# ROOT REGENERATION OF CONIFERS

# A KEY TO SUCCESSFUL SURVIVAL AND GROWTH

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## INTRODUCTION

The successful establishment of plantations depends on the capacity of the transplanted seedlings for the rapid regeneration and re-extension of roots. The capacity to regenerate roots or 'Root Regeneration Potential' (RRP) of nursery stock is believed to depend on the following items:

(1) The inherent pattern of root phenology of each species (and perhaps type) of nursery stock.

(2) The environmental conditions on the nursery before lifting and transplanting.

(3) The physiological condition of the nursery stock at time of planting as it relates to (1) and (2) above and to the conditions the stock encounter's during lifting, packing, storing and shipping.

(4) The effectiveness of the planting job and the environmental conditions encountered after planting.

The moisture adsorption capacity of the roots of newly transplanted seedlings is generally low because it depends upon damaged, suberized roots that lack either root hairs or mychorrizal contact with the moisture films associated with the soil particles. If roots are not regenerated and extended into the soil soon after planting, inefficient soil moisture adsorption combined with transpiration stress leads to levels of 'Plant Moisture Stress' (PMS) that inhibit or stop both root regeneration and extension, and shoot elongation (Cleary 1968, Stone and Jenkinson 1970, Day and MacGillivray 1975, Day and Butler 1976). Thus, unless seedlings have a high RRP at time of planting, they wither, go into 'check', and may eventually die even when soil moisture is 'adequate' and transpiration is 'normal' for rooted seedlings.

Poor plantation survival is usually attributed to 'poor nursery

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stock' (poor in size, dry wt. and top/root ratio) or to soil or atmospheric drought, rather than to the physiological condition of the stock in terms of its RRP at time of planting. In California, the physiological condition of ponderosa pine (Pinus ponderosa Laws.) and douglas fir (Pseudotsuga menziesii (Mirb.) Franco) stock in terms of RRP was shown to be more important than either the size of nursery stock or the field environment in successful plantation establishment (Stone and Schubert 1959a and b, Stone et al. 1962, Stone and Bensler 1962, Stone et al. 1963, and Schubert and Adams 1971).

The RRP of nursery stock is the most important indicator of the physiological condition of the stock because of its role in post-planting seedling establishment. RRP patterns vary between species and differ with seed origin (Stone and Schubert 1959, Stone et al. 1963, Stupendick 1973, and Day, Stupendick and Butler 1976.) It also varies with the climatic and edaphic environment of the nursery (Stone et al. 1963. Krugman and Stone 1966, Herman et al. 1973, Day, Stupendick and Butler 1976, and Fraser 1976) and with the environment after planting (Stone and Jenkinson 1970, Day and MacGillivray 1975, and Day and Butler 1976). Seasonal variation in photoperiod, in diurnal air temperature (Bowen 1970 and Fraser 1976), and in soil moisture supply (Stone and Jenkinson 1970, Day and MacGillivray 1975, and Day and Butler 1976) all have an effect on the RRP of nursery stock.

In spite of inadequate documentation, root periodicity and associated RRP appear to be as much a function of seedling root phenology as bud break, foliation, lammas growth and dormancy are in the phenology of the crown.

Documentation of the RRP patterns of each of the principal species and types of nursery stock is vital for scheduling lifting for successful outplanting or cold storage. Knowledge of the environmental factors that affect RRP patterns are urgently needed. Possibly by alteration of current irrigation, soil management, storage and other practices, RRP peaks may be adjusted so that only stock with a high RRP is shipped.

The objective of this paper is to present information on the RRP of 2+0 (rising to 3+0) black spruce (Picea mariana (Mill.) B.S.P.) as an example of the work on RRP that has been in progress in Ontario over the last decade.

