ROOT GROWTH POTENTIAL AND BUD DORMANCY OF THREE NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE

by

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(ABSTRACT)

A two year study examined Root Growth Potential (RGP) in a hydroponic system and Dormancy Release Index (DRI) in one-year-old (1-0) and two-year-old (2-0) eastern white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), and Scotch pine (*Pinus sylvestris* L.) seedlings with emphasis on eastern white pine. During 1985-86 all three species of 2-0 stock displayed a similar pattern of RGP with high levels of RGP limited to mid-March. Only 2-0 eastern white pine had a statistically significant relationship between RGP and DRI; however, this relationship was not consistent in 1986-87. The RGP/DRI relationship in 2-0 eastern white pine was strong over both years within a DRI range of 0.22 to 1.00. One-year-old and 2-0 eastern white pine stock had very different patterns of RGP over both years with 1-0 stock maintaining much wider "lifting windows" for high RGP. Cold storage (2C) of 2-0 eastern white pine resulted in variable effects on RGP although it typically progressed dormancy release.

There were no strong RGP trends between northern and

southern provenances of 1-0 eastern white pine and heritability values indicate that RGP is under minimal genetic control in 1-0 eastern white pine seedlings. Northern and southern provenances did display clear differences in seedling morphology and seasonal patterns of shoot activity.

Results of a field outplanting study show that RGP does show promise as a measure of 2-0 eastern white pine seedling quality. The predictive abilility of RGP was increased on non-irrigated versus irrigated seedlings. A comparison of greenhouse versus growthroom RGP testing demonstrated the validity of using greenhouse RGP testing of 2-0 eastern white pine.

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have been a continueing source of personal motivation.

DEDICATION

To Lisa and our future child,

for giving me inspiration.

TABLE OF CONTENTS

Appendix

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTODUCTION AND OBJECTIVES

Initial survival of forest tree seedlings after planting is largely dependent on physiological readiness to produce new roots and thereby re-establish contact with the soil (Smith 1962). Root Growth Potential (RGP), a measure of the ability of a bareroot seedling to produce new roots, has been shown to be a good indicator of survival probability after planting (Feret et al. 1984).

Examination in other species has revealed strong seasonal patterns of high and low RGP (Ritchie and Dunlap 1980). An understanding of these patterns can be applied to create lifting and planting schedules most conducive to successful outplanting (Ritchie and Dunlap 1980, Jenkinson 1975). Since RGP has not been studied in eastern white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), and Scotch pine (*Pinus sylvestris* L.), three important commercial conifers, an examination of the seasonal pattern of RGP is a critical first step in understanding RGP in these species.

RGP has been shown to be very responsive to nursery management practices. The most critical factors that can be manipulated are date of lifting and duration of cold storage (Feret and Kreh 1984 , Ritchie 1985). The control of these can greatly influence RGP at time of planting. Nursery management logistics demand that most seedlings spend some time in cold storage prior to planting. Due to potentially large changes in RGP during storage and the correlation of RGP to subsequent field performance (Ritchie and Dunlap 1980, Feret and Kreh 1985), an efficient nursery regime will match species (and even seed source) lifting dates and storage durations to maximize RGP. Such "lifting windows" have already been established at some western nurseries (Jenkinson 1975).

There is substantial evidence that RGP is closely linked to bud dormancy. Root Growth Potential has been shown to peak as the chilling requirement for dormancy release is fulfilled, and then to decline, perhaps due to an internal competition for photosynthate between roots and shoots (Ritchie and Dunlap 1980). Chilling requirements for forest tree species generally range from 260 to 2000 hours of temperatures below 5C (Nelson and Lavender 1979). Berry (1965) found that two year old eastern white pine seedlings needed eight weeks exposure at 4C to completely break dormancy. His study was performed in a controlled environment where constant temperature was maintained. An incorporation of chilling sum negation by intermittent warm temperatures is critical and makes the model more complex (Richardson et al. 1974, Erez et al. 1979).

A thorough understanding of the relationship between dormancy status, chilling hours, and RGP would, therefore, be very useful. Working knowledge of these relationships may make nursery management of RGP a matter of keeping track of chilling hours.

Date of lifting establishes the dormancy status of the seedling as it enters storage. Cold storage duration further influences the dormancy status at time of planting (Ritchie and Dunlap 1980). Interactions between lift-date and storage give the nurseryman a potentially useful management tool to maximize RGP and improve field performance. Interactions may even be more important for situations where northern pines are grown in southern nurseries. Natural temperature regimes may not provide the chilling hours necessary to allow acceptable RGP.

In work done with 13 geographic sources of ponderosa pine, Jenkinson (1975) found four distinct seasonal patterns of RGP. Dewald et al. (1985) have also concluded that RGP in loblolly pine is under relatively strong genetic control. Differences in the pattern of RGP have been shown in several other species (Ritchie and Dunlap 1980). A highly efficient nursery management system would take into account genetic origin to maximize RGP at time of planting. Once again, this could prove especially important where northern species are being grown in southern nurseries.

A relationship has been reported between root growth and field survival and performance (Feret and Kreh 1985, Sutton 1980, Rhea 1977, Jenkinson 1978, Ritchie 1985).

Sutton (1980) indicated that the relationship between RGP and field performance might be strengthened if seedlings are outplanted on a stressful site. If this relationship can be determined then perhaps minimum acceptable RGP limits can be set for different planting sites, different moisture conditions and/or different planting dates.

Root Growth Potential testing is typically conducted in greenhouses (Dewald et al. 1984, Jenkinson 1975, Carlson 1985, Krugman and Stone 1966). Although RGP tests performed in a greenhouse are far less expensive, they do not permit the experimental control of tests performed in an environmentally controlled growthroom. In studies involving seasonal variation, the greenhouse environment will vary in regard to light quantity, light quality, and temperature extremes. Such variation in the testing environment is tolerable only if it is established that it does not significantly influence RGP. A comparison of seasonal patterns of RGP from seedlings simultaneously tested in a greenhouse and a growthroom would establish the adequacy of greenhouse RGP testing.

With the above considerations in mind, the specific objectives of this study were to:

1. determine the seasonal pattern of RGP in one-year-old and two-year-old eastern white pine, two-year-old red pine, and two-year-old Scotch pine seedlings and its relationship to the bud dormancy cycle and the chilling sum requirement (chapter 3);

2. determine the affect of variable lifting dates and cold storage duration on RGP and bud dormancy status for two-year-old eastern white pine seedlings (chapter 3);

3. determine the influence of genetic control on RGP and shoot activity for half-sib families of one-year-old eastern white pine seedlings from northern and southern provenances (chapter 4);

4. determine the relationship between RGP at time of planting and first year field performance for non-irrigated (stressed) and irrigated two-year-old eastern white pine seedlings (chapter 5);

5. determine if greenhouse RGP testing provides similar results compared to environmentally controlled growthroom RGP testing of two-year-old eastern white pine seedlings (chapter 6);

CHAPTER 2

LITERATURE REVIEW

Initial survival of forest tree seedlings after planting is largely dependent on physiological readiness to produce new roots and thereby re-establish contact with the soil (Smith 1962). Root Growth Potential (RGP), a measure of the ability of a bare-root seedling to produce new roots, has been shown to be to a good indicator of survival probability after planting. Feret and Kreh (1985) found RGP to have a significantly stronger relationship to subsequent field performance of loblolly pine seedlings compared to standard morphological traits (seedling height and diameter, root/shoot ratio, etc.) used in the past. Direct relationships have been found between root growth and subsequent field performance following planting in several of the Pinaceae, including: loblolly pine (Pinus taeda L.), ponderosa pine (Pinus ponderosa Laws), and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franko.) (Feret et al. 1984, Jenkinson and Nelson 1983, Ritchie and Dunlap 1980, Brissette and Roberts 1984).

There have been several notable exceptions where RGP has not predicted or has been a poor predictor of first year survival and/or first year growth (Rhea 1977, Sutton 1983, Brissette and Roberts 1984, Dewald et al. 1985). In the latter two cases, the authors noted that first year survival was excellent and that field conditions were not very stressful. This implies that differences in root growth and general seedling physiological condition may be of varying importance under different field conditions.

RGP is apparently under relatively strong genetic control (Feret et al. 1984, Jenkinson 1975). Dewald et al. (1985) found significant differences between half-sib families in loblolly pine with heritabilities ranging 0.34 - 0.37 for two independent samples of seedlots over two years. These values indicate that selection for RGP could be successful. They also found the seedlot X lift-date interaction was also highly significant and proposed that different optimum lifting and planting dates exist for different loblolly pine families. Carlson (1985) further showed differences between half-sib families of loblolly pine and found that manipulation of lift-date and storage duration often interacted with genotype in the expression of RGP. Carlson (1986) also found that RGP rank of open pollinated families of loblolly pine can change with different soil temperatures indicating the potential importance of genetic X environmental interactions in the expression of RGP. Work done with ponderosa pine has also showed strong patterns of genetic variation of RGP. Depending on the seed source, four seasonal patterns of RGP were deliniated (Jenkinson, 1975).

Although there typically are differences between species and even between seed sources within species, a general seasonal trend in RGP seems to pervade. This includes: a late summer low, an increase in mid autumn to a mid to late winter peak, and a sharp drop coinciding with renewed shoot growth in the spring. This pattern is evidently linked to bud dormancy and internal competition for carbohydrates between roots and shoots (Ritchie and Dunlap 1980).

In species that undergo true dormancy and to a lesser extent in species that experience a quiescent period, the seasonal development of RGP coincides with the accumulation of chilling hours. RGP typically peaks just prior to fulfillment of the chilling requirement and subsequent shoot activity (Ritchie and Dunlap 1980). This response has been demonstrated in ponderosa pine. Krugman and Stone (1966) allowed ponderosa pine seedlings to experience various numbers of cold nights (6C) before testing for RGP. Root Growth Potential was less than 10 cm per seedling until the seedlings were exposed to 90 cold nights. There was then a linear increase up to nearly 100 cm per seedling at 150 cold nights. Carlson (1985) found that unstored loblolly pine seedlings also showed increased RGP as natural chilling increased. Similar relationships have been found in white fir (Abies concolor Gord.), western hemlock (Tsuga heterophylla (Raf.) Sarg.), and Douglas-fir (Ritchie and Dunlap 1980).

There have been notable exceptions which present opposing evidence to the validity of a positive dormancy release/RGP relationship. Ritchie et al. (1985) found that lodgepole pine (Pinus contorta Doug.) seedlings lifted between October 4 and November 1 had the highest seasonal RGP while being the deepest in dormancy for the time period studied. Carlson (1985) also found that although artificial chilling of autumn lifted loblolly pine seedlings decreased bud dormancy, it significantly reduced RGP as well.

The relationship of RGP to chilling sums may explain the variability of RGP peaks in regard to magnitude and timing within a nursery from year to year (Ritchie and Dunlap, 1980). The relationship is apparently not so simple, though, as it has been shown that temperatures above the natural chilling range may fully or partially negate any chilling sum accumulation. This effect has been seen in western hemlock and ponderosa pine (Ritchie and Dunlap 1980). Richardson et al. (1974) developed mathematical models relating environmental temperatures to dormancy release in peach trees. Their models give weighted chill-unit contributions to different temperature intervals depending on the dormancy release efficiency of the interval. High temperature intervals were given negative values. Further work with peach trees has shown that high temperature negation of chilling sums is dependent on the duration of chilling and the frequency of high temperature infusion. For instance, exposure to two days of warmth following four days of chilling would show little or no chilling negation while a 1/3 day exposure to warmth following a 2/3 day cold period would provide substantial chilling negation (Erez et al. 1979). There are probably large interspecific differences in the range of temperatures that will effectively result in dormancy release. Garber (1983) found that a broad temperature range (0-12C) was equally effective in satisfying the chilling requirement in loblolly pine.

Very cold temperatures may also interrupt the physiological processes associated with chilling sum accumulation and dormancy release (Ritchie and Dunlap 1980). With the above factors in mind, it is possible that nurseries in very cold regions and in regions that experience intermittent winter warm periods may produce seedlings that are not chilling satiated. Depending on the bud dormancy/RGP relationship of the species in question, seedlings may not produce satisfactory RGP.

The exact physiological mechanisms involved in the RGP/bud dormancy relationship are not clear but the following scenario, synthesized from past work, has been proposed by Ritchie and Dunlap (1980) for Douglas-fir. At the end of the summer, moisture stress and photoperiod induce the onset of bud dormancy. As dormancy deepens, growth inhibitors (probably abscisic acid) accumulate in the buds. The promoter/inhibitor ratio thus decreases and seedlings become physiologically dormant. At this point RGP reaches its low level. Accumulated chilling results in an increase in the promotor/inhibitor ratio resulting in an increase in the activity of auxins and/or gibberellins. The effect is a gradual release from dormancy. As dormancy weakens, there is an increase in the export of auxins and gibberellins from buds to needles. This stimulates the production of root promoters which are then exported to the roots causing an increase in RGP. As RGP continues to increase, it becomes under the influence of an internal carbohydrate source-sink regime. RGP peaks just prior to budbreak before shoot elongation becomes a stronger sink for carbohydrates.

RGP has been shown to vary by factors such as lift-date, cold storage duration, and planting stock desiccation (Ritchie and Dunlap 1980, Feret et al. 1985b). RGP response to lift-date may be related to bud dormancy status as discussed above. Studies with Douglas-fir have shown that cold hardiness and drought resistance also show seasonal patterns with a low in the autumn, high in the winter, and a low in the spring (Lavender and Wareing 1972). Thus, physiological status is probably also an important factor in the mid-winter RGP peak.

It must be remembered that RGP is the potential ability of a seedling to regenerate roots, and is measured under ideal growing conditions. Ritchie (1985) points out that often a seedling is planted before soil temperatures would allow its RGP to be expressed and by the time soil temperature has reached a range that is favorable to root growth, shoot growth is underway and RGP is very low. He attempts to reconcile this paradox by proposing that RGP is a good predictor of field performance because it is well correlated with other seedling quality attributes that directly impact performance, specifically cold hardiness and stress resistance. Using this rationale, RGP can be considered a general indicator of seedling vigor.

The effect of cold storage is related to both the time of lifting and the storage duration. Ritchie et al. (1985) found that cold storage increased, decreased, or maintained RGP depending on lift-date. Response to cold storage may be related to shoot physiology. In some species a minimum chilling period might be necessary before seedlings can be successfully stored and cold storage might satisfy dormancy requirements if the seedling was lifted at the proper time (Ritchie and Dunlap 1980, Garber 1983). Storage duration may also influence RGP (Ritchie and Dunlap 1980). The storage duration that can be endured while maintaining satisfactory

RGP may also depend on seedling dormancy status at time of lifting (Ritchie and Stevens 1979, Garber 1983).

Carlson (1985) studied the relationship of lift-date and storage duration on RGP and dormancy status of loblolly pine seedlings in comparison to seedlings receiving natural chilling in the field. Although cold storage of November lifted seedlings increased dormancy release, autumn stored seedlings displayed a significant decrease in RGP with the accumulation of artificial chilling. Since seedlings attaining a similar number of natural chilling hours and having a similar dormancy status showed increased RGP, he concluded that the effects of storage on decreasing RGP of loblolly pine are not mediated by dormancy status. Thus, cold storage can affect numerous seedling physiological systems which may increase, decrease, or have no effect on RGP.

RGP can also be affected by handling procedures at time of planting. Feret et al. (1985b) found a logarithmic rate of reduction in RGP of loblolly pine seedlings as root systems were exposed to varying durations of ambient conditions. RGP may also be influenced by nursery practices including nitrogen fertilization, top clipping, organic matter soil amendments, and undercutting during the growing season (Feret et al. 1984).

CHAPTER 3

ROOT GROWTH POTENTIAL AND BUD DORMANCY IN THREE NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE

Abstract

A two year study examined Root Growth Potential (RGP) and Dormancy Release Index (DRI) in 1-0 and 2-0 eastern white pine (*Pinus strobus* L.), 2-0 red pine (Pinuse resinosa Ait.), and 2-0 Scotch pine (*Pinus sylvestris* L.) seedlings grown in a Virginia nursery with emphasis on 2-0 eastern white pine. During 1985-86, 2-0 eastern white pine, 2-0 red pine, and 2-0 Scotch pine seedlings displayed similar patterns of RGP with a sharp RGP peak limited to mid-March. All three species of 2-0 stock showed a linear relationship between RGP and DRI although only 2-0 eastern white pine displayed a statistically significant relationship. Combining 2-0 eastern white pine data from the two years results in a strong linear relationship between RGP and DRI within a DRI range of 0.22 to 1.00. Outside of this range, the relationship between RGP and DRI was inconsistent between years. The 1986-87 seasonal pattern for 2-0 eastern white pine was different than the prior year with seedlings having higher autumn levels and a less pronounced spring RGP peak. The latter may have been due to large differences in spring temperatures between the two years. One-year-old and 2-0 stock of eastern white pine had very different patterns of RGP over both study years. One-year-old stock typically had higher levels of RGP and maintained wider "lifting windows" for high RGP. Cold storage (2C) of 2-0 eastern white pine seedlings resulted in an increase, decrease, or no significant effect on RGP although it typically progressed dormancy release.

Introduction

Initial survival of forest tree seedlings after planting is largely dependent on physiological readiness to produce new roots and thereby re-establish contact with the soil (Smith 1962). Root Growth Potential (RGP), a measure of the ability of a bare-root seedling to produce new roots, has been shown to be to a good indicator of survival probability after planting. Direct relationships have been found between root growth and subsequent field performance following planting in several of the Pinaceae, including: loblolly pine (Pinus taeda L.), ponderosa pine (Pinus ponderosa Laws), and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franko.) (Feret et al. 1984, Jenkinson and Nelson 1983, Ritchie and Dunlap 1980, Brissette and Roberts 1984).

Although there typically are differences between species and even between seed sources within species, a general seasonal trend in RGP seems to pervade. This includes: a late-summer low, an increase in mid-autumn to a mid to late-winter peak, and a sharp drop coinciding with renewed shoot growth in the spring. This pattern is often cited as strongly linked to bud dormancy and internal competition for carbohydrates between roots and shoots (Ritchie and Dunlap 1980).

In species that undergo true dormancy and to a lesser extent in species that experience a quiescent period, the seasonal development of RGP often coincides with the accumulation of chilling hours. RGP typically peaks just prior to fulfillment of the chilling requirement and subsequent shoot activity (Ritchie and Dunlap 1980). This relationship has been demonstrated in ponderosa pine. Krugman and Stone (1966) allowed ponderosa pine seedlings to experience various numbers of cold nights (6C) before testing for RGP. Root Growth Potential was less than 10 cm per seedling until the seedlings were exposed to 90 cold nights. There was then a linear increase in RGP up to nearly 100 cm per seedling at 150 cold nights. Carlson (1985) found that unstored loblolly pine seedlings also showed increased RGP as natural chilling increased. Similar relationships have been found in white fir (*Abies concolor*(Gord.) Engelm.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and Douglas-fir (Ritchie and Dunlap 1980).

There have been notable exceptions contradicting evidence the positive dormancy release/RGP relationship. Ritchie et al. (1985) found that lodgepole pine (*Pinus contorta* Doug.) seedlings lifted between October 4 and November 1 had the highest seasonal RGP while being the deepest in dormancy for the time period studied. Carlson (1985) also found that although artificial chilling of fall lifted loblolly pine decreased bud dormancy, it significantly reduced RGP.

The relationship of RGP to chilling sums may explain the variability in magnitude and timing of RGP peaks within a nursery from year to year (Ritchie and Dunlap, 1980). The relationship is apparently not so simple, though, as it has been shown that temperatures above the natural chilling range may fully or partially negate any chilling sum accumulation. This effect has been observed in western hemlock and ponderosa pine (Ritchie and Dunlap 1980) and peach (Richardson et al. 1974). There are probably also large interspecific differences in the range of temperatures that will effectively result in dormancy release. Garber (1983) found that a broad temperature range (0 to 12C) was effective in satisfying the chilling requirement in loblolly pine. Very cold temperatures may interrupt the physiological processes associated with chilling sum accumulation and dormancy release (Ritchie and Dunlap 1980).

With the above factors in mind, it is possible that nurseries in either very cold regions or in regions that experience intermittent winter warm periods may produce seedlings that are not chilling satiated. Depending on the bud dormancy/RGP relationship of the species in question, these nurseries may not produce seedlings with satisfactory RGP. This might prove especially important where northern species are being grown in southern nurseries.

The effect of cold storage is related to both the time of lifting and the storage duration. Ritchie et al. (1985) found that cold storage increased, decreased, or maintained RGP depending on lift date. Response to cold storage may be related to shoot physiology. In some species a minimum chilling period might be necessary before seedlings can be successfully stored.

Cold storage might satisfy dormancy requirements if the seedling is lifted at the proper time (Ritchie and Dunlap 1980, Garber 1983). Storage duration may further influence RGP (Ritchie and Dunlap 1980). The duration of storage that can be endured while maintaining satisfactory RGP may depend on dormancy status at the time of lifting (Ritchie and Stevens 1979, Garber 1983,). Carlson (1985) studied the relationship of lift-date and cold storage duration on RGP and dormancy status of loblolly pine seedlings in comparison to seedlings recieving natural chilling in the field. Although cold storage of November lifted seedlings increased dormancy release, fall stored seedlings displayed a significant decrease in RGP with the accumulation of artificial chilling. Since seedlings attaining a similar number of chilling hours in nature and having a similar dormancy status showed increased RGP, Carlson (1985) concluded that the effects of storage on decreasing RGP of loblolly pine are not mediated by dormancy status. Thus, cold storage can effect numerous tree physiological systems which may produce an increase, decrease, or have no effect on RGP.

With the above considerations in mind, a two year study was initiated that was designed to:

1. examine the seasonal pattern of RGP and bud dormancy for eastern white (*Pinus strobus* L.), red (*Pinus resinosa* Ait.), and Scotch (*Pinus sylvestris* L.) pines using two-year-old nursery stock lifted from a Virginia nursery;

2. determine if there are any differences in RGP and bud dormancy between one-year-old and two-year-old eastern white pine;

3. determine the affect of variable lifting dates and cold storage duration on RGP and bud dormancy of two-year-old eastern white pine.

Methods and Materials

Seasonal Root Growth Potential

Year One

One-year-old (1-0) and two-year-old (2-0) eastern white, 2-0 red, and 2-0 Scotch pine seedlings were hand lifted on ten occasions between October 15, 1985 and April 21, 1986. Seedlings were lifted from the Virginia Department of Forestry's Augusta nursery (Waynesboro, VA). On each lift date, seedlings were randomly selected from each of three randomly pre-established blocks per age/species combination. Seedlings were wrapped in polyethylene bags, placed in an ice chest, and transported to the Virginia Polytechnic Institute and State university campus located in Blacksburg, VA.

On either the day of the lift or the day after, 15 seedlings per age/species/block combination were placed in a hydroponic RGP testing system as described by Dewald et al. (1984). Blocking for the RGP test was maintained as from the nursery. After 21 days in the test system, seedlings were removed and all new short roots (≥ 0.5 cm. and < 1.5 cm.) and new long roots (≥ 1.5 cm) were counted, and the total length of new long roots was measured. Seedling height and root collar diameter were measured on each seedling. Dry weights (constant weight at 60C) of lateral roots, tap roots, needles, and stems were determined for all seedlings from one lift-date per age/species combination.

