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Growth and Crown Vigor of 25-Year-Old Shortleaf Pine Progenies on a Littleleaf Disease Site

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ABSTRACT

Control-pollinated progenies of shortleaf pines that appeared to be resistant to littleleaf disease were planted on a test site near Union, SC, in 1965. The planting was assessed at ages 17 and 25 to identify progenies with superior growth and resistance to pest problems associated with littleleaf disease sites. Among the 30 progenies in the experiment, 2 produced more than 12 cubic feet of total volume growth per tree and an additional 5 produced more than 11 cubic feet per tree. However, at age 25 even the best growing progeny had individual trees with visual crown symptoms of littleleaf disease. A control seedlot from open-pollinated shortleaf pines ranked low in performance (7 ft^3/tree) and crown vigor. All trees with crown densities of less than 50 percent, regardless of parents, were growing poorly and in accelerated decline. There was a close relationship between rankings in volume growth at ages 17 and 25, indicating that candidates for future tree improvement programs can be reliably selected at an early age.

Keywords: Tree decline, forest health, tree-ring chronologies, *pinus echinata*.

Introduction

Shortleaf pine (*Pinus echinata* Mill.) has the largest natural range of any southern pine (fig. 1). Although it is well adapted to a broad range of environmental conditions, its growth, health, and survival can be severely reduced on poorly aerated soils with poor internal drainage. On these sites, trees often decline at an early age. Their crowns become sparse, cone production is prolific, and growth is reduced. Fine roots are lost to infection by the soilborne fungus *Phytophthora cinnamomi* Rands and other pathogