VARIATION IN ROOT GROWTH POTENTIAL OF LOBLOLLY PINE FROM SEVEN NURSERIES

Peter P. Feret, Robert C. Freyman, and Richard E. Kreh[1/]

Abstract.--Loblolly pine (*Pinus taeda* L.) seedlings lifted over a period from October to April from seven nurseries located from Virginia to Texas were examined for root growth potential (RGP). Fewer than 20 percent of the 128 samples analyzed showed a significant relation between RGP and seedling size. Nurseries differed in RGP magnitude but followed similar trends with RGP increasing from a low in autumn to a peak in early March. Samples lifted after March 11 showed a large RGP decrease. Outplanted seedling survival and growth are consistently correlated with RGP, while seedling size measures were weakly and irregularly correlated with outplanting survival and growth

Additional keywords: Nursery management, seedling growth, *Pinus taeda*, root regeneration potential.

INTRODUCTION

Root growth potential (RGP), a measure of the ability of a bare-root seedling to produce new roots, has been used as an indicator of general physiological readiness to survive and grow after outplanting. Changes in seedling physiology in response to varied environments may be monitored by measuring RGP. For instance, RGP changes in many species during the lifting season from a low in autumn to a peak in late winter or early spring (Ritchie and Dunlap, 1980; Feret et al., 1984b), is diminished by seedling dessication (Feret et al., 1985), and is modified by nursery cultural practices (Feret et al., 1984a; 1984b; 1985). Because seedling RGP appears to indicate seedling quality (Feret and Kreh, 1985a; 1985b), this study was undertaken to explore the trends and variability of loblolly pine RGP from various nurseries throughout the Southeast.

METHODS

Seven nurseries and six organizations participated in this study (Figure 1). One nursery grew seedlings for three organizations, and two organizations had more than one nursery produce seedlings. In total, there were nine nursery-organizational groups. Seedlings from a given nursery underwent the current cultural practices for that nursery and were from

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[1/] Associate Professor, Laboratory Specialist, and Research Associate, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061. We wish to acknowledge with appreciation the technical assistance of J. R. Bird (Reynolds Homestead Research Center), and the cooperation of the personnel employed at the several state and industrial nurseries involved in this study including: Champion Timberlands, Chesapeake Corp., Continental Forest Industries, International Paper, Westvaco, and the Virginia Div. of Forestry.