Year Two

One-year-old and 2-0 eastern white pine seedlings were hand lifted on 11 occasions between October 10, 1986 and April 14, 1987. RGP testing was conducted as in the prior year except for the following exceptions. Only the number of new short and new long roots were counted. Individual tree dry weights were measured on one lift-date per age class.

Dormancy Release Index

The bud dormancy cycle was examined by using a Dormancy Release Index (DRI) (Ritchie and Dunlap 1980, Ritchie 1984). This index is based on the premise that as a seedling progresses from predormancy to true dormancy, it takes an increasingly longer period to reach terminal bud break even if subjected to an ideal environment. At the time of true dormancy the seedling will not break bud even if subjected to ideal conditions. After this, a transition period occurs where the time needed to break bud gradually diminishes.

DRI is defined as:

$$DRI = \frac{DBB}{\text{mean days to terminal budbreak}}$$

where DBB is the number of days needed to break bud in fully chilled, post dormant seedlings. DBB should be established for the species being studied and the test environment being utilized. DRI will be close to one before predormancy and will then diminish until it approaches zero which signifies the state of true dormancy. During the transitory stage of post dormancy DRI increases. A DRI of one indicates a complete release from dormancy and a DRI greater than one indicates that dormancy has been released and there has been further heat accumulation.

Year One

Dormancy Release Indices were established for 2-0 eastern white, 2-0 red, and 2-0 Scotch pine seedlings. Sampling coincided with seasonal RGP testing described above. On each lift date and for each species, 5 seedlings per block were potted individually in one liter (11 cm. diameter) plastic pots using Promix BX[R]. Seedlings were then placed into a growth chamber and maintained at 20C day and night temperatures with a 16 hour photoperiod (60 uM $m^{-2} \cdot s^{-1}$ photosynthetic photon flux density). Seedlings were checked daily and when the terminal bud scales parted to expose new needles, the date was recorded. The numerator of the DRI formula, DBB, was established by cold storing (2C) seedlings lifted in February for 15 weeks and then subjecting them to DRI testing.

Chilling hour accumulation at the nursery was measured using a biophenometer (model # TA52, Omnidata International, Logan, Utah). This instrument recorded the hourly temperature as one of five temperature intervals: > 10, 8 - 10, 5 - 7, 0 - 4, and < 0C. The biophenometer was located within a seedling nursery bed at ground level, and shaded with a vented, protective cover.

Year Two

Dormancy Release Indexes were established for 1-0 and 2-0 eastern white pine seedlings. Sampling coincided with seasonal RGP testing as described above. One-year-old seedlings set bud later than 2-0 seedlings and so DRI testing for 1-0 seedlings did not begin until November 8. Also, due to space constraints, 1-0 white pine could not be tested on two lift dates (Nov. 24 and Dec. 17). DBB was established for 1-0 seedlings in the same manner described above with seedlings lifted in January. Chilling hour accumulation was again measured using a biophenometer.

Cold Storage of 2-0 eastern white pine

Year One

Seedling sampling coincided with RGP testing as described above. On each lift date, seedlings were double wrapped in polyethylene bags and placed into cold storage (2C). On three testing dates, March 19, April 26, and June 4, subsamples from each lift date/block combination were included in an RGP and DRI test as described above.

Year Two

Sampling coincided with RGP testing as described above but seedling storage was restricted to three lift dates (November 24, January 21, and February 24). On these dates seedlings were wrapped in Kraft-poly bags and were placed in cold storage (2C) for two storage durations. After four and eight weeks in cold storage, seedlings were tested for RGP.

Statistical Analyses

Analyses of Variance (ANOVA), using a randomized, complete block design, was used for analyses of seasonal RGP and DRI and for analyses of the effects of cold storage on RGP and DRI. The average number of new roots was analyzed using a square root transformation and DRI was analyzed using a natural log transformation, both to satisfy the assumptions for ANOVA. When used, comparisons between means were made using Duncan's Multiple range test at the alpha = 0.05 level.

Linear regression, using individual tree data, was used to determine correlations between morphological attributes and RGP. Linear regression, using block means, was used to analyze the relationship of DRI and chilling hours. All combinations of temperature ranges were used and only data where DRI $\leq$ 1.00 were used in analyses. To determine the relationship between RGP and DRI, linear regression, using lift-date means, was used. Again, only data where DRI $\leq$ 1.00 were used in analyses. The RGP/DRI relationship was also analyzed for 2-0 eastern white pine seedlings using data combined from both years. To eliminate effects due to year, the RGP mean per lift-date was expressed as a percent of the maximum RGP of the year the seedlings were lifted.

Results

Seasonal Root Growth Potential

During the first year of sampling, correlations between the number and length of new roots was high for all age/species combinations tested ($R^2 \geq 0.94$). Due to the high correlation, all subsequent values and analyses will refer to number of new roots.

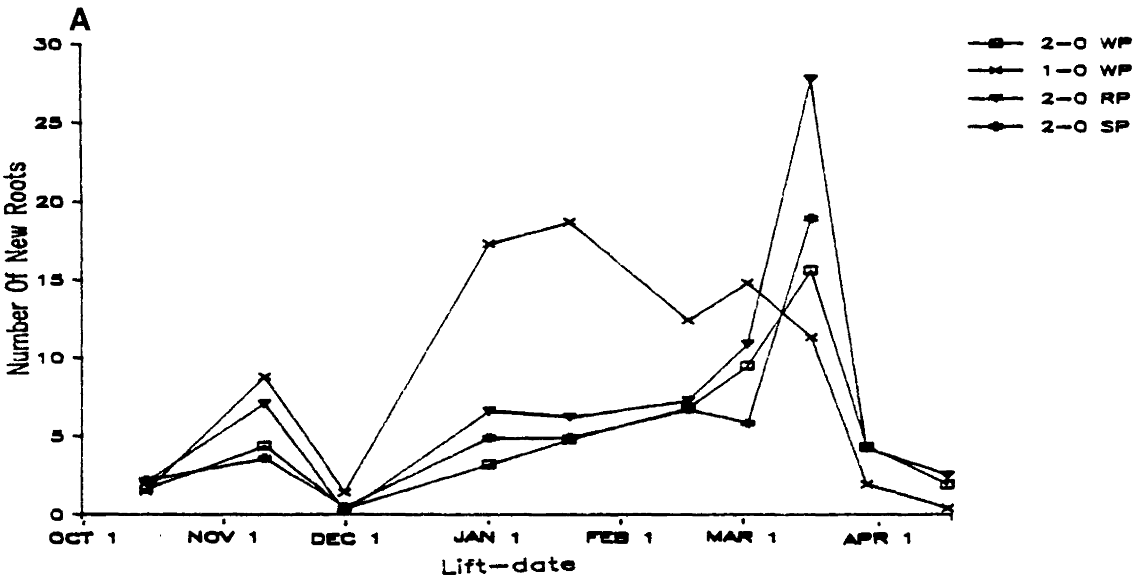
Lift-date was a significant source of variation (p <

0.001) in both years for all age/species combinations. Two-year-old eastern white, red, and Scotch pine seedlings all showed similar seasonal RGP patterns with high levels of RGP being limited to the March 18 lift-date (Figure 1).

Two-year-old eastern white pine had quite different patterns of RGP over the two seasons studied (Figure 1). In the first year there was a decrease into late autumn and then RGP increased at low but steadily increasing levels through the winter until a sharp peak in mid-March. After mid-March, RGP dropped dramatically. In the second year the autumn peak was more pronounced, mid-winter levels remained low, the spring peak was later and of lower magnitude, and the precipitous RGP decline was absent.

One-year-old and 2-0 eastern white pine seedlings showed considerable differences in seasonal RGP development during both years of testing (Figure 1). In both years, age, lift-date, and the age X lift-date interaction were all highly significant ($p < 0.001$). Generally, over both years, 1-0 stock maintained high levels of RGP throughout much of the testing period. Conversely, high levels of RGP for 2-0 stock was generally limited to early autumn and late winter/early spring.

Morphological attributes were not significantly correlated to RGP for either red or Scotch pines (Table 1). Morphological attributes were significantly correlated to



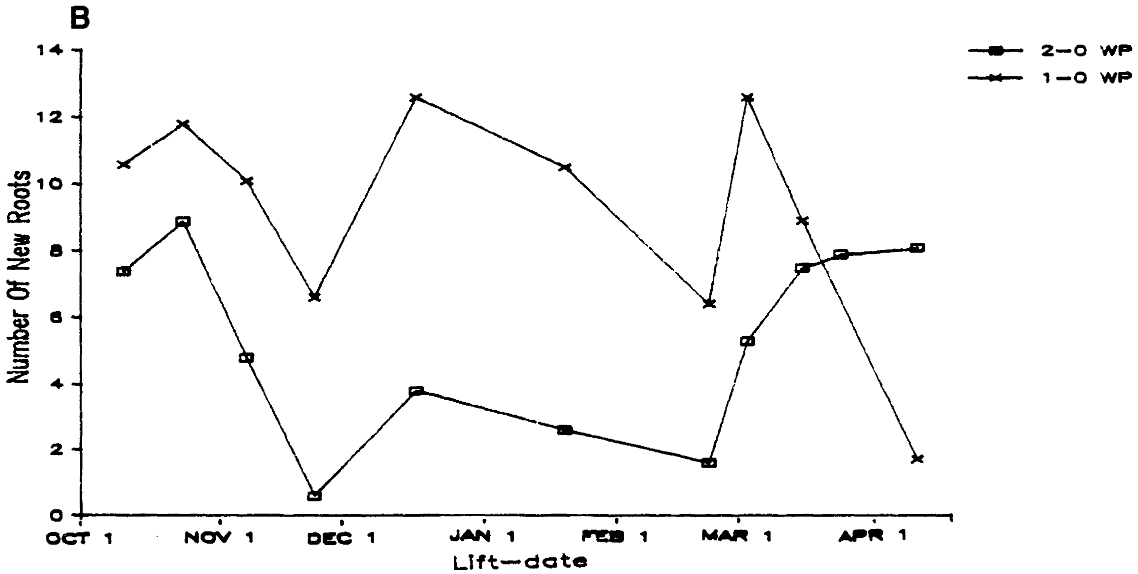


Figure 1. Mean seasonal Root Growth Potential (RGP) (number of new roots) for (A) 1-0 and 2-0 eastern white pine (WP), 2-0 red pine (RP), and 2-0 Scotch pine (SP) seedlings lifted between October 15, 1985 and April 21, 1986 and (B) for 1-0 and 2-0 eastern white pine seedlings lifted between October 10, 1986 and April 14, 1987 from the Virginia Dept. of Forestry's Augusta nursery.

Table 1. Correlation coefficients (r) between seedling morphological attributes and RGP (number of new roots) for 1-0 and 2-0 eastern white pine (WP), 2-0 red pine (RP), and 2-0 Scotch pine (SP) seedlings lifted during 1985-86 (Year 1) and 1986-87 (Year 2).

Morphological attribute		Species 1-0 WP[1]	2-0 WP	2-0 RP	2-0 SP
Shoot length	Year 1	0.16 ns[2]	0.40 **	0.11 ns	0.27 ns
	Year 2	0.60 **	0.10 ns	--	--
Root collar diameter	Year 1	0.48 **	0.37 *	0.13 ns	0.17 ns
	Year 1	0.52 **	0.07 ns	--	--
Needle dry wgt.	Year 1	0.44 **	0.53 **	-0.12 ns	0.16 ns
	Year 2	0.55 **	0.16 ns	--	--
Stem dry wgt.	Year 1	0.44 **	0.38 *	-0.11 ns	0.12 ns
	Year 2	0.59 **	0.02 ns	--	--
lateral root dry wgt.	Year 1	0.50 **	0.63 **	-0.24 ns	0.25 ns
	Year 2	0.52 **	0.05 ns	--	--
Tap root dry wgt.	Year 1	0.54 **	0.56 **	-0.14 ns	0.11 ns
	Year 2	0.40 **	0.01 ns	--	--
Root/shoot ratio (dry wgt.)	Year 1	-0.04 ns	0.08 ns	0.01 ns	0.11 ns
	Year 2	-0.30 ns	-0.18 ns	--	--

[1] 1-0 WP Year 1 - lifted November 30, 1985, N = 45.
Year 2 - lifted January 21, 1987, N = 45.
2-0 WP Year 1 - lifted March 19, 1986, N = 45.
Year 2 - lifted March 5, 1987, N = 45.
2-0 RP Year 1 - lifted January 3, 1986, N=30
2-0 SP Year 1 - lifted February 19, 1986, N=45

[2] ns P > or = 0.10, * P < 0.05, ** P < 0.01

RGP in both 1-0 and 2-0 eastern white pine although correlations were non-significant for 2-0 stock during the second year of study (Table 1).

Dormancy Release Index

The minimum days to break bud for a fully chilled seedling was estimated as 13, 17.5, 35, and 44 for 1-0 and 2-0 eastern white pine, 2-0 red pine, and 2-0 Scotch pine, respectively. These values were then used as the numerator (DBB) in the DRI formula. During 1985-86, both 2-0 red pine and 2-0 Scotch pine seedlings reached a plateau and full dormancy release by the January 3 lift-date (Figure 2A, Table 2). Two-year-old eastern white pine seedlings continued significant increases in dormancy release through the winter months and were 80 percent released (DRI = 0.8) from dormancy by the March 19 lift-date (Figure 2A, Table 2). Two-year-old eastern white pine seedlings had a similar pattern of dormancy release during 1986-87 (Figure 2b, Table 2). One-year-old eastern white pine was almost fully released from dormancy by January 21 (Figure 2b, Table 2).

Accumulated hours in five temperature ranges for both years, by lift-date, are shown in Table 3. The temperature range 0 to 7C was most highly and consistently correlated to dormancy release for all age/species combinations studied.

The relationship between DRI and chilling hours was

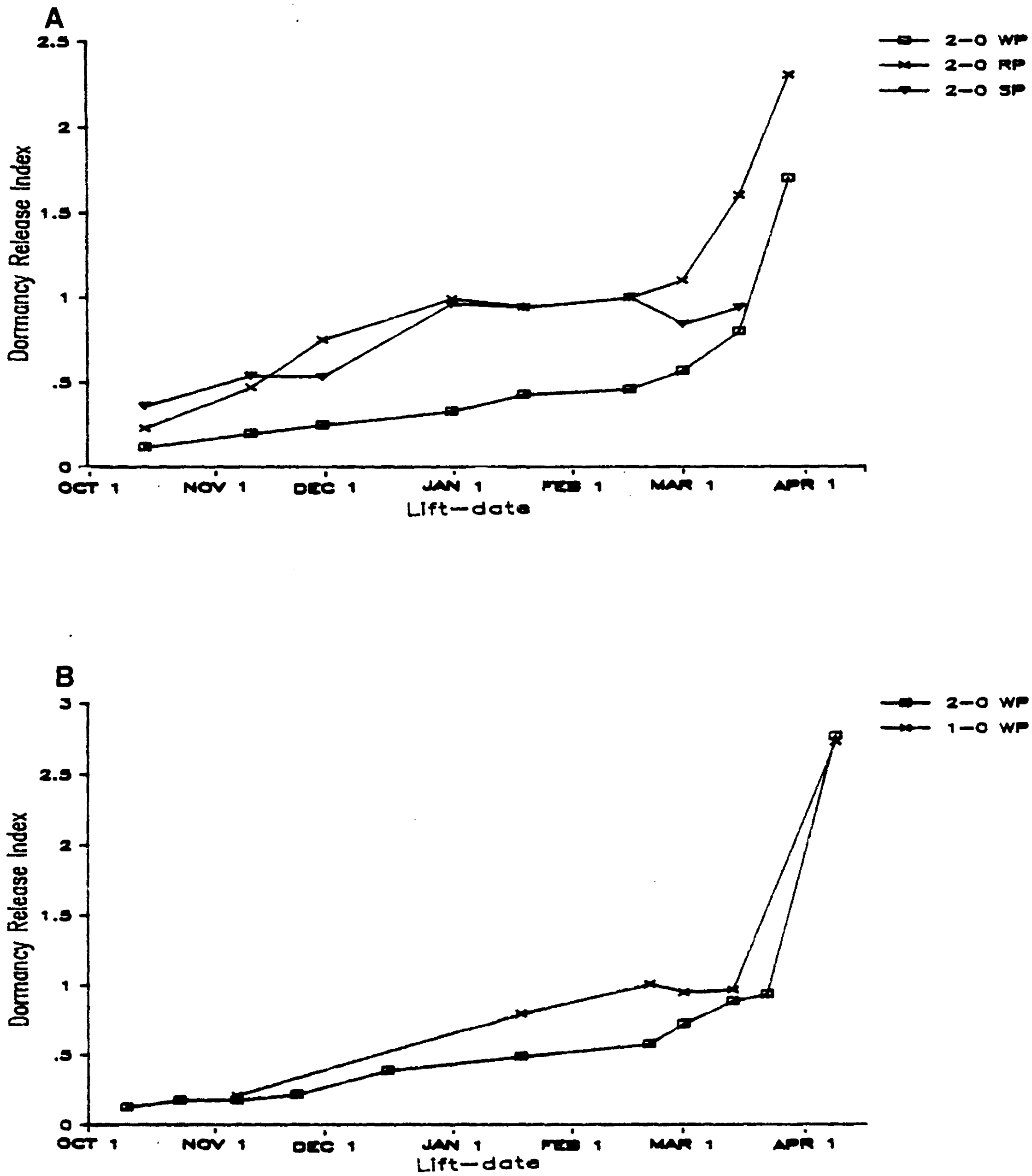


Figure 2. Dormancy Release Index (DRI) by lift-date for (A) 2-0 eastern white pine (WP), 2-0 red pine (RP), and 2-0 Scotch pine (SP) seedlings lifted between October 15, 1985 and April 21, 1986 and for (B) 1-0 and 2-0 eastern white pine seedlings lifted between October 10, 1986 and April 14, 1987 from the Virginia Dept. of Forestry's Augusta nursery.

Table 2. Mean seasonal Dormancy Release Index (DRI) for 2-0 eastern white pine (WP), 2-0 red pine (RP), and 2-0 Scotch pine (SP) seedlings lifted during 1985-86 (Year 1) and for 1-0 and 2-0 eastern white pine lifted during 1986-87 (Year 2).

	Species			
Lift date	1-0 WP	2-0 WP	2-0 RP	2-0 SP
Year 1				
Oct. 15, 1985	*[1]	0.12 a[2]	0.23 a	0.36 a
Nov. 11, 1985	*	0.20 b	0.47 b	0.54 b
Nov. 30, 1985	*	0.25 bc	0.75 c	0.53 b
Jan. 3, 1986	*	0.31 c	0.99 d	0.96 c
Jan. 22, 1986	*	0.44 d	0.94 d	0.93 c
Feb. 19, 1986	*	0.46 de	1.00 d	1.00 c
Mar. 5, 1986	*	0.57 e	1.10 d	0.84 c
Mar. 19, 1986	*	0.82 f	1.60 e	0.93 c
Apr. 2, 1986	*	1.71 g	2.30 f	*
Apr. 21, 1986	*	**[3]	**	*
Year 2				
Oct. 10, 1986	***[4]	0.13 a	*	*
Oct. 24, 1986	***	0.18 b	*	*
Nov. 8, 1986	0.21 a	0.18 b	*	*
Nov. 24, 1986	*	0.22 c	*	*
Dec. 17, 1986	*	0.39 d	*	*
Jan. 21, 1987	0.80 b	0.49 e	*	*
Feb. 24, 1987	1.01 b	0.58 f	*	*
Mar. 5, 1987	0.95 b	0.73 g	*	*
Mar. 18, 1987	0.97 b	0.89 h	*	*
Mar. 27, 1987	*	0.94 h	*	*
Apr. 14, 1987	2.73 c	2.77 i	*	*

[1] Not sampled on this date.

[2] Means followed by the same letter are not significantly different at the alpha = 0.05 level using Duncans multiple range test, comparisons of means only made within age/species/year.

[3] Seedlings had already broken bud in nursery beds.

[4] Terminal bud formation not progressed enough for DRI test.

Table 3. Accumulated hours, per lift date, in five temperature ranges measured during the 1985-86 and 1986-87 lifting seasons at the Virginia Department of Forestry's Augusta nursery.

	Temperature Range (C)				
Lift date	< 0	0 - 4	5 - 7	8 - 10	> 10
1985-86					
Oct. 15	0	0	0	0	0
Nov. 11	1	53	35	198	361
Nov. 30	1	77	95	336	595
Jan. 3	236	488	172	424	600
Jan. 22	473	662	209	432	600
Feb. 19	674	1107	232	435	600
Mar. 5	788	1255	277	453	611
Mar. 19	831	1345	338	498	707
Apr. 2	860	1400	375	549	872
1986-87					
Oct. 10	0	0	0	0	0
Oct. 24	0	47	59	52	181
Nov. 8	0	53	104	114	432
Nov. 24	31	181	205	172	474
Dec. 17	123	384	329	244	500
Jan. 21	307	896	445	260	500
Feb. 24	421	1610	460	260	500
Mar. 5	460	1746	480	275	506
Mar. 18	515	1894	518	305	532
Mar. 27	517	1967	555	362	574
Apr. 14	523	2102	620	428	741

very strong for all age/species combinations (Table 4). Using the generated models (Table 4), full dormancy release during 1985-86 is predicted to occur after 2741, 616, and 698 hours of chilling hour accumulation for 2-0 eastern white pine, 2-0 red pine, and 2-0 Scotch pine seedlings, respectively. Estimates of chilling hour requirements for 1986-87 are 1947 and 2989 hours of chilling accumulation for 1-0 and 2-0 stock, respectively. The second year value for 2-0 eastern white pine is well within the standard error of the first year estimate.

Relationship of Root Growth Potential and Dormancy Release

During 1985-86, all three species of 2-0 stock showed a linear relationship between DRI and RGP but only 2-0 eastern white pine seedlings clearly showed a strong significant relationship (Figure 3). During 1986-87, in both 1-0 and 2-0 eastern white pine seedlings, the linear relationship between RGP and DRI was non-significant (Figure 4). For 1986-87 2-0 eastern white pine (Figure 4), if the data from the first three lift dates are removed then the result is a highly significant relationship between RGP and DRI (R^2 = 0.81, p = 0.006).

Combining both years of 2-0 eastern white pine data further shows a significant positive correlation between DRI and RGP within the DRI range of 0.22 to 1.00 (Figure 5).

Table 4. Linear regression models of chilling hours (CH) (0-7C) on Dormancy Release Index (DRI).[1]

Age/Species	Model	R^2	Std. Error	N	P
Year 1					
2-0 WP	DRI = 0.150 + 0.00031(CH)	0.83	0.095	23	<.001
2-0 RP	DRI = 0.378 + 0.00101(CH)	0.79	0.145	12	<.001
2-0 SP	DRI = 0.414 + 0.00084(CH)	0.93	0.067	10	<.001
Year 2					
1-0 WP	DRI = 0.163 + 0.00043(CH)	0.92	0.110	9	<.001
2-0 WP	DRI = 0.133 + 0.00029(CH)	0.93	0.077	27	<.001

[1] Block means were used and only data to and including full dormancy release was used for analyses. Block means are based on 15 seedlings for RGP and 5 seedlings for DRI.

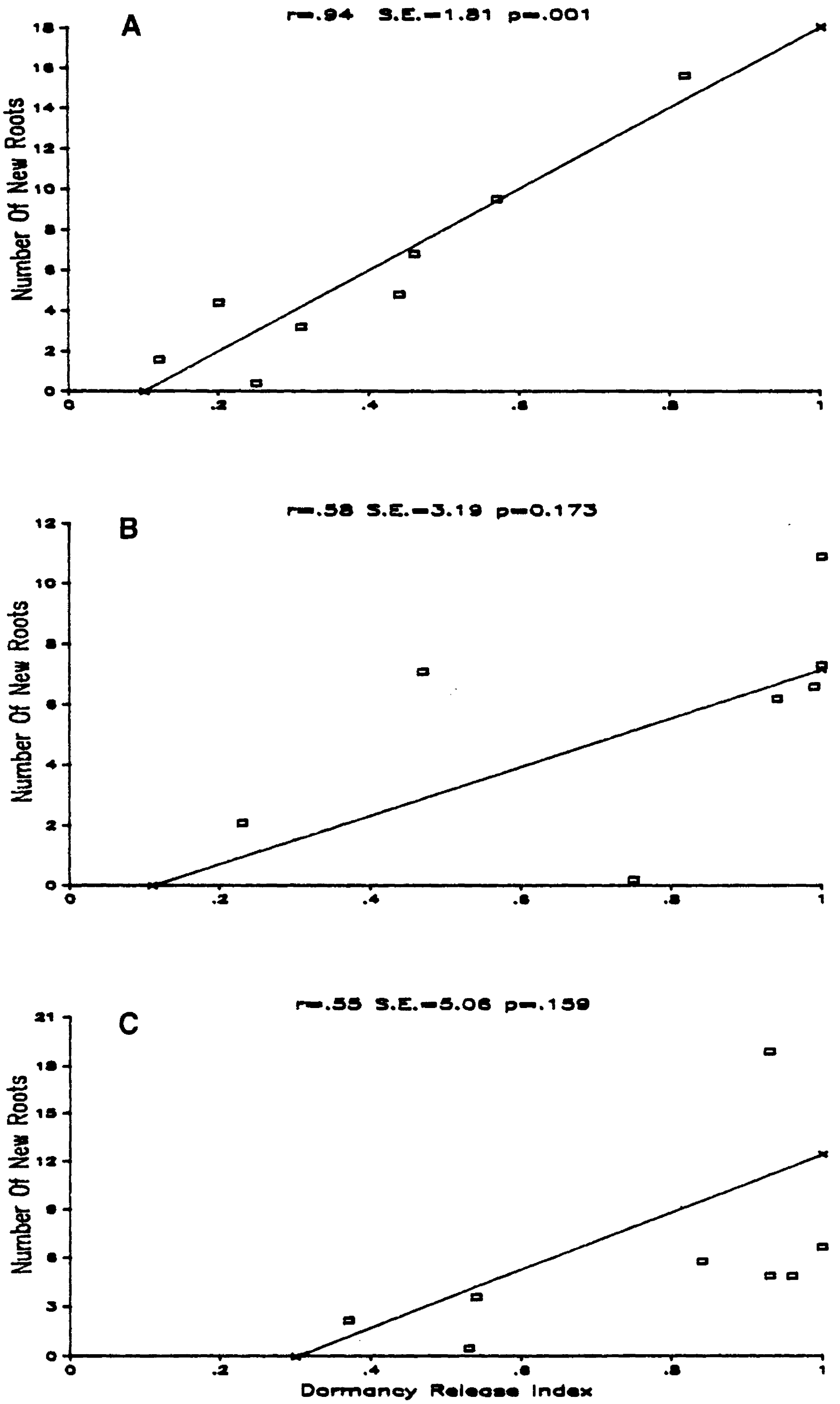
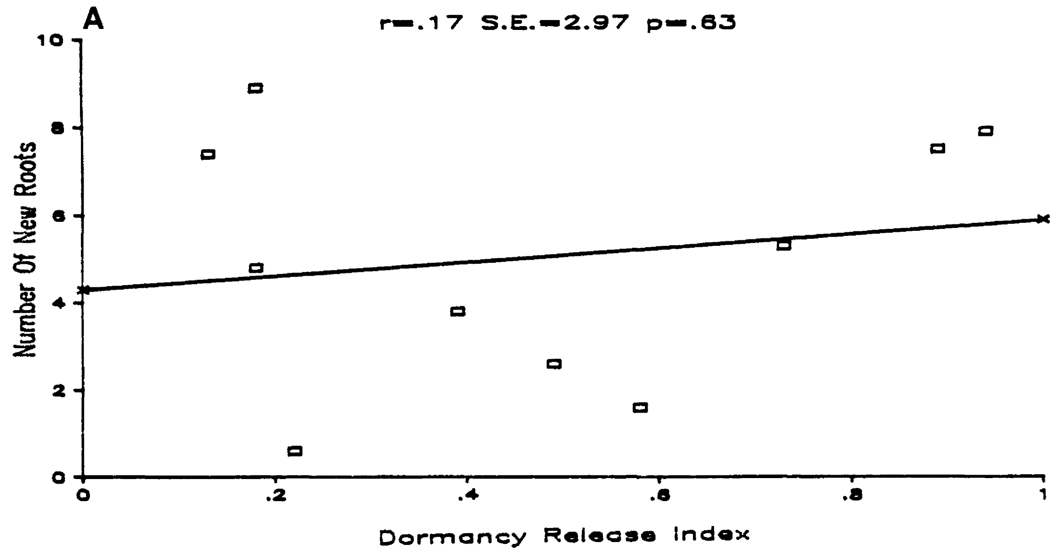


Figure 3. The relationship between Root Growth Potential (RGP) (number of new roots) and Dormancy Release Index (DRI) for (A) 2-0 eastern white pine, (B) 2-0 red pine, and (C) 2-0 Scotch pine seedlings lifted between October 15, 1985 and March 18, 1986 from the Virginia Dept. of Forestry's Augusta nursery. (includes lift-dates where DRI $\leq$ 1.0).



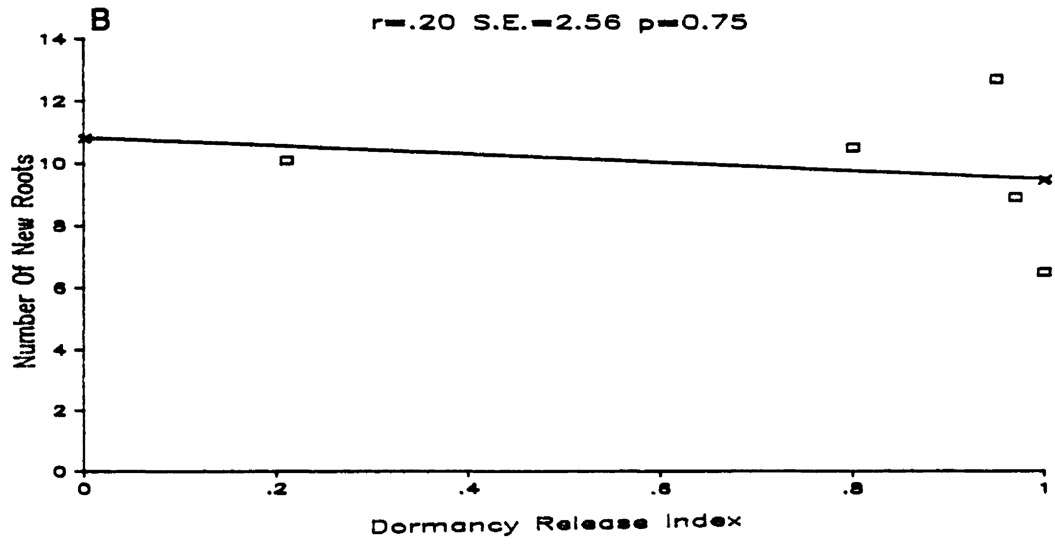


Figure 4. The relationship between Root Growth Potential (RGP) (number of new roots) and Dormancy Release Index (DRI) for (A) 1-0 eastern white pine and (2) 2-0 eastern white pine seedlings lifted between October 10, 1986 and March 27, 1987 from the Virginia Dept. of Forestry's Augusta nursery. (includes liftdates where DRI $\leq$ 1.0).

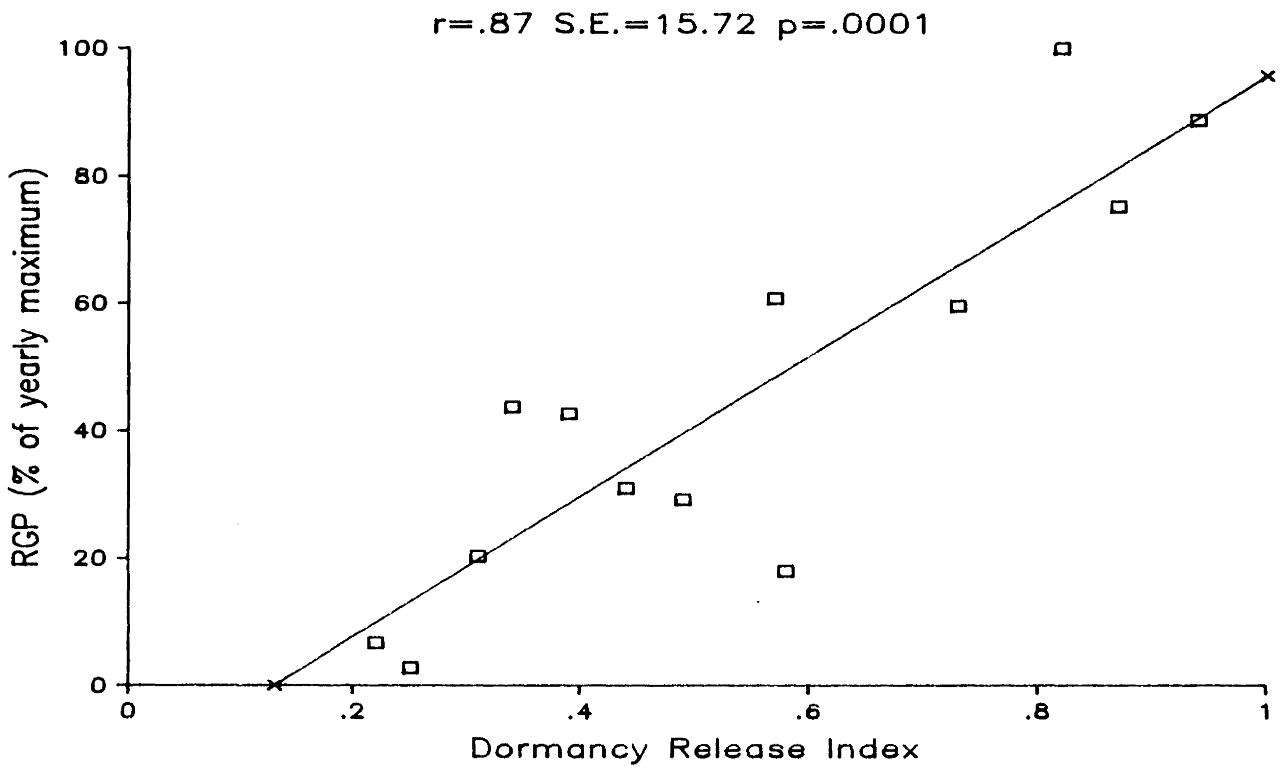


Figure 5. The relationship between Root Growth Potential (RGP) and Dormancy Release Index (DRI) within the range of DRI of 0.22 to 1.00 from 2-0 eastern white pine seedlings lifted in 1985-86 and 1986-87 from the Virginia Dept. of Forestry's Augusta nursery. Mean values per lift-date are used and RGP is expressed as a percentage of the maximum RGP for the year of the lift.

Outside this range of DRI, RGP response between the two years was inconsistent.

Cold Storage of 2-0 Eastern White Pine Seedlings

During 1985-86, no seedling from the June 4 test-date grew new roots therefore this test-date was not included in analyses. During the first year of study, seedlings lifted through the January 22 lift-date were capable of being cold stored at least until March 19 with either no effect or with a significant increase in RGP (Figure 6). After this date, cold storage had no effect or significantly decreased RGP. Lift-date, test-date, and the lift-date X test-date interaction were all highly significant ($p < 0.001$). Due to the significant interaction, test-date means are compared by lift-date (Figure 6).

During 1985-86, lift-date and test-date both significantly affected DRI ($p > 0.001$) while the interaction term was non-significant ($p = 0.97$) (Figure 7). Comparisons of overall average test-date means resulted in two groups. The fresh and March 19 test-date did not differ significantly but both were significantly lower than the April 26 and June 4 tests, which did not differ significantly (Figure 7).

During 1986-87, lift-date and storage duration both significantly affected RGP ($p = 0.046$ and $p = 0.007$, respectively) while the interaction term was non-significant

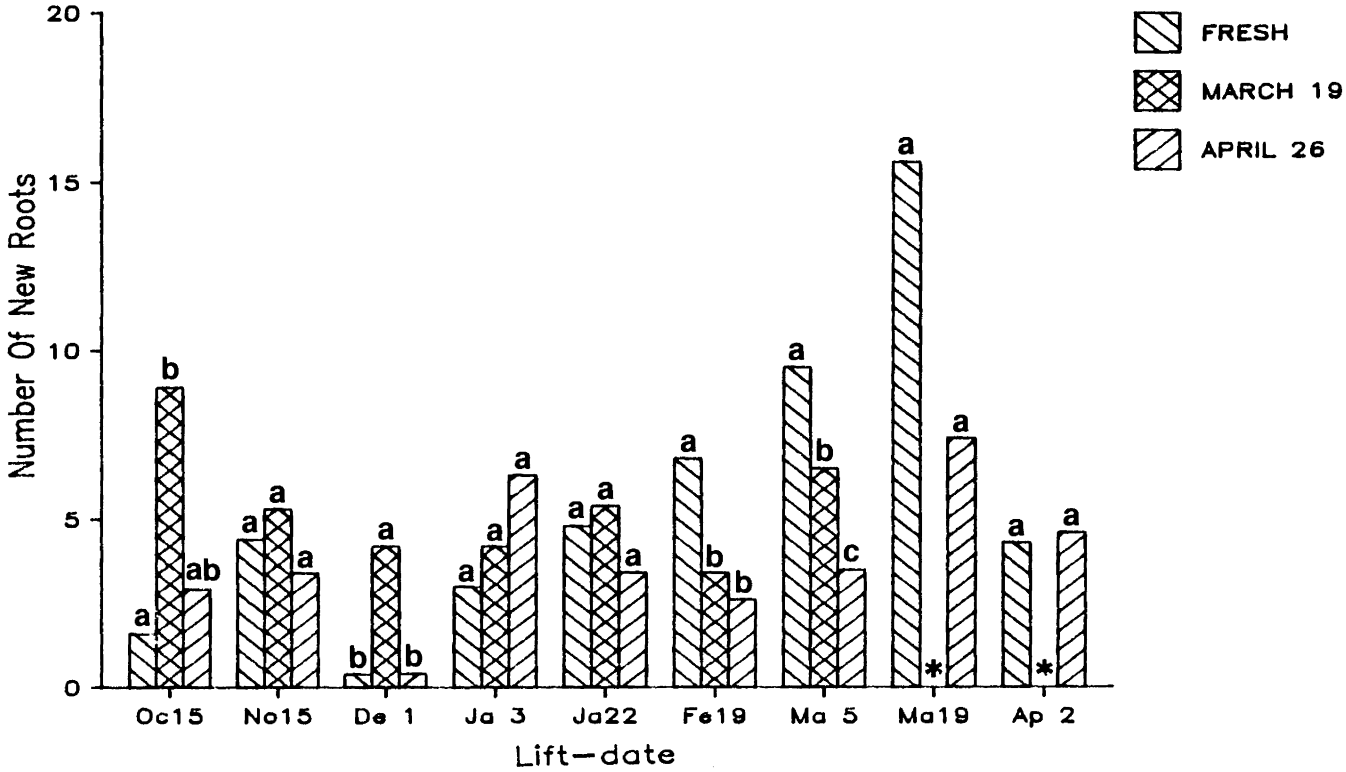


Figure 6. Root Growth Potental (RGP) (number of new roots) of 2-0 eastern white pine seedlings lifted on nine occassions between October 15, 1985 and April 2, 1986 from the Virginia Dept. of Forestry's Augusta nursery. RGP was tested immediately (fresh) and on three later dates (March 19, April 26, and June 4[1]) after cold storage (2C).[2]

[1] No root growth on this test-date.

[2] Means with same letter are not significantly different at the alpha = 0.05 level using Duncans multiple range test, comparisons are made only within lift-dates.

* lift-date was either concurrent with or past test-date.

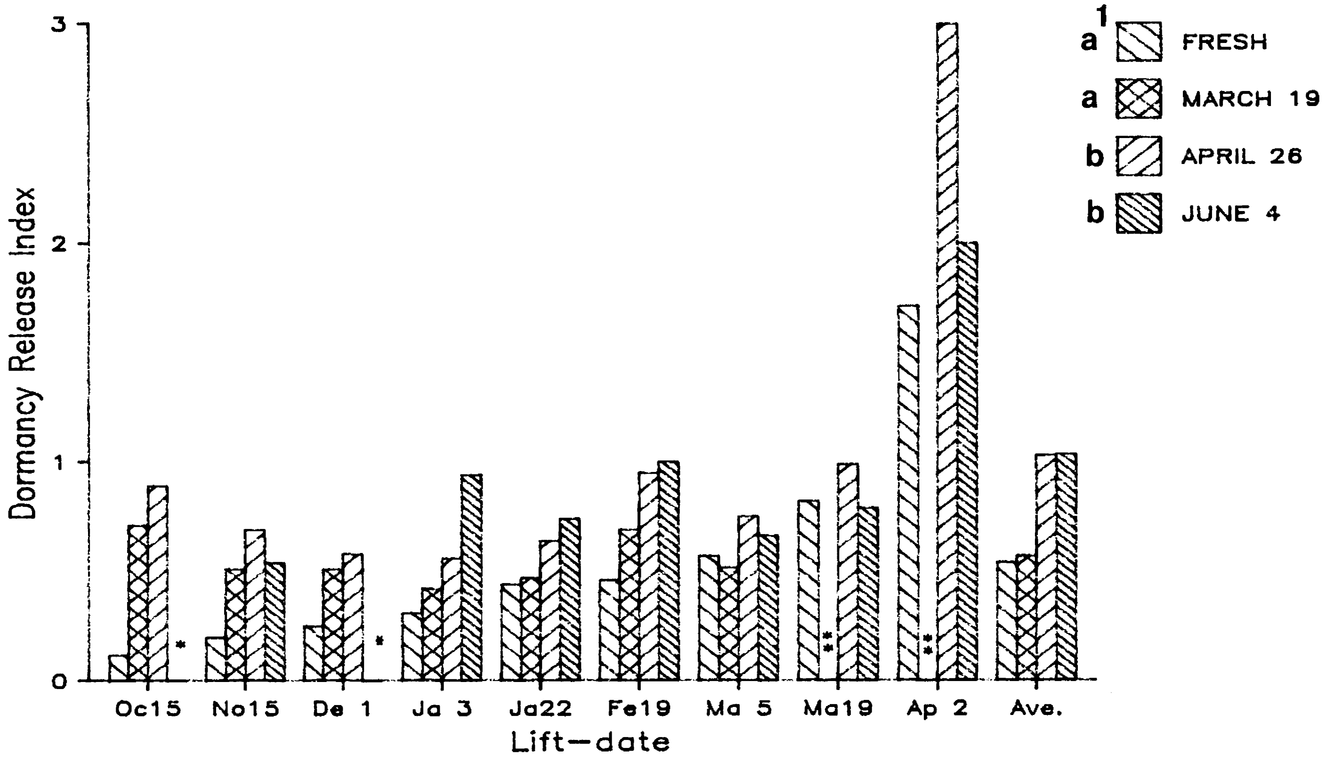


Figure 7. Dormancy Release Index (DRI) by lift-date and overall average DRI (Ave.) of 2-0 eastern white pine seedlings lifted on nine occassions between October 18, 1985 and April 2, 1986 from the Virginia Dept. of Forestry's Augusta nursery. DRI was tested immediately after lifting (fresh) and on three later dates (March 19, April 26, and June 4) after cold storage (2C).

* missing data.

** lift date was either concurrent with or past test-date.

[1] Test-dates accompanied by the same letter do not vary significantly in overall average RGP using Duncans Multiple Range test at the alpha = 0.05 level.

(p = 0.144) (Figure 8). Comparison of means shows that eight weeks in cold storage significantly increased RGP over both freshly tested seedlings and seedlings cold stored for four weeks (Figure 8).

Discussion

The differences in minimum days to break bud for the four different age/species combinations studied were large. This is in contrast to a statement by Ritchie (1984) who states that although DBB should be determined exerimentally for each species, it probably does not vary amoung species by more than a few days. Differences recorded in this study may be pronounced due to the low light levels of the growthroom environment utilized. Each species may interact differently to these levels and this may affect speed of bud break. Since the same growthroom environment was used over the course of the experiment and since it is the relative speed of bud break which is important, the DRI values are appropriate. An examination of Figure 2 and Table 2 further supports the suitability of the DBB estimates. In each case, if and when DRI reaches a plateau, it is at a DRI of aproximately equal to one indicating that seedlings entered quiescence after full release from dormancy.

