Immature Loblolly Pine Growth and Biomass Accumulation: Correlations with Seedlings Initial First-Order Lateral Roots

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*ABSTRACT. Five to seven years after being graded by first-order lateral root (FOLR) numbers and outplanted, loblolly pine (*Pinus taeda *L.) seedlings were excavated using a commercial tree spade and root systems re-evaluated. Current competitive position of trees was related to initial FOLR numbers of 1-0 seedlings. Current FOLR numbers were comparable among tree size classes, but root diameters where the spade severed the root were different. The dominant and codominant individuals had much larger FOLR cross sectional area at the severed point. The larger diameter laterals allow exploration of larger soil volume since they extended greater distances from the tree. Root biomass allometric equations were developed from excavating 175 individuals in 3 separate plantations. Root biomass was readily predicted based on either stem diameter breast height squared (D^2H), or total aboveground biomass. Approximately 75% of standing tree biomass was aboveground and 25% belowground for all initial root grades, current crown classes, and sites. Subsoil compaction layers appeared to have a major impact on tree development at any specific location within a plantation. Compaction layers affected heights and diameters but not root/top ratios or the relative competition position based on initial FOLR numbers. These compaction layers resulted in plate-like taproots that suggested further root penetration was unlikely. South. J. Appl. For. 22(2):117–123.*

A series of nursery studies was conducted from 1984-1990 by the USDA Forest Service's Institute of Tree/Root Biology (ITRB) in Athens, Georgia, to determine the heritability values for first-order lateral roots (FOLR) of half-sib loblolly pine (*Pinus taeda* L.) progeny. Seed from approximately 150 individual mother trees from the Georgia Forestry Commission's seed orchard was used for this research. These nursery studies clearly demonstrated that development of FOLR was under considerable genetic control, with family means heritability (h^2) values ranging from 0.60 to 0.77 (Kormanik et al. 1990, 1991). These studies also showed that seedling competitive status in the nursery was highly correlated with FOLR numbers, even when different nursery protocols were used to grow seedlings (Kormanik et al. 1990, 1991). When inferior stem characteristics repeatedly appeared among half-sib progeny having low FOLR numbers in our nursery heritability tests (Kormanik et al. 1990, 1991), the obvious question was whether the early nursery performance of individuals could be related to performance after outplanting. The importance of this issue was reinforced by Grigsby (1971) who reported that inferior type 1 seedlings, which were similar to our inferior seedlings, produced only about one-half the stem volume as the best two grades. In our long-term studies, the effect of initial FOLR numbers on subsequent growth has been substantial; however, some anomalies have occurred that have been difficult to reconcile based on initial root assessment and actual growth of individuals at specific locations within the plantations. Our current excavation research was designed to clarify variability in performance among and within seedling grades when they are outplanted under variable edaphic conditions.

Traditionally, the primary seedling characteristics used for grading loblolly pine for outplanting has been root collar diameter *(RCD)* and height *(HGT),* with lesser emphasis on bud characteristics and needle fascicle maturity (Grigsby 1971, May 1984, Wakeley 1954, 1969). Characteristically,

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seedlings from the higher grades outperformed those from lesser morphological grades. However, in spite of various refinements and modifications in grading standards (Dorman 1976), variation in volume production among individual trees exist both within and among grades and progeny. In general, this response has also emerged in these long-term tests, which raises questions regarding the value of grading nursery stock for artificial regeneration of forest stands.

Root biomass has been studied in an attempt to explain variation in aboveground biomass. Root biomass estimates using allometric relationships and regression methodology to develop prediction models have been obtained from a few excavated trees in older stands (Pehl et al. 1984, Van Lear et al. 1984, Van Lear and Kapeluck 1995). In younger plantations, seedling excavation studies have shown significant correlations between aboveground and belowground biomass. Many such studies have been reported using seedlings of differing morphological stem grades, but few have included intensive long-term serial measurements of the same individual (Dorman 1976, Grigsby 197 1, Mexal and Burton 1978). There has been little research performed on using seedling initial root morphological characteristics as a major grading criterion.

