Early Growth of Planted Spruce

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Observations were made on the growth of white spruce (Picea glauca [Moench] Voss) and Engelmann spruce (P. engelmanni Parry) each planted at a single location in the interior of British Columbia. In both species bareroot stock (either 2+0 seedlings or 2+1 transplants) with a low root growth capacity made only limited height growth during the first two seasons after planting. In the first season, many short stem units were formed, whereas in the second season, stem units were much longer but many fewer. The length of needles formed after planting by the bareroot trees was, in the first season, only about half that of needles formed the previous year in the nursery.

Needle length increased slightly in the second year. Container-grown trees (1+0 seedlings from 336 ml containers), which had a high root growth capacity, made relatively good height growth in the first season when they formed long needles and stem units. Height growth by these seedlings was much less in the second season, however, as were needle length and stem unit number, but not stem unit length. Application of slow release N,P,K fertilizer at planting improved shoot growth by bareroot trees more in the second season than the first. In contrast, the container-grown stock made a large shoot growth response to fertilization in both the first and the second seasons. The results are consistent with the hypothesis that, as root establishment proceeds, shoot growth tends to be limited by the supply, first of water, then of mineral nutrients. This implies that the early growth of planted spruce can be maximized by using stock with a high root growth capacity, or other
adaptations to drought, and applying slow release fertilizer at planting.
Observations on the white spruce revealed an acceleration in shoot growth by
both stock types during the third season. This followed the establishment, by
the end of the second season, of root systems several metres in diameter. A
large difference in height:diameter ratio, observed at the time of planting,
between the container grown and bareroot white spruce disappeared entirely in
the course of the first 3 growing seasons.
Introduction

Height growth by newly planted forest trees is often less than could be expected of well-established plants of similar size and genotype growing on a similar site. Restricted shoot growth consequent upon transplanting, commonly referred to as planting check (Smith and Walters 1963, Sutton and Tinus 1983), rarely lasts more than one or several seasons. Its direct effect on plantation productivity is thus slight. Indirectly, however, planting check can have a major impact on yield by putting planted stock at a disadvantage in the competition with other vegetation. This disadvantage can be countered by weed control, but only at considerable expense and often with less than complete success. There is great incentive therefore to seek means by which the duration and severity of planting check can be minimized.

Provided it is well-proportioned and has been physiologically pre-adapted to the planting site, a newly planted tree differs little from an established seedling except in the limited radial and vertical extent of its root system. It is a reasonable hypothesis, therefore, that planting check is due primarily to restricted uptake of water or mineral nutrients. Much evidence supports this interpretation. Newly planted trees are characterized by elevated levels of moisture stress (Baldwin and Barney 1976) and by mineral nutrient deficiency (Nambiar and Zed 1980). Close correlations have been observed between the root growth capacity of forest nursery stock and its height growth after transplanting to the forest (Burdett et al. 1983). Early height growth of planted trees can be increased by fertilization (Carlson 1981) and irrigation (Sutton 1968). It can also be increased by weed control; apparently due to an increase in the availability of water and mineral
nutrients (Nambiar and Zed 1980).

Planting check is frequently a factor contributing to the failure of spruce (*Picea* spp.) plantations (Laing 1932, Weatherell 1953, Armson 1958, White 1960, Weetman 1961, Mullin 1963, Burgar and Lyon 1968, Vyse 1981). Attempts to improve early shoot growth of planted spruce by fertilization at the time of planting have generally been unsuccessful (White 1960, Sutton 1982); although fertilizing checked trees a year or two after planting can be beneficial (Weatherell 1953, White 1960). Irrigation in the first season can increase shoot growth, however, especially under dry conditions (Sutton 1968).

These findings suggest that there can be two phases to planting check; the first being due to moisture stress, the second to mineral nutrient deficiency. Observations reported here on the early growth of planted white spruce (*Picea glauca* [Moench] Voss) and Engelmann spruce (*P. engelmannii* Parry) are consistent with this hypothesis and suggest that the first phase can be eliminated by the use of stock with a high root growth capacity, the second by the application of slow release N,P,K fertilizer at planting.

**Materials and Methods**

A trial with white spruce was established in 1980 on a bench of the Fraser River at 53° 23'N and 120° 20'W in the central interior of British Columbia (McHale River plot). The elevation was 730 m, the soil a sandy alluvium. A trial with Engelmann spruce was established the following year at 50° 32'N and 116° 22'W in southeastern B.C. (Gopher Creek plot). The elevation was 1750 m, the soil a silt loam. Both sites had been recently logged and there was little competition at the time of planting.