The chilling hour requirements as calculated from the models in Table 4 are generally within the range normally

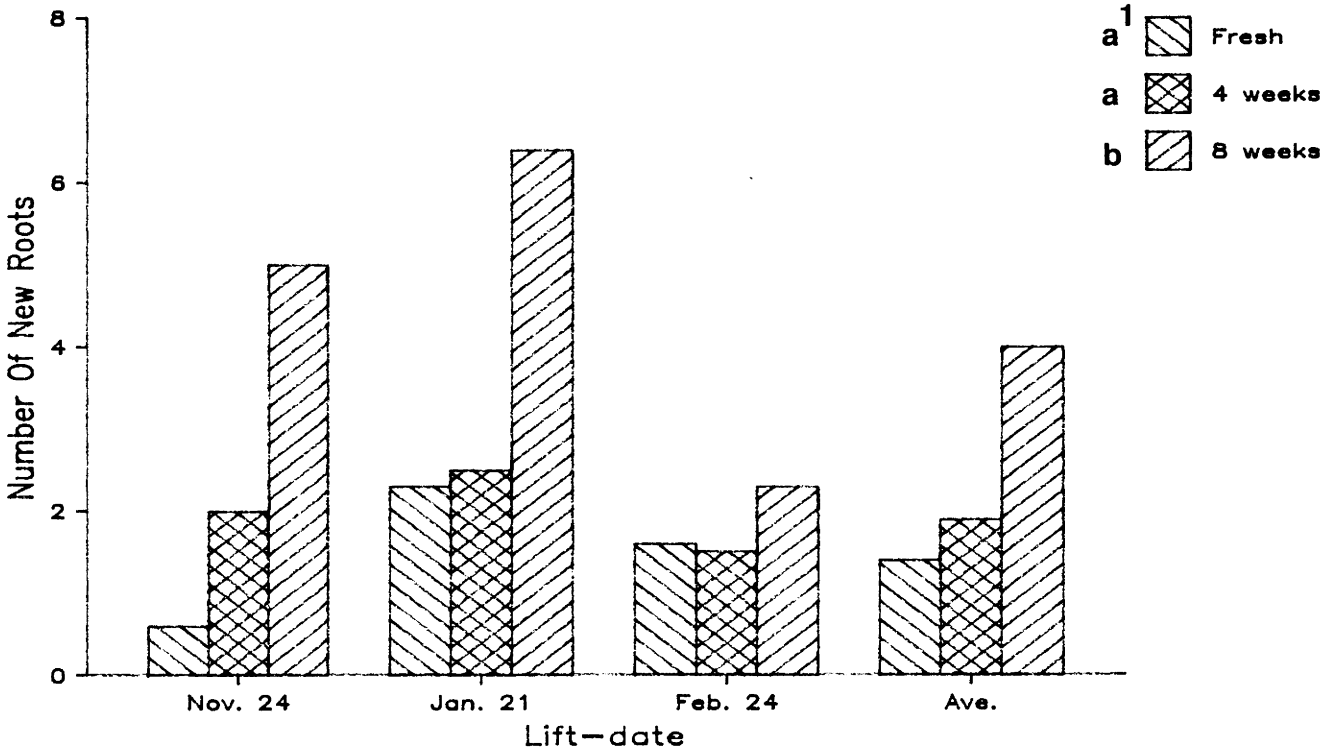


Figure 8. Root Growth Potential (RGP) (number of new roots) by lift-date and overall average RGP (Ave.) of 2-0 eastern white pine seedlings lifted on November 24, 1986, January 21, 1987, and Febuary 24, 1987 from the Virginia Dept. of Forestry's Augusta nursery. RGP was tested immediately after lifting (fresh) and after four and eight weeks of cold storage (2C).

[1] Test-durations accompanied by the same letter do not vary significantly in overall average RGP using Duncans Multiple Range test at the alpha = 0.05 level.

seen in forest tree species (Nelson and Lavender 1979). Only 2-0 eastern white pine seems to have an unusually large chilling sum requirement as estimated from modeling the relationship of DRI and chilling sums. Ritchie (1984) explained a similar circumstance with Douglas-fir. He stated that the DRI value is artifactual in the sense that it expresses DBB as a reciprical and hence presents a skewed view of actual dormancy intensity. A difference of DRI values of 0.1 and 0.2 with respect to DBB is far greater than the difference between DRI values of 0.5 and 0.6. Thus, small variations in DBB in late winter will show up as larger differences in DRI, magnifying any experimental or random error. Regardless, DRI is still a preferred method as it linearizes dormancy release and allows direct comparisons between species and between testing environments.

Although first year results suggest that there is a positive RGP/DRI relationship in 2-0 eastern white pine, there was no significant linear relationship the second year when data from all lift-dates are included in the analyses. In fact, during the second year, some of the highest RGP levels observed in 2-0 eastern white pine occurred when seedlings were deepest in dormancy (October 10 and 24) (Figures 1 and 2). This is similar to patterns reported by Ritchie et al. (1985). Analyses of second year data of 1-0 eastern white pine also shows no significant RGP/DRI relationship. This obviously should be viewed with caution due to the fact that DRI data is not available from November 8 to January 21, a time interval where DRI changes from 0.21 to 0.80 (Table 2). Also, it is possible that 1-0 stock had not yet reached full rest on the November 8 lift-date. Since buds were not fully set just two weeks before (October 24), it is likely that full rest was not achieved until at least late November. If this were true then there may have been a positive RGP/DRI relationship in the 1-0 stock.

Ritchie and Dunlap (1980), synthesizing past work, proposed the following model for the RGP/DRI relationship. As dormancy deepens, growth inhibitors (probably abscisic acid) accumulate in the bud. The promotor/inhibitor (promotors are probably auxins and/or gibberellins) ratio thus decreases and seedlings become physiologically dormant. Accumulated chilling results in an increase in the promotor/inhibitor ratio which results in an increase in the activity of auxins and/or gibberellins. The effect is a gradual release from dormancy. As dormancy weakens, there is an increase in the export of promotors from buds to needles. This stimulates the production of root promotors which are then exported to the roots and increases RGP.

Following the above scenario, as seedlings enter full rest the production of root promotors is halted. Depending on seedling physiological status, there may be enough residual root promotor present when seedlings have just entered rest to still permit high RGP. This may be the case in this study with 2-0 eastern white pine during the second year and also with lodgeole pine (Ritchie et al. 1985). When data from the first three lift-dates are removed from analyses (Figure 4A), then the result is a highly significant positive relationship between RGP and DRI.

Combining both years of 2-0 eastern white pine data further shows a positive correlation between DRI and RGP within certain limits of DRI (Figure 5). Outside this range of DRI, RGP response between the two years was inconsistent. The question still remains if whether in this case the correlation between RGP and DRI is due to a cause/effect relationship. It may simply be as dormancy is being released other seasonal factors that may influence root growth are also changing (such as: soil and air temperatures, seedling photosynthetic ability, day length, etc.).

Peak RGP may also depend on nursery environmental conditions and the influence of shoot activity on source/sink relationships. In the first year of study 2-0 eastern white pine, 2-0 red pine, and 2-0 Scotch pines all had sharp peaks of RGP on March 19. This corresponds to the first lift-date in which there was a sharp increase in temperature accumulation over 10C (Table 3). Warm temperature accumulation during the spring of the second year of study was delayed in comparison to the first year. Hours of temperature accumulation above 10C two weeks prior to March 19 was only 27 percent of the year before. The sharp spring peak was also not observed the second year (Figure 1). Also not observed in the second year was the precipitous drop in RGP in 2-0 eastern white pine (Figure 1). This may have been due to lower spring temperatures that delayed shoot activity. By the April 14 lift-date, when there had been substantial warm temperature accumulation (Table 3), shoot activity may have been high enough to prevent a sharp RGP peak but not high enough to cause a precipitous drop in RGP.

One of the most interesting points from this study were the very different patterns of seasonal RGP of 1-0 and 2-0 eastern white pine. One-year-old stock typically had higher overall levels of RGP and maintained much wider "lifting windows" for high RGP. As mentioned, the DRI/RGP relationship for 1-0 stock in this study is not clear so it is not possible, at this point, to ascertain how much DRI might contribute to the different RGP patterns of the two age classes. Since a 1-0 seedling exhibits indeterminate growth, as contrasted to the fixed growth of 2-0 stock, this does suggest that different bud dormancy patterns might be important.

In the first cold storage study, seedlings lifted from October 15 until April 2 did not grow any roots when tested on June 4. This seems to indicate that the testing environment may have become unfavorable for root growth during the June 4 test-date. Due to the very warm early spring, average daily temperatures were not that different on the three test-dates after cold storage. The average temperature and average daily high temperatures were (22.9C and 30.9C), (23.1C and 31.6C), and (24.2C and 32.1C) for the March 19, April 26, and June 4 RGP tests, respectively. It seems unreasonable that these temperature differences could have been prohibitive to root growth.

The effect of cold storage on RGP during the first year of study were variable and thus difficult to interpret (Figure 6). Mold formation on seedlings during cold storage may have confounded first year results. At least some mold was found in all bags of seedlings but the extent of molding did differ between bags, although apparently in a random fashion. Mold was not observed during the second year and this may or may not have been the result of switching from polyethylene to Kraft-Poly bags. Results from the second year cold storage study are more consistent and point to the utility of cold storage for maintaining or increasing RGP. Results from both years suggest that cold storage before February may be most successful in regard to RGP response.

The effects of cold storage on dormancy release were less variable. For lift-dates before March 5, cold storage almost always increased DRI (Figure 7). These results are similar to those of Carlson (1985) who found that although cold storage of loblolly pine seedlings resulted in either increased or decreased RGP, cold storage was as effective as natural chilling in promoting terminal budbreak.

Summary

During the first year of study 2-0 eastern white pine, 2-0 red pine, and 2-0 Scotch pine seedlings showed similar patterns of RGP with a sharp peak limited to mid-March. Red pine and Scotch pine seedlings were completely released from dormancy by January while 2-0 eastern white pine continued dormancy release through March. All three species of 2-0 stock showed a relationship between RGP and DRI though 2-0 eastern white pine displayed the only statistically significant relationship. Combining 2-0 eastern white pine data from both years results in a strong relationship between RGP and DRI within a DRI range of 0.22 to 1.00. Outside of this range in DRI, the relationship between RGP and DRI was inconsistent between years. The chilling hour requirement for 2-0 red pine and 2-0 Scotch pine was estimated at approximately 600 and 700 hours, respectively. The chilling hour requirement for 1-0 and 2-0 eastern white pine seedlings was estimated at approximately 2000 and 2700-3000 hours, repectively.

The RGP patterns for 2-0 eastern white pine seedlings were different over the two years. Seedlings during 1986-87 produced higher autumn levels and a less pronounced spring peak in RGP than seedlings lifted in 1985-86. The latter may have partly due to the between year differences of the onset of warm spring weather. One-year-old and 2-0 stock of eastern white pine had very different patterns of RGP over both study years. One-year-old stock typically had higher overall levels of RGP and maintained much wider "lifting windows" of high RGP. Due to missing data, this could not be attributed to any differences in dormancy release between 1-0 and 2-0 stock.

Cold storage (2C) of 2-0 eastern white pine resulted in inconsistent effects on RGP depending on lift-date and storage duration. Eight weeks of storage significantly increased RGP compared to seedlings tested immediatly after lifting and those stored for four weeks. Cold storage before February was generally most successful in regard to RGP response. Cold storage before March 5 almost always progressed dormancy release.

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CHAPTER 4

ROOT GROWTH POTENTIAL AND SHOOT ACTIVITY OF NORTHERN AND SOUTHERN PROVENANCES OF 1-0 EASTERN WHITE PINE SEEDLINGS GROWN IN A VIRGINIA NURSERY

Abstract

Root Growth Potential (RGP) and shoot activity were examined from October until April using northern and southern half-sib families of 1-0 eastern white pine (*Pinus strobus* L.) seedlings grown in a Virginia nursery. There were significant differences in RGP between northern and southern provenances and this was apparently due to the larger size of seedlings of southern origin. Heritability estimates indicate that RGP is under minimal genetic control in 1-0 eastern white pine seedlings. Southern provenances maintained higher shoot activity at the end of the RGP test during the autumn months. By April, northern provenances had surpassed southern provenances in shoot activity. Large differences in shoot activity did not result in large RGP differences indicating that bud dormancy status does not highly influence RGP in 1-0 eastern white pine seedlings.

Introduction

Initial survival after planting is largely dependent on a tree's physiological readiness to produce new roots and thereby re-establish contact with the soil (Smith 1962). Root Growth Potential (RGP), a measure of the ability of a bare-root seedling to produce new roots, has been shown to be to a good indicator of survival probability after planting. Direct relationships have been found between root growth and subsequent field performance following planting in several of the *Pinaceae*, including: loblolly pine (*Pinus taeda* L.), ponderosa pine (*Pinus ponderosa* Laws), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franko.) (Feret et al. 1984, Jenkinson and Nelson 1983, Ritchie and Dunlap 1980, Brissette and Roberts 1984).

RGP is apparently under relatively strong genetic control (Feret et al. 1984, Jenkinson 1975). Dewald et al. (1985) found significant differences between loblolly pine half-sib families. Heritabilities ranged from 0.34 to 0.37 for two independent samples of seedlots lifted over two years indicating that selection for RGP could be successful. They also found the seedlot X lift-date interaction was significant and proposed that different optimum lifting and planting dates exist for different loblolly pine families. Carlson (1985) further showed differences between half-sib families of loblolly pine and found that manipulation of lift-date and storage duration often interacted with genotype in the expression of RGP. Carlson (1986) also found that RGP rank of open pollinated families of loblolly pine can change with soil temperature indicating the potential importance of genetic X environment interactions in the expression of RGP. Work done with ponderosa pine has also showed strong patterns of genetic variation of RGP. Depending on the seed source, four seasonal patterns of RGP were delineated (Jenkinson, 1975).

Although there typically are differences between species and often between seed sources within species, a general seasonal trend in RGP seems to pervade. This includes: a late summer low, an increase in mid-autumn to a mid to late winter peak, and a sharp drop coinciding with renewed shoot growth in the spring (chapter 3). This pattern is often cited as strongly linked to bud dormancy and internal competition for carbohydrates between roots and shoots (Ritchie and Dunlap 1980).

Mergen (1963) examined dormancy release in northern and southern sources of eastern white pine (Pinus strobus L.). In general, the seedlings from regions having shorter growing seasons broke dormancy more rapidly after exposure to normal outside temperatures during the fall and winter. If a relationship exists between RGP and bud dormancy then this may contribute to genetic differences in RGP. A highly efficient nursery management system would take into account genetic origin to maximize RGP at time of planting. This may prove especially important with eastern white pine, a species with a large geographic range, that is produced commercially in southern nurseries. Clinal differences in bud phenology of eastern white pine may be expressed maximal when seedlings are planted near the southern edge of the species range. Depending on the RGP/bud dormancy relationship, this may result in genetic differences in overall RGP levels and/or patterns of seasonal RGP.

This study was initiated to examine the relative importance of genetic control of RGP using one-year-old (1-0) eastern white pine seedlings grown in a Virginia nursery from seed of northern and southern origins.

Methods and Materials

On April 21, 1986 seed from 29 half-sib families of eastern white pine were hand planted in three replicate blocks along a section of commercial nursery bed of the Virginia Department of Forestry's Augusta nursery (Waynesboro, VA.). Seed came from two northern provenances (New Hampshire and Maine) and one southern provenance (North Carolina). After planting, the seedbeds were subjected to the operational irrigation and fertilization schedule normally used at the Augusta nursery.

In September, 1986, seedlots were inventoried for seedling number and seedbed density. Due to differential germination, 17 half-sib families were chosen which had seedbed density of approximately 21 seedlings/ft^2. Seed origin for these families is shown in Table 5.

On ten occasions between October 10, 1986 and April 14, 1987, seedlings were hand lifted for RGP testing. On each lift date, seedlings were randomly selected from each family/block combination. Seedlings were wrapped in polyethylene bags, placed in an ice chest, and transported to the Virginia Polytechnic Institute and State University campus located in Blacksburg, VA.

On either the day of the lift or the day after, approximately eight seedlings per family/block combination were placed in a hydroponic RGP testing system as described

Table 5. Origin of seed-sources used in study of RGP and bud activity of 1-0 eastern white pine.

Family	Seed-source origin
NH-01	Boscowen, New Hampshire
NH-03	Alton, New Hampshire
NH-04	New Boston, New Hampshire
NH-05	North Umberland, New Hampshire
NH-06	Conway, New Hampshire
NH-09	San Down, New Hampshire
NH-10	New Boston, New Hampshire
ME-12	Passadumkeag, Maine
ME-13	Passadumkeag, Maine
ME-14	Chelsea, Maine
ME-15	Passadumkeag, Maine
NC-16	Burke County, North Carolina
NC-18	Caldwell County, North Carolina
NC-19	Caldwell County, North Carolina
NC-21	Burke County, North Carolina
NC-22	Burke County, North Carolina
NC-23	Burke County, North Carolina

by Dewald et al. (1984). Blocking for the RGP test was maintained as from the nursery. After 21 days in the test system, seedlings were removed and all new white roots ($\geq$ 0.5 cm.) were counted. Seedling height and root collar diameter were measured on each seedling. Each seedling was also rated by the following shoot activity scale as adapted from Jenkinson (1980):

1) Dead.
2) No apparent activity.
3) Terminal buds swollen.
4) Terminal starting to flush.
5) Terminal flushing with measurable elongation.
6) Terminal flushing with measurable elongation and needles flushing.
7) Already growing, no fully set bud.

Dry weights (constant weight at 60C) of lateral roots, tap roots, needles, and stems were determined for all seedlings from the January 1, 1987 lift-date.

The experiment was arranged as a randomized complete block design. Analyses of Variance (ANOVA), using block means, was used to analyze RGP and morphological attributes. The square root transformation was used for number of roots to facilitate meeting the assumptions of ANOVA. When used, comparisons between means were made using Duncan's Multiple Range Test at the alpha = 0.05 level. Linear regression was used to determine correlations between morphological attributes and RGP both by provenance and on combined data. Chi Square analyses was performed by lift-date to test for the dependence of shoot activity on family.

Half-sib heritability values were estimated for RGP (total number of new roots produced.) Heritability was calculated as four times the intraclass correlation, which was based on the ratio of family variance to total variance (Falconer 1983) from an ANOVA using individual tree values. Heritabilities were calculated per lift-date as well as on combined data, similar to Barker's (1973) treatment of heritability estimates between different locations. Heritabilities per lift-date were calculated as:

$$h^2 = \frac{4(V_{family})}{(V_{family} + V_{block} + V_{(family\ X\ block)} + V_{error})}$$

The combined lift-date heritability was calculated as:

$$h^2 = \frac{4(V_{family})}{(V_{family} + V_{block} + V_{(family\ X\ lift)} + V_{(family\ X\ lift\ X\ block)} + V_{error})}$$

The standard errors of the heritability estimates were calculated as four times the intraclass correlation variance (Falconer 1983):

$$V_t = \frac{2[1+(n-1)t]^2(1-t)^2}{n(n-1)\ (N-1)}$$

where: t = intraclass correlation
N = number of half-sib families
n = number of individuals per family

RESULTS

Root Growth Potential

Analyses of variance resulted in provenance and lift-date both being significant sources of variation in RGP at the alpha = 0.01 level. The provenance X lift-date interaction was non-significant ($p = 0.47$). The North Carolina provenance overall mean RGP was 6.4 new roots which was significantly greater than either of the two other provenances. The two northern provenances did not differ significantly with the overall RGP means being 5.4 and 4.9 for the New Hampshire and Maine provenances, respectively. Provenance RGP by lift-date and averaged over all lift-dates is shown in Figure 9.

Seedlings from the Maine provenance had the highest correlations between morphological attributes and RGP (Table 6). With the exception of lateral root dry weight, morphological attributes were consistently and significantly correlated with RGP within each provenance as well as on combined data (Table 6). When root collar diameter was used as a covariate in the analyses of seasonal RGP, provenance was no longer significant ($p = 0.15$); however, family(provenance) was still a significant source of variation ($p < 0.01$).

RGP heritability estimates with associated standard errors per lift-date as well as on combined lift-dates are

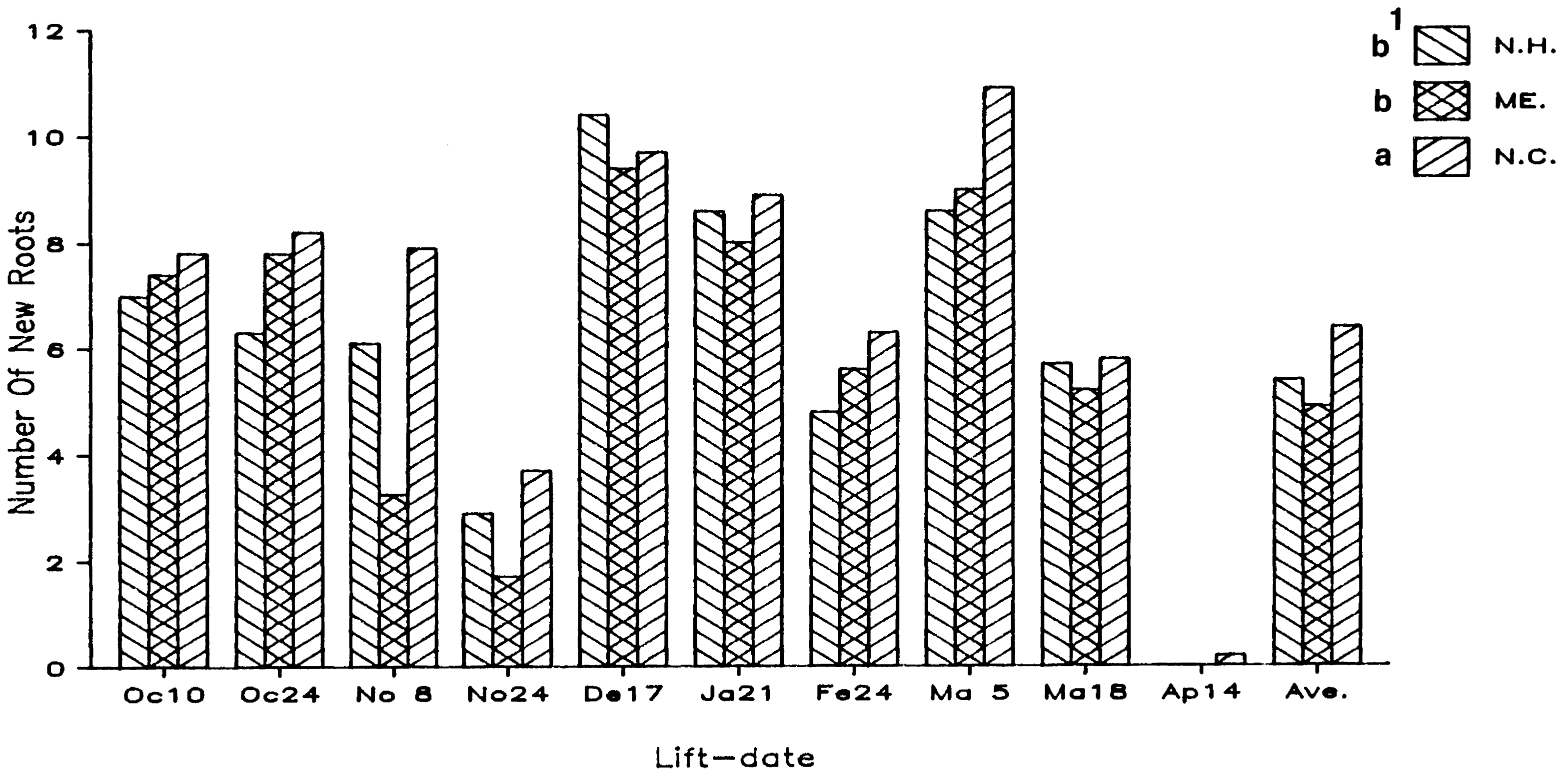

Figure 9. Root Growth Potential (RGP) (number of new roots) for New Hampshire (N.H.), Maine (ME.), and North Carolina (N.C.) provenances of 1-0 eastern white pine seedlings by lift-date and for overall average (Ave.) RGP. Seedlings were lifted between October 10, 1986 and April 14, 1987 from the Virginia Department of Forestry's Augusta nursery.

[1]Provenances accompanied by the same letter do not vary significantly in overall average RGP using Duncans Multiple Range test at the alpha = 0.05 level.

Table 6. Correlation coefficients (r) for regression of morphological attributes on Root Growth Potential (RGP) (number of new roots) for 1-0 eastern white pine seedlings lifted on January 21, 1987 from the Virginia Department of Forestry's Augusta nursery. Regressions were calculated by provenance (New Hampshire, Maine, and North Carolina) and on combined data.