The purpose of this study was: (1) to determine the relationships between initial seedling FOLR number, subsequent root morphology several years after outplanting, and total standing biomass of immature sized loblolly pine and (2) to develop allometric equations for root biomass derived from stem measurements.

Materials and Methods

Plantation History

Between 1987 and 1989, half-sib loblolly pine seedlings from 78 mother trees in the nursery trials for FOLR heritability were used to establish long-term studies at the Department of Energy's (DOE) Savannah River Site located near Aiken, South Carolina. Over 15,000 seedlings were measured for RCD, HGT, and FOLR numbers, tagged, and machine-planted in three plantations at densities of 1500-1625 seedlings/ha. The number of graded seedlings planted were 4400, 4800, and 6600, respectively, for 1987, 1988, and 1989.

In addition to number of FOLR, the individually tagged seedlings were placed in four vigor classes based primarily on FOLR numbers and their competitive status in the nursery beds (Kormaniket al. 1990, 1991). In the 1987 planting, low vigor seedlings were those with three or fewer FOLR and progressively higher vigor classes have FOLR numbers in the ranges of 4 to 5, 6 to 7, and 8 or more. The vigor classes for seedlings outplanted in 1988 and 1989 were produced with a modified nursery protocol (Kormanik et al. 1992). Low vigor seedlings outplanted during these 2 yr had two or fewer FOLR numbers with progressively higher vigor classes having FOLR numbers in the ranges 3-5, 6-7, and 8 or more.

Site Description and Site Preparation

All three plantations were established after naturally regenerated mixed pine/hardwood stands had been harvested from this upper Coastal Plain site. Pines were originally the predominant trees in these stands that had developed after land acquisition in the mid- 1940s. All stands were relatively flat with slopes of 2% or less. The soil in the youngest plantation 1 (age 5) was a Dothan series classified as fine-loamy, siliceous, thermic Plinthic Paleudults. In plantation 2 (age 6) the soils were a gradation between the Orangeburg series and the Lucy series with Lucy sand being the primary soil at the sampling locations. The Orangeburg soils are classified as fine-loamy, siliceous, thermic Typic Paleudults while the Lucy soils are loamy, siliceous, thermic Arenic Paleudults. In plantation 3 (age 7), the soils were of Vauclose Series which are classified as fine-loamy, siliceous thermic Typic Hapludults. Soils in the plantations have been all classified as suitable for forestry with loblolly pine being the preferred species (USDA 1990). A distinct plow layer, characteristic of abandoned farmlands in the Piedmont and upper Coastal Plain soils, was present in plantations 1 and 3. No such plow layer was evident in the primarily Lucy soils of plantation 2 as this plantation had essentially unrestricted root penetration.

Before the plantations were established, standing residuals were felled, the sites root raked, and the debris put into windrows approximately 100 m apart. A single post-planting treatment applied to these plantations was banded (30 cm) herbicidal application of glyphosate in July following outplanting.

Tree Selection

To determine how a tree's competitive position related to both initial and current FOLR numbers, a group of three trees was selected for excavation from 14, 18, and 15 locations in each of the three plantations, respectively. Tree selection was based upon the smallest, average, and largest tree dbh determined by measuring 25-30 adjacent trees at each excavation point. No gaps or missing trees were permitted adjacent to specific sampled trees. Preliminary soil profile examinations were undertaken to assure visually uniform soil characteristics at a specific sampling location. Few locations larger than 0.12 ha were found in any plantation that could be easily approached with the tree spade while maintaining the soil profile and tree constraints we wanted to maintain within any group of three trees.

These excavation points were selected based on uniformity at site and stand conditions. Border trees that had to be removed to enter the stand were sampled to compare root relationships between border and inner row individuals.

