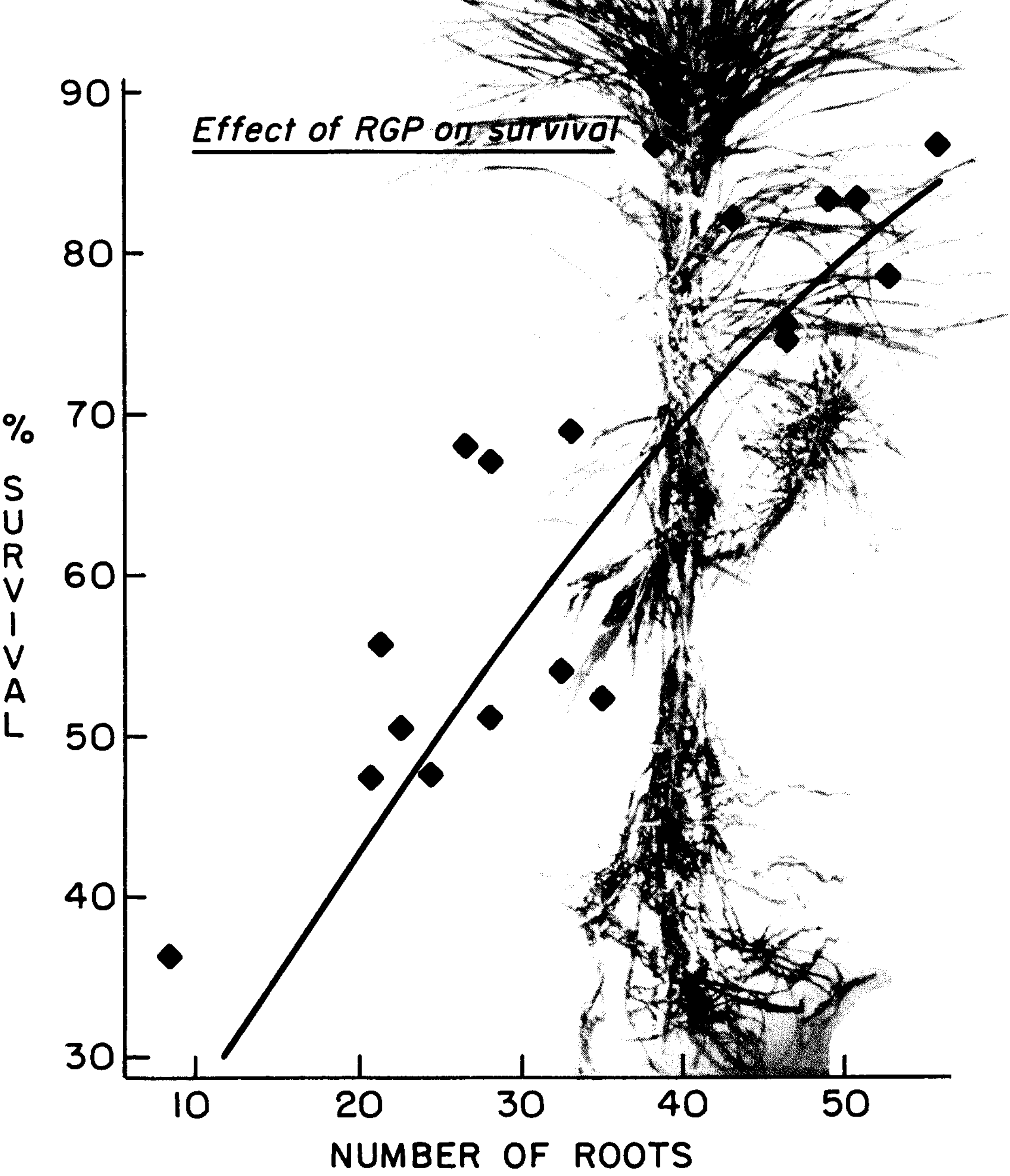

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Root Growth Potential of Loblolly Pine *(Pinus taeda* L.*)* Seedlings from Twenty Southern Nurseries[1]