## METHODS

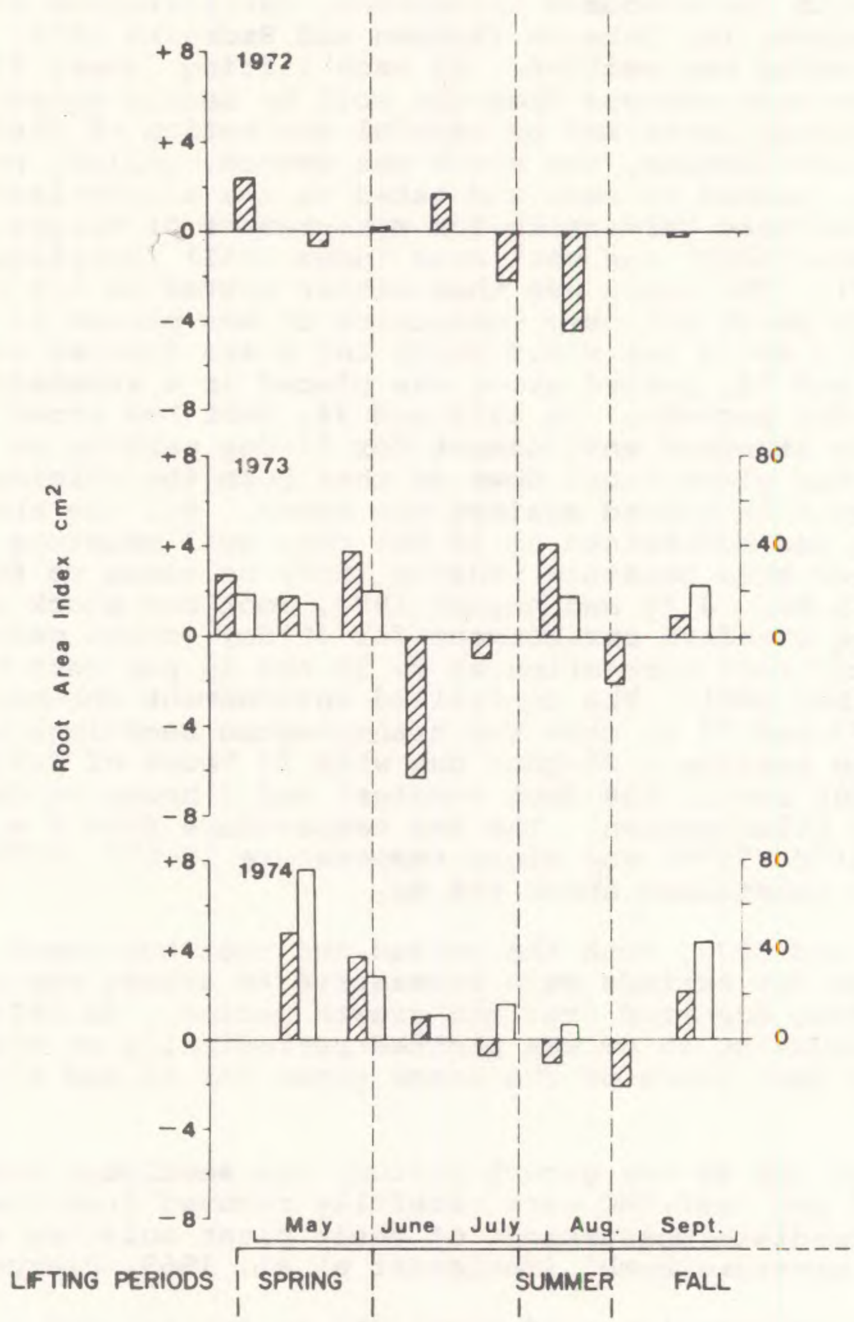
In 1972, 73 and 74, 2+0 (rising to 3+0) black spruce seedlings of Site Region 3W origin (Hills 1952) were lifted from randomly selected plots in the nursery beds on the Thunder Bay Forest Station. In each year, 250 to 500 seedlings were lifted soon after the soil thawed, and at approximately three-week intervals thereafter. The nursery beds selected for sampling were treated in accordance with the standard irrigation, fertilization and weed control practices for Ontario (Armson and Sadreika 1974) except that root pruning was omitted. At each lifting (every 21 days) the seedlings were removed from the soil by deeply undercutting the rooted plough layer and by careful extraction of their root systems. After lifting, the stock was washed, culled, pruned to 23 cm (9 in), packed in moss and taken to the silvicultural laboratory at Lakehead University for measurement of height, root collar diameter (RCD) and root area index (RAI) (Morrison and Armson, 1968). The stock was then either potted in 7.5 cm (3 in) diameter x 23 cm (9 in) deep containers or was placed in 30.5 cm (12 in) x 15.3 cm (6 in) x 2.5 cm (1 in) glass fronted root boxes. In 1972, 73 and 74, potted stock was placed in a standard environment for 21-day periods. In 1973 and 74, root box stock was placed in the standard environment for 21-day periods at an angle of 45° with the glass front down so that both the original and new roots could be traced against the glass. All the above mentioned stock was maintained at 15 per cent soil moisture content (SMC) (0.1 bar soil moisture tension (SMT) or close to field capacity. In May, July and August 1974, root box stock was also placed in the standard environment for 40-day growth periods in order to study root elongation at 8, 10 and 15 per cent SMC (1.5, 0.6 and 0.1 bar SMT). The controlled environment chambers used in 1972, 1973 and 74 to grow the transplanted seedlings were programmed to provide a 20-hour day with 16 hours of full illumination at 54,000 Lux (5,000 foot candles) and 2 hours of dawn and dusk at half illumination. The day temperature from 6 a.m. to 6 p.m. was 24°C (75°F) and night temperature 15.0°C (60°F). Humidity was maintained above 60% RH.