Tree Excavation

A commercial tree spade that excavated a cone 1.22 m diameter x 1.37 m deep was used to extract 175 individual trees from the three plantations. A total of 50, 78, and 47 trees including border trees were excavated and evaluated from the three plantations. The different number excavated among the plantations is a reflection of the site variability and logistics of moving the large tree spade within specific plantations. Coarse root biomass (kg), ht (m), dbh (cm), aboveground biomass (kg), FOLR number, FOLR diameters (cm) at the point severed by the tree spade, depth (cm) of surface FOLR, and total root depth (cm) were obtained for each excavated tree.

Biomass Determinations

Aboveground biomass was expressed as stem green weight obtained immediately after felling. For each tree, all fine and coarse roots were obtained from within the cone. On approximately one-third of these trees, all lateral roots to a 2-3 mm diameter in the soil outside the cone were excavated. Fine feeder roots less than 2 mm were sampled if they were attached to an excavated root. These root samples were washed of adhering soil and weighed to obtain root biomass. The allometric regression models for total root biomass were based on the trees where root data were obtained from within and outside the cone. Total root biomass was defined as the sum of these two root weights. We did not measure total root biomass outside the cone because feeder roots represent only a small percentage of the standing tree total biomass and a secondary consideration was that it was not practical to know exactly from which individual tree the sample originated.

Statistical Analysis

We computed descriptive statistics for aboveground and belowground components for trees within the plantations and the border trees. The aboveground components analyzed were dbh, ht, D^2H, and total top biomass. The belowground components consisted of FOLR number, surface FOLR depth, total root depth, cone root biomass, and total root biomass. FOLR cross-sectional area for a given tree was computed as the sum of the cross-section areas of each FOLR severed by the tree spade. The root/shoot ratio was defined as the ratio of belowground root biomass to total aboveground biomass, with the assumption that the small percentage of fine feeder roots not recovered was negligible.

Differences in aboveground and belowground characteristics for border and inner plantation trees were compared using a two-sample t-test at the 0.05 significance level. This test indicated whether we could pool these data for further analysis. Correlation coefficients calculated between aboveground and belowground components were computed. Allometric relationships were developed between aboveground and belowground components. The typical log-log model was fitted to help linearize the relationship and ensure homogeneity of the variance. After parameter estimation, the log-log model was transformed back to arithmetic units using the bias correction of Baskerville (1972). Tree biomass distributions for top and root cone components were developed for each stand.

Results and Discussion

Characteristics and Relationships for Aboveground and Belowground Components

No significant differences were found between inner and border tree characteristics for any of the stands except number of FOLR in the youngest plantation (Table 1). Thus, we pooled the inner and border trees to increase the sample size for further analyses. Basically, the aboveground and belowground components varied by soil conditions as much as by plantation age. FOLR depths (inner and border individuals combined) in the plantations were similar to each other. The FOLR depths observed in the Piedmont plateau and upper Coastal Plain soils are related to the depth of the plow layer. The old plow layer zone is characteristically the most friable, contains the most organic matter and has the greatest concentration of higher order roots. Lateral roots

Table 1. Means of aboveground and belowground characteristics for the inner and border trees in each of the three loblolly pine plantations.’