In both trials bareroot stock (2+0 at McHale River, 2+1 at Gopher Creek)
from a B.C. Ministry of Forests nursery was planted together with considerably larger 1+0 container-grown trees (from 336 ml containers) of the same seedlot raised at the B.C. Ministry of Forests laboratory in Victoria. The bareroot trees averaged 15 to 17 cm in height when planted, the container stock 28 to 37 cm. The root growth capacity of the bareroot stock, as measured by the number of roots elongating more than 1 cm in one week under standard conditions in a controlled environment chamber (Burdett 1979), was approximately one tenth that of the container-grown trees.

At McHale River, trees were planted in 2 blocks of 8 rows. Each row contained 6 bareroot and 8 container-grown trees in alternating groups of 3 and 4. Alternate trees in every row were fertilized at planting with 40 g of 18,6,12 (N,P,K) Osmocote fertilizer (9 month release at 25°C) placed around the tree over an area approximately 30 cm in diameter.

At Gopher Creek, trees were planted in 2 blocks each of 4 randomized 25-tree rows of each stock type. The trees in 2 randomly selected rows of each stock type in each block were fertilized at planting with 30 g of 18,6,12 (N,P,K) Osmocote (9 month release at 25°C) applied as at McHale River.

Tree heights were measured immediately after planting and each fall. At McHale River, ground-line diameter was also measured each fall. Stem volume was estimated as the product of one third basal area and height.

In late October 1982, 14 trees per treatment at McHale River and 16 at Gopher Creek were harvested at random and the following measurements made: annual leader length; length of needles formed during the final year in the nursery and in each subsequent year; number of needles borne by each annual leading shoot; and the number of needle primordia in the terminal resting bud.
Stem unit length (i.e., length of stem between adjacent needle bases) was calculated by dividing annual shoot length by needle number. Needle length was estimated as the mean length of 10 needles from the mainstem near the middle of each year's growth. Needle primordia in the terminal resting bud were counted with the aid of a binocular microscope after dissecting out the unextended shoot, bisecting it longitudinally and placing the halves cut-face down on a microscope slide.

Treatment effects were evaluated by analysis of variance.

Results and Discussion

Observations on white spruce planted at McHale River were similar in many respects to those on Engelmann spruce planted at Gopher Creek. The results of the two trials will therefore be considered together.

During the first growing season bareroot trees made only limited height growth (Figs. 1 and 2). The leading shoots comprised many stem units (Fig. 3) but they were abnormally short compared with those formed in subsequent years (Fig. 4). Needles formed on the leading shoot were also short (Fig. 5); less than half the length of needles formed the previous year in the nursery.

Application of slow release N,P,K fertilizer at planting had only minor effects on first season shoot growth by the bareroot trees (Figs. 1-6). At McHale River for example, fertilization increased percent stem volume growth by only 13%.

Percent height growth during the first growing season by the unfertilized container stock was only slightly greater than that of the unfertilized bareroot trees (37% mean value for both plots versus 30%); although, reflecting the difference in initial height (see Materials and Methods), it
was approximately three times greater in absolute terms (Figs. 1 and 2).

Unlike the bareroot trees, the container stock produced long needles and stem units during the first season (Figs. 1, 4 and 5). Also unlike the bareroot trees, the container stock became more or less severely chlorotic by the end of the first growing season. Chlorosis was largely prevented by fertilization at planting. Fertilization also increased height growth by approximately 25% (Fig. 2). Both stem unit length and number were greater in the fertilized trees (Figs. 3 and 4); although only at Gopher Creek was the effect on stem unit number statistically significant (P < 5%). Measurements made only at McHale River showed a large increase due to fertilization in ground-line diameter (Fig. 6). The effects of fertilization on height and diameter growth at McHale River combined to increase first season percent stem volume growth by 60%.

An explanation of the difference between stock types in fertilizer response is suggested by the 10-fold difference between them in root growth capacity measured during a one-week laboratory assay (see Materials and Methods). If this difference was reflected in the extent of first season root establishment, the bareroot trees, having the lower root growth capacity, were likely to have been very much more prone to moisture stress than the container stock. Thus, whereas mineral nutrient supply appears to have been the major factor limiting first season shoot growth by the container-grown trees, moisture supply may have been the chief limitation to shoot growth in the case of the bareroot trees.

After the first growing season, shoot extension by spruce seedlings occurs largely through the elongation of preformed stem units contained in the
previous season's terminal resting bud. Stem units sometimes elongate in the year they are initiated, however; the process being known as free growth (Jablanczy 1971). The observations reported here allow several conclusions about the significance of the number of primordial stem units in the previous season's terminal resting bud in determining first season height growth of planted trees. During the first season after planting, height growth by the bareroot trees was limited in spite of the large number of stem units comprising the leading shoot (Figs. 1 and 3). Evidently, therefore, the use of stock with a large number of stem units in the terminal bud provides no assurance of satisfactory first season shoot growth, since stem unit elongation may, as in this instance, be severely limited (Fig. 4).