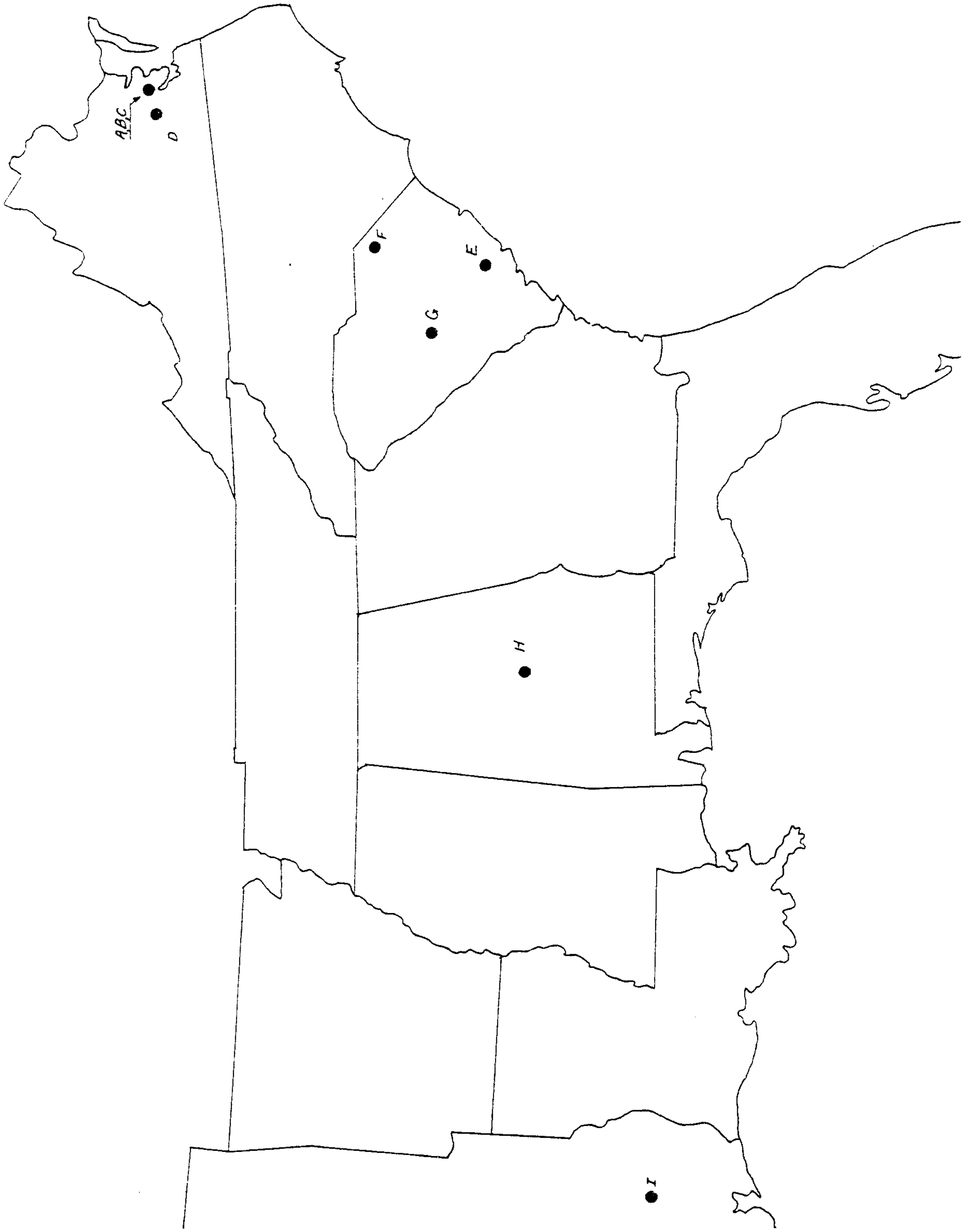


Figure 1.--Nursery-organizational group locations.

seed sources used by the individual organizations. Thus, nursery and seed source effects were confounded. Seedlings were lifted at various times of the year, generally, beginning in October and ending in April. After lifting, seedlings were packed in coolers with ice and shipped to the the Virginia Tech Reynolds Homestead Research Center, located in Critz, Virginia. Root growth potential was measured by growing a 30-seedling sample under a 16-hour photoperiod in a greenhouse maintained at 27 ^{o} C day temperature and above 15^{o} C at night. Seedlings were planted in watertight trays (15/tray) containing 0.013 m^3 Promix BX^{R}. After being watered to field capacity, trays were immersed in a constant-temperature water bath held at 20^{o} C. After 24 days, seedlings were hydraulically excavated and RGP recorded as number of new roots and total length of new roots. Seedling height, root collar diameter, and root and shoot dry weight also were recorded. Seedlings from 47 shipments (randomly selected from the nine nursery-organizational groups) were also outplanted upon being received. Most outplanted samples contained 50 trees (5 trees/plot, replicated 10 times). Height, groundline diameter, and survival were recorded after one year.