	Provenance			
Morphological attribute	N.H. (N=152)	ME. (N=87)	N.C. (N=126)	Combined data (N=365)
Shoot height	0.285 *	0.429 *	0.379 *	0.326 *
Root collar diameter	0.286 *	0.559 *	0.328 *	0.333 *
Needle dry wgt.	0.365 *	0.548 *	0.378 *	0.391 *
Stem dry wgt.	0.331 *	0.463 *	0.357 *	0.343 *
Lateral root dry wgt.	0.068 ns	0.541 *	0.596 *	0.179 *
Tap root dry wgt.	0.273 *	0.562 *	0.176 *	0.248 *

* Correlation was significant at the alpha = 0.05 level.
ns Correlation was not significant at the alpha = 0.10 level.

shown in Table 7.

Morphological Attributes

Comparison of provenance means from the January 21 lift-date show that, generally, there are clear differences between northern and southern provenances in seedling morphology (Table 8). The North Carolina provenance was significantly larger than both northern provenances in shoot length, root collar diameter, stem dry weight, and tap root dry weight. The North Carolina provenance had a significantly larger needle dry weight than the New Hampshire provenance but was not significantly larger than the Maine provenance. There were no significant differences between provenances in lateral root dry weight. There were no significant differences between the New Hampshire and Maine provenances in any of the morphological attributes measured.

Shoot Activity

Chi Square analyses, by lift-date, resulted in shoot activity being dependent on provenance on each lift-date ($p < 0.001$). Figure 10 shows that northern provenances had visually inactive shoots at the end of the 21 day RGP test from October 10 to December 17. Conversely, this was a transitory stage for the South Carolina provenance where terminal buds were flushing at the end of the October 10

Table 7. Heritability estimates (h^2) by lift-date and for combined lift-dates for 1-0 eastern white pine Root Growth Potential (RGP). Seedlings were lifted from the Virginia Department of Forestry's Augusta nursery on ten occasions between October 10, 1986 and April 14, 1987.

Lift-date	h^2	Std. Error
October 10, 1986	0.11	±0.11
October 24, 1986	-0.37	±0.18
November 8. 1986	0.23	±0.15
November 24, 1986	0.42	±0.20
December 17, 1986	0.01	±0.08
January 21, 1987	0.35	±0.18
February 24, 1987	-0.30	±0.17
March 5, 1987	0.37	±0.19
March 18, 1987	0.38	±0.19
April 14, 1987	0.85	±0.29
Combined	0.08	±0.04

Table 8. Mean values for morphological attributes of 1-0 eastern white pine seedlings from three provenances (New Hampshire, Maine, and North Carolina). Seedlings were lifted from the Virginia Department of Forestry's Augusta nursery on January 21, 1987.

	Provenance		
Morphological attribute	N.H.	ME.	N.C.
Shoot length (cm)	6.9 b[1]	6.8 b	8.7 a
Root collar diameter (mm)	1.7 b	1.8 b	2.1 a
Needle dry wgt. (g)	0.278 b	0.337 ab	0.400 b
Stem dry wgt. (g)	0.086 b	0.098 b	0.140 a
Tap root dry wgt. (g)	0.065 b	0.066 b	0.087 a
Lateral root dry wgt. (g)	0.070 a	0.074 a	0.085 a

[1] Means followed by same letter within rows do not differ significantly at the alpha = 0.05 level.

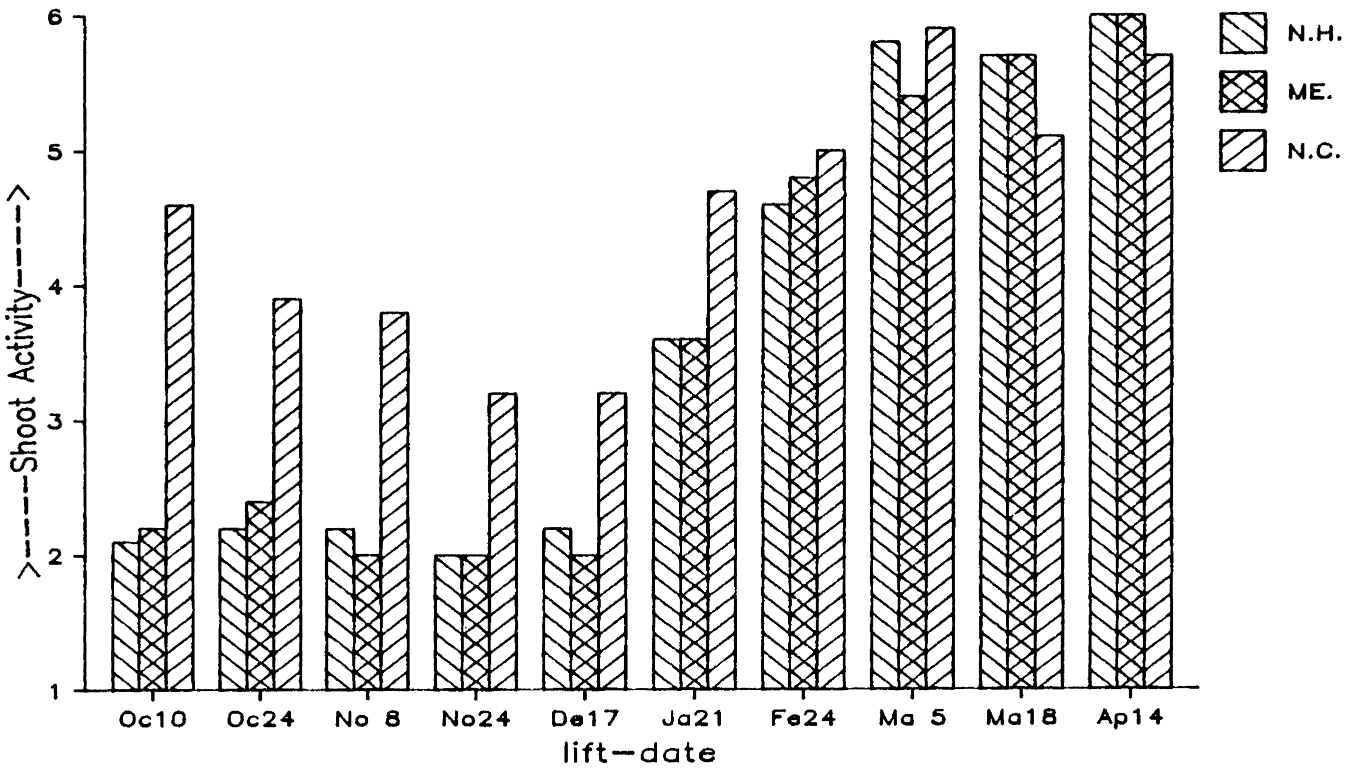

Figure 10.Seasonal shoot activity of New Hampshire (N.H.), Maine (M.E.), and North Carolina (N.C.) provenances of 1-0 eastern white pine seedlings as reflected in shoot activity scale value (described in text) at the end of a 21 day hydroponic Root Growth Potential (RGP) test. Seedlings were lifted between October 10, 1986 and April 14, 1987 from the Virginia Department of Forestry's Augusta nursery.

test and bud activity progressively decreased to swelling terminal buds at the end of the December 17 test (Figure 10). From January 21 to April 14, northern provenances first accelerated and then surpassed the North Carolina provenance in bud activity at the end of the RGP test. An inventory of seedlings lifted on April 14 showed that 98 percent of seedlings of northern provenances had already broken bud in the nursery bed. Only 15 percent of southern seedlings had broken bud in the nursery bed.

Discussion

In contrast to all other variables examined in this study, there was no clear north-south pattern apparent in seedling RGP (Figure 9). In fact, when root collar diameter is used as a covariate, provenance is no longer a significant source of variation. The higher RGP of southern provenances is apparently due to these seedlings being generally larger and thus having more resources to generate more root growth.

As mentioned, even when using root collar diameter as a covariate, family is still a significant source of variation. Although there are significant genetic differences, the standard errors associated with heritability estimates from the first nine lift-dates and for the combined estimate (Table 8) indicate that RGP in

1-0 eastern white pine is under minimal genetic control. This is further supported by the fact that heritability estimates for the October 24 and February 24 lift-dates are negative values. This is due to negative estimates for the family component of variance for these lift-dates. In light of the large standard errors associated with these estimates, it is reasonable to assume that neither the component estimate or the heritability differed significantly from zero.

Only the latest lift-date, April 14, had a relatively high heritability (0.85 ± 0.29). The range in RGP was low at this lift with the best family (N.C. 16) averaging 2.4 new roots, ten families ranging 0.25 to >0 new roots, and five families growing 0 new roots. This minimal selection differential indicates that selection in 1-0 stock would still not be gainful even for late lift-dates.

Although this study was undertaken using 1-0 bare-root eastern white pine seedlings, it is the normal industry practice to lift and outplant 2-0 seedlings. One-year-old and 2-0 stock have been shown to have very different patterns of seasonal RGP (Chapter 3) with 2-0 seedlings having a much more limited period of high RGP. It is possible that genetic control of 2-0 eastern white pine seedlings is stronger. Considering the short "lifting windows" for 2-0 stock, this probably deserves further study.

The patterns of shoot growth in northern and southern provenances of eastern white pine are typical of forest tree species (Wright 1976). Northern provenances had minimal visual shoot activity during the first lift-date (Figure 2). This indicates that they were already in full rest. These northern provenances had all been transferred over 600 miles south of their origin and the early dormancy induction was probably due to a photoperiod response. Conversely, the southern provenances were transferred slightly north of their origin. These southern provenances have adapted under much warmer autumn conditions and continue growth under shorter photoperiods than the northern provenances, thus the southern provenances maintained higher shoot activity through the autumn (Figure 10). The general size superiority (Table 8) of southern provenances is probably largely due to the differences in timing of dormancy induction which allowed southern provenances to continue growing until a later date.

Mergen (1963) examined dormancy release in northern and southern sources of three-year-old eastern white pine seedlings. In general, seedlings from regions having shorter growing seasons broke dormancy most rapidly. His experiment was undertaken in a northern environment (Connecticut) and apparently all seed sources had entered full rest by late September. Differences in autumn shoot activity between northern and southern provenances seen in this study are more influenced by differential dormancy induction rather than differential dormancy release. By spring (Figure 10), northern provenances had surpassed southern provenances in shoot activity. Northern provenances may have been more rapidly responding to heat accumulation, (Wright 1976). This is further supported by the large differences in budbreak in the nursery beds on the April 14 lift-date.

The large differences in autumn shoot activity between northern and southern provenances (Figure 10) were not accompanied by any large differences in autumn RGP between the sources (Figure 9). This largely dismisses the importance of seedling dormancy status in controlling RGP in 1-0 eastern white pine seedlings. Dormancy status has previously been considered an important factor in RGP (Ritchie and Dunlap 1980). Two-year-old stock of eastern white pine has a very different pattern of seasonal RGP than 1-0 stock (Chapter 3). The relationship of RGP to dormancy status is strong within a range of bud dormancy status although it is not clear if this is a causative relationship (Chapter 3). If bud dormancy plays a larger role in controlling RGP in 2-0 stock, then seed source differences in 2-0 eastern white pine seedlings may be greater than those displayed using 1-0 stock.

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CHAPTER 5

ROOT GROWTH POTENTIAL AS A PREDICTOR OF FIRST YEAR FIELD PERFORMANCE FOR NON-IRRIGATED AND IRRIGATED EASTERN WHITE PINE SEEDLINGS

Abstract

Root Growth Potential (RGP) has been shown to be a good predictor of survival probability after outplanting. It has been suggested that the relationship between RGP and field performance might be strengthened when seedlings are planted on a stressful site. An experiment was conducted where seedlings of known RGP were planted at two levels of water stress. Eastern white pine (*Pinus strobus* L.) seedlings were hand lifted from nursery beds on eight occasions from October 15, 1985 to March 19, 1986. Seedlings from the first seven lifts were stored at 2C and following the last lift-date, seedlings from all eight lift-dates were included in a 21 day hydroponic RGP test. These treatments resulted in sets of seedlings with varying RGP. Subsets of seedlings from each lifting date were included in a field outplanting test. A split-plot design was used for the study with irrigated versus non-irrigated treatments as mainplots and lift-date as subplots. RGP does show promise as a measure of eastern white pine seedling quality. The consistent ability of a seedling lot to produce new roots appears to be more important than the average number of new roots or morphological attributes in predicting field performance. RGP was significantly correlated with height increase and the relationship was strengthened on non-irrigated plots.

Introduction

Good quality forest tree seedlings providing low mortality and rapid growth are always a desired component of any reforestation program. Nurserymen have long sought a seedling grading system that will accurately and consistently predict outplanting success. Although it has been decades since Wakeley (1948) first discussed the importance of seedling physiological status, morphological grading still remains the industry's principal method of rating seedling quality.

In 1955, Stone introduced the concept of Root

Growth Potential (RGP) as a simple method of measuring the ability of a bare-root seedling to produce new roots after planting. Theoretically, a seedling with high RGP could rapidly re-establish contact with the soil and thus capitalize on available soil moisture and nutrients. More recently, Ritchie (1985) has suggested that RGP may be considered a general measure of seedling vigor because it is actually an indirect test of the status of several critical physiological systems.

Since being introduced by Stone (1955), RGP has been the focus of numerous studies and, in general, RGP is a good predictor of seedling field performance. Direct relationships have been found between RGP and subsequent field performance in several members of the Pinaceae, including: loblolly pine (Pinus taeda L.), ponderosa pine (Pinus ponderosa Laws), lodgepole pine (Pinus contorta Dougl.), and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franko.) (Feret et al. 1984, Jenkinson and Nelson 1983, Ritchie et al. 1985, Ritchie and Dunlap 1980).

There have been several notable exceptions where RGP has not predicted or has been a poor predictor of first year survival and/or first year growth (Rhea 1977, Sutton 1983, Brissette and Roberts 1984, Dewald et al. 1985). In the latter two cases, the authors noted that first year survival was excellent and that field conditions were not very stressful. This implies that differences in root growth and general physiological condition may be of varying importance under different field conditions.

This study was undertaken to examine the relationship of RGP and first year field performance under two levels of moisture stress using eastern white pine (Pinus strobus L.). There have been no previously reported experiments examining RGP/field performance with eastern white pine. An understanding of RGP-field performance relationships might be helpful for allocating seedlings of differing physiological quality to sites of varying quality.

Methods and Materials

Two-year-old eastern white pine seedlings were hand lifted on eight occasions from October 15, 1985 to March 19, 1986. Seedlings were lifted from the Virginia Division of Forestry's Augusta nursery (Waynesboro, VA.). On each lift-date, seedlings were randomly selected from each of three pre-established blocks. Seedlings from the first 7 lift-dates were double wrapped in polyethylene bags and placed into cold storage at 2C.

Following the last lift-date, 15 seedlings per block/lift date combination were included in a 21 day hydroponic RGP test as described by Dewald et al.(1984). Blocking for the RGP test was maintained as from the nursery. Following the test new white roots greater than or equal to 0.5 centimeter in length were counted. Dry weight of roots and shoots were determined after drying to a constant weight at 60C.

Three days after the initiation of the RGP test (March 23 and 24, 1976) subsamples from each block/lift-date combination were outplanted at the Reynolds Homestead Research Center (Critz, Virginia). The outplanting consisted of three replicate blocks (maintained as from the nursery and the RGP test) planted on a plowed and disked old field site. A split-plot design was used with irrigated vs non-irrigated treatments as the mainplot and lift-dates as subplots. Each mainplot was then randomly planted, using 0.5 meter spacing, with eight seedlings from each of the appropriate block/lift-date combinations. Seedlings were root pruned to 12 cm below root collar, the same procedure used for the RGP test.

Drip irrigation was provided around the stem of each seedling in a irrigation treated mainplot. Water was provided as needed so that irrigated trees received no less than 2.54 centimeters of natural and/or supplemented precipitation per week. On July 17, all plots were hand weeded. On two dates, June 24 and July 17, mid-day needle water potential was measured on two randomly selected seedlings from each outplanting mainplot for both the

January 3 and the March 19 lift-dates. Seedling water potential was measured on a single needle fascicle using a pressure bomb.

Seedling height growth and diameter growth was determined by measuring seedlings at time of outplanting and again on September 5. Survival data was collected on May 30, June 24, July 17, and September 5.

To assess the effect of the irrigation treatment, seedling water potential, survival, height growth, and diameter growth were analyzed using Analyses of Variance with a split-plot design. General linear regression was used to determine the relationships between morphological traits and RGP measurements to survival, height growth, and diameter growth. Morphological traits used were root collar diameter, shoot weight, root weight, and root/shoot ratio. RGP measurements used were number of roots and percent poor seedlings (a poor seedling was defined as one producing less than 2 new roots). Analyses were made using block means. Data from irrigated and non-irrigated treatments were analyzed separately.

Results

Irrigation Treatments

Analyses of variance showed no significant effect due to irrigation on end of season survival, height increment, relative height increment (height increment/initial height), diameter increment, and relative diameter increment (diameter increment/initial diameter). Survival as measured on May 30 and seedling water potential as measured on both June 24 and July 17 did show significant differences in irrigation treatment at the alpha = 0.05 level. Means for both irrigation treatments are shown in Table 9.

Precipitation data for the time period studied and survival for two irrigation treatments are shown in Figure 11.

Predictions of Field Performance

Morphological Traits.

With a few exceptions, morphological traits were generally not significantly correlated to field performance (Table 10). Root/shoot ratio was significantly and positively correlated ($P \leq .05$) to height increment on non-irrigated plots. Root collar diameter was significantly and positively correlated in one instance but was not a consistent predictor of first year field performance.

Seedling RGP.

Seedling RGP was more consistently correlated with first year field performance than morphological traits (Table 10). Although RGP was inconsistent in predicting seedling survival and showed no significant correlations

Table 9. Means of first year field performance for irrigated (Irr) and non-irrigated (Non) eastern white pine seedlings.

	Irr	Non	
% Survival (May 30)	89	77	**
% Survival (Sept. 5)	74	76	ns
Hgt Increment (cm)	10.10	8.00	ns
Relative Hgt. Inc. (Hgt Inc./initial hgt.) (%)	48	40	ns
Diameter Increment (mm)	1.76	1.69	ns
Relative Diam. Inc. (Diam. inc./init. diam.) (%)	44	44	ns
Needle Water Potential (MPa)			
June 24	-1.13	-1.58	**
July 17	-1.18	-1.57	**

ns P > 0.10 : * P < or = 0.10 ; ** P < or = 0.05 ;
*** P < or = 0.01

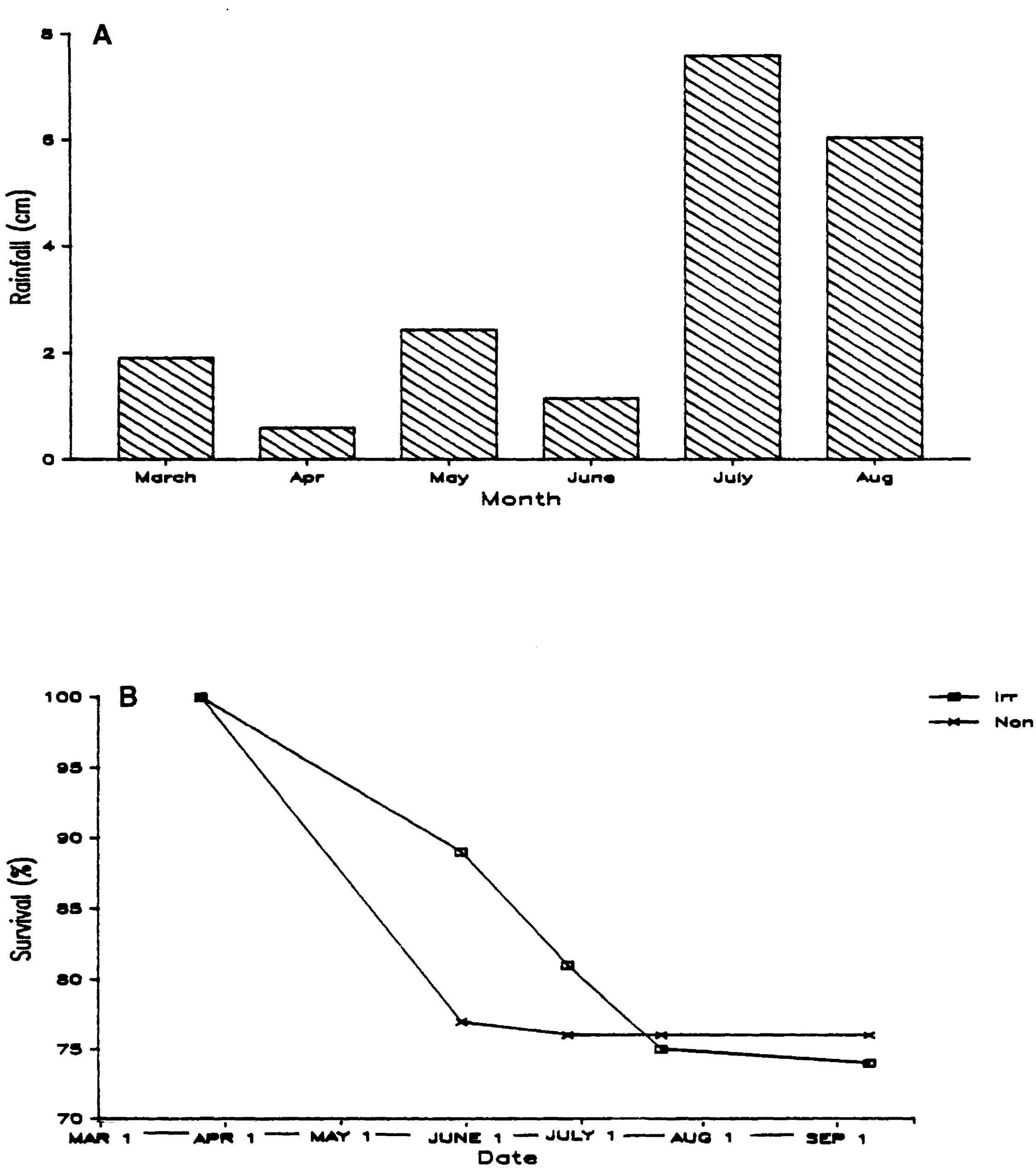

Figure 11.(A) Spring and summer precipitation at Reynolds Homestead Research Center, Critz, VA. and (B) first year survival for irrigated (Irr) and non-irrigated (Non) outplanted eastern white pine seedlings.

Table 10. Correlations (n = 24) between first year field performance and Root Growth Potential (RGP) and morphological traits of irrigated (Irr.) and non-irrigated (Non.) eastern white pine seedlings.