Characteristic	Plantation 1 (age) 5			Plantation 2 (age) 6			Plantation 3 (age) 7		
	Inner (n = 45)	Border (n = 5)	All (n = 50)	Inner (n = 54)	Border (n = 24)	All (n = 78)	Inner (n = 40)	Border (n = 7)	All (n = 47)
Aboveground characteristics									
Dbh (cm)	7.8	6.2	7.7	7.8	7.2	7.6	12.4	14.2	12.7
Height (m)	4.80	4.40	4.76	5.29	4.83	5.15	7.66	7.76	7.68
D^2H (m^3)	0.0338	0.0193	0.0324	0.0357	0.0301	0.0340	0.1309	0.1572	0.1348
Total top biomass (kg)	28.1	16.7	27.0	25.2	21.7	24.1	64.0	79.1	66.3
Belowground characteristics									
Number of FOLR	13.6	9.0	13.2	8.8	9.2	8.9	14.5	16.1	14.7
FOLR cross section area (cm^2)	49.6	22.2	46.9	32.2	28.3	31.0	82.8	108.3	86.6
FOLR depth (cm)	20.5	19.6	20.4	21.2	19.6	20.7	22.7	23.1	22.8
Total root depth (cm)	79.8	86.6	80.5	107.3	107.6	107.4	94.0	101.4	95.1
Root biomass (kg)	9.6’			8.7[3]	6.8[4]	8.2[5]	22.6[6]	—	—
Proportion of total tree biomass in roots	0.25’		—	0.27[3]	0.27[4]	0.27’	0.23[6]	—	—
Cone root biomass (kg)	7.3	4.5	7.0	7.2	6.4	6.9	16.2	20.7	16.9
Proportion of root biomass in cone	0.79[2]		—	0.80[3]	0.80[4]	0.80[5]	0.83[6]		—
Root/shoot ratio	0.33[2]	—	—	0.37[3]	0.37[4]	0.37[5]	0.30”	—	—

[1] No significant differences between inner and border trees within a stand were detected for any characteristic except number of FOLR (first-order lateral roots) in plantation 1.
[2] Based on n = 16 observations.
[3] Based on n = 14 observations
[4] Based on n = 5 observations.
[5] Based on n = 19 observations.
[6] Based on n = 18 observations.

Table 2. Correlation coefficients between root characteristics and aboveground characteristics of young loblolly pine trees.

Root characteristic	Plantations	n	Correlation coefficients [1] Dbh	Height	D^2H	Total top biomass
No. of FOLR[2]	1	50	0.36*	0.31*	0.38*	0.47*
	2	78	0.31*	0.22*	0.27*	0.27*
	3	47	0.40*	0.30*	0.34*	0.42*
Total root biomass	1	16	0.92*	0.85*	0.91*	0.97*
	2	19	0.84*	0.86*	0.93*	0.93*
	3	18	0.93*	0.81*	0.95*	0.96*
FOLR cross sectional area	1	50	0.80*	0.71*	0.80*	0.92*
	2	78	0.67*	0.61*	0.67*	0.73*
	3	47	0.82*	0.61*	0.78*	0.80*
Root/shoot ratio	1	16	0.37	0.10	0.30	0.23
	2	19	-0.12	-0.14	-0.06	-0.10
	3	18	-0.01	0.12	0.03	0.01
Proportion of total tree biomass in roots	1	16	0.37	0.11	0.30	0.23
	2	19	-0.11	-0.15	-0.06	-0.10
	3	18	-0.00	0.12	0.04	0.03
Proportion of root biomass in cone	1	16	-0.37	-0.22	-0.35	-0.34
	2	19	0.40	0.42	0.27	0.25
	3	18	-0.33	-0.36	-0.28	-0.34

1 Correlation coefficients followed with an • are significantly different from zero at the 0.05 level.
2 These are current numbers of FOLR (first-order lateral roots) on excavated trees.

tend to be concentrated along and above the plow layer for some years. However, variations in total root depth in plantation 2 (age 6) was related to the unrestricted root penetration common to Lucy soils and reflected soil depth variation and results of past land use and erosion. The root/shoot ratio and proportion of tree biomass in roots were similar for all three plantations. The proportion of root biomass in the cone tended to be greatest in the oldest plantation which may indicate that as the stands age and crown closure occurs, roots increase in diameter more than length: crown closure is reflected by lateral root competition below ground. Soil differences may also have played a role, especially in plantation 2, where the soil was a deep sandy loam without obvious subsoil compaction layers. This favors deeper root penetration rather than lateral expansion.

Several aboveground measurements were correlated with belowground variables (Table 2). Total root biomass, FOLR cross-sectional area, and current number of FOLR were significantly correlated with aboveground components. The root/shoot ratio, the proportion of total tree biomass in roots, and the proportion of root biomass in the excavated cone were not significantly correlated with any of the aboveground tree measurements. This does not imply that there is no difference among the plantations but that the relative proportions were comparable among individuals regardless of their size within a plantation.

