wall? In this study, every fifth root in WP seedlings was an adventitious root, whereas every tenth root was adventitious for WOP seedlings. If seedlings were planted deeply, the difference was even greater.

Even though adventitious roots were twice as common among WP seedlings, such adventitious roots were thinner than in WOP seedlings. Therefore, the adventitious root area was almost the same in both cases, or even higher in WOP seedlings. Approximately 30% of the root area (40% in deeply planted seedlings) was composed of adventitious roots.

Black spruce obviously develops more adventitious roots if planted deep and with paper, but to what extent, if at all, do the adventitious roots contribute to growth performance? McClain (1978) showed that height growth of black spruce seedlings planted in Ontario tubes was as high as for seedlings planted in plugs if they developed adventitious roots.

In the present study, adventitious roots did not seem to have any positive effect on either height or diameter growth; in fact, seedlings without adventitious roots had better height and diameter increments, especially for WOP seedlings. However, we cannot say how seedlings with adventitious roots would have performed if they had not developed adventitious roots.

One of the most important criticisms of paperpots in a number of studies is that they cause instability in the trees as a result of poor development of the root system. In the present study, the root systems were less symmetrical in WP than in WOP seedlings, but the differences were small and not significant. The differences were more pronounced for number of roots than for root area, indicating that there were more small roots more evenly distributed in WOP seedlings and these roots may contribute to more symmetrical root systems in the future. It is uncertain, however, whether an asymmetrical root system can become more symmetrical; Eis (1974) maintained that the asymmetry of a root system is set before 10 years of age whereas Gillgren (1972), Lähde and Mutka (1974) and Hultén and Jansson (1978) reported that root asymmetry decreases with age.

Another measurable component of root development is root spiraling, which is a common phenomenon in all containerized seedlings, and especially in paperpots. Removing the paper did not seem to decrease the number of spiraling roots. Root area of spiraling roots, on the other hand, was highest in WP seedlings close to the ditch. Considering the degree to which each root spiraled provided a root spiraling index that was highest over all for WP seedlings close to the ditch. Root spiraling index gives a more accurate estimate of the problem since it considers both the degree of twisting and the proportion of the root system that spirals.

These results suggest that much of the observed root deformation was already established in the container before the seedling left the nursery; this state will persist even after planting when the paper has been removed.

However, the negative effect of spiraling may be decreased by removing the paper container at the time of planting. After the paper has been removed, unconstrained roots can start to grow more freely, as was indicated by the reduced degree of spiraling in WOP seedlings. Spiraling roots did not grow as well as nonspiraling roots in WOP seedlings, as is shown by the lower area of spiraling roots in those seedlings.

Closeness to ditch may have had a negative effect on root distribution, with less symmetry and more spiraling for seedlings close to the ditch, a result that is borne out by Sundquist's (1988) study of root development by seedlings close to a ditch in a plowed, clearcut area.

Finally, it is important to point out that the results of this study indicate that some of the problems associated with the use of paperpots can partly be ameliorated by simply removing the paper at the time of planting. However, other negative effects of the paperpot system, which are common to other containerized seedling systems, cannot be corrected.

It may be difficult and costly to get the planting staff to remove the paper on each seedling before planting. Therefore, a simpler way to handle the problem with the paper would be to switch to the Ecopot container or a similar solution. There are two advantages offered by such a switch: seedlings are planted without constraining paper, and nurseries that have already invested in the paperpot system can preserve their investment and still deliver a high-quality seedling.

CONCLUSIONS

1. The non-cellulose, artificial-fiber elements of the paper container were still present after 4 years. Under the conditions in the present study, very few roots had been able to penetrate the paper wall.
2. Seedlings without paper had significantly higher height and diameter increments, and this was more pronounced in the fourth (last) year of recorded growth.
3. Seedlings close to a ditch grew better than those further away, probably because of the combined effects of drainage (improved aeration) and microsite disturbance (warmer microclimate).
4. Total numbers of roots and root area were greater in seedlings without than those with paper, especially at the level in the root system where the paper would normally be.
5. Development of adventitious roots was favored by deep planting and not removing the paper. However, seedlings without adventitious roots showed better height and diameter growth than seedlings with adventitous roots.
6. Asymmetrical root distribution and root spiraling were more pronounced in seedlings planted with the paper still on and closer to a ditch. However, much of the root development and deformation was already established in the nursery before planting.