RESULTS

Seedling Size and RGP

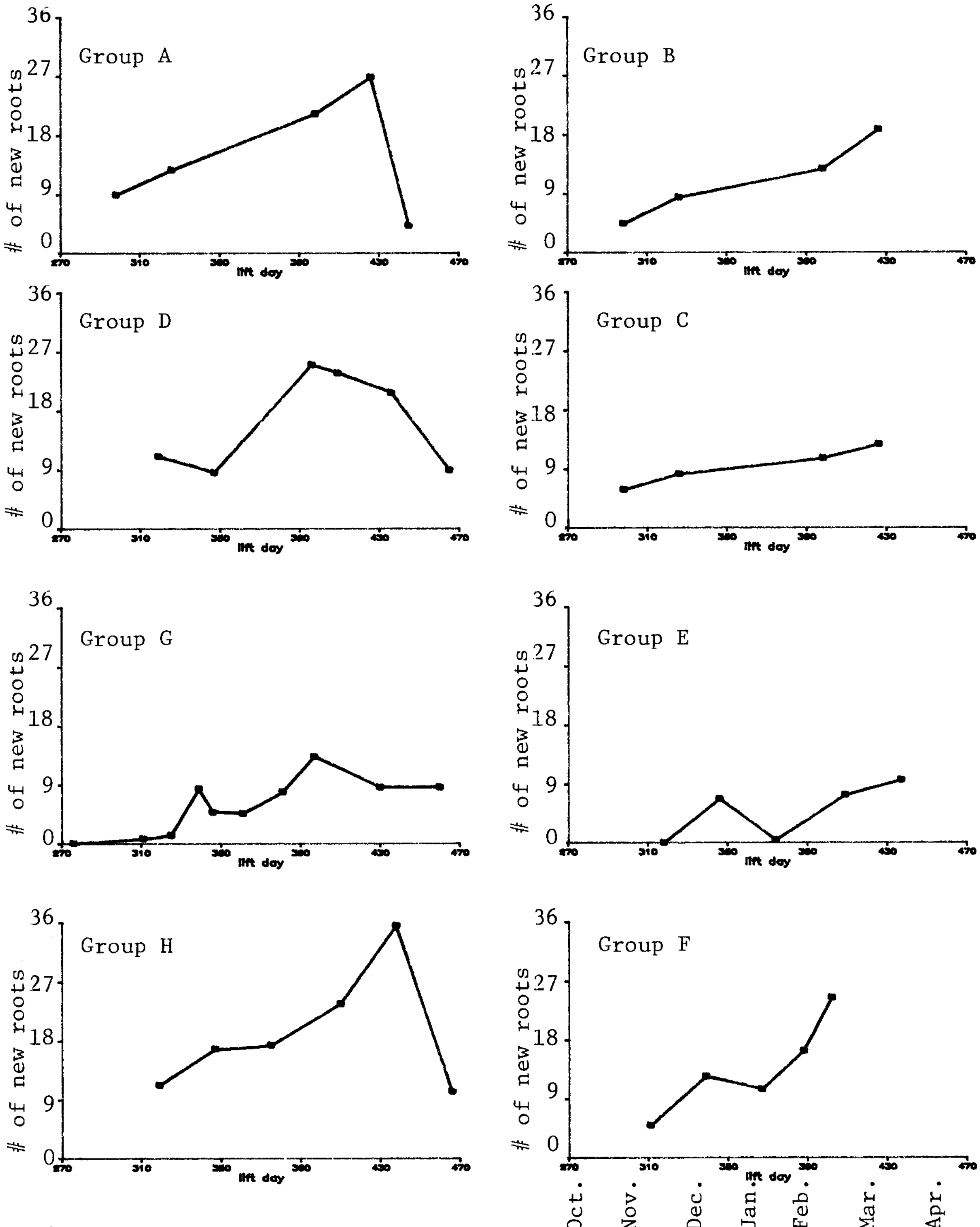
The correlation between seedling size measures and RGP (number of new roots) was determined for each of the 128 samples received. The relationship between RGP and seedling height, root collar diameter, volume index (D^2 x H), and the ratio, height/diameter, was significant in fewer than 20 percent of the samples. Height was significantly correlated with RGP in about 20 percent of the samples, while the other measures correlated in fewer than 15 percent of the samples. Of the samples that did have a significant linear relationship, the correlation was low, usually less than 0.40.

Nursery, Lift Date, and RGP

Seedlings produced at different nurseries differed in absolute level of RGP but showed relatively similar trends of seedling RGP change over the lifting season (Figure 2). In general, nurseries fell into two groups: those that showed a quadratic trend in RGP (A, D. G, H, I--left side of Figure 2) and those that showed a linear trend (B, C, E, F--right side of Figure 2). All nurseries show an increase in RGP from a low in the fall to a peak in late February-early March. Samples lifted after March 11 showed a large decrease in RGP (groups A, D, H, I).