In 1972, 73 and 1974, both the potted and root box stock grown for 21 and 40-day periods were remeasured to assess the change RAI in $cm^2$ that occurred over the growth period. In 1973 and 74, the root elongation in cm was plotted periodically on the glass front of the root boxes of the stock grown for 21 and 40-day periods.

At the end of the 40-day growth period, the seedlings grown at 8, 10 and 15 per cent SMC were carefully removed from the root boxes for immediate measurement of their plant moisture stress (PMS) in a 'pressure bomb' (Sholander et al. 1965, Pierpont 1967).

Analysis of the covariance of final RAI on initial RAI in cm2 was used to determine the significance of differences in RAI. Analysis of variance of root elongation in cm and PMS in bars

FIGURE 1: THE ROOT PERIODICITY OF BLACK SPRUCE IN 1972, 1973 AND 1974. INCREMENT OR DECREMENT IN ROOT AREA INDEX IN cm² (HATCHED BARS) AND ROOT ELONGATION IN cm (OPEN BARS).



was used to determine the significance of differences in root elongation and plant moisture stress.

## RESULTS

The root regeneration potentials (RRP's) of black spruce seedlings lifted from the nursery at three-week intervals in 1972, 73 and 74 are given in Figure 1. The mean increment or decrement of the root system in $cm^2$ of root area index (RAI) 21 days after transplanting is given for each of the above years. The mean elongation of the root system in cm 21 days after transplanting was not measured in 1972 and so can only be given for 1973 and 74. The data in Figure 1 show that any increase in RAI is always accompanied by root elongation. They also show that a decrement in RAI of up to 1 $cm^2$ may occur even when the roots elongate up to 15 cm, and that a decrement in RAI of from 1 to 6 $cm^2$ always occurs when the roots fail to elongate after transplanting. These facts indicate that the original roots of black spruce deteriorate after transplanting and decline in RAI up to 6 $cm^2$ unless new roots are elongated. Thus RAI 21 days after transplanting is a function of the decrease in area of the old root system and increase in area of the newly regenerated roots.

A comparison of RRP in 1972, 73 and 74 in Figure 1 shows that there was considerable variation in RRP from year to year in the spring, summer and fall lifting periods. Such variation in RRP is probably related to seasonal variation in environmental conditions on the Thunder Bay Forest Station which will be discussed later. Analyses of covariance of final on initial RAI and analyses of variance of root elongation in each year showed that significant differences in RRP were common. Although space does not permit a detailed discussion of the significance of differences, differences in positive or negative RAI of 2 $cm^2$ and differences in elongation exceeding 4 cm were usually significant.

The RRP's of black spruce seedlings lifted from the nursery on May 16, July 4 and August 12, 1974 are given in Figures 2 and 3. Figure 3 shows the mean increment or decrement the root system in cm2 of RAI 40 days after transplanting into soil maintained at 8, 10 and 15% SMC (1.5, 0.6 and 0.1 bar SMT). Figure 3 shows the mean periodic and cumulative root elongation in cm over the 40-day post-transplanting period. The data in Figure 2 show that the RRP expressed in $cm^2$ of RAI were generally higher in May than in July and higher in July than in August 1974 (cf Figure 1). These data also show that RRP in $cm^2$ of RAI was always highest at 15% SMC (0.1 bar SMT) was intermediate at 10% SMC (0.8 bar SMT) and lowest at 8% SMC (1.5 bar SMT). The data in Figures 2 and 3 show that RRP expressed in cms of root elongation over the 40-day post-transplanting period were of a similar nature to the RAI data given in Figure 1. In May root elongation had started by the 8th day after transplanting and elongation at 15% SMC was faster than at either 10 or 8% SMC. In July root elongation did not start before the 16th day after transplanting at 15 and 10% SMC and was delayed until the 24th day at 8% SMC. After these delays the rates of root elongation were highest at 15, intermediate at 10 and lowest at 8% SMC. In August root elongation was minimal until the 24th day after transplanting at 15 and 10% SMC and was delayed until the 32nd day at 8% SMC. After these delays root elongation was again highest at 15, intermediate at 10 and lowest at 8% SMC. Analysis of covariance of final on initial RAI and analysis of variance of root elongation at 40 days showed that the differences in RRP between May and July were non-significant but that the differences between May or July and August were highly significant. They also showed that the differences between 15, 10 and 8% SMC were all highly significant.