Allometric equations were developed from total root biomass and FOLR cross-sectional area because these were the root variables that exhibited the best relationships with the aboveground variables (Table 3). Models were formed using either of two independent variables to predict total root biomass and FOLR cross sectional area. One was D^2H, an easily obtained variable in the field and characteristically computed from routine forest surveys. The other was total top biomass *(TBTOTAL)* which is a variable commonly obtained or estimated in recent tree biomass research studies. These equations are useful for survey situations and for intensive research projects. The allometric equations had high R^2's for

Table 3. Allometric equations for predicting total root biomass and FOLR (first-order lateral roots) cross-section area of young loblolly pine trees.

Plantation	Equation*	n	Range of independent variable (min-max)	R^2**	MSE**
Total root biomass (kg)					
1	$y = 177.504\,(D^2H)^{0.83683}$	16	0.009-0.067	0.90	0.0386
2	$y = 86.121\,(D^2H)^{0.68153}$	19	0.004-0.093	0.87	0.0538
3	$y = 136.912\,(D^2H)^{0.96418}$	18	0.045-0.298	0.93	0.0283
1	$y = -0.283\,(TBTOTAL)^{1.04787}$	16	7.3–60.8	0.95	0.0198
2	$y = 0.420\,(TBTOTAL)^{0.95697}$	19	4.5-51.7	0.90	0.0412
3	$y = 0.304\,(TBTOTAL)^{0.99702}$	18	22.7-137.9	0.93	0.0256
FOLR cross sectional area (cm’)					
1	$y = 693.784\,(D^2H)^{0.77613}$	50	0.005-0.094	0.71	0.1302
2	$y = 273.594\,(D^2H)^{0.62912}$	78	0.003-0.093	0.55	0.2058
3	$y = 769.086\,(D^2H)^{1.07550}$	47	0.022-0.298	0.77	0.1237
1	$y = 1.046\,(TBTOTAL)^{,14529}$	50	7.3–60.8	0.87	0.0593
2	$y = 2.025\,(TBTOTAL)^{0.86331}$	78	4.5-51.7	0.61	0.1764
3	$y = 0.751\,(TBTOTAL)^{,13677}$	47	11.8-137.9	0.79	0.1136

• The units of measure for D^2H and *TBTOTAL* are m^3 and kg, respectively.
• * Based on the log-log model.

total root biomass and FOLR cross sectional area (Table 3). The D^2H variable was nearly as good a predictor of total root biomass and FOLR cross-sectional area as was total top biomass.

Root Morphology and Biomass

The excavations revealed that under uniform appearing site conditions, variations in soil characteristics affect how individual trees develop within a stand, but not the standing biomass percentages between roots and tops (Figure 1). The root cone biomass is the total root biomass within the extracted cone since it contains both fine and coarse roots. However, our estimate of total root biomass (inside and outside the cone) did not include fine roots 2 mm or less in diameter outside the cone. This should be an adequate approximation since although most available data indicate that feeder root production may account for up to two-thirds of annual carbon utilization, it rarely represents more than 1% of the standing tree biomass (Marshall and Waring 1985).