Cold Storage and RGP

Seedlings from six nursery-organizational groups were cold-stored for four or eight weeks before RGP testing (Figure 3). Three of the six groups showed a significant storage effect. Of these three groups, two had a significant increase in RGP due to storage (groups B and F), and one a decrease (group I). The difference between four or eight weeks of storage for the six groups was not significant.



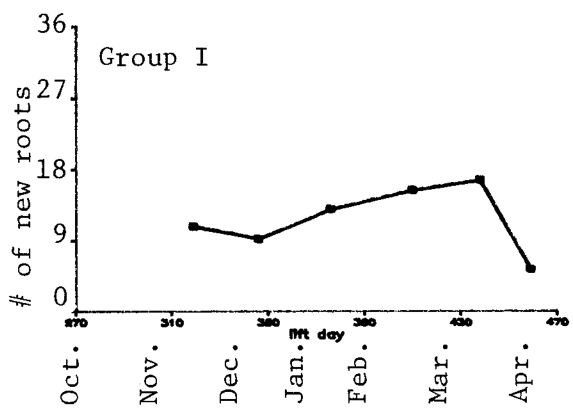


Figure 2.--Relationship between RGP (number of new roots) and lift day for nine nursery-organizational groups. Groups on left show spring RGP decline. (October 1, 1983 = 274; April 1, 1984 = 457)