A comparison of the plant moisture stress (PMS) values of the tops and roots of the black spruce seedlings grown at each SMC level are given in Figure 4. PMS at 40 days was found to be the exact opposite of RRP, thus when RRP was highest (as in May at 15 per cent SMC) PMS was lowest, and when RRP was lowest (eg. in August at 8% SMC) PMS was highest. The significance of the differences between PMS values were similar to those for RRP, even though when RRP was high PMS was low and vice versa.

## DISCUSSION

### Seasonal Root Regeneration Potential

Black spruce nursery stock varied greatly in its ability to regenerate roots both during each growing season and from year to year in 1972, 73 and 74 (Figure 1). Variation in root regeneration potential (RRP) expressed in terms of increase or decrease in the size of newly transplanted root system in $cm^2$ of root area index (RAI) was great over a 21-day post-transplanting period. The maximum change in RAI over this 21-day period was from an increment of 30 per cent, as in late June 1973 and late May 1974, to a decrement of 30 per cent as in late June 1973 (Figure 1). Variation in RRP expressed in cm of root elongation was also great over the 21-day post-transplanting period. Root elongation varied from 0 in June and mid-August 1973 to 80 cm in May 1974 (Figure 1).

The RRP patterns of black spruce in 1972, 73 and 74 will be discussed in relation to the three 'conventional' lifting and shipping periods on the Thunder Bay Forest Station: (1) 'Spring lifting', April 25 to June 5, (2) 'Summer lifting', July 20 to

August 21, and (3) 'Fall lifting', August 21 to freeze up (Figure 1).

Spring Lifting Period (April 25 to June 5)

Figure 1 shows that black spruce had high RRP's after the first lift in 1972, 73 and 74. It also shows that RRP was low in 1972 and high in 1973 and 74 during the remainder of the spring lifting period. Daily soil moisture balances computed for the nursery soil by the Thornthwaite method (Thornthwaite and Mather 1957) showed that there was the potential for severe deficits in available soil moisture from mid-May to late June and from mid-August to mid-September 1972. As irrigation on the Thunder Bay Forest Station is usually not started until after spring lifting, it is probable that drought in May 1972 was responsible for the reduction in RRP observed after the second (late May) lift. It is also possible that a severe drought in the seedbeds in late July and August 1972 was responsible for the increasingly negative RAI's. Daily soil moisture balances computed for 1973 and 74 showed that even though the beds were not irrigated before spring lifting, available soil moisture was in excellent supply in both years. In addition, both in 1973 and 74 available soil moisture was satisfactory because of abundant rainfall in 1973 and improved irrigation practices in 1974. The monthly precipitation potential evapotranspiration water balance diagrams given in Figure 5 summarize the climatic and soil moisture differences on the nursery in 1972, 73 and 74. A comparison of the spring lifting periods in Figure 5 clearly shows the drought responsible for the poor RRP in the late spring of 1972.

Summer Lifting Period

Figure 1 shows that the RRP of black spruce was erratic in the interval between the end of the spring and the beginning of the summer lifting periods. RRP values during this interval are of little consequence for it is impractical to lift nursery stock with fleshy roots and soft shoots. The large negative RAI that followed the mid-June lift in 1973 is an example of the hazardous nature of lifting stock just after a period of very active root and top growth.

Figure 1 also shows that the RRP of black spruce is equally erratic during the summer lifting period. In the summer lifting period in 1972 there was a severely negative RAI which corresponded closely with the drought that began in mid-August that year (Figure 5). In 1973 and 1974 satisfactory levels of available soil moisture related to abundant rainfall in 1973 and greatly improved irrigation in 1974 appear to have improved RRP during

FIGURE 2. The effect of lifting date and total soil moisture content on the mean increment or decrement of black spruce roots in $cm^2$ of root area index (RAI).