Field Performance		Seedling RGP: New roots (number)	Seedling RGP: % poor seedlings (%)	Morphological traits: Root collar diameter (mm)	Morphological traits: Shoot wgt. (g)	Morphological traits: Root wgt. (g)	Morphological traits: Root to shoot ratio
Survival (%)							
May 30	Irr.	.05 ns	-.25 ns	.00 ns	.33 ns	.31 ns	.01 ns
	Non.	.04 ns	-.15 ns	.03 ns	.06 ns	.10 ns	.10 ns
Sept. 5	Irr.	.09 ns	-.44**	.00 ns	.33 ns	.31 ns	.29 ns
	Non.	.10 ns	-.22 ns	-.07 ns	.04 ns	.03 ns	.16 ns
Height increment							
Total (cm)	Irr.	.20 ns	-.31 ns	.36*	.05 ns	.11 ns	.31 ns
	Non.	.25 ns	-.52***	.31 ns	.03 ns	.27 ns	.44 **
Relative (%)	Irr.	.24 ns	-.37*	.03 ns	.15 ns	.01 ns	.29 ns
	Non.	.40**	-.60***	.06 ns	.01 ns	.26 ns	.47**
Diameter increment							
Total (cm)	Irr.	.25 ns	-.08 ns	.13 ns	.18 ns	.21 ns	.13 ns
	Non.	.09 ns	-.21 ns	.40**	.12 ns	.05 ns	.21 ns
Relative (%)	Irr.	.21 ns	-.16 ns	---[1]	.02 ns	.05 ns	.11 ns
	Non.	.04 ns	-.10 ns	---[1]	.17 ns	.23 ns	.16 ns

ns P > or = 0.10 ; * P < or = 0.10 ; ** P < or = 0.05 ; *** P < or = 0.01

1 regression not run due to dependency of variables

with diameter increment, it was a consistent predictor of relative height increment. RGP showed better correlations with height increment on non-irrigated plots. RGP as measured as percent poor trees (percentage of seedlings in RGP test growing less than 2 new roots) was more often correlated with field performance than RGP as measured by average number of new roots.

F tests show no significant differences in slope or intercept between irrigated and non-irrigated data in a regression of percent poor trees on relative height increment. However, when separate equations are fit to both sets of data, the regression using the non-irrigated data provides a much better fit than that using the irrigated data (Figure 12).

Discussion

Although there were no significant irrigation differences as reflected in end of season survival or growth, there were definite differences in seedling stress levels between the two treatments as is seen by the significant differences in seedling water potential. Irrigation seems to have postponed mortality (Figure 11) but did not prevent it. Apparently, certain seedlings were of such low quality that they could not survive even with sufficient moisture.

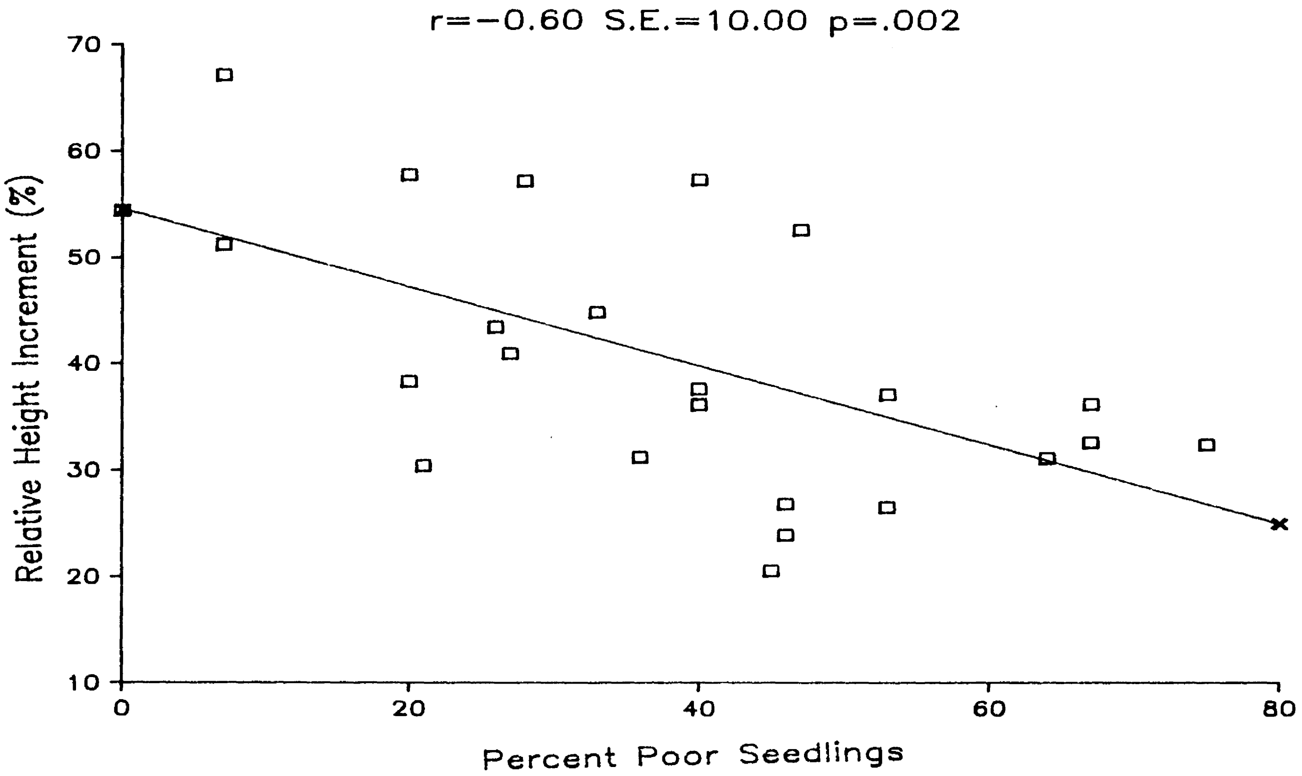

Figure 12. Relationship between percent poor seedlings and relative height increment for non-irrigated outplanted 2-0 eastern white pine seedlings.

It is not surprising that first year height growth did not differ significantly between irrigation treatments as eastern white pine exhibits fixed growth which is highly influenced by production of needle primordia the previous summer in the nursery. Since relative height increment was increased 17 percent on irrigated plots, it does appear that cell elongation and/or division of the pith meristem was enhanced by irrigation. The lack of any difference in relative diameter increment may have been because most diameter growth occurs in the second half of the summer and by then rainfall was providing more adequate soil moisture.

RGP was a better predictor of height increment on non-irrigated plots than on irrigated plots. It appears that performance attributes such as RGP and some material attributes such as root/shoot ratio become more influential on first year field performance as field conditions become more severe.

Percent poor trees accounted for 36 percent of the variation in relative height growth of non-irrigated trees which was considerably better than any morphological trait. Since eastern white pine is a determinant species, RGP may provide as good or better correlations with second year growth. General vigor during the first summer could potentially impact needle primordia production which will largely determine the next years growth.

Although RGP did not show a good linear relationship with survival, it does seem to have some value as a predictor of seedling survival. Figure 13 shows a plot of percent survival versus percent poor seedlings for both irrigated and non-irrigated trees. There appears to be a threshold level at about 35 percent poor seedlings below which there is consistently high outplanting survival. Seedling lots with less than 35 percent poor seedlings (42 percent of those tested) in the RGP test resulted in an average of 88 percent survival with a coefficient of variation (C.V.) of 15 percent. Seedling lots with over 35 percent poor seedlings in the RGP test were highly variable in survival response and resulted in an average of 66 percent survival with a C.V. of 38 percent. Irrigated and non-irrigated seedlings show approximately the same response.

Percent poor seedlings was a better predictor of both survival and height growth than average number of new roots. Storing seedlings apparently did not provide a large enough range in the average number of new roots produced. The average number of new roots, after storage, from the first 7 liftdates only ranged from approximately 3 to 8, while lift 8 (March 19) seedlings produced an average of 16 new roots (Chapter 1). March 19 seedlings generally displayed the best first year field performance. An average number of

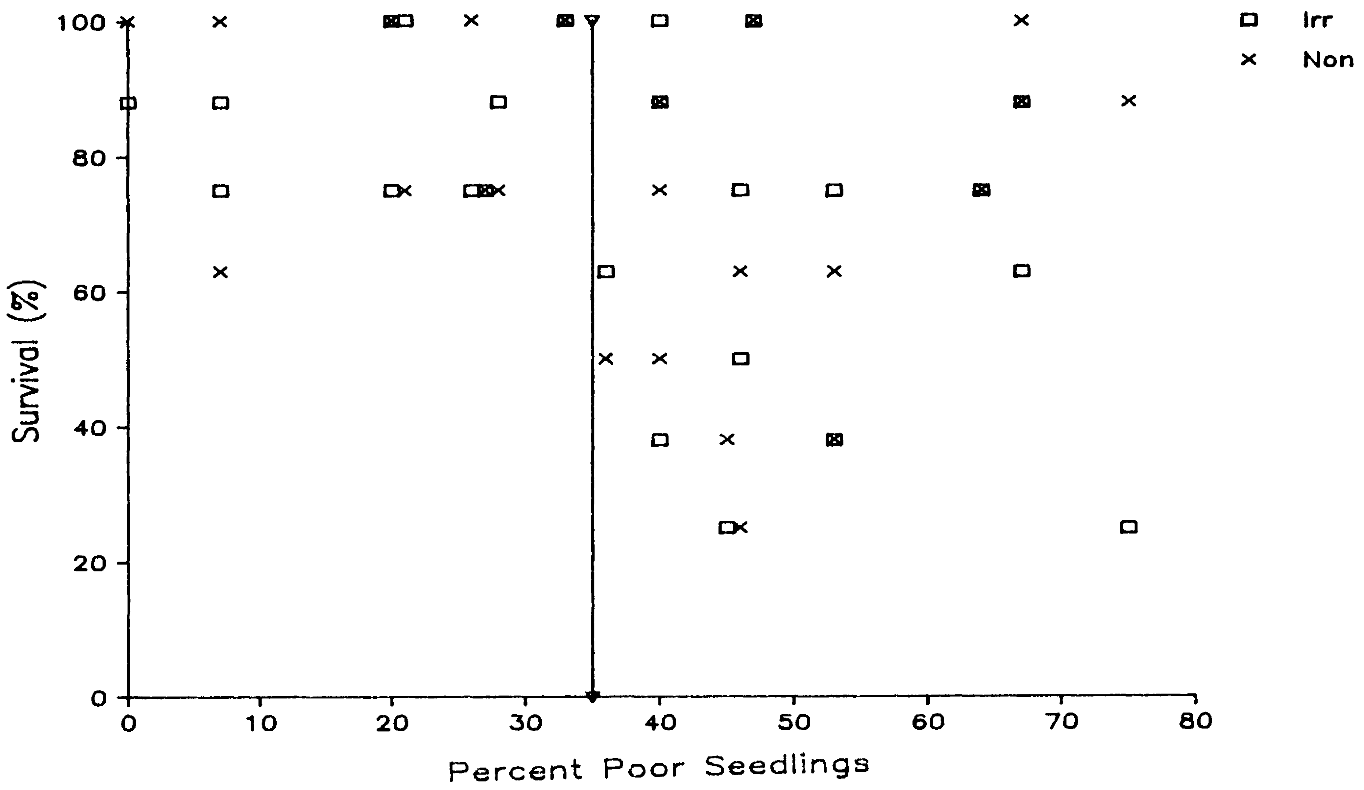

Figure 13. Relationship between percent poor seedlings and first year survival for irrigated (Irr) and non-irrigated (Non) outplanted 2-0 eastern white pine.

new roots produced of 3 versus 8 is apparently unimportant in regard to field performance. Conversely, storage treatments did provide a large range in percent poor seedlings (Figure 13). In this case, this higher variability between seedlots makes percent poor seedlings a much more useful measure of seedlot quality than the average number of new roots produced.

Conclusions

It appears from this study that RGP does show promise as a measure of eastern white pine seedling quality. In this study, the consistent ability of a seedling lot to produce roots appears to be more important than the average number of new roots or than morphological attributes in predicting field performance. A threshold seems to exist where the best seedling lots, by measuring percent poor seedlings, provide consistently excellent survival. RGP is significantly correlated with height increase and the relationship is strengthened on non-irrigated plots.

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CHAPTER 6

COMPARISON OF GREENHOUSE AND ENVIRONMENTALLY CONTROLLED GROWTHROOM ROOT GROWTH POTENTIAL TESTING OF 2-0 EASTERN WHITE PINE SEEDLINGS

Abstract

Two-year-old eastern white pine (*Pinus strobus* L.) seedlings were measured for Root Growth Potential (RGP) over two years in both a greenhouse and an environmentally controlled growthroom. Analyses of variance resulted in no significant differences (alpha = 0.05) between testing environments for either year. This study demonstrates the validity of using greenhouse RGP testing for 2-0 eastern white pine.

Introduction

Stone (1955) introduced the concept of Root Growth Potential (RGP) as a simple method of measuring the ability of a bare-root seedling to produce new roots after planting. Since then, RGP has been the focus of numerous studies and, in general, RGP has proven to be a good predictor of seedling field performance (Feret and Kreh 1985, Feret et al. 1984, Jenkinson 1978, Ritchie et al. 1985, Ritchie and Dunlap 1980).

RGP testing is typically conducted in greenhouses (Dewald et al. 1984, Jenkinson 1975, Carlson 1985, Krugman and Stone 1966). Although RGP tests conducted in greenhouses are far less expensive, they do not permit the experimental control possible if tests were performed in an environmentally controlled growthroom. In studies examining seasonal variation, the greenhouse environment will vary in regard to light quantity, light quality, and temperature extremes. Such variation in the testing environment is tolerable only if it is established that it does not significantly influence RGP. This study was initiated to compare the seasonal patterns of RGP simutaneously tested in a greenhouse and growthroom environment, using 2-0 eastern white pine (Pinus strobus L.).

Methods and Materials

Two-year-old (2-0) eastern white pine seedlings were hand lifted on nine occasions btween November 11, 1985 and April 21, 1986 and on eleven occasions between October 10, 1986 and April 14, 1987. Seedlings were lifted from the Virginia Department of Foresty's Augusta nursery (Waynesboro, VA.). On each lift date seedlings were randomly selected from each of three blocks. Blocks were randomly pre-established in commercial nursery beds at the start of each lifting season. Seedlings were wrapped in polyethylene bags, placed in an ice chest, and transported to the Virginia Polytechnic and State University campus located in Blacksburg, VA.

On either the day of the lift or the day after, 15 seedlings per block were placed in a greenhouse hydroponic RGP testing system as described by Dewald et al. (1984). Another 15 seedlings per block were placed in a duplicate system located in an environmentally controlled growthroom. The growthroom was maintained at 20C day and night temperatures and a 16 hour photoperiod (60 uM $m^{-2} \cdot s^{-1}$

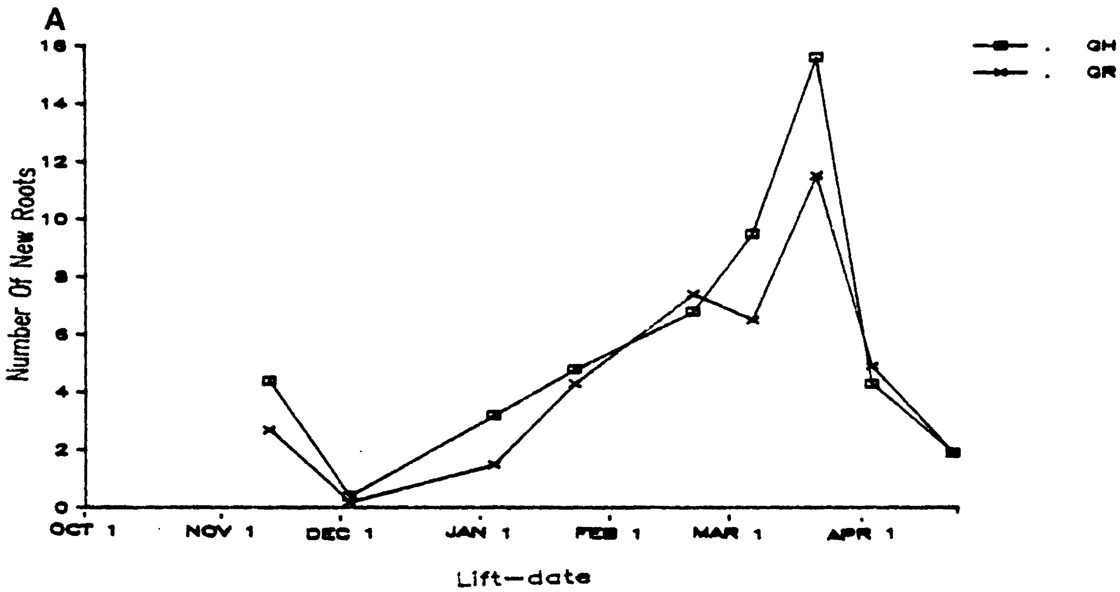
photosynthetic photon flux density). After 21 days in the two environments, seedlings were removed and all new roots greater than 0.5 cm were counted.

The two years of data were analyzed separately. Analyses of Variance using a completely randomized block the two testing environments. Correlations between values obtained in the two environments, using lift means, were also computed.

Results and Discussion

Greenhouse RGP testing provided comparable results to environmentally controlled growthroom RGP testing for both years studied (Figure 14). Analyses of variance result in no significant differences in testing environment at the 0.05 level for either year. The correlations between the two systems for 1985-86 and 1986-87 were 0.93 and 0.88, respectively.

Apparently, changes in seedling physiology of 2-0 eastern white pine pine have more influence on the seasonal patterns of RGP than does any flux in the greenhouse environment. This may or not hold true for other species. This study demonstrates the validity of using greenhouse RGP testing for 2-0 eastern white pine.



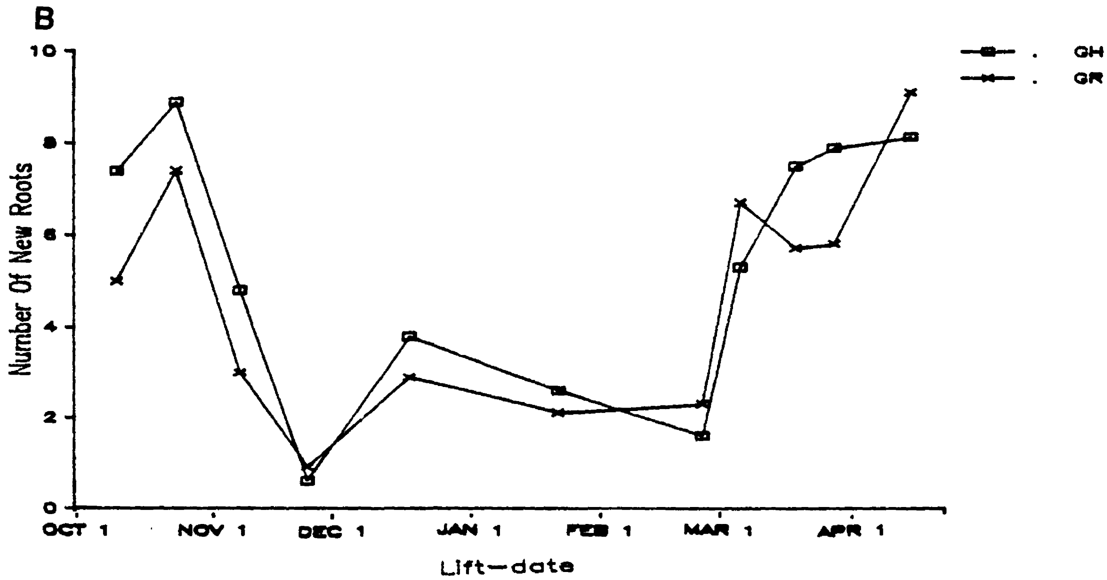


Figure 14. Seasonal RGP (number of new roots) for greenhouse (GH) and growth room (GR) tested 2-0 eastern white pine seedlings lifted during (A) 1985-86 and (B) 1986-87 from the Virginia Dept. of Forestry's Augusta nursery.

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CHAPTER 7

OVERALL SUMMARY AND CONCLUSIONS

During the first year of study two-year-old (2-0) eastern white, red, and Scotch pine seedlings had similar patterns of seasonal Root Growth Potential (RGP) with a sharp RGP peak limited to mid-March. All three species of 2-0 stock displayed a positive linear relationship between RGP and Dormancy Release Index (DRI); however, only in 2-0 eastern white pine seedlings was this relationship statistically significant. The RGP/DRI relationship in 2-0 eastern white pine seedlings was not consistent for both years of the study. The RGP/DRI relationship in 2-0 eastern white pine was strong during both years within the DRI range of 0.22 to 1.00 which takes place from approximately early-December to late-March. Although seedlings are progressing through dormancy during this period, the nursery environment is also progressing through a transition period. RGP may or may not be causatively correlated to DRI. The RGP/DRI relationship may be due to dormancy release being correlated to the development of nursery environmental conditions that promote increased RGP. Further study is necessary to eliminate the confounding nursery environment effects so that the true RGP/DRI relationship of 2-0 eastern white pine seedlings can be determined. A study such as by Stone et al. (1963) where potted seedlings were subjected to specific hours of cold while all other conditions remained standard may be useful for this purpose.

One-year-old and 2-0 eastern white pine seedlings displayed quite different seasonal patterns of RGP over both years studied. Although missing DRI data for 1-0 stock makes it difficult to relate this to differences in dormancy release between the two age classes, the genetics study showed that vast differences in shoot activity between northern and southern provenances of 1-0 stock did not translate into RGP differences. Thus, this casts doubt on the importance of DRI differences in influencing the vast seasonal RGP differences witnessed between 1-0 and 2-0 eastern white pine. Further studies that provide information on why 1-0 and 2-0 stock difer in RGP patterns may provide key insights into the physiology of root growth.

Regardless of the lack of physiological explanations, the large differences in RGP between 1-0 and 2-0 bare-root stock point to the possibility of outplanting 1-0 eastern white pine in lieu of the normal industry practice of outplanting 2-0 stock. Over both years 1-0 stock had much wider "lifting windows" for high RGP than 2-0 stock. In fact, while high periods of RGP were very limited in 2-0 stock, 1-0 stock maintained relatively high RGP over most lift-dates. In addition, 1-0 seedlings were only about 1/5 the size of 2-0 stock in needle and stem dry weight (Table A1). Thus, the higher root growth of 1-0 stock supports a smaller seedling. Theoretically, this would result in a seedling which is able to maintain a much more favorable water status therefore promoting higher levels of photosynthesis and growth in general. This may also minimize transplant "shock" during the first year. If 1-0 stock can be outplanted successfully, there is a final advantage in that they can be produced at a substantially lower cost than 2-0 stock. Additional research is necessary to evaluate the feasibility of outplanting 1-0 eastern white pine seedlings.

Although there were large differences in RGP between age classes within eastern white pine there was little genetic differences within the species using 1-0 stock. This is in spite of the fact that half-sib families from near the southern and northern boundaries of the species range were utilized. Northern and southern provenance differences were observed in seedling morphology with southern provenances generally having the largest seedlings. Although, southern provenances did have slightly higher overall RGP, there were no significant differences in RGP between provenances when a morphological attribute such as root collar diameter was used as a covariate in analyses. When using analyses of covariance, family was still a significant source of variation in RGP although heritability values suggest RGP is under minimal genetic control in 1-0 eastern white pine.