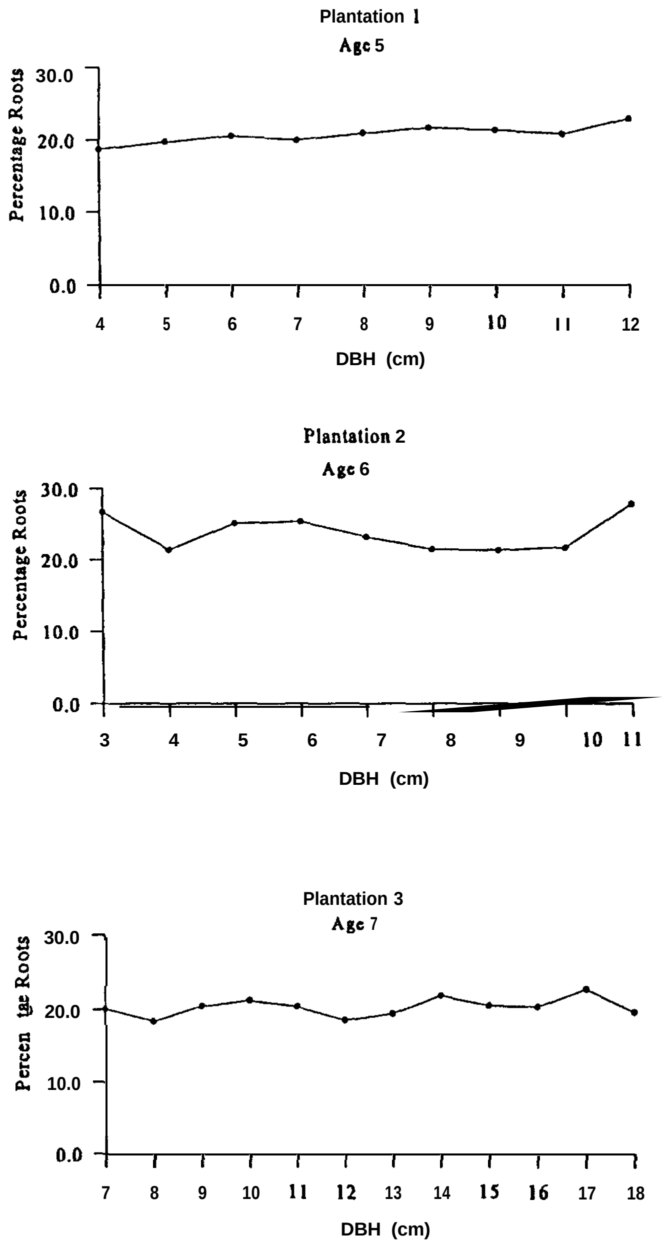

Figure 1. The relationship of root biomass as a percentage of total tree biomass and dbh for immature loblolly pine.

The FOLR depth and total root depth clearly reflect past land use (Table 1). We observed that the FOLR depth was clearly influenced by the old plow layer, which was visible after more than 50 yr postagricultural use. Multiple taproots or sinker roots developed at the subsoil interface with the plow layer in plantations 1 and 3. These intermittent or discontinuous compacted layers occurred as shallow as 30-35 cm, completely restricting further root penetration and resulting in a distinct plate root system (Busgen and Munch 1929). In plantation 2, the subsoil was a sandy loam, and the trees characteristically had a single tap root.

Thesecompaction layers significantly affected tree growth and root development in plantations 1 and 3 and may be the major cause of the variation in biomass production within specific initial FOLR root grades in these two plantations. Overall, these discontinuous subsoil compaction layers probably affected standing biomass production in trees as much as the original FOLR number grades (Kormanik et al. 1990, 1991). They did not, however, completely alter the overall effect of FOLR numbers when seedlings were outplanted. However, subsoil compaction may well represent a major cause of variation within and among seedling grades within plantations regardless of the initial grading system used to assess seedling vigor.

Initial FOLR numbers at time of outplanting have a significant bearing on future competitive potential of individual trees through age seven (Table 4). The significantly less growth in dbh, root collar diameter, total root biomass, top biomass, and volume (D^2H) for the plantation trees with the fewest initial FOLR embody important considerations relative to long-term economic and biological potential. These data indicate that for a given area within a plantation, one would expect only one-third to one-half of the yield from seedlings with the lowest initial FOLR grades compared to the higher grades. Furthermore, the productivity gap between the lower and higher initial FOLR grades will probably become greater as the smaller individuals fall into intermediate and suppressed crown classes. In this regard, it is especially important to note that regardless of the initial FOLR numbers of individual trees, little differences were noted in the current FOLR numbers when those same trees were excavated (Table 4).