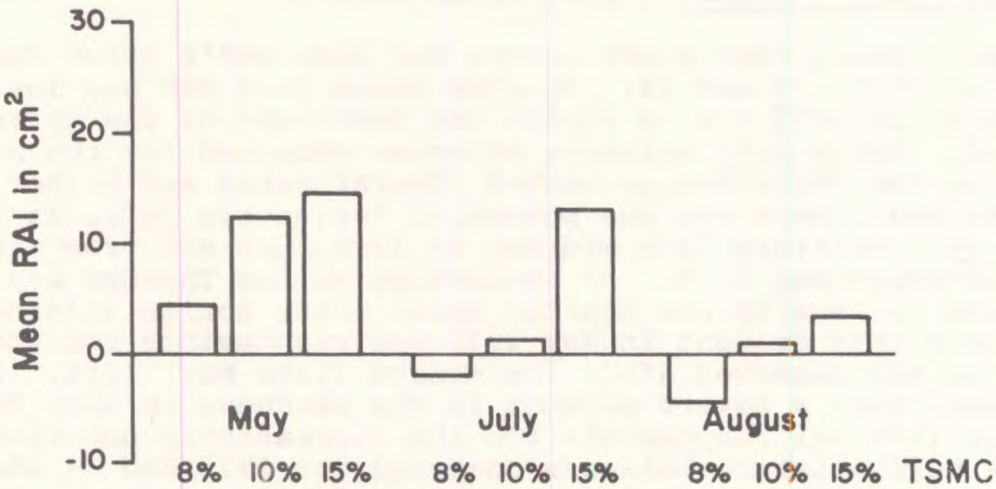



FIGURE 4. The effect of lifting date and total soil moisture content on the mean plant moisture stress of tops and roots (PMS) in bars.

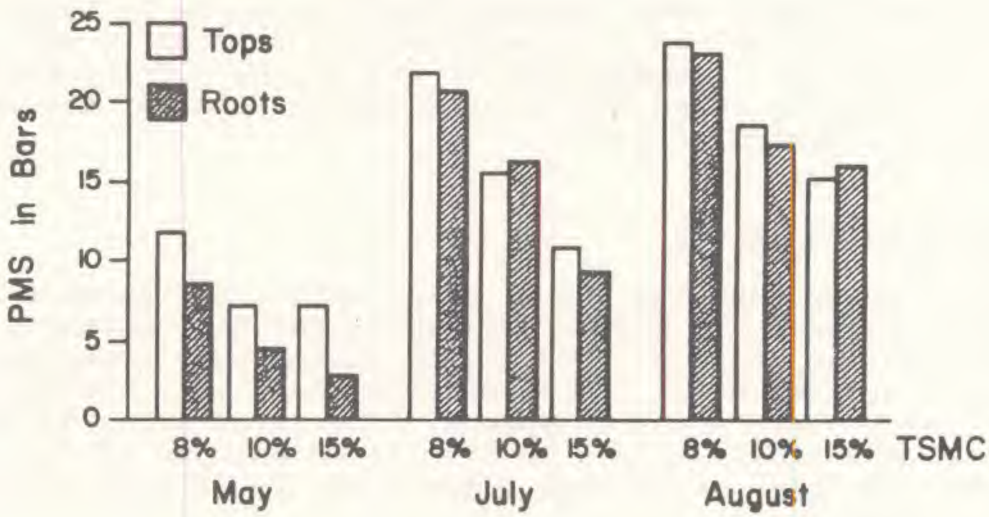
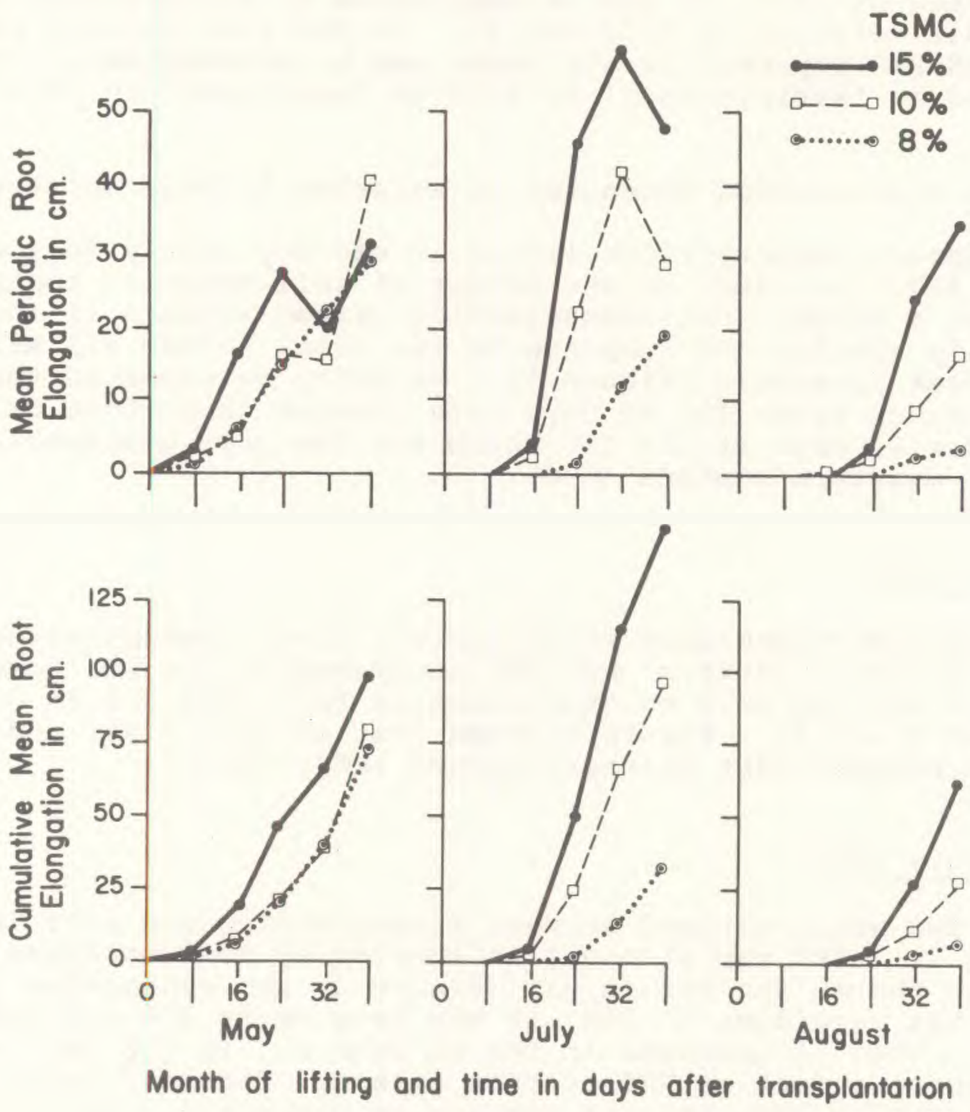


FIGURE 3. The effect of lifting date and total soil moisture content on the mean periodic and cumulative mean elongation of black spruce roots in cm2.



the summer lifting period.

Fall Lifting Period (August 21 to end of season)

Figure 1 shows that the RRP of black spruce was severely negative in mid-August 1972, 73 and 74 regardless of satisfactory available soil moisture in 1973 and 74. As the fall lifting period advanced RRP improved in all years and by mid-September it could be rated as 'satisfactory' in 1972 or 'excellent' in 1973 or 74.

## Root Regeneration Potential in Relation to Soil Moisture Supply

Black spruce nursery stock lifted in mid-May, early July and mid-August 1974 for study of the effect of soil moisture content on RRP over a 40-day post-transplanting period (Figure 2) showed a generally similar RRP response to the stock lifted all season at three-week intervals (Figure 1). As might be expected the RAI's of the stock grown for 40 days were greater than those of the stock grown for 21 days at 15% SMC which was the only comparable level of soil moisture content (SMC).

Mid-May 1974

Black spruce regenerated roots shortly after transplanting at all levels of SMC (Figure 3) but RRP increased as the SMC rose from 8 to 15% and the soil moisture tension fell from 1.5 to 0.1 bar (Figures 2 and 4). Figure 4 shows that as RRP in RAI and elongation increased plant moisture stress (PMS) fell.

Early July 1974

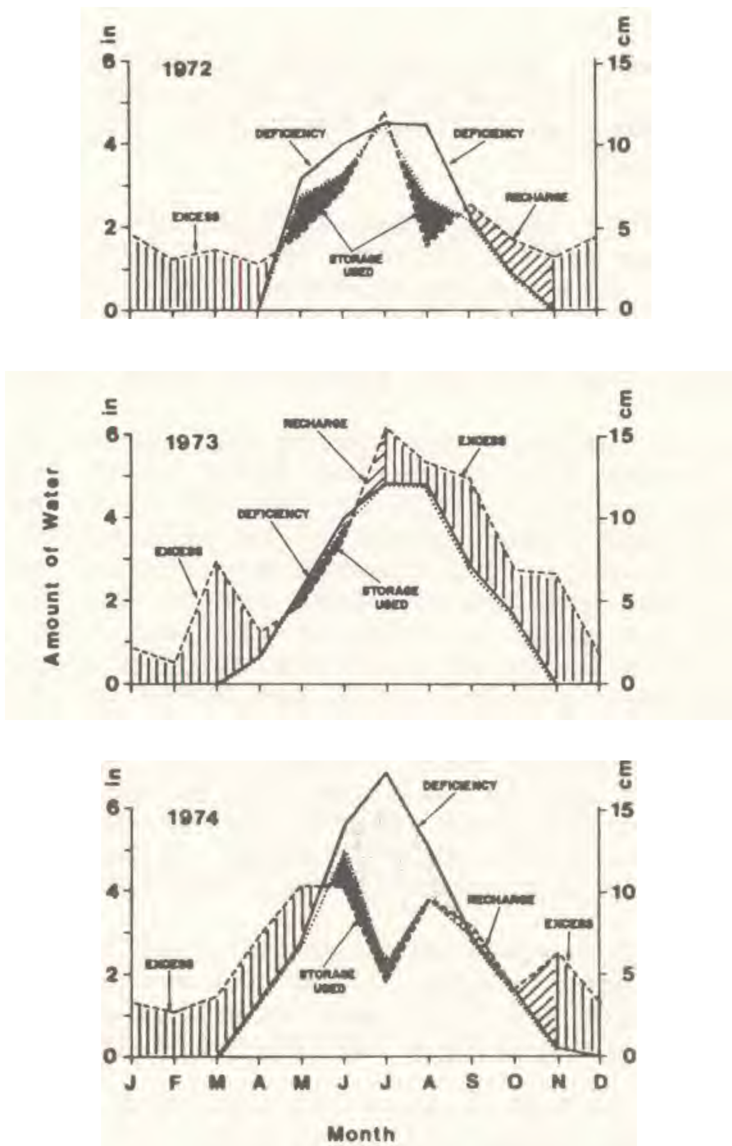
Almost two weeks elapsed between transplanting and root initiation (Figure 3). RRP was strongly influenced by soil moisture supply and even though the RRP in RAI (Figure 2) and elongation (Figure 3) was excellent at 15%, it was less so at 10% and poor at 8% SMC. Thus an increase in SMT of from 0.1 to 1.5 bar had a very severe effect on RRP at this season. Figure 3 again shows that as RRP in both RAI and elongation increased, PMS fell. In early July, PMS was generally higher at all levels of SMC than in mid-May.

Mid-August 1974

At this season three weeks elapsed between transplanting and root

FIGURE 5: DIAGRAMS OF MONTHLY PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION IN RELATION TO THE WATER BALANCE IN THE PLOUGH LAYER OF THE NURSERY SOIL (STORAGE 4.0 cm).

POTENTIAL EVAPOTRANSPIRATION
ACTUAL EVAPOTRANSPIRATION



initiation (Figure 3). RRP was again strongly influenced by soil moisture supply but was generally poorer both in RAI (Figure 2) and in elongation (Figure 3) than in early July. Again an increase in SMT of from 0.1 to 1.5 bar had a severe effect in reducing RRP. Figure 4 shows that as RRP in both RAI and elongation increased, PMS again fell. However, PMS in August was generally higher at all levels of SMC than in July.

## CONCLUSION

The results clearly show that black spruce nursery stock of good appearance and of shippable grade may or may not be able to regenerate and elongate sufficient roots for satisfactory establishment after out-planting.

Black spruce stock usually has a high root regeneration potential (RRP) during the spring lifting period (April 25 to June 5), but if soil drought is allowed to occur on the nursery before spring lifting, as in 1972, FRP may be severely impaired. Unpublished work on black spruce stock in the spring of 1975 (Kenney 1976) also confirmed that drought before lifting impairs RRP.

In the interval between the spring and summer lifting periods and during the summer lifting period (July 21 to August 21) RRP is erratic. The erratic nature of the RRP patterns of black spruce during the summer again appear to be related to the effects of variation in climatic and edaphic environment on the nursery on the inherent RRP pattern of black spruce and on the physiological condition of the stock at time of lifting. For example, in the summer of 1972 a burst of root activity in a moist late June followed the poor drought inhibited RRP's of mid-May and early June. In the summer of 1973, RRP was severely negative in mid-June because seedlings were transplanted just after a long period of prolific root growth in a cool moist spring. In the summer of 1974 the RRP pattern more closely approximates the 'expected' pattern owing to growth in a 'normal° climate and in soil that was maintained at a reasonable soil moisture content by irrigation.

Black spruce had dangerously low RRP's at the beginning of the fall lifting season (August 21 to the end of the season), but by mid-September with improved soil moisture supply and seasonal chilling, RRP improved to a satisfactory level.

The results also clearly show that the RRP of transplanted or outplanted black spruce will vary both with season and the soil moisture content of the transplant bed or planting site. In mid-May 1974, RRP was high and elongation was immediate. A reduction in soil moisture content (SMC) of from 15 to 8% SMC (0.1 to 1.5

bar SMT) only reduced root elongation. By early June, RRP was considerably lower and root elongation was delayed two to three weeks. As before, a reduction in SMC reduced root elongation. By mid-August, RRP was very low and elongation was poor after a delay of three weeks or more.