Conversely, the statistically significant increase due to fertilization in the number of stem units comprising the leading shoots of container seedlings at Gopher Creek (Fig. 3) indicates that the number of primordia in the previous year's terminal resting bud places no upper limit on first season shoot extension by planted stock even if there is an upper limit to stem unit length.

Compared with their growth during the first season, shoot growth by the container-grown seedlings was severely checked in the second season. In this they conformed to what appears to be a common pattern in both bareroot and container-grown stock (Armit 1970, Vyse 1981). Height growth of the fertilized trees was reduced by well over half (Figs. 1 and 2); this being due primarily to a sharp reduction in stem unit number (Fig. 3). Needle length was reduced by about half (Fig. 5) and, according to measurements made at McHale River, there were large reductions in stem diameter increment and percent stem volume growth (Figs. 6 and 7).
In the second season, as in the first, the container stock showed improved shoot growth in response to fertilization at planting. Percent height growth at the two sites was increased by an average of 94%; this being due primarily to an increase in stem unit number (Fig. 3). Measurements made only at McHale River indicate that fertilization increased ground-line diameter growth and percent stem volume growth by 50% and 66%, respectively.

These large fertilizer responses indicate that in the second season, as in the first, mineral nutrient supply was the main factor limiting shoot growth by the container stock. The reduction in shoot growth from the first season to the second thus suggests a corresponding intensification of mineral nutrient deficiency. This could have occurred through the dilution, with growth, of mineral nutrients accumulated in the nursery. That such dilution did occur is indicated by the foliar chlorosis which developed at the end of the first season. It seems likely therefore that the second season reduction in shoot growth evident in the fertilized trees (Figs. 1-6) could have been prevented by applying more fertilizer or by extending the period of fertilizer release.

Shoot growth by the bareroot trees was also less in the second year than the first. At both sites height growth declined substantially, although not as much as in the container-grown trees (Figs. 1 and 2). At McHale River, ground-line diameter increment fell sharply and percent stem volume growth was reduced by more than two thirds (Figs. 6 and 7). A sharp reduction from the first season to the second in the number of stem units comprising the leading shoot (Fig. 3) more than offset the effect on height growth of a concomitant tripling in stem unit length (Fig. 4). Needles formed in the second season
were longer than those formed in the first; although they were still much shorter than needles formed in the nursery (Fig. 5).

A further difference between the first and second season performance of the bareroot trees was that, in the second season, shoot growth was increased greatly by fertilization at the time of planting. Percent height growth at the two sites was increased by an average of 60%. At McHale River the increase in height appears to have been due primarily to an increase in stem unit number (Fig. 3) rather than length (Fig. 4). At Gopher Creek, however, there was an increase in both the length (Fig. 4) and number (Fig. 3) of stem units comprising the leading shoot. Measurements at McHale River showed that fertilization increased percent ground-line diameter increment and percent stem volume growth by 13% and 73%, respectively.

The response to fertilization indicates that by the second season, shoot growth by the bareroot trees was not severely limited by moisture stress. The pattern of growth displayed by the bareroot trees is thus consistent with the hypothesis that, as root establishment proceeds, growth tends to be limited first by water supply, later by the supply of mineral nutrients. This implies that planting check can be prevented, or at least reduced in severity and duration, by using stock with a high root growth capacity and other phenotypic adaptions to drought (Burdett 1983) and by applying slow release fertilizer at the time of planting.

The magnitude of the improvement in early growth possible through adoption of this prescription is suggested by the stem volume data for the white spruce at McHale River (Figs. 7 and 8). During the 3 years of observation, percent stem volume growth of the container stock was 33% greater than that of the
bareroot trees which, at the time of planting had a much lower root growth capacity. Percent stem volume growth by the fertilized container stock was 88% greater than that of the unfertilized container stock and 150% greater than that of the unfertilized bareroot trees. In the face of significant competition such effects could make the difference between plantation success or failure.

Whether fertilization at planting would be beneficial on all sites remains to be seen. Current trials in British Columbia have demonstrated, however, a consistent response over a range of sites in stock with a high root growth capacity.

It also remains to be seen which elements must be applied, and in what combination, to achieve the maximum response to fertilization at planting. Depending on the relative availability of mineral nutrients in the soil, the absorbing capacity of a newly planted tree's root will be less deficient with respect to some elements than to others. It is uncertain, therefore, whether the responses to N, P, K fertilization reported here were due to all three of the elements applied or only one or two of them.

Observations in the third growing season, made only at McHale River, indicated that by then shoot growth had begun to accelerate. Both stock types showed substantial increases over the previous season in height and diameter increments (Figs. 2 and 6). The increase in height growth was due almost entirely to an increase in stem unit number (Fig. 3).

Fertilization at planting caused large increases in third year height, stem diameter and stem volume growth (Figs. 2, 6 and 8); but these were probably due to the compounding of gains made in the first two years since
percent stem volume growth was little affected by fertilization (Fig. 7). Similarly, the effect of fertilization on third year stem unit number (Fig. 3) and number of needle primordia in the terminal resting bud (Table 1) was probably only a reflection of the greater size attained by the fertilized trees at the end of the second season. The fertilized container stock at McHale River, for example, had about twice the stem volume of unfertilized trees at the end of the second season (Fig. 8) and produced leaders in the following season with almost twice as many stem units (Fig. 3).

Examination of the height and stem diameter data gathered at McHale River reveals a large change over 3 years in the ratio of these measurements in the case of the container-grown, but not the bareroot, stock (Fig. 9). At planting the height:diameter ratio of the container stock was 73. By the end of the third season it had fallen to 43. This is very close to the height:diameter ratio maintained by the bareroot plants throughout the period of observation.

The sharp reduction in height:diameter ratio of the container stock indicates that height measurements alone can be a poor index of biomass accumulation in newly planted trees. It indicates also that, to obtain rapid early height growth, planting stock with a low height:diameter ratio should be used since, otherwise, dry matter will be diverted largely to growth in stem diameter rather than height.

The progress of root development was investigated by excavating several root systems at the end of the second growing season. Lateral roots averaged over a metre in length; the longest being 1.78 m. Vertically, roots were followed to a depth of more than 50 cm. Since shoot growth did not accelerate
until the third growing season it appears that a root system several metres in
diameter was required before the trees achieved a satisfactory balance between
root spread and shoot mass. There were no obvious differences in root length
between the container-grown and bareroot trees, but the container-grown plants
appeared to have many more roots.
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Table 1. Needle primordia in terminal bud of trees harvested in late October 1982

<table>
<thead>
<tr>
<th>Stock type</th>
<th>Planting site</th>
<th>Date of planting</th>
<th>Fertilizer treatment</th>
<th>Number of primordia</th>
</tr>
</thead>
</table>
| 2+0 bareroot | McHale River    | Spring, 1980     | -                    | 156±19 
| 2+0 bareroot | McHale River    | Spring, 1980     | +                    | 180±20  
| 615 plug    | McHale River    | Spring, 1980     | -                    | 196±23  
| 615 plug    | McHale River    | Spring, 1980     | +                    | 287±26  
| 2+1 bareroot | Gopher Creek    | Spring, 1981     | -                    | 86±8    
| 2+1 bareroot | Gopher Creek    | Spring, 1981     | +                    | 104±16  
| 615 plug    | Gopher Creek    | Spring, 1981     | -                    | 101±7   
| 615 plug    | Gopher Creek    | Spring, 1981     | +                    | 194±14  

1 mean and standard error
Figure 1. Container-grown (above) and bare-root Engelmann spruce at Gopher Creek photographed 2 growing seasons after planting. Seedlings at left were fertilized at the time of planting with 30g 18,6,12 (N,P,K) slow release fertilizer. Second season needles of the container-grown plants are shorter than those formed in the first season, whereas in the bare-root trees the opposite is the case. Second season leader length of the fertilized trees is several times that of the unfertilized, but is not outstanding compared with that of the smaller, naturally-established seedlings shown adjacent to the unfertilized plug (upper right).
Figure 2. Annual height increments calculated from field observations. Standard errors are indicated by bar lengths.
Figure 3. Number of stem units comprising the annual leading shoot of harvested trees (i.e., number of needles on leading shoot). Standard errors indicated by bar lengths.
Figure 4. Stem unit length from observations on harvested trees. Standard errors are indicated by bar lengths.
Figure 5. Length of needles formed in the nursery and after planting. Data obtained by measurement of 10 needles from the middle of each year's growth from harvested trees. Standard errors are indicated by bar lengths.
Figure 6. Annual ground-line caliper increments at McHale River. Calculated from field observations. Standard errors indicated by bar lengths. First season increments are the difference between end of season diameters and the mean diameter of a sample of the planting stock used.
Figure 7. Percent stem volume growth at McHale River calculated from annual field observations of height and ground-line caliper. Standard errors are indicated by bar lengths.
Figure 8. Stem volume growth at McHale River. Data calculated from field observation of height and ground-line caliper. Standard errors are indicated by bar lengths.
Figure 9. Time course of changes in the ratio of height to ground-line calipers in bareroot and container-grown white spruce planted at McHale River. Data were calculated from treatment mean heights and calipers. The ratio differed little between fertilized and unfertilized stock which were, therefore, treated together.