Number of current FOLR are similar to those reported by Mexal and Burton (1978) for 2- to 4-yr-old loblolly pine. They reported the number of lateral roots and their distribution was positively correlated with seedling performance and that the number of lateral roots was the most important root variable. The number of lateral roots increased from 7 at age 2 and appeared to stabilize at 11.6 by age 4. Only in the oldest plantation 3 (age 7) did the large and medium size classes exceed those reported by Mexal and Burton (1978). However, while current FOLR number may stabilize early in the life of a stand, the FOLR cross-sectional area differed between the three size classes of trees within and among each plantation (Table 4). The larger diameter lateral roots extend greater horizontal distances and thereby exploit greater soil

Table 4. Means and correlation coefficients *(r)* for initial first-order lateral root number (FOLR) and specific growth parameters for small, medium, and large diameter trees from three loblolly pine plantations.

	Plantation 1				Plantation 2				Plantation 3			
	Dbh size class (Age 5)				Dbh size class (Age 6)				Dbh size class (Age 7)			
Variable*	Small	Medium	Large	*r*	Small	Medium	Large	*r*	Small	Medium	Large	*r*
Initial FOLR no.	2.9^{ab}	2.4^{b}	4.4”	—	2.7^{ab}	4.8^{b}	5.1”	—	3.0^{b}	3.9^{ab}	5.1”	—
Dbh (cm)	5.5’	7.4^{b}	10.1”	0.30**	5.3’	8.0^{b}	9.7”	0.33**	9.7’	13.1^{b}	15.7”	0.37**
Root collar diameter (cm)	9.0’	10.7^{b}	13.8”	0.35**	8.7”	11.7^{b}	14.1”	0.38**	13.0	17.1^{b}	20.1”	0.38**
Height(m)	3.88	4.76^{b}	5.64	0.29**	4.10’	5.38^{b}	6.05”	0.28**	6.95^{b}	7.82”	8.36”	0.18
Current FOLR no.	12.2^{ab}	11.5^{b}	15.8”	0.34**	7.5^{b}	9.9”	9.3^{ab}	0.33**	12.5^{b}	16.3”	15.7^{ab}	0.16
FOLR cross section area (cm’)	21.66^{b}	38.06^{b}	80.46^{a}	0.43**	16.66’	32.24^{b}	45.59”	0.11**	47.64’	89.45^{b}	128.03”	0.31**
Surface FOLR depth (cm)	19.0^{b}	20.0^{ab}	23.0	0.01	20.0	22.0”	20.0	0.07	22.0	24.0	22.0	–0.16
Total root depth (cm)	76.0	81.0	85.0	0.09	100.0”	109.0^{ab}	113.0”	0.28**	88.0	98.0	100.0”	0.11
Root cone biomass (kg)	3.52’	6.01^{b}	11.53”	0.35**	3.84’	6.79^{b}	10.65”	0.32**	8.91’	16.93^{b}	25.76”	0.34**
Total root biomass (kg)	4.46	9.43^{b}	15.79”	0.32**	4.93^{b}	6.89^{b}	13.61”	0.53**	11.92^{b}	18.37^{b}	35.77”	0.46
Top biomass (kg)	14.03’	23.64^{b}	43.06”	0.38**	11.65’	24.71^{b}	37.51”	0.30**	35.43”	67.49^{b}	99.97”	0.36**
D^2H (m’)	0.01‘	0.03^{b}	0.06	0.32**	0.01’	0.03^{b}	0.06”	0.32**	0.07	0.14^{b}	0.21”	0.34**
Root cone %	83.2	78.6	75.5	-0.27	76.5”	84.2”	80.2”	0.27	85.2	83.5”	80.8”	–0.01
% root biomass	23.9	24.0”	26.5”	–0.22	29.0	23.5”	26.6””	–0.04	23.5”	20.9	23.6”	-0.16

* Means for a variable within a plantation followed by the same letter are not significantly different based on the Bonferroni t-test at the 0.05 experimentwise level (each comparison was tested at the 0.05/3 = 0.0167 level).