RECOMMENDATIONS

Remove the paper container when planting black spruce paperpot seedlings under site conditions similar to those in the present study. Instead of moving away from the paperpot system *per se*, consider switching to Ecopot (or similar) containers, where the paper is easily removed before planting. Following these recommendations will provide seedlings with a chance for higher growth, better root development and greater stability.

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APPENDIX 1: Variables used in the seedling/root study analysis.

Number	Name	Description and codes
1	DICLASS	Classes for distance to ditch (m): 2 and 6 m. Treated as a dummy variable.
2	SEEDBED[a]	Dominant seedbed material where the seedling is planted: 24 categories.
3	MICROTOP[a]	Microtopography on which the seedling is planted. Coded from 1 to 7, where 1 is lowest and 7 is highest. Treated as a dummy variable.
4	SLASH[a]	Estimate of % of slash covering a circle around the seedling within a radius of 30 cm.
5	EXPOSURE[a]	The degree of exposure of the seedling. Coded from 0 to 5, where 0 is very exposed and 5 very protected. Treated as a dummy variable.
6	MINERAL	Estimate of % of mineral soil in a circle within a radius of 30 cm. Treated as a dummy variable: 0 = no mineral soil, 1 = mineral soil is available.
7	STOCKTYP	Stock type. Treated as a dummy variable: 1 = with paper, 2 = paper has been removed.
8	VISPR88[a]	Vitality, spring 1988. Coded from 0 to 5, where 0 = dead seedling and 5 = very healthy. Treated as a dummy variable.
9	HESPR87	Height (cm) in spring 1987.
10	HESPR88	Height (cm) in spring 1988.
11	DIAM88	Root collar diameter (mm) in spring 1988.
12	VIFA88[a]	Vitality in fall 1988. Coded from 0 to 5, where 0 = dead seedling and 5 = very healthy. Treated as a dummy variable.
13	HEFA89	Height (cm) in fall 1989.
14	DIAM89	Root collar diameter (mm) in fall 1989.
15	HESPR89	Height (cm) in spring 1989.
16	HEFA90	Height (cm) in fall 1990.
17	DIAM90	Diameter (mm) 5 cm above ground in fall 1990.
18	HEINC90	Height increment (cm) in 1990.
19	COMP90	Estimate of the competition surrounding each seedling. Coded from 1 to 3, where 1 = no competition and 3 = severe competition (mainly from alder bushes). Treated as a dummy variable.
20	SOIL	Soil type, where: 1 = *Sphagnum* moss and lightly decomposed peat, 2 = very well decomposed peat, 3 = 1 or 2 plus 15% mineral soil, 4 = 1 or 2 plus 50% mineral soil, and 5 = 1 or 2 plus 90% mineral soil.
21	DISURF	Distance (mm) from original surface to present surface.
22	DIPLUG	Distance (mm) from original surface to the top of the plug.
23	NEWLEAD	Whether or not a new leader had taken over from the original leader: 1 = new leader, 0 = original leader. Treated as a dummy variable.
Root Area (roots with diameter >1 mm)		
24	RAA	Root Area (mm^2) Above at a distance of 10 cm from the center of the stem. Above = roots arising from the top of the plug and above the paper.
25	RAT	Root Area (mm^2) Through at a distance of 10 cm from the stem. Through = roots penetrating the paper wall or arising where the wall was before its removal.
26	RAB	Root Area (mm^2) Below at a distance of 10 cm from the stem. Below = roots arising below the paper, from the bottom of the plug.
27	RA1	Root Area (mm^2) in 1st quadrant, 10 cm from the stem.
28	RA2	Root Area (mm^2) in 2nd quadrant, 10 cm from the stem.
29	RA3	Root Area (mm^2) in 3rd quadrant, 10 cm from the stem.
30	RA4	Root Area (mm^2) in 4th quadrant, 10 cm from the stem.
31	RA5	Root Area (mm^2) 5 cm from the stem.
32	RA10	Root Area (mm^2) 10 cm from the stem.
33	RA25	Root Area (mm^2) 25 cm from the stem.