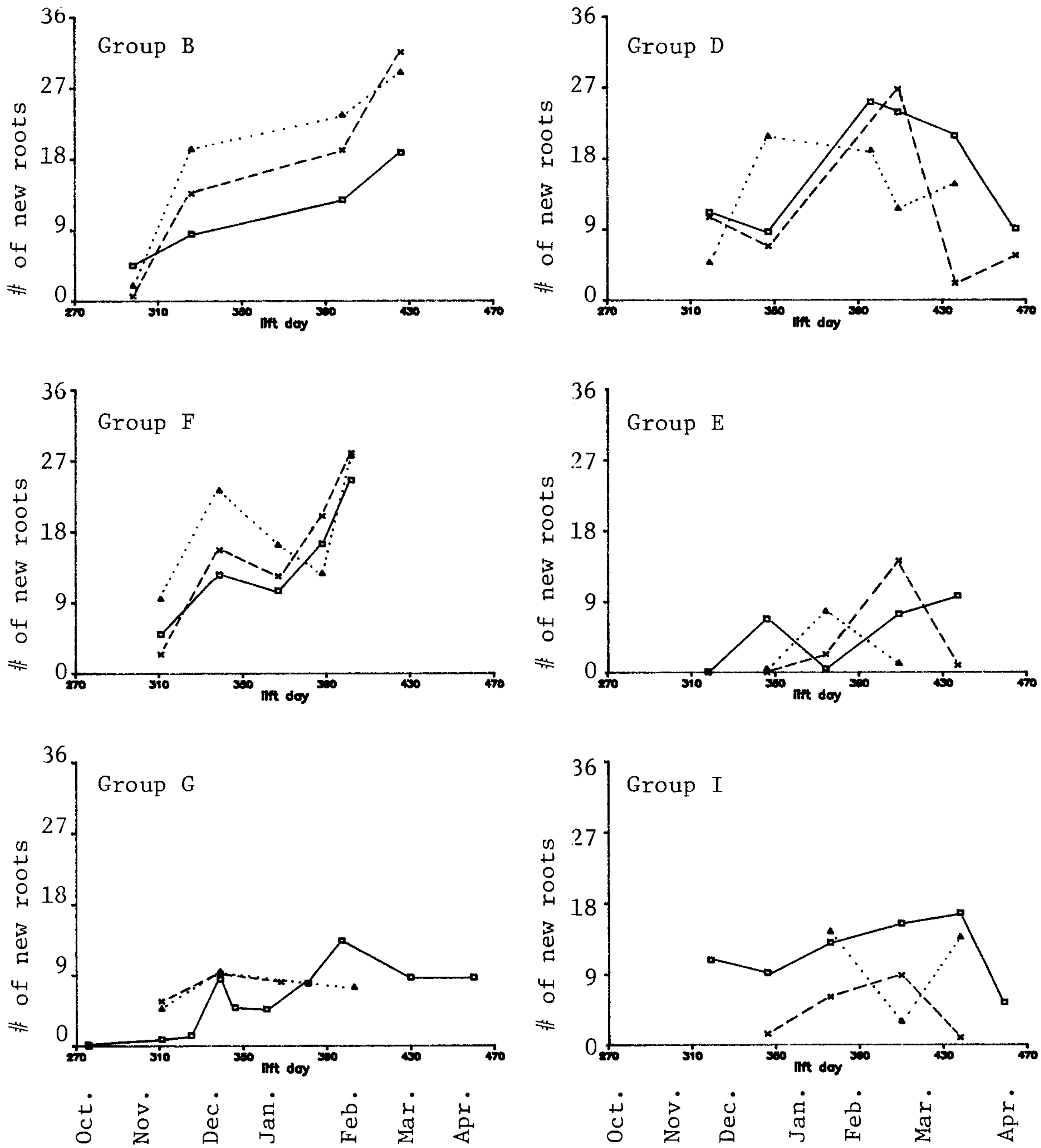


Figure 3.--Cold storage effects on RGP (number of new roots). Cold significantly (α = .05) increased RGP in groups B and F and significantly decreased RGP in group I. Mean RGP for stored seedlings was generally greater for groups B, F, and G, and less in groups D, E, and I. (□ = nonstored, x = 4 weeks storage, ▲ = 8 weeks storage) (October 1, 1983 = 274; April 1, 1984 = 457)

Outplanting Performance and RGP

Table 1 presents correlations between seedling RGP and outplanting performance. Correlations presented are based on the 47 samples for which both RGP and field performance data were available. RGP was significantly correlated with field performance with *r* values generally greater than 0.40.

For seedlings planted after March 1, correlations between RGP and field performance were high, ranging from 0.44 to 0.87 (Table 2). In contrast, seedling samples planted before February 1 showed no significant relationship between RGP and field performance (Table 3).

Outplanting Performance and Seedling Morphology

Correlations between seedling morphological attributes and field performance using all seedling samples are presented in Table 1. Generally, the relationship between outplanting performance and seedling size was not significant. However, the few significant relationships that were found indicated that larger seedlings grew better and had better survival than smaller seedlings, although their relative growth rate was inferior to small seedlings. Seedlings with a large shoot/root ratio (dry weight basis) tended to perform less well than those with a small shoot/root ratio, particularly with respect to their relative height growth and survival.

Table 1.--First-year seedling outplanting performance - seedling measurement correlations: all samples

	Growth Increment[x]			Relative Growth Increment[x]			
	Height	Basal Area	Volume Index	Height	Basal Area	Volume Index	First Year Survival[xx]
Number of new roots[Y]	.44**	.47**	.47**	.38**	.44**	.49**	.42**
Length of new roots[Y]	.50**	.51**	.51**	.46**	.55**	.61**	.43**
Height	.11	.17	.24	-.17	-.28	-.23	.11
Root collar dia.	.17	.28	.34*	-.05	-.36*	-.27	.19
Shoot dry weight	.04	.13	.18	-.24	-.34*	-.34*	.14
Root dry weight	.23	.24	.31*	.05	-.26	-.16	.38**
Shoot/root (dry weight)	-.29	-.14	-.19	-.38**	-.02	-.18	-.56**

* P < or = 0.05 ; ** P < or = 0.01
Y root growth potential measures
x n = 44 xx n = 47

Table 2.--Seedling outplanting performance - seedling measurement correlations: samples lifted after March 1

	Growth Increment[x]			Relative Growth Increment[x]			
	Height	Basal Area	Volume Index	Height	Basal Area	Volume Index	First Year Survival[x]
Number of new roots[Y]	.60*	.51	.44	.64*	.68**	.73**	.79**
Length of new roots[Y]	.68**	.55*	.48	.74**	.81**	.87**	.84**
Height	-.21	-.07	.01	-.47	-.11	-.20	-.38
Root collar dia.	.17	.42	.49	-.18	-.17	-.21	-.70**
Shoot dry weight	-.07	.02	.12	-.37	-.32	-.35	-.62*
Root dry weight	.21	.29	.40	-.14	-.21	-.22	-.49
Shoot/root (dry weight)	-.49	-.50	-.57*	-21	-.04	-.05	.11