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INTRODUCTION

"The quality of planting stock is the degree to which that stock realizes the objectives of management (to the end of the rotation or achievement of specified sought benefits) at minimum cost. Quality is fitness for purpose" (*30*). Morphological grades have long been the primary basis for assessing the quality of tree seedlings. Such grading has been only moderately effective in predicting potential field performance (*24*), however, because of commonly occurring variation in "physiological quality" within seedling grades (*3,31*). Recent research on seedling quality has focused more on physiological condition as related to vigor and stress resistance (*19,26*). Such research is revealing much about the nature of physiological quality, but no single, universally applicable test of physiological quality is available.

A seedling attribute known to be an important factor in field performance, the ultimate measure of seedling quality, is root growth potential (RGP) (*20*). The finer, more efficient, absorbing roots of bare-root nursery seedlings are largely lost or damaged between lifting and planting. Therefore, early survival and growth after planting must depend largely on new root growth for replacement of water lost by transpiration. The level of RGP influences the chance for survival of any planted seedling, depending on the environment of the planting site. Poor correlations between RGP and early field performance have been reported (*25*), but good correlations have been demonstrated for several coniferous species, such as lodgepole pine, *Pinus contorta* Dougl., (*4,5*), Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco (*13,22*), ponderosa pine, *P. ponderosa* Laws. (*23*), white spruce, *Picea glauca* (Moench) Voss (*5*), and loblolly pine, *Pinus taeda* L. (*18*).

Wakeley (*28*) reported that certain southern nurseries pro-

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[1] This study was supported by the Auburn University Southern Forest Nursery Management Cooperative.

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duced seedlings with consistently better than average performance when outplanted. If current consistent performance differences among nurseries could be established they could provide a basis for discovering some of the underlying causes. It would be helpful initially to determine how effective various measures of seedling morphology are as predictors of RGP. Nursery practices could then be adjusted to produce seedlings with higher performance potential.

As a first step toward this objective, a study was begun in the fall of 1982 to determine (1) the range of variation in RGP of loblolly pine seedlings produced under the varying site and cultural conditions at different southern forest nurseries and (2) how much of this variation could be accounted for by morphological differences.

METHODS

During a 10-day period of December 1982, seedlings from 20 southern forest nurseries were sampled, table 1. Seed source varied among nurseries but all seeds originated from Livingston Parish, Louisiana. At each nursery a 0.6-meter-wide strip of seedlings across one bed was carefully hand-lifted, placed in an ice-cooled, insulated container and, as soon as possible, transported to a single cold storage room (2°C) until planting. Bed density of the 20 samples averaged 347 seedlings per square meter, with a range from 145 to 673.

TABLE 1. NURSERIES SAMPLED, WITH LIFTING DATES AND PERIODS OF COLD STORAGE

Location	Nursery	Lifting date	Days in cold Storage[1]
State nurseries			
Atmore, Ala.	Edward A. Hauss Nursery	Dec. 9	11
Autaugaville, Ala.	John R. Miller Nursery	Dec. 15	5
Opelika, Ala.	Jake Stauffer Nursery	Dec. 17	3
Chiefland, Fla.	Andrews Forest Nursery	Dec. 15	3
Milton, Fla.	Munson Forest Nursery	Dec. 9	11
Reidsville, Ga.	Page-Walker Nursery	Dec. 11	8
Columbia, La.	Columbia Forestry Nursery	Dec. 14	5
DeRidder, La.	Beauregard Nursery	Dec. 12	5
Oberlin, La.	Oberlin Nursery	Dec. 13	5
Mt. Olive, Miss.	Mt. Olive Forest Nursery	Dec. 8	11
Waynesboro, Miss.	Waynesboro Forest Nursery	Dec. 13	5
Industry nurseries			
Pine Hill, Ala.	MacMillan-Bloedel Corporation	Dec. 13	5
Magnolia, Ark.	Weyerhauser Company	Dec. 9	5
Perry, Fla.	Buckeye Cellulose Corporation	Dec. 14	3
Archer, Fla.	Container Corporation	Dec. 16	3
Lee, Fla.	St. Regis Paper Company	Dec. 13	3
Statesboro, Ga.	Continental Forest Industries	Dec. 16	3
Cedar Springs, Ga.	Great Southern Paper Company	Dec. 7	13
Glennville, Ga.	ITT Rayonier Incorporated	Dec. 11	8
Bellville, Ga.	Union Camp Corporation	Dec. 9	8

[1] Before potting.

Sampling at individual nurseries was not entirely random. Instead, an attempt was made to include a broad range of average morphological grades among the samples. No seedling measurements were made prior to lifting. The nursery managers were asked to identify sections of their nurseries where they believed that seedling "quality" was appreciably above or below average. From these judgments, samples were classified as "good," "average," or "poor" at lifting. Sampling within a given section of a nursery was random. Of the samples obtained from 20 nurseries, 12 were listed as "average," 7 "good," and 1 "poor."

After all samples were collected and stored, each was removed, graded and sorted by root collar diameter, and culls discarded. From each sample, 20 seedlings with root collar diameters between 3 and 5 millimeters were randomly selected (except for exclusion of seedlings with southern fusiform rust, *Cronartium fusiforme* Hedg. & Hunt, or severe stem or root deformities and, when possible, seedlings over 25 centimeters in height).

On December 20, selected seedlings were root-pruned 18 centimeters below the root collar, and new, white root tips were removed from the remaining roots. The seedlings were then transplanted into sand-filled, 2-liter milk cartons with drainage holes, one seedling per carton. The cartons were randomly placed on a rooting bed of a heated greenhouse. Temperature in the rooting medium was maintained by electric cables buried in the bed beneath the cartons and set to maintain a temperature of 27°C near the bed surface.

The seedlings remained on the rooting bed for 28 days. Natural photoperiod was extended to 16 hours with incandescent bulbs. Temperatures at half-depth in the sand of the cartons were monitored daily from 12 mercury-in-glass thermometers systematically placed to sample all areas of the bed. Air temperature and relative humidity were recorded by a hygrothermograph placed on the bed adjacent to the seedlings.

Temperatures measured in the cartons at about half-depth averaged approximately 26.5°C over the duration of the rooting period, with a diurnal fluctuation of about 1.0°C to 2.5°C and a maximum difference of 2.0°C due to position in the bed. Average daytime air temperature (6:00 a.m. to 6:00 p.m.) was 22.2°C and average nightime temperature was 18.9°C. Relative humidity averaged 57 percent during the daytime.

Watering was done manually and all cartons were kept adequately watered. All seedlings were fertilized at 1 week and again at 3 weeks with half-strength Hoagland's solution (*12*).

The weather in the South during the fall of 1982 was unusually mild. For example, on December 7, the earliest lifting date at any nursery, only 132 chilling hours (0°-8°C) had accumulated at Auburn, Alabama, compared to 240 hours in 1980. On December 17, the latest lifting date, 208 chilling hours had accumulated, compared to 304 hours in 1980 (J.M. Boyer, personal communication). Root growth potential of coniferous seedlings has been found to increase with chilling during the late fall and early winter until the chilling requirement of the dormant buds has been satisfied (*20*). All of the seedlings had ceased terminal growth before lifting, but many resumed growth some time after transplanting into the greenhouse. Therefore, the seedlings' terminal buds were inspected 5 days before removal from the pots. A bud was classed as active if it had visibly swollen, to the extent of revealing some of the green primary leaf tips, or was elongating, table 2.

TABLE 2. MEAN ROOT GROWTH MEASUREMENTS AND NUMBER OF ACTIVE SEEDLINGS FROM EACH OF 20 NURSERIES[1]

Nursery of origin	No. of active buds[2]	Chilling hours prior to lifting[3]	Total chilling hours[4]	Root weight	Root number		Root length	
					Total ≥ 0.5	≥ 1.5 cm	Total ≥ 0.5	≥ 1.5
				mg			*cm*	*cm*
1	19			94	57.0	17.5	100.8	64.5
2	13	167	431	146	52.7	23.8	137.6	101.1
3	16			124	50.7	23.3	129.9	98.7
4	16	100	349	157	49.5	25.2	133.9	101.4
5	14	64	136	114	47.0	18.5	94.3	64.2
6	15			80	47.0	17.3	94.2	63.3
7	19	267	339	72	44.1	15.9	101.3	70.4
8	18	229	349	101	39.3	10.0	61.2	34.7
9	12	100	292	58	34.8	12.2	76.1	51.2
10	12	64	136	45	32.3	7.8	50.2	27.0
11	15	237	357	45	31.9	11.1	64.0	42.1
12	10	133	205	37	28.8	11.2	58.2	40.0
13	14			45	28.7	5.9	39.3	17.8
14	9	126	198	63	27.1	4.7	35.6	16.2
15	15	153	465	38	26.1	5.2	34.3	16.3
16	6	320	440	53	24.4	6.5	37.4	20.8
17	14	100	292	31	23.1	4.0	28.5	12.7
18	2	113	185	33	21.8	4.0	27.3	13.3
19	17			24	21.2	4.3	30.4	15.7
20	7	212	476	22	11.3	1.3	11.6	4.2

[1] Sample size = 389 seedlings.
[2] Number of buds elongating or swollen 5 days before lifting from greenhouse.
[3] Chilling hours accumulated to lifting date at nearest National Weather Service recording tation.
[4] Including hours in cold storage.

Few forest tree nurseries monitor chilling hours at their sites. However, the National Weather Service maintains the Southeastern Agricultural Weather Service Center at Auburn University. This agency began recording chilling hour data at its existing network of stations in Alabama, Georgia, and Florida in the fall of 1982. Fourteen of the nurseries in this study are located in those states. Recording stations were located within 20 miles or less of seven of the nurseries and bracketing pairs of stations within 50 miles or less of the other seven, enabling reasonable estimates of chilling hours. One nursery in another state provided chilling hours recorded on site, table 2.

At the end of the growth period the seedlings were carefully removed from the cartons, washed free of sand, and placed in cold storage (2°C) until measurement. The presence of a root rot, *Fusarium* sp., on some seedlings from one nursery had been diagnosed after planting in the greenhouse was completed. Seedlings from this source were individually inspected after lifting, and nine diseased seedlings were discarded.

All new roots of the remaining seedlings were measured to the nearest 0.5 centimeter, excised, oven-dried, and weighed. The foliage was stripped from the seedlings and the stems

TABLE 3. MEANS OF SEVERAL MORPHOLOGICAL VARIABLES FOR EACH OF THE 20 NURSERY SAMPLES

Nursery of origin	Original root weight	Foliage weight	Stem length	Stem weight	Length/ weight ratio	Shoot/ root ratio
	Grams	*Grams*	*cm*	*Grams*		
1	0.84 (0.27)[1]	1.20 (0.48)	16.0 (4.3)	0.68 (0.30)	26.1 (8.4)	2.20 (0.45)
2	.91 (0.24)	1.22 (0.35)	20.7 (2.8)	.77 (0.20)	28.3 (6.0)	2.24 (0.38)
3	.87 (0.24)	1.34 (0.45)	22.3 (2.7)	.88 (0.24)	26.7 (5.4)	2.60 (0.59)
4	.67 (0.17)	.87 (0.20)	12.6 (2.6)	.33 (0.08)	38.9 (8.0)	1.89 (0.52)
5	.49 (0.15)	.97 (0.29)	16.8 (2.6)	.49 (0.15)	37.0 (10.0)	3.03 (0.67)
6	.55 (0.21)	1.00 (0.40)	21.6 (2.6)	.61 (0.18)	38.1 (11.0)	3.00 (0.69)
7	.57 (0.19)	.92 (0.33)	22.0 (2.8)	.68 (0.19)	33.6 (6.8)	2.90 (0.70)
8	.70 (0.23)	1.15 (0.37)	17.3 (3.0)	.56 (0.18)	33.1 (8.1)	2.47 (0.53)
9	.60 (0.20)	1.04 (0.40)	20.2 (3.9)	.62 (0.22)	35.5 (10.2)	2.85 (0.84)
10	.62 (0.18)	.61 (0.22)	22.1 (2.2)	.68 (0.18)	35.1 (11.0)	2.11 (0.33)
11	.63 (0.16)	1.14 (0.30)	21.9 (2.5)	.65 (0.17)	33.6 (8.4)	2.92 (0.65)
12	.44 (0.14)	1.06 (0.46)	21.9 (2.3)	.63 (0.18)	36.8 (9.9)	3.89 (0.90)
13	.55 (0.15)	.82 (0.30)	18.8 (3.5)	.54 (0.21)	37.2 (8.4)	2.55 (0.96)
14	.81 (0.23)	1.04 (0.30)	18.1 (2.9)	.63 (0.19)	30.4 (7.1)	2.11 (0.46)
15	.47 (0.15)	.92 (0.36)	20.3 (3.5)	.54 (0.18)	39.8 (10.1)	3.22 (0.90)
16	.54 (0.16)	1.12 (0.31)	21.4 (2.2)	.64 (0.11)	34.0 (5.1)	3.36 (0.63)
17	.47 (0.20)	.92 (0.27)	20.3 (2.5)	.61 (0.16)	35.0 (8.4)	3.67 (1.21)
18	.68 (0.22)	1.26 (0.38)	21.9 (2.2)	.88 (0.22)	27.0 (9.6)	3.31 (0.68)
19	.33 (0.14)	.57 (0.23)	20.9 (2.2)	.53 (0.13)	41.9 (9.8)	3.64 (1.27)
20	.43 (0.17)	.94 (0.34)	23.3 (2.8)	.67 (0.20)	37.0 (9.4)	3.97 (0.92)

[1] Standard deviation of means.

were severed from the roots. Stem length and the oven-dry weights of the foliage, stem, and old roots were obtained for each seedling, table 3. A total of 21 seedlings from nine of the nurseries produced no new roots while in the greenhouse. Of these, seven (three from one nursery) were clearly dead and a number of the remainder were obviously dying by lifting time. Data from dead and dying seedlings are included in statistical analyses reported here. Analyses excluding these seedlings gave fundamentally similar results. Data for two seedlings from one nursery were excluded because their dry weight measurements were lost.

RESULTS

Individual Seedlings

New root growth varied from none to a maximum of 112 roots (totalling 279.5 centimeters in length). Five parameters of new root growth were obtained from seedling measurements: (1) total number $\geq$ 0.5 centimeter, (2) number $\geq$ 1.5 centimeters, (3) total length $\geq$ 0.5 centimeter, (4) length $\geq$ 1.5 centimeters, and (5) total weight. The means of the respective measurements for each of the 20 nursery samples are presented in table 2.

Linear regression analyses were performed to test the correlation of each parameter to each of six morphological variables. The resulting correlation coefficients and their levels of significance are given in table 4. Seedbed density of the samples was also tested as a variable, but was not significantly correlated to any measure of new root growth. Each morphological variable tested was correlated to all or most of the root growth parameters. The correlations were highest in most cases for total number of new roots ($\geq$ 0.5 centimeter in length), although lengths were highly correlated with numbers ($r = 0.8667$).

A forward stepwise regression was then performed, with total number of new roots as the response variable and setting the significance level at 0.05 for inclusion of variables in the model. This produced the following predictive equation:

Number of new roots = 35.29 + 17.70 (original root weight)
(S.E. of estimate = 17.64)
+ 17.08 (foliage weight)
- 0.77 (stem length)
- 4.39 (shoot/root ratio)

TABLE 4. CORRELATION COEFFICIENTS AND SIGNIFICANCE LEVELS FOR SEVERAL MORPHOLOGICAL VARIABLES, LIFTING DATE, TIME IN COLD STORAGE, AND TERMINAL BUD BREAK WITH FIVE ROOT GROWTH PARAMETERS