(cont'd)

Number	Name	Description and codes (concl.)
34	RARA	Root Area (mm^2) Ratio Above between 25 and 5 cm from the center of the stem. Above = see variable 24.
35	RART	Root Area (mm^2) Ratio Through between 25 and 5 cm from the center of the stem. Through = see variable 25.
36	RARB	Root Area (mm^2) Ratio Below between 25 and 5 cm from the center of the stem. Below = see variable 26.
Root Spiraling		
37	NRSP	Number of spiraling roots >1 mm diameter 5 cm from the stem.
38	RASP	Root Area (mm^2) of SPiraling roots (>1 mm diameter) 5 cm from the stem.
39	DEG	Degrees (°) to which each root is spiraling. See Figure 4.
40	RSPIND	Root spiraling INDex = Σ (RASP*DEG)/RA5
Number of Roots		
41	NRA	Number of all Roots coming out Above at 10 cm. Above = see variable 24.
42	NRT	Number of all Roots coming out Through at 10 cm. Through = see variable 25.
43	NRB	Number of all Roots coming out Below at 10 cm. Below = see variable 26.
44	NR1	Number of all Roots 10 cm from the stem in the 1st quadrant.
45	NR2	Number of all Roots 10 cm from the stem in the 2nd quadrant.
46	NR3	Number of all Roots 10 cm from the stem in the 3rd quadrant.
47	NR4	Number of all Roots 10 cm from the stem in the 4th quadrant.
48	NR5	Number of all Roots 5 cm from the stem.
49	NR10	Number of all Roots 10 cm from the stem.
50	NR25	Number of all Roots 25 cm from the stem.
51	NRRA	Number of all Roots Ratio Above. Ratio of the number of all roots at 25 and at 5 cm from the stem (i.e., no. at 25/no. at 5) arising Above the paper. Above = see variable 24.
52	NRRT	Number of all Roots Ratio Through. Ratio of the number of all roots at 25 and 5 cm from the stem (no. at 25/no. at 5) penetrating Through the paper. Through = see variable 25.
53	NRRB	Number of all Roots Ratio Below. Ratio of the number of all roots at 25 and 5 cm from the stem (i.e., no. at 25/ no. at 5) arising Below the paper. Below = see variable 26.
Adventitious Roots		
54	NADVR	Number of ADVentitious Roots 5 cm from the stem. All adventitious roots arise above the paper.
55	TNR	Total Number of all Roots 5 cm from the stem arising above the paper.
56	NADVR1	Number of ADVentitious Roots >1 mm in diameter 5 cm from the stem.
57	RAADVR	Root Area of ADVentitious Roots >1 mm in diameter 5 cm from the stem.
58	TNR1	Total Number of Roots >1 mm in diameter 5 cm from the stem arising above the paper.
59	TRA	Total Root Area of all roots >1 mm in diameter 5 cm from the stem.
Additional variables		
60	N/SLOC	Location of seedling (on the northern or southern side of the ditch). Quadrants 1 and 4 point towards the ditch. 1 = North, with quadrants 1 and 4 pointing north and the seedling planted on the southern side of the ditch, 2 = South, with quadrants 1 and 4 pointing south and the seedling planted on the northern side of the ditch. Treated as a dummy variable.
61	DISUR	New DIstance (mm) to the SURface from the root collar after splitting the root.
62	ADVRNEW	Number of ADVentitious Roots, based on to the NEW distance to the surface (DISUR).
63	NEEDWEI	Dry WEIght (g) of NEEDles.

[a] Further details on these variables are available from Wally Creek study files on deposit at Forestry Canada, Ontario Region.