* P < or = 0.05; ** P < or = 0.01
Y root growth potential measures
x n = 13

Table 3.--First-year seedling outplanting performance - seedling measurement correlations: samples lifted before February 1

	Growth Increment[x]			Relative Growth Increment[x]			
	Height	Basal Area	Volume Index	Height	Basal Area	Volume Index	First Year Survival[xx]
Number of new roots[Y]	.33	.35	.41	.22	.39	.43	.38
Length of new roots[Y]	.24	.27	.32	.16	.34	.36	.36
Height	.21	.10	.16	.04	-.32	-.19	.28
Root collar dia.	.10	.01	.04	.06	-.43*	-.29	.47*
Shoot dry weight	-.03	.02	.02	-.22	-.26	-.31	.29
Root dry weight	.22	.03	.07	.23	-.20	-.06	.60**
Shoot/root (dry weight)	-.28	.03	-.04	-.49*	-.02	-.24	-.57**

* P < or = 0.05 ; ** P < or = 0.01
Y root growth potential measures
x n = 21 xx n = 24

Seedlings lifted and planted after March 1 showed less sensitive responses to seedling size, as there were few significant correlations between field performance and size attributes (Table 2). However, smaller seedlings survived better than larger seedlings. For seedlings planted before February 1, the opposite was true (Table 3).

DISCUSSION

Assuming root growth potential is an accurate measure of a seedling's physiological quality, the data analyzed from this study strongly suggests that seedling size, within the range investigated (sample averages for root collar diameters ranged from 2.8 to 6.0 mm and heights from 17 to 35 cm), has a relatively week relationship with RGP. Samples were comprised of plantable seedlings, and it is to this group that these results apply. While traditional measures of seedling morphology may, under some circumstances, be useful gauges of seedling quality (South et al., 1985; Venator, 1981; Xydias, 1980; Williston, 1974), they are largely fixed once growth ceases and cannot account for endogenous changes that occur while the seedlings are held in the nursery beds or in cold storage. Having 15-20 percent of the samples showing a significant correlation between a seedling size measure and RGP does not represent a clear and consistent relationship between the two measurements. Even in those samples which did show a significant correlation, the correspondence is so low that size measurement could not be used as a practical predictor of RGP.

Effects of cold storage are unclear. While groups B and F show a consistent and significant increase in RGP due to cold storage at every lift except the first, other groups show erratic trends throughout the lifting season. The response of seedlings from group B is what one might expect, where the earliest lift, containing seedlings not ready for cold, is harmed in storage, with subsequent loss of RGP, while seedlings lifted later were ready for natural cold and while in cold storage received additional cold sums which improved in RGP over unstored seedlings. However, the fact that groups B, F, and G showed generally positive cold storage effects and groups D, E, and I generally negative trends makes any conclusion impossible.

The data from this study confirms past work which showed an increase in RGP from a low in fall to a peak in early spring to a sharp drop later in spring (Ritchie and Dunlap, 1980). Though not all groups showed a large spring drop in RGP, only those seedlings lifted after March 11 possessed low RGP. For instance, seedlings from groups A, B, and C all raised at the same nursery, show similar increase in RGP during the lifting season, but apparently only seedlings from group A were lifted late enough to show the RGP decrease.

The data from outplanted seedlings tends to support the idea that RGP is a sensitive measure of a seedling's general physiological condition. Since seedling size measures and RGP are generally unrelated, one would expect that only one of the types of measures would correlate well with field performance. As shown in Tables 1 and 2, RGP measures are significantly correlated, and by comparison, more strongly correlated with outplanting performance than are seedling size measures.

No individual size measure is consistently correlated with outplanting performance. In Table 1 shoot/root ratio (shoot dry weight/root dry weight) is correlated only with survival and relative height increment. Root collar diameter is correlated only with volume index increment and relative basal area increment. Height is not significantly correlated with any growth measure.