Northern and southern provenances did show interesting trends in regard to patterns of shoot activity from October until April. Southern provenances maintained higher shoot activity at the end of the RGP test during the autumn months. This was probably largely a photoperiod response. By April, northern provenances had surpassed southern provenances in shoot activity and this was probably due to northern provenances responding more quickly to spring heat accumulation. Differences in shoot activity between provenances was clearly mediated by selection pressures in the respective regions.

As mentioned, the large genetic differences in shoot activity between the provenances did not result in large RGP differences. This indicates that bud dormancy status does not highly influence RGP in 1-0 eastern white pine seedlings. More genetic differnences in RGP might be expected in 2-0 eastern white pine seedlings if the RGP/DRI relationship witnessed in 2-0 stock proves to be of a causitive nature.

First year storage results point to the potential degrading effects of mold formation in seedling bundles. Mold formation occured even at storage temperatures of 2C. It is becoming a routine practice in the western United States to store conifer seedlings at -2C (Hee 1987). This practice may be useful with eastern species such as eastern white pine. Further studies should include sub-freezing storage treatments to evaluate RGP response to storage.

The outplanting study resulted in RGP being a good predictor of first year relative height growth of 2-0 eastern white pine seedlings. The predictive ability of RGP was increased on non-irrigated versus irrigated seedlings. The consistent ability of a seedling lot to produce new roots was a better predictor of height growth than the average number of new roots produced by the seedling lot. This is apparently due to the fact that storage treatments did not result in a wide range in the average number of new roots produced between seedling lots. In retrospect, it may have been better to have used seedlings that had been subjected to varied nursery cultural practices, from different nurseries, or had been subjected to different levels of dessication to create a wide range in average number of new roots. To remove confounding effects, perhaps a combination of the above treatments could be used. Thus, the importance of the above factors and of new root growth could be assessed.

Thus, eastern white pine can be seen to be a particularly good species to continue further investigation into the physiology that controls RGP. Two-year-old stock maintained narrow "lifting windows" of high RGP during both years. Although seasonal patterns were quite different during both years the high correlation between greenhouse and growth room testing indicate that seedling physiology highly influences RGP. These changes in seedling physiology may be mediated through internal and/or external control. Conversely, from October to the end of March, it is an exception when 1-0 stock does not have high RGP. As mentioned, an examination into why the two age classes perform so differently may answer numerous questions regarding root growth. These factors, along with a strong pattern of bud dormancy, would make eastern white pine a fine candidate species for modeling the control of root growth.

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APPENDIX A

MORPHOLOGICAL DATA FOR 1-0 AND 2-0 EASTERN WHITE PINE, 2-0 RED PINE, AND 2-0 SCOTCH PINE SEEDLINGS LIFTED IN 1985-86 AND 1986-87 FROM THE VIRGINIA DEPT. OF FORESTRY'S AUGUSTA NURSERY

Table A1. Means of seedling morphological attributes for 1-0 and 2-0 eastern white pine (WP), 2-0 red pine (RP), and 2-0 Scotch pine (SP) seedlings lifted during 1985-86 (Year 1) and 1986-87 (Year 2) from the Virginia Dept. of Forestry's Augusta nursery.

Morphological attribute		Species			
		1-0 WP	2-0 WP	2-0 RP	2-0 SP
Shoot length (cm)	Year 1	10.92	20.22	15.63	29.41
	Year 2	9.17	21.64	--	--
Root collar diameter (mm)	Year 1	2.22	4.78	4.76	6.06
	Year 2	2.09	4.76	--	--
Needle dry wgt. (g)	Year 1	0.54	2.66	3.88	3.38
	Year 2	0.40	1.99	--	--
Stem dry wgt. (g)	Year 1	0.33	1.57	1.34	2.66
	Year 2	0.13	1.27	--	--
Lateral root dry wgt. (g)	Year 1	0.13	0.29	0.29	0.26
	Year 2	0.09	0.24	--	--
Tap root dry wgt. (g)	Year 1	0.08	0.56	0.58	0.91
	Year 2	0.08	0.51	--	--
Root/shoot ratio (dry wgt.)	Year 1	0.24	0.20	0.17	0.20
	Year 2	0.35	0.22	--	--

Year 1 - For each species, $N \geq 360$.
Year 2 - For each age, $N = 45$.

APPENDIX B

ROOT GROWTH POTENTIAL DATA OF 17 HALF-SIB FAMILIES OF 1-0 EASTERN WHITE PINE SEEDLINGS LIFTED DURING 1986-87 FROM THE VIRGINIA DEPT. OF FORESTRY'S AUGUSTA NURSERY

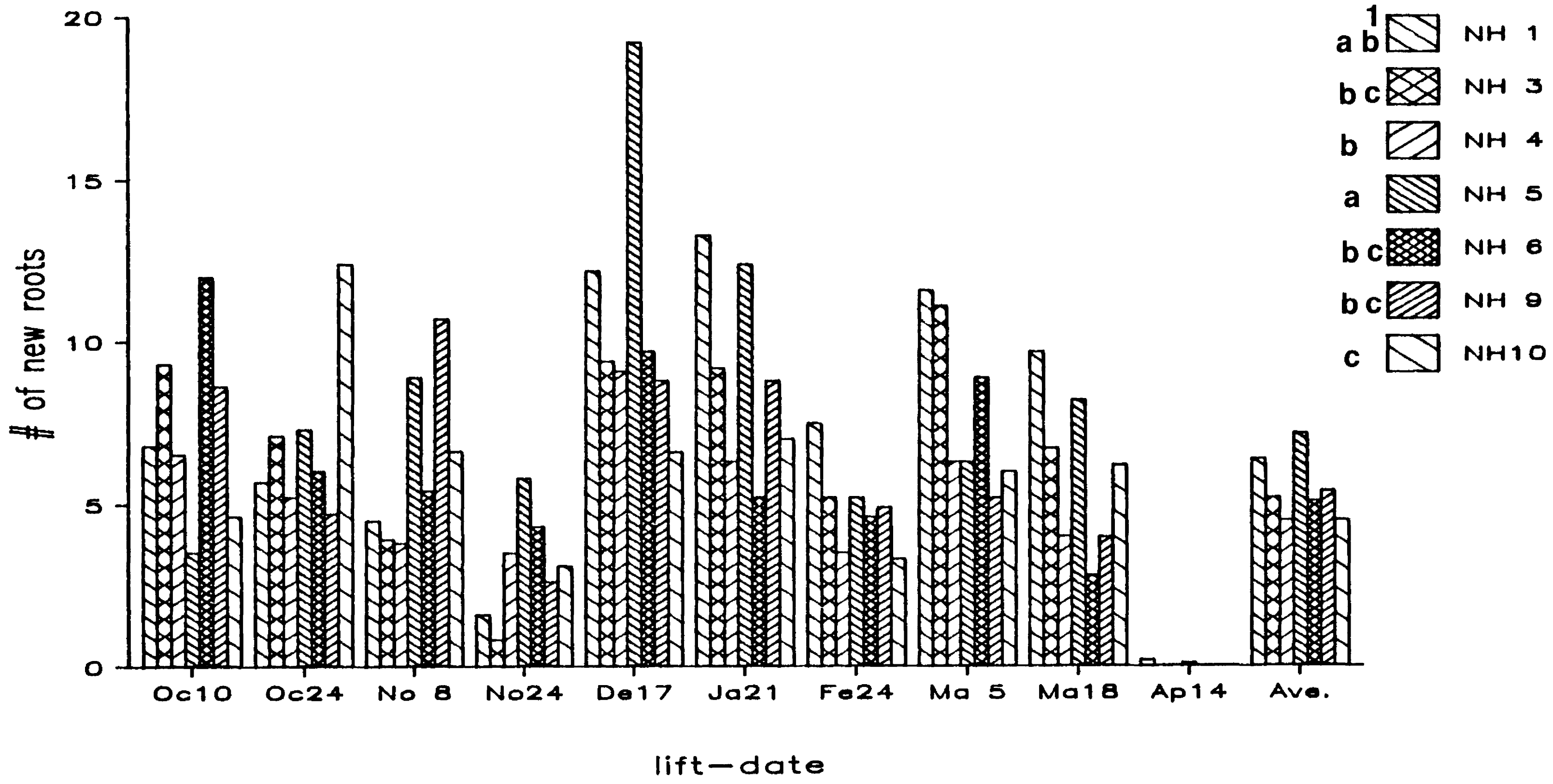

Figure B1. Root Growth Potential (RGP) (number of new roots) for seven New Hampshire families of 1-0 eastern white pine seedlings (NH 1,3,4,5,6,and 9) by lift-date and for overall average (Ave.) RGP. Seedlings were lifted between October 10, 1986 and April 14, 1987 from the Virginia Department of Forestry's Augusta nursery.

[1] Families accompanied by the same letter do not vary significantly in overall average RGP using Duncans Multiple Range test at the alpha = 0.05 level.

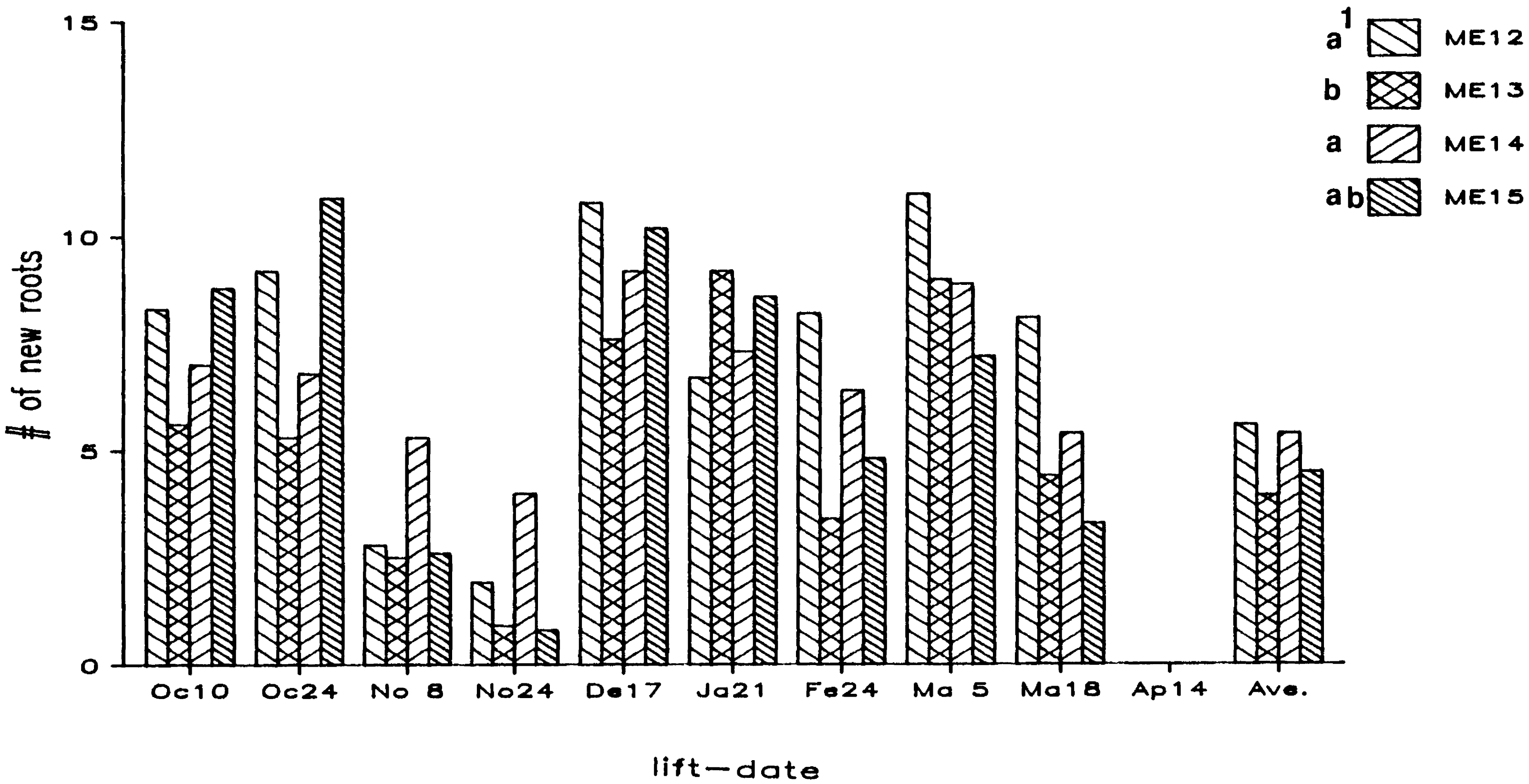

Figure B2. Root Growth Potential (RGP) (number of new roots) for four Maine families of 1-0 eastern white pine seedlings (ME 12, 13, 14, and 15) by lift-date and for overall average (Ave.) RGP. Seedlings were lifted between October 10, 1986 and April 14, 1987 from the Virginia Department of Forestry's Augusta nursery.

[1] Families accompanied by the same letter do not vary significantly in overall average RGP using Duncans Multiple Range test at the alpha = 0.05 level.

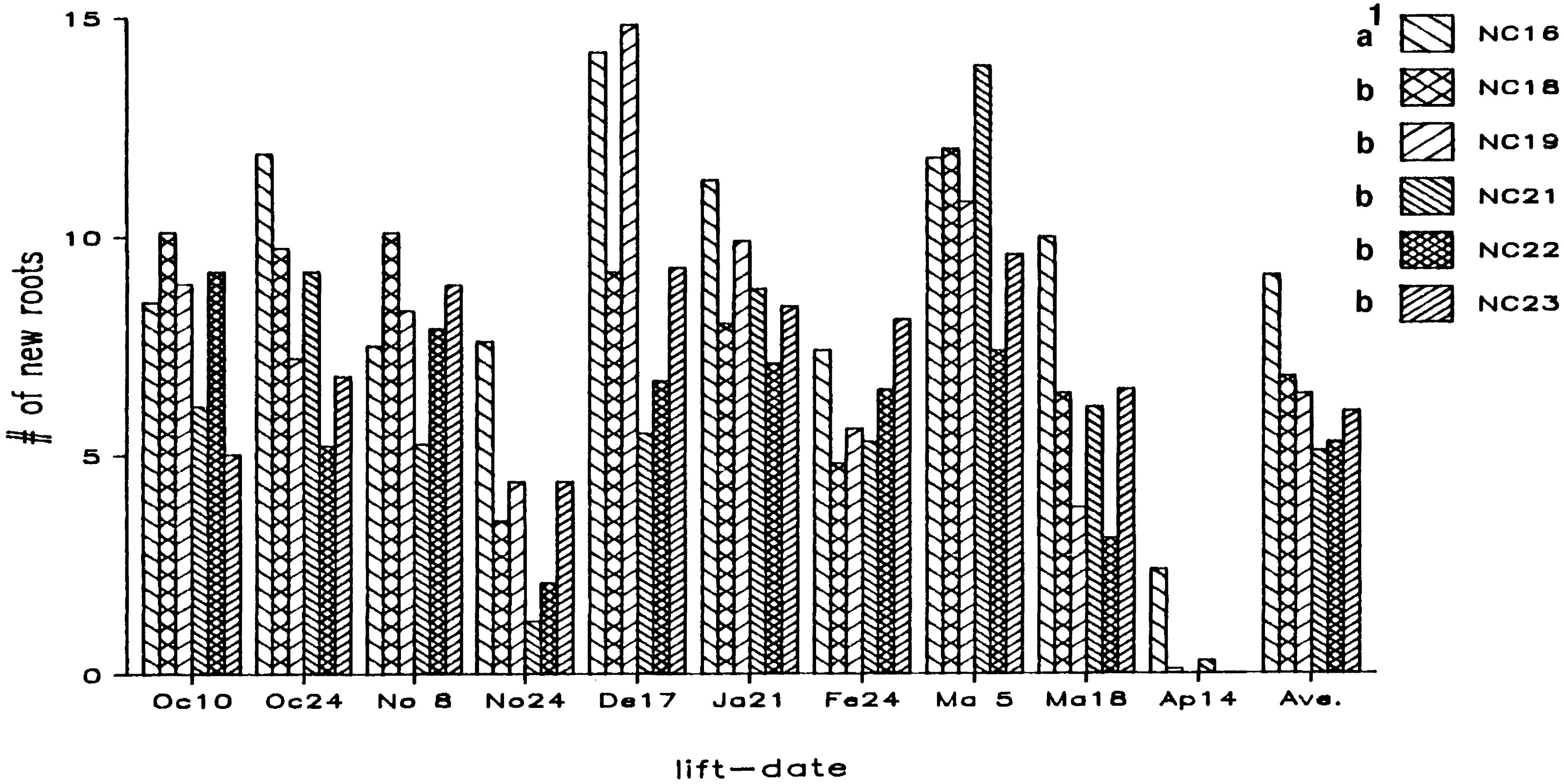

Figure B3. Root Growth Potential (RGP) (number of new roots) for six North Carolina families of 1-0 eastern white pine seedlings (NC 16, 18, 19, 21, 22, and 23) by lift-date and for overall average (Ave.) RGP. Seedlings were lifted between October 10, 1986 and April 14, 1987 from the Virginia Division of Forestry's Augusta nursery.

[1] Families accompanied by the same letter do not vary significantly in overall average RGP using Duncans Multiple Range test at the alpha = 0.05 level.