Root growth parameter	Statistic	Original root weight	Foliage weight	Stem length	Stem weight	Length/ weight ratio	Shoot/ root ratio	Lifting date	Days in cold storage	Terminal bud break[1]
Individual seedlings (n = 389)										
Total number $\geq$ 0.5 cm	r	0.5194	0.3931	−0.1416	0.2099	−0.3206	−0.3276			
	p	.0001	.0001	.0051	.0001	.0001	.0001			
Number $\geq$ 1.5 cm	r	.3963	.2959	− .1817	.0903	− .2170	− 2714			
	p	.0001	.0001	.0003	.0753	.0001	.0001			
Total length	r	.4586	.3348	− .1573	.1384	− .2600	− .3089			
	p	.0001	.0001	.0019	.0063	.0001	.0001			
Length $\geq$ 1.5 cm	r	.4003	.2949	− .1520	.1088	− .2238	− .2704			
	p	.0001	.0001	.0027	.0319	.0001	.0001			
Total weight	r	.4607	.2882	− .2615	.0657	− .2518	− .3490			
	p	.0001	.0001	.0001	.1965	.0001	.0001			
Sample means (n = 20)										
Total number $\geq$ 0.5 cm	r	.6310	.3512	− .4616	− .0055	− .3766	− 6576	0.2844	−0.0330	0.6066
	p	.0029	.1290	.0405	.9815	.1017	.0016	.2380	.8902	.0046
Number $\geq$ 1.5 cm	r	.5375	.3423	− .3843	.0319	− .2608	− .5321	.1375	.0753	.4894
	p	.0145	.1396	.0944	.8939	.2668	.0157	.5744	.7524	.0285
Total length	r	.5884	.3505	− .3597	.0162	− .3105	− .5750	.1548	.0956	.5147
	p	.0063	.1297	.1193	.9460	.1827	.0080	.5268	.6885	.0202
Length $\geq$ 1.5 cm	r	.5634	.3576	− .3253	.0290	− .2939	− .5274	.1119	.1290	.4749
	p	.0097	.1216	.1616	.9032	.2085	.0169	.6484	.5878	.0343
Total weight	r	.6517	.3691	− .5830	− .1227	− .3284	− .6717	.0367	.1801	.4086
	p	.0019	.1093	.0070	.6063	.1575	.0012	.8814	.4474	.0737

[1] Number of buds elongating or swollen 5 days before removal from cartons.

The percentage of the total variation in RGP explained by the equation is relatively low ($r^2 = 0.3140$). However, it should be clearly understood that the regression was computed from individual seedlings ($n = 389$) rather than nursery sample means. Thus, the variation in morphological measurements included genetic and environmental influences within, in addition to between, samples as well as any genetic-environmental interactions. The ability to explain approximately 31 percent of the variation in RGP among individual seedlings, from various seed sources grown independently at 20 widely separated locations under different cultural regimes, indicates the biological importance of these morphological traits. The equation shows that, on the average, RGP was greatest for large seedlings with high root weight and a relatively short but heavily foliated stem. In general, these characteristics correspond to criteria of high quality in morphological grading, suggesting that RGP may be an important factor in the field performance of planted loblolly pine.

Sample Means

Correlation coefficients were computed to determine whether significant correlations existed between the means of the various RGP measurements for each of the 20 nursery samples and their respective lengths of growing season, nursery lifting dates, numbers of days in cold storage prior to planting, and numbers of active terminal buds 5 days before lifting in the greenhouse. Of these, only terminal bud activity was correlated positively with all RGP measurements. Again, the highest correlation was with total number of new roots, table 4. The correlation of terminal bud activity with RGP was recomputed using the estimated RGP adjusted for significant morphological variables and, as would be expected, the correlation increased ($r = .7376$, $p = 0.0002$). The positive correlation suggests that seedlings which began shoot growth, also began root growth earlier in the greenhouse.