The data shows that RGP measured at planting time correlates best with outplanting performance of spring-planted seedlings, while RGP measured on fall- or winter-planted seedlings has little relation with outplanting performance (compare Tables 1 and 3). This is not surprising when one considers that cool soil temperatures at the time of planting would not allow much, if any, new root growth (Barney, 1951; Heninger and White, 1974; Nambiar et al., 1979); hence, RGP (measured in the lab) could not be expressed in the field. Seedlings planted in the fall or winter at locations such as at Critz, Virginia, on the upper Piedmont, would not be expected to express their potential RGP soon after planting. By the time fall- and winter-planted seedlings begin to produce new roots upon soil warming in the spring, a change in RGP from that measured in the fall would not be unexpected. Therefore, the RGP measured in the fall or winter is not the "effective RGP" when root growth begins. Low correlations between fall and winter RGP and outplanting performance would be expected. The fact that RGP and outplanting performance are well-correlated in the spring strongly suggests that RGP is a good indicator of the potential of a seedling to survive and grow if the conditions are such at the time of planting to allow root growth. This means that RGP measured in the fall or winter is meaningful for those areas having fall and winter conditions allowing root growth soon after planting.

While the correlations used in the comparisons above are linear, data from samples lifted after March 1 (which show the strongest linear correlations) indicate that the relation between survival and RGP is better described with a nonlinear equation (Figure 4). This nonlinear relationship between survival and RGP has been reported by others (Burdett et al., 1983), is evident in data presented by Beineke and Perry (1965; see Figure 3), and is also confirmed by our data (unpublished). In the data presented here, survival increases as RGP increases up to an RGP of about 15 new roots. Thereafter, survival does not increase substantially. This indicates that the importance of the first few roots for survival is great, with diminishing returns for additional increments of RGP. This also suggests that, while having a high average RGP is important, it is more important to produce a high proportion of seedlings with at least some RGP. Seedlings should perhaps be assessed from the standpoint of the percentage of a seedling sample that is above or below a certain RGP value. For the samples lifted after March 1, the percentage of "poor" seedlings (seedlings that had 1 or 0 new roots) gives a correlation of -0.84 (r^2 = 0.71) with survival, and the relation is linear (Figure 5). From the equation in Figure 5, survival of 80 percent would not be expected until samples contained 10 percent or fewer "poor" seedlings. The regression equation

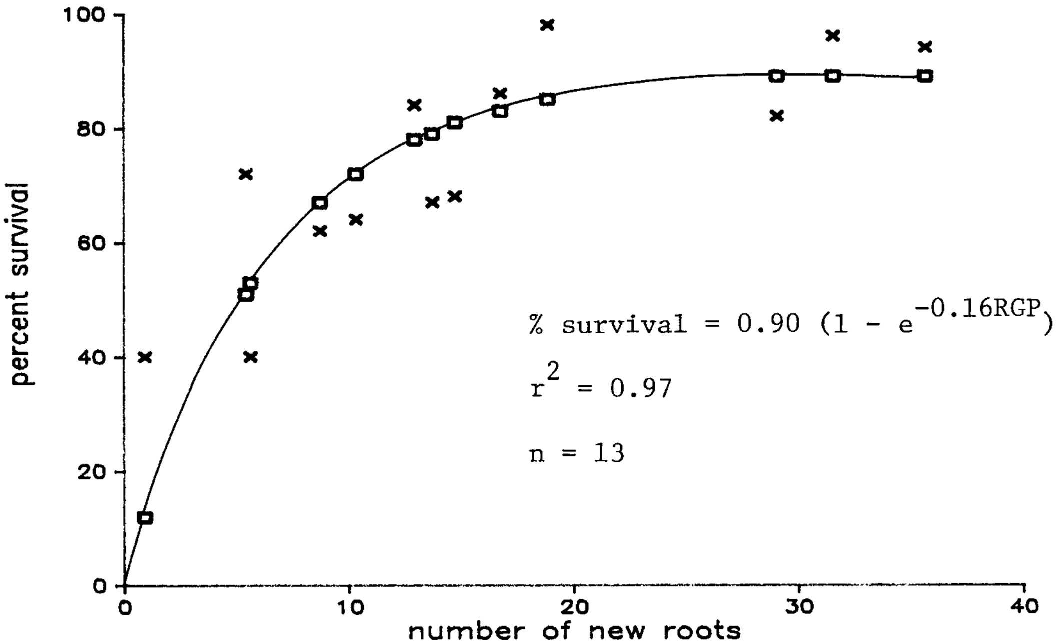


Figure 4.--Relationship between percent survival and RGP (number of new roots) of seedlings lifted after March 1, 1984. (□= predicted value, x = observed value)