APPENDIX C

RGP COMPUTER DATA FILES

```
DATA YR1WPDW;
COMMENTS ***** FILE, YR1WPDW DAT **********************
THESE DATA ARE FROM A 1985-86 RGP EXPERIMENT USING ONE-YEAR-OLD
AND TWO-YEAR-OLD EASTERN WHITE SEEDLINGS LIFTED FROM THE AUGUSTA
NURSERY. RGP DATA AND EXPLANTIONS OF VARIABLES CAN BE FOUND IN THE
FILE TITLED: YR1WPRGP DAT.
  DRY WEIGHTS (GRAMS) (CONSTANT WEIGHT AT 60C) WERE MEASURED AFTER
  SEEDLINGS SPENT  21 DAYS IN HYDROPONIC RGP TESTING SYSTEM.
  NEWGT= NEEDLE DRY WEIGHT. MEASURED TO 2ND DECIMAL PLACE (0.0X).
  STWGT= STEM DRY WEIGHT. MEASURED TO 2ND DECIMAL PLACE (0.0X).
  LRTWGT= LATERAL ROOT DRY WEIGHT. MEASURED TO 3RD DEC. PLACE (0.00X).
  TRTWGT= TAP ROOT DRY WEIGHT. MEASURD TO 3RD DECIMAL PLACE (0.00X);
INPUT #1 AGE DATE BLOCK TREE
      #2 NEWGT STWGT LRTWGT TRTWGT;
  IF DATE=315 THEN LIFT=2;
  IF DATE=334 THEN LIFT=3;
  IF DATE=22 THEN LIFT=5;
  IF DATE=64 THEN LIFT=7;
  IF DATE=78 THEN LIFT=8;
CARDS;
      11.000  334.000     1.000     1.000
       1.450    1.040     0.102     0.141
      11.000  334.000     1.000     2.000
       0.560    0.440     0.072     0.043
      11.000  334.000     1.000     3.000
       0.810    0.560     0.141     0.106
      11.000  334.000     1.000     4.000
       0.860    0.620     0.126     0.080
      11.000  334.000     1.000     5.000
       0.850    0.580     0.086     0.109
      11.000  334.000     1.000     6.000
       1.090    0.810     0.196     0.104
      11.000  334.000     1.000     7.000
       1.050    0.830     0.134     0.124
      11.000  334.000     1.000     8.000
       1.430    1.020     0.062     0.144
      11.000  334.000     1.000     9.000
       1.190    0.950     0.178     0.117
      11.000  334.000     1.000    10.000
       0.620    0.410     0.094     0.096
      11.000  334.000     1.000    11.000
       0.880    0.600     0.066     0.100
      11.000  334.000     1.000    12.000
       0.520    0.390     0.078     0.050
      11.000  334.000     1.000    13.000
       0.880    0.650     0.061     0.089
      11.000  334.000     1.000    14.000
       0.810    0.560     0.085     0.072
      11.000  334.000     1.000    15.000
       0.420    0.270     0.050     0.067
      11.000  334.000     2.000     1.000
       0.730    0.480     0.045     0.077
      11.000  334.000     2.000     2.000
       0.990    0.700     0.078     0.111
      11.000  334.000     2.000     3.000
```

```
DATA YR1WPRGP;
COMMENT********** FILE, YR1WPRGP DAT ********************
THESE DATA ARE FROM A 1985-86 RGP STUDY USING ONE-YEAR-OLD AND
TWO-YEAR-OLD EASTERN WHITE PINE SEEDLINGS LIFTED FROM THE AUGUSTA
NURSERY.
FOR INFORMATION SEE THESIS TITLED "ROOT GROWTH POTENTIAL OF THREE
NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE" BY KURT H.
JOHNSEN OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA.
STUDY WAS A RANDOMIZED, COMPLETE BLOCK DESIGN USING THREE BLOCKS.
ON 10 LIFT-DATES, 15 SEEDLINGS WERE LIFTED FROM PRE-ESTABLISHED
BLOCKS PER AGE-CLASS. BLOCKING IN THE RGP TEST WAS MAINTAINED AS FROM THE
NURSERY.
 AGE CLASSES ARE CODED AS FOLLOWS:
   AGE 11 = ONE-YEAR-OLD
   AGE 12 = TWO-YEAR-OLD
LIFT 1 = 10/15/85
LIFT 2 = 11/11/85
LIFT 3 = 11/30/85
LIFT 4 = 1/3/86
LIFT 5 = 1/22/86
LIFT 6 =2/19/86
LIFT 7 = 3/5/86
LIFT 8 = 3/19/86
LIFT 9 = 4/2/86
LIFT 10 = 4/21/86
NS = NUMBER OF NEW ROOTS > 0.5 AND < 1.5 CM
NL = NUMBER OF NEW ROOTS > OR = 1.5 CM
SHT = SHOOT LENGTH FROM ROOT COLLAR TO TERMINAL BUD (CM).
RCD = ROOT COLLAR DIAMETER (MM).
BUD IS AS IN FILE TITLED: FAMRGP DAT.
1986-87 E. WHITE PINE RGP DATA IS LOCATED IN FILE TITLED: YR2WPRGP DAT;
INPUT  #1 AGE DATE BLOCK TREE NS NL
       #2 SHT RCD BUD;
IF DATE = 288 THEN LIFT=1;
IF DATE = 315 THEN  LIFT=2;
IF DATE = 334 THEN  LIFT=3
IF DATE = 3 THEN  LIFT=4;
IF DATE = 22 THEN LIFT=5
IF DATE=50 THEN LIFT=6;
IF DATE = 64 THEN  LIFT=7;
IF DATE=78 THEN LIFT=8;
IF DATE=92 THEN LIFT=9;
IF DATE=111 THEN LIFT=10;
CARDS;
      11.000  3.000  2.000  1.000 23.000  9.000
       8.000  2.500  2.000
      11.000  3.000  2.000  2.000  5.000  5.000
      11.000  2.300  2.000
      11.000  3.000  2.000  3.000  6.000  7.000
      11.000  2.200  2.000
      11.000  3.000  2.000  4.000 15.000 12.000
      13.000  2.900  2.000
      11.000  3.000  2.000  5.000 15.000 17.000
      15.000  2.700  2.000
      11.000  3.000  2.000  6.000 18.000  5.000
```

```
DATA YR2WPRGP;
COMMENT ******** FILE, YR2WPRGP DAT ****************
THESE ARE DATA ARE FROM A 1986-87 RGP EXPERIMENT USING ONE-YEAR-OLD
AND TWO-YEAR-OLD EASTERN WHITE PINE SEEDLINGS LIFTED FROM THE AUGUSTA
NURSERY.
FOR INFORMATION SEE THESIS TITLED "ROOT GROWTH POTENTIAL OF THREE
NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE" BY KURT H. JOHNSEN
OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA.
15 SEEDLINGS WERE LIFTED ON 11 DATES FROM EACH OF THREE BLOCKS PER
AGE CLASS. SEEDLINGS WERE THEN PLACED INTO A 21 DAY HYDROPONIC RGP
TEST WITH BLOCKING BEING MAINTAINED AS FROM THE NURSERY. ONE-YEAR-OLD
SEEDLINGS WERE NOT LIFTED ON 3/27/87.
AGE CLASSES;
   1 = ONE-YEAR-OLD
   2 = TWO-YEAR-OLD
LIFT 1 = 10/10/86
LIFT 2 = 10/24/86
LIFT 3 = 11/8/86
LIFT 4 = 11/24/86
LIFT 5 = 12/17/86
LIFT 6 = 1/21/87
LIFT 7 = 2/24/87
LIFT 8 = 3/5/87
LIFT 9 = 3/18/87
LIFT 10 = 3/27/87
LIFT 11 = 4/14/87
 SEEDLINGS WERE EITHER FOR RGP IMMEDIATLY AFTER LIFTING IN A
 GREENHOUSE (TEST=1) OR IN A GROWTHROOM (TEST=2) OR ELSE SEEDLINGS
 WERE RGP TESTED IN A GREENHOUSE AFTER 4 WEEKS (TEST=3) OR
 8 WEEKS (TEST=4) OF COLD STORAGE (2C).
 NS= NUMBER OF NEW ROOTS > 0.5 AND < 1.5 CM.
 NL= NUMBER OF NEW ROOTS > OR = 1.5 CM.
 SHT = SHT LENGTH FROM ROOT COLLAR TO TERMINAL BUD (CM).
 RCD = ROOT COLLAR DIAMETER (MM).
 BUD = BUD ACTIVITY SCALE AS DESCRIBED IN FILE TITLED: FAMRGP DAT
 DRY WGTS (CONSTANT WGT AT 60C) WERE MEASURED AT THE END OF THE RGP TEST
FOR ONE-YEAR-OLD SEEDLINGS LIFTED 1/21/87 AND FOR TWO-YEAR-OLD SEEDLINGS
LIFTED ON 3/5/87. WEIGHTS ARE IN GRAMS TO 3RD DECIMAL PLACE (0.00X).
NEWGT=NEEDLE DRY WEIGHT.
STWGT=STEM DRY WEIGHT.
LRTWGT=LATERAL ROOT DRY WEIGHT.
TRTWGT=TAP ROOT DRY WEIGHT.
1985-86 EASTERN WHITE PINE RGP DATA IS LOCATED IN
FILE TITLED YR1WPRGP DAT;
INPUT AGE LIFT TEST BLOCK NL NS SHT RCD BUD NEWGT STWGT LRTWGT TRTWGT;
CARDS;
2 1 2 3  00 04 014 . 4
2 1 2 3  10 08 022 . 2
2 1 2 3  00 02 018 . 2
2 1 2 3  02 01 012 . 3
2 1 2 3  00 06 022 . 2
2 1 2 3  00 01 012 . 3
2 1 2 3  00 02 014 . 3
2 1 2 3  00 00 024 . 2
2 1 2 3  02 14 019 . 3
```

```
DATA WPRGPFLD;
COMMENT********** FILE WPRGPFLD DAT **************************
THESE ARE DATA ARE FROM AN RGP OUTPLANTING STUDY ESTABLISHED ON MARCH 23
AND 24, 1986 AT THE REYNOLDS RESEARCH FARM.
THE STUDY UTLIZED TWO-YEAR-OLD EASTERN WHITE PINE SEEDLINGS LIFTED FROM
THE AUGUSTA NURSERY.
THE STUDY UTILIZED A SPLIT PLOT DESIGN WITH IRRIGATION TREATMENTS AS
THE MAIN PLOT AND LIFT-DATE AS THE SUBPLOTS. THERE ARE THREE COMPLETE
BLOCKS.
IRRIGATION WAS PROVIDED VIA INDIVIDUAL DRIP TUBES, SO THAT EACH IRRIGATED
SEEDLING RECEIVED AT LEAST 2.54 INCHES OF NATURAL AND/OR SUPPLEMENTAL
PRECIPITATION PER WEEK.
ALL SEEDLINGS INCLUDED IN OUTPLANTING WERE FROM SUBSETS OF SEEDLING
LOTS TESTED FOR ON MARCH 19. BLOCKING IN OUTPLANTING STUDY IS MAINTAINED
AS FROM RGP TESTING AND FROM NURSERY. 8 SEEDLINGS PER LIFT-DATE WERE
RANDOMLY PLANTED PER SUBPLOT.
FOR INFORMATION SEE THESIS TITLED "ROOT GROWTH POTENTIAL AND BUD DORMANCY
OF THREE NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE" BY
KURT H. JOHNSEN OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA
RGP DATA FROM FIRST 7 LIFT-DATES ARE LOCATED IN DATA FILE
TITLED: YR1WPSTO DAT.
RGP DATA FROM THE LAST LIFT- DATE (LIFT 8) ARE LOCATED IN
DATA FILE TITLED: YR1WPRGP DAT.
SEEDLING HEIGHT FROM ROOT COLLAR TO TERMINAL BUD (CM) AND ROOT COLLAR
DIAMETER (MM) WAS MEASSURED AT THE TIME OF PLANTING AND THEN ON
9/5/86.
    INITHGT= INITIAL SEEDLING HEIGHT AT TIME OF PLANTING (CM)
    INITRCD= INITIAL SEEDLING ROOT COLLAR DIAMETER AT TIME
             OF PLANTING (MM).
     FINHGT= HEIGHT OF SEEDLING ON 9/5/86 (CM).
     FINRCD= ROOT COLLAR DIAMETER ON 9/5/86 (MM).
IRRIGATION  TREATMENTS (IRR) ARE CODED AS FOLLOWS:
    1 = IRRIGATED
    2 = NON-IRRIGATED;
     INPUT  #1 BLOCK LIFT TREE IRR INITHGT INITRCD
            #2 FINHGT FINRCD;
     CARDS;
       1.000  3.000  6.000  2.000 23.000  3.800
      30.000  5.800
       1.000  8.000  3.000  2.000 28.000  4.100
      40.000  7.000
       1.000  8.000  4.000  2.000 25.000  5.600
      43.000  7.900
       1.000  4.000  7.000  2.000 16.000  4.300
      29.000  5.900
       1.000  8.000  5.000  2.000 12.000  3.400
      20.000  4.400
       1.000   2.000  2.000  2.000 17.000  3.800
      27.000  5.500
       1.000  1.000  3.000  2.000 18.000  4.200
      25.000  4.400
       2.000  6.000  6.000  1.000 20.000  4.900
      37.000  6.800
       2.000  3.000  2.000  1.000 29.000  4.000
      35.000  6.200
```

```
DATA FAMDW;
COMMENT*****  FILE, FAMDW DAT ************************
THESE ARE DRY WEIGHT DATA FROM A 1986-87 RGP STUDY USING 17 HALF-SIB
FAMILIES OF ONE-YEAR-OLD EASTERN WHITE PINE. RGP DATA , FAMILY ORIGINS
AND INFO ON STUDY DESIGN ARE LOCATED IN FILE TITLED:  FAMRGP DAT
FOR INFORMATION SEE THESIS TITLED "ROOT GROWTH POTENTIAL AND BUD DORMANCY
OF THREE NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE" BY
KURT H. JOHNSEN OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA
SEEDLINGS WERE HAND LIFTED FROM THE AUGUSTA NURSERY ON 1/21/87.
DRY WEIGHTS (CONSTANT WEIGHT AT 60C) WERE MEASURED AFTER SEEDLINGS
SPENT 21 DAYS IN HYDROPONIC RGP TEST.
DRY WEIGHTS MEASURED IN GRAMS TO 3RD DECIMAL PLACE (0.00X).
    NEWGT= NEEDLE WEIGHT
    STWGT= STEM WEIGHT
    LRTWGT= LATERAL ROOT DRY WEIGHT
    TRTWGT= TAP ROOT WEIGHT;
INPUT  #1 FAM LIFT TEST REP TREE NEWGT
       #2 STWGT LRTWGT TRTWGT;
CARDS;
       1.000  6.000  1.000  1.000  1.000  0.257
       0.097  0.036  0.059
       1.000  6.000  1.000  1.000  2.000  0.304
       0.110  0.053  0.066
       1.000  6.000  1.000  1.000  3.000  0.395
       0.078  0.156  0.068
       1.000  6.000  1.000  1.000  4.000   .
         .      .      .
       1.000  6.000  1.000  1.000  5.000  0.196
       0.077  0.044  0.051
       1.000  6.000  1.000  1.000  6.000  0.211
       0.076  0.044  0.055
       1.000  6.000  1.000  1.000  7.000  0.222
       0.102  0.082  0.076
       1.000  6.000  1.000  1.000  8.000  0.304
       0.099  0.050  0.069
       1.000  6.000  1.000  2.000  1.000  0.318
       0.106  0.091  0.084
       1.000  6.000  1.000  2.000  2.000  0.248
       0.082  0.035  0.096
       1.000  6.000  1.000  2.000  3.000  0.317
       0.126  0.042  0.081
       1.000  6.000  1.000  2.000  4.000  0.440
       0.148  0.074  0.080
       1.000  6.000  1.000  2.000  5.000  0.233
       0.087  0.040  0.099
       1.000  6.000  1.000  2.000  6.000  0.471
       0.123  0.055  0.105
       1.000  6.000  1.000  2.000  7.000  0.266
       0.160  0.047  0.071
       1.000  6.000  1.000  3.000  1.000  0.138
       0.047  0.028  0.058
       1.000  6.000  1.000  3.000  2.000  0.217
       0.090  0.086  0.061
       1.000  6.000  1.000  3.000  3.000  0.182
       0.061  0.062  0.054
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DAT FAMRGP;
COMMENT***** FILE,  FAMRGP INDTR *********************
THESE ARE DATA FROM A 1986-87 RGP STUDY USING 17 HALF-SIB FAMILIES OF
ONE-YEAR-OLD EASTERN WHITE PINE SEEDLINGS GROWN AT THE AUGUSTA NURSERY.
FOR INFORMATION SEE THESIS TITLED "ROOT GROWTH POTENTIAL OF THREE
NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE" BY KURT H. JOHNSEN
OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA.
STUDY WAS A RANDOMIZED, COMPLETE BLOCK DESIGN WITH BLOCKS ESTABLISHED AT
THE NURSERY AND MAINTAINED IN THE GREENHOUSE DURING HYDROPONIC RGP TEST.
FAMILY ORIGINS FOLLOW: 1=BOSCOWEN,N.H., 3=ALTON,N.H., 4=NEW BOSTON,N.H.
5=NORTH UMBERLAND,N.H., 6=CONWAY,N.H., 9=SAN DOWN,N.H., 10=NEW BOSTON,NH
12 AND 13 AND 15=PASSADUMKEAG,ME., 14=CHELSEA,ME.,
16 AND 21 AND 22 AND 23=BURKE CTY, N.C., 16 AND 18=CALDWELL CTY,N.C..
SEEDLINGS WERE LIFTED ON TEN OCCASIONS, ON EACH LIFT APPROX. 8 SEEDLINGS
PER FAMILY PER BLOCK WERE LIFTED.
   LIFT 1 = 10/10/86
   LIFT 2 = 10/24/86
   LIFT 3 = 11/8/86
   LIFT 4 = 11/24/86
   LIFT 5 = 12/17/86
   LIFT 6 = 1/21/87
   LIFT 7 = 2/24/87
   LIFT 8 = 3/5/87
   LIFT 9 = 3/18/87
   LIFT 10 = 4/14/87
NEW ROOTS WERE COUNTED AFTER 21 DAYS IN A HYDROPONIC SYSTEM.
   NS= NUMBER OF ROOTS > 0.5 AND < 1.5 CM IN LENGTH.
   NL= NUMBER OF ROOTS > OR = 1.5 CM IN LENGTH.
   SHT= SHOOT LENGTH FROM ROOT COLLAR TO TERMINAL BUD IN CENTEMETERS
   RCD = ROOT COLLAR DIAMETER IN MILLIMETERS
   BUD = RATING ON BUD ACTIVITY SCALE AS FOLLOWS:
       1= DEAD
       2= NO APPARENT ACTIVITY
       3= TERMINAL BUDS SWOLLEN
       4= TERMINAL STARTING TO FLUSH
       5= TERMINAL FLUSHING, MEASURABLE ELONGATION
       6= TERMINAL FLUSHING, MESURABLE ELONGATION, NEEDLES FLUSHING
       7= ALREADY GROWING
DRY WEIGHTS FOR ALL SEEDLINGS FROM 1/21/87 CAN BE FOUND IN FILE TITLED
FAMDW DAT;
INPUT FAM LIFT TEST BLOCK TREE NL NS SHT RCD BUD;
CARDS;
023 1 1 1 01 01 24 009 . 3
023 1 1 1 02 00 00 009 . 1
023 1 1 1 03 00 00 007 . 6
023 1 1 1 04 00 02 007 . 4
023 1 1 1 05 00 00 006 . 1
023 1 1 1 06 00 00 008 . 3
023 1 1 1 07 02 01 006 . 3
012 1 1 1 01 03 16 007 . 2
012 1 1 1 02 02 04 007 . 2
012 1 1 1 03 01 02 007 . 2
012 1 1 1 04 01 06 008 . 2
012 1 1 1 05 00 05 007 . 2
012 1 1 1 06 04 05 008 . 2
```

```
DATA SCOTRGP;
COMMENT *********** FILE, SCOTRGP DAT *********************
THESE DATA ARE FROM A 1985-86 RGP STUDY USING TWO-YEAR-OLD SCOTCH
PINE LIFTED FROM THE AUGUSTA NURSERY.
FOR INFORMATION SEE THESIS TITLED "ROOT GROWTH POTENTIAL OF THREE
NORTHERN PINES WITH EMPHASI ON EASTERN WHITE PINE" BY KURT H.
JOHNSEN OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA.
NRTS = NUMBER OF NEW ROOTS > 0.5 CM.
LRTS = TOTAL LENGTH OF NEW ROOTS > 0.5 CM.
FOR INFORMATION ON EXPERIMENTAL DESIGN AND ALL OTHER VARIABLES
SEE FILE TITLED: REDRGP DAT.
DRY WEIGHT DATA ONLY FOR 11/30/85 AND 2/19/86 LIFT-DATES;
INPUT #1 LIFT BLOCK TREE SHT RCD BUD
      #2 NRTS LRTS NEWGT STWGT LRTWGT TRTWGT;
CARDS;
        1.000  1.000  1.000 29.000  5.200  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000  2.000 26.000  4.400  2.000
        1.000  2.000  .  .  .  .
        1.000  1.000  3.000 36.000  7.700  2.000
        5.000 17.000  .  .  .  .
        1.000  1.000  4.000 21.000  3.600  2.000
        2.000  5.000  .  .  .  .
        1.000  1.000  5.000 3.  6.400  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000  6.000 31.000  7.500  2.000
        1.000  1.000  .  .  .  .
        1.000  1.000  7.000 34.000  8.800  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000  8.000 3.  5.700  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000  9.000 35.000  7.800  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000 1. 32.000  5.200  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000 11.000 34.000  6.200  2.000
        1.000  1.000  .  .  .  .
        1.000  1.000 12.000 33.000  7.400  2.000
        2.000  3.000  .  .  .  .
        1.000  1.000 13.000 34.000  8.800  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000 14.000 37.000  6.600  2.000
        0.000  0.000  .  .  .  .
        1.000  1.000 15.000 34.000  8.400  2.000
        0.000  0.000  .  .  .  .
        1.000  2.000  1.000 31.000  5.400  2.000
        0.000  0.000  .  .  .  .
        1.000  2.000  2.000 37.000  6.900  2.000
        0.000  0.000  .  .  .  .
        1.000  2.000  3.000 27.000  3.700  2.000
        0.000  0.000  .  .  .  .
        1.000  2.000  4.000 34.000  5.600  2.000
        0.000  0.000  .  .  .  .
        1.000  2.000  5.000 35.000  5.100  2.000
        0.000  0.000  .  .  .  .
```

```
DATA REDRGP;
COMMENT ********* FILE, REDRGP DAT *******************
THESE DATA ARE FROM A 1985-86 RGP STUDY USING TWO-YEAR-OLD RED
PINE LIFTED FROM THE AUGUSTA NURSERY.
FOR INFORMATION SEE THESIS TITLED "ROOT GROWTH POTENTIAL OF THREE
NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE" BY KURT H.
JOHNSEN OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA.
EXPERIMENT WAS SET UP AS A RANDOMIZED COMPLETE BLOCK DESIGN
USING THREE BLOCKS THAT WERE RANDOMLY PRE-ESTABLISHED IN NURSERY
BEDS. BLOCKING FROM NURSERY WAS MAINTAINED IN RGP TEST.
SEEDLINGS WERE LIFTED ON 10 OCCASIONS.
  LIFT 1= 10/15/85
  LIFT 2= 11/11/85
  LIFT 3= 11/30/85
  LIFT 4= 1/3/86
  LIFT 5= 1/22/86
  LIFT 6= 2/19/86
  LIFT 7= 3/5/86
  LIFT 8= 3/19/86
  LIFT 9= 4/2/86
  LIFT 10= 4/21/86
  NS= NUMBER OF NEW ROOTS > 0.5 AND < 1.5 CM.
  NL= NUMBER OF NEW ROTS > OR = 1.5 CM.
  SHT,RCD, AND BUD ARE AS FROM FILE TITLED: YR1WPRGP DAT
  NEWGT,STWGT,TRTWGT, AND LRTWGT ARE AS FROM FILE TITLED: YR1WPDW DAT.
DRY WEIGHT DATA ONLY FOR 10/15/85 AND 1/3/86 LIFT-DATES;
 INPUT #1 LIFT BLOCK TREE NS NL SHT
       #2 RCD BUD NEWGT STWGT LRTWGT TRTWGT;
CARDS;
       1.000  1.000  1.000  4.000  0.000 13.000
       3.800  2.000  3.440  0.700  0.176  0.366
       1.000  1.000  2.000  0.000  0.000 11.000
       3.000  2.000  0.940  0.270  0.051  0.144
       1.000  1.000  3.000  0.000  1.000 12.000
       3.100  2.000  1.210  0.380  0.084  0.163
       1.000  1.000  4.000  0.000  0.000 11.000
       3.200  2.000  1.730  0.360  0.069  0.173
       1.000  1.000  5.000  4.000  0.000 15.000
       4.300  2.000  4.210  0.970  0.151  0.552
       1.000  1.000  6.000  0.000  0.000 16.000
       5.800  2.000  6.810  1.750  0.268  0.766
       1.000  1.000  7.000  1.000  0.000 11.000
       2.800  2.000  0.910  0.240  0.097  0.127
       1.000  1.000  8.000  1.000  0.000 19.000
       6.700  2.000  7.870  2.240  0.380  1.133
       1.000  1.000  9.000  1.000  0.000 12.000
       4.100  2.000  2.790  0.650  0.141  0.372
       1.000  1.000 10.000  0.000  0.000  9.000
       2.100  2.000  0.970  0.170  0.051  0.120
       1.000  1.000 11.000  0.000  0.000 16.000
       5.200  2.000  4.850  1.170  0.215  0.660
       1.000  1.000 12.000  1.000  0.000 14.000
       5.100  2.000  4.830  1.130  0.348  0.625
       1.000  1.000 13.000  0.000  0.000 18.000
       6.400  2.000  6.050  1.720  0.302  0.871
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DATA YR1WPSTO;
COMMENT ******** FILE, YR1WPSTO DAT *************************
THESE DATA ARE FROM A 1985-86 RGP STORAGE STUDY USING TWO-YEAR-OLD
EASTERN WHITE PINE SEEDLINGS. SEEDLINGS WERE LIFTED ON 9 OCCASIONS
AND WERE TESTED FOR RGP ON THREE DATES AFTER COLD STORAGE (2C).
RGP DATA FOR FRESHLY LIFTED MATERIAL CAN BE FOUND IN THE FILE
TITLED: YR1WPRGP DAT.
FOR INFORMATION SEE THE THESIS ENTITLED "ROOT GROWTH POTENTIAL OF
THREE NORTHERN PINES WITH EMPHASIS ON EASTERN WHITE PINE" BY KURT H.
JOHNSEN OR CONTACT KURT H. JOHNSEN, UNIVERSITY OF GEORGIA.
EXPERIMENT WAS ESTABLISHED AS A RANDOMIZED COMPLETE BLOCK DESIGN.
LIFT,BLOCK, SHT, RCD, AND BUD ARE AS DESCRIBED IN FILE
TITLED: YR1WPRGP DAT.
  NRTS= NUMBER OF NEW ROOTS > OR = 0.5 CM.
  LRTS= TOTAL LENGTH OF NEW ROOTS > 0.5 CM.
  TEST 1 = MARCH 19 TEST-DATE.
  TEST 2 = APRIL 26 TEST-DATE.
  TEST 3 = JUNE 4 TEST-DATE;
INPUT #1 LIFT TEST BLOCK SHT RCD BUD
      #2 NRTS LRTS;
CARDS;
       1.000  1.000   1.000 24.000   5.400   3.000
      27.000 44.000
       1.000  1.000   1.000 21.000   4.400   3.000
      18.000 18.000
       1.000  1.000   1.000 24.000   5.200   3.000
       7.000  7.000
       1.000  1.000   1.000 21.000   3.900   3.000
       0.000  0.000
       1.000  1.000   1.000 20.000   4.300   2.000
       0.000  0.000
       1.000  1.000   1.000 29.000   9.100   6.000
      28.000 39.000
       1.000  1.000   1.000 23.000   4.400   4.000
      15.000 15.000
       1.000  1.000   1.000 27.000   5.500   2.000
       0.000  0.000
       1.000  1.000   1.000 18.000   5.500   2.000
       2.000  2.000
       1.000  1.000   1.000 21.000   4.900   3.000
      18.000 21.000
       1.000  1.000   1.000 17.000   3.700   2.000
       0.000  0.000
       1.000  1.000   1.000 26.000   5.400   6.000
      28.000 46.000
       1.000  1.000   1.000 19.000   3.300   2.000
       0.000  0.000
       1.000  1.000   1.000 19.000   3.700   3.000
      17.000 21.000
       1.000  1.000   1.000 16.000   2.900   2.000
       0.000  0.000
       1.000  1.000   2.000 19.000   4.200   2.000
      15.000 16.000
       1.000  1.000   2.000 22.000   6.900   5.000
      37.000 40.000
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