It is apparent by inspection, however, that even when allowing for some discrepancies in chilling hour estimates, table 2, there is no consistent relationship between sample RGP's and their respective chilling hours. Regressions of RGP on chilling hours prior to lifting and total after storage were performed for the eight nurseries with nearby recording stations and for all 15 stations. In all cases the correlation coefficients were low and nonsignificant.

TABLE 5. AVERAGE NUMBER OF NEW ROOTS FOR EACH NURSERY SAMPLE, IN ORDER OF RANK, BEFORE AND AFTER ADJUSTMENT FOR MORPHOLOGICAL DIFFERENCES BETWEEN SAMPLES[1]

Nursery of origin	Unadjusted values, number of new roots	Nursery of origin	Adjusted values, number of new roots
1	57.0	5	49.1
2	52.7	6	49.0
3	50.7	1	48.2
4	49.5	3	47.3
5	47.0	4	46.1
6	47.0	2	42.5
7	44.1	7	40.4
8	39.3	10	38.2
9	34.8	19	34.8
10	32.3	9	34.5
11	31.9	8	33.8
12	28.8	12	33.6
13	28.7	13	32.2
14	27.1	15	30.6
15	26.1	11	30.4
16	24.4	17	28.5
17	23.1	16	25.8
18	21.8	14	20.9
19	21.2	20	18.6
20	11.3	18	17.5

[1] Samples not connected by the same vertical line differed significantly at the 0.05 level.

An analysis of variance was performed on the total numbers of new roots to test for differences among samples from different nurseries. An analysis of covariance was also performed to remove the effects of the significant morphological variables before testing for sample differences. The mean numbers of new roots before and after adjustment, listed in order of rank and showing significant differences, are given in table 5.

DISCUSSION

Individual Seedlings

The most important morphological indicator of high RGP was original root weight, table 4. The morphological indicator of potential field performance most often used for southern pines is root collar diameter (*21*). The seedlings in this study had a relatively narrow diameter range, but a positive relationship of RGP with diameter is shown indirectly by the positive correlation with stem weight and the negative correlations with stem length and stem length/weight ratio. Stem length/weight ratio is not retained in the final model because it accounted for little additional variation. It was significantly, negatively correlated with original root weight ($r = -0.6843$, $P = 0.0001$).

Most new roots of the experimental seedlings were extensions of existing first and second order laterals or roots initiated near their ends, which were broken during lifting, and were not new laterals initiated directly from the taproot. This pattern was previously reported for Monterey pine, *P. radiata* D. Don (*17*). The more fibrous the root system the greater the potential number of new roots; thus, the higher correlation of original root weight with number than with length of new roots suggests that the heavier root systems tended to be more branched or fibrous.

Large leaf area promotes high RGP because early root growth is at least partly, if not largely, dependent upon current photosynthesis, as previously shown for Douglas-fir (*14*), red pine, *P. resinosa* Ait (*27*), and loblolly pine (*2*). Conifers do not accumulate as large reserves of starch for the winter as hardwoods (*11*) and evidently do not readily mobilize their reserves until bud break.

The negative correlation of RGP with stem length is an interesting though less influential factor. Although seedlings of greater total weight with low shoot/root ratios had higher RGP, seedlings of a given weight with short stems were predisposed to produce more roots than those with taller stems.

Chapman (*6*) found that lower height/diameter ratios were associated with better survival and growth rates of shortleaf pine. Plantings of loblolly pine on moist sites in Oklahoma (*1*) showed no effect of seedling height on either survival or first-year height increment, but on droughty sites shorter seedlings were superior in both respects. Initial height of Monterey pine (*P. radiata* D. Don) and Douglas-fir at planting in New Zealand has recently been shown to have little relation to subsequent height growth because of the tendency of shorter seedlings to make up height deficits within 2 years after planting (*7*). "Sturdiness" of seedlings or height/diameter ratio has become a recognized index of seedling quality in New Zealand (*8*).