The following recommendations can be made:

1. Black spruce nursery stock should only be lifted in the spring lifting period. The soil moisture content of seedbeds to be spring lifted should always be regularly checked between thawing and lifting and irrigation must be used to ensure that the SMC stays cLose to field capacity (12 to 15 per cent).

2. Black spruce should not be lifted between the spring and summer lifting periods until further research shows how dependable high RRP's can be induced at this season. Present results show that summer lifting may be attempted if the soil is well irrigated throughout the season. It is probably hazardous.

3. The fall lifting period for black spruce must be delayed until mid-September until further research shows how dependable high RRP's can be induced in late August and early September.

4. Black spruce may be transplanted or outplanted into soils up to 1.5 bar soil moisture tension when RRP is high in May. However, outplanting at other times will be hazardous unless the soil is very moist and is at field capacity (0.1 bar soil moisture tension).

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LITERATURE CITED

Armson, K.A. and V. Sadreika. 1974. Forest tree nursery management and related practices. Ont. Min. Nat. Res., Div. For., For. Manage. Br., Toronto, Ont. 177 p.

Bowen, G.D. 1970. Effect of soil temperatures on root growth and on phosphate uptake along Pinus radiata roots. Aust. J. Soil. Res. 8: 31-42.

Cleary, B.D. 1968. Water stress measurements and their application to forest management. Proc. Western Refor., San Francisco, Calif. pp. 29-33.

Day, R.J. and G.R. MacGillivray. 1975. Root regeneration of fall lifted white spruce nursery stock in relation to soil moisture content. For. Chron. 51: 196-199.

Day, R.J. and J.M. Butler. 1976. Root regeneration of spring and summer lifted black spruce and jack pine nursery stock in relation to soil moisture content. Submitted for publication.

Day, R.J., J.T. Stupendick and J.M. Butler. 1976. Root periodicity and root regeneration potential are keys to successful plantation establishment. Proc. Plantation Establishment Symp., Kirkland Lake, Ont., Sept. 21-23, 1976. 16 p.

Fraser, P.J. 1976. The effect of pre-lifting cold treatment on the root regenerating potential of overwinter stored red pine seedlings. Lakehead Univ., School of Forestry, Deg. IV Thesis. 30 p.

Hermann, R.K., P.D. Lavender and J.B. Zaerr. 1972. Lifting and storing western conifer seedlings. Oreg. State Univ., School For., Res. Pap. No. 24. 41 p.

Kenney, W.A. 1976. Feasibility of using spring lifted and freezer stored (-4 $^{0}$C) white and black spruce nursery stock to extend the planting season. Lakehead University, School of Forestry, Degree IV Thesis. 24 p.

Krugman, S.L. and E.C. Stone. 1966. The effect of cold nights on the root regeneration potential of ponderosa pine seedlings. For. Sci. 12: 451-458.

Morrison, I.K. and K.A. Armson. 1968. The Rhizometer - a new device for measuring roots of tree seedlings. For. Chron. 44: 26-29.

Schubert, G.H. and R.S. Adams. 1971. Reforestation practices for conifers in California. State Calif., Dep. Conserv., Div. For., Resour. Agency, Sacramento, Calif. 359 p., cf. pp. 76-85.

Stone, E.C. and G.H. Schubert. 1959a. Root regeneration of ponderosa pine seedlings lifted at different times of the year. For. Sci. 5: 322-332.

Stone, E.C. and G.H. Schubert. 1959b. The physiological condition of ponderosa pine (Pinus ponderosa Laws.) planting stock as it affects survival and cold storage. J. For. 57: 838-841.

Stone, E.C. and R.W. Benseler. 1962. Planting ponderosa pine in the California pine region. J. For. 60: 462-466.

Stone, E.C., J.L. Jenkinson and S.L. Krugman. 1962. Root regeneration potential of Douglas fir seedlings lifted at different times of the year. For. Sci. 8: 288-297.

Stone, E.C., G.H. Schubert, R.W. Benseler, F.J. Baron and S.K. Krugman. 1963. Variation in root regeneration potential of ponderosa pine from four California nurseries. For. Sci. 9: 217-225.

Stone, E.C. and J.L. Jenkinson. 1970. Significance of soil water on root growth capacity of ponderosa pine transplants. For. Sci. 16: 230-239.

Stupendick, J.T. 1973. Root regenerating potential of three species of coniferous nursery stock on the Thunder Bay Forest Station. Lakehead University, School of Forestry, Degree IV Thesis. 23 p..