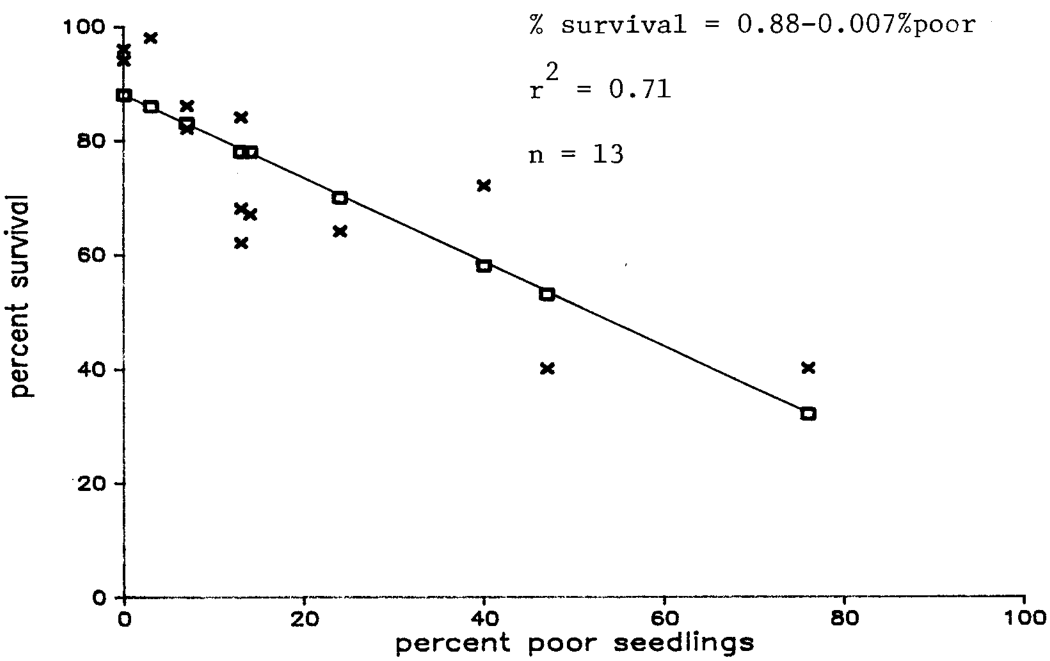


Figure 5.--Relationship between percent survival and percent poor seedlings (seedlings that produced 0 or 1 new roots) out of a 30-seedling sample. Seedlings were lifted after March 1, 1984. (□= predicted value, x = observed value)

relating average number of new roots (usually per 30-seedling sample) and percentage of poor seedlings:

$$\% \text{ poor seedlings} = (10.5 - 1.9 \sqrt{\# \text{ new roots}})^2; \; n = 127, \; r^2 = 0.80,$$

predicts that a level of 10 percent or fewer poor seedlings may be expected only when a sample average of 15 new roots is attained. This sample average of approximately 15 new roots produced after the 24-day test period in the testing system used at Critz, Virginia agrees with past data as the average needed so that good field performance may be confidently expected. It is of interest to note that of the samples received, less than half averaged at least 15 new roots. For most groups, samples did not average 15 new roots until after mid-December.

That the proportion of "poor" seedlings is as informative with respect to survival as is average RGP implies that RGP tests could be designed to determine this quantity (proportion of "poor") and that as short an RGP test period as is possible to determine which seedlings will expess RGP and which will not is all that is needed (DeWald et al., 1984).

As to which RGP measure is best--number of new roots or new root length--it appears that number of new roots is an adequate measure and easier and quicker to determine. Number of new roots explains 90 percent of the variation in new root length, and comparison of the correlations between field performance and RGP as number of new roots or new root length shows little difference between the two measures. Therefore, it appears that either number of new roots or new root length will adequately describe a seedling RGP.

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