. * Signifies that the correlation coefficient rfor initial FOLR number and the specific growth parameter is significantly different from zero at the 0.05 level.

volumes, thus affecting biomass accumulation in both roots and tops.

Approximately 25% of the total biomass was in root regardless of either initial FOLR numbers or occurrence of a compacted subsoil layer (Table 4). This is comparable to root/total biomass ratios of 20% and 28% reported for 48- and 25-year-old loblolly pine, respectively, in other studies (Van Lear and Kapeluck 1995, Pehl et al. 1984).

Root Development Observations

The depths of root penetration were comparable in the three plantations. In plantation 2 (6 yr old), which had a deep loamy sand to sandy loam subsoil, some taproots extended down to 1.5 m and maintained a single or double apex with no evidence of impediment to further root penetration. In plantations 1 and 3, the taproots generally became flattened and platelike at about 1.0 m. Stumps that had been removed to establish plantations 1 and 3 also exhibited the same deep penetration restrictions.

Excavation of lateral roots outside the excavated cone indicated lateral root horizontal extension was limited in the three plantations despite their 2.4 x 3.0 m spacing. When no gaps existed in the plantations, manual excavation of lateral roots outside the tree spade cone showed that lateral root extension decreased rapidly midway between the rows. This area tended to be the zone of dense feeder root development. A few locations were sampled within the plantations where gaps from missing trees were adjacent to a selected sample tree. Here we found that lateral roots from the surviving adjacent trees readily invaded the soil volume in the gap. This is similar to what has been found by Zarnoch et al. (1993) for fine roots. It was clear that competition belowground is mirrored by crown competition.

These plantations are now approximately 20 yr from a commercial harvest for pulp production and 60 or more years from lumber or veneer rotation. It is of interest to speculate on how these initial root grades will separate out in the future for both stem productivity and long term stand stability as the trees mature. It was on shallow soils such as these that Hurricane Hugo (1989) did extensive damage on the Savannah River Forest site where this long-term study is being maintained.

Conclusions

Site uniformity is desirable for a study where individual tree data is to be followed for extended periods that might encompass a single rotation of from 25-60 yr. We felt that such uniformity was present in 1987-1989 at each of these plantations which were 5 to 7 ha in size. Each individual location was represented by a single soils mapping unit, and the soil series were all classified as desirable for planting loblolly pine. However, when selecting individual locations within each plantation for root excavations, uniformity was found to be only superficial as a result of past agricultural practices. Depth to old residual plow layers varied, and other compaction zones from old road beds and trails occurred extensively. These soil irregularities were accompanied by significant variation in seedling performance both within and among FOLR classes. In general, however, we found that at a given location within a plantation, a seedling current competitive position was related to initial FOLR when it was outplanted.

Basically we observed the following:

1. There was a significant difference for initial FOLR numbers among the three tree grade groups within a plantation, and this trend was significant for most of the other biomass variables.
2. Variation in depth to impervious or discontinuous soil compaction layers had a major impact on tree standing biomass at any given excavation point. This did not diminish the importance of initial FOLR numbers of individual seedling at that specific location. The seedlings with the least standing biomass were in general those that had the lowest number of initial FOLR when outplanted.
3. Immature loblolly pines have approximately 25% of standing biomass in the root system which is comparable to that reported for 25 and 48 yr old loblolly pine.
4. The root/shoot ratio and proportion of total biomass in roots of immature individuals were independent of tree size and, thus, the standing biomass distribution of the tops and roots remain relatively constant over tree size. Big trees had big root systems and small trees had small root systems.
5. There is a significant but weak relationship between current FOLR numbers and aboveground biomass but the relationship becomes very good when FOLR cross-sectional area of these roots is considered. Total root biomass (as opposed to cone root biomass) provides the strongest correlation with top biomass.

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