Drew and Ledig (*9*) determined that the allometric ratio of top to root growth for loblolly pine tends to remain constant for at least the first 2 years of development through the action of feedback mechanisms. Foliage weight of the seedlings in this study, a major determinant of RGP, table 4, was more strongly correlated with stem weight than stem length ($r = 0.6732$, $p = 0.0001$ and $r = 0.2320$, $p = 0.0001$, respectively). Thus, increased height growth sometimes reported for seedlings which are taller at planting is probably often confounded with seedling diameter or differences in shading from competition. If differences in sturdiness of seedlings in this study were more culturally induced than genetic in origin, it appears that selectively restricting height growth in the nursery should improve survival without sacrificing subsequent height growth.

Sample Means

The adjusted means are relatively independent of morphological differences and provide some measure of the physiological quality of the samples with respect to RGP. A comparison of the ranking before and after adjustment shows that most samples of high morphological quality also appeared to have high physiological quality, in that only one sample in the top 10 morphologically was replaced after adjustment. This supports the thought expressed by Wakeley (*29*) that a tendency for morphological grade to coincide with physiological quality explains the general correlation between seedling survival and morphological grade. However, Wakeley also stated that morphological and physiological quality do not necessarily coincide. An illustration of this may be provided by sample S, which moved from 19th to 9th place after adjustment.

After adjustment for morphological differences, a majority of the total variation in RGP was still accounted for by differences among samples. In the analysis of covariance, the total model sum of squares is approximately 87,000. When nursery sample is the first independent variable included in the model, its sum of squares is 61,000 (SAS Type I SS). If all morphological variables are included, nursery samples explain a total of 34,000 (SAS Type IV SS). These differences are, of course, attributable to both genetic and environmental effects. In view of the localized origin of the seed sources, it seems possible that a significant portion of the remaining differences in RGP is environmental in origin, i.e. due to differences in soil conditions, weather, or cultural practices affecting growth.

It is known that the endogenous, or internal, annual growth cycle of most temperate-zone plants can be overridden by manipulating environmental factors to either strongly limit or stimulate growth, resulting in improper synchronization with the natural environment (*15*). For example, extending irrigation to maintain shoot growth beyond its natural period will delay bud formation and development, requiring a longer period of chilling to terminate dormancy. The lack of correlation between chilling hours and RGP of the samples in this study suggests that much of the variation in RGP was induced by the effect of cultural practices upon dormancy status at time of lifting.

If differences in dormancy were influenced by the timing of shoot growth cessation, this could provide a possible explanation for some of the interrelationships among morphological variables correlated with RGP. In a 3-year study of the development of southern pine seedlings in the nursery, Huberman (*10*) found a tendency toward alternation between root activity and top activity. Considerable increase in root weight occurred late in the season, which he attributed largely to deposition of reserve foods. Lyr and Hoffmann (*16*) reported that root growth of Scotch pine, *P. sylvestris* L., is weak during formation of new shoots and needles and increases considerably after expansion of the needles. They suggested this might be true of other *Pinus* species and correlated with strong consumption of assimilates by the growing shoot.

Interestingly, the stem length/weight ratio of seedlings in this study was negatively correlated with original root weight as well as RGP ($r = -0.6843$, $p = 0.0001$ and $r = -0.3206$, $p = 0.0001$, respectively), but not with stem length ($r = -0.0917$, $p = 0.0708$). Low length/weight ratios, therefore, resulted largely from an increase in stem diameter, specific gravity, or both.

This study establishes differences in RGP only for 1982 and for a single lifting date at each nursery. Presumably, colder weather during the fall of 1982 would have reduced the range of RGP exhibited by different samples. However, lifting at southern nurseries ordinarily begins in early December and the estimated full chilling hour requirement for loblolly pine is not usually achieved at Auburn, Alabama, until late December or early January.

CONCLUSIONS

This study demonstrates that wide, and probably important, differences in root growth potential can occur during some years among loblolly pine seedling crops produced at different nurseries. A portion of this variation is expressed visibly by differences in seedling morphology, which can be measured and relatively easily controlled. However, a significant and probably greater degree of variation in RGP can exist among seedlings of similar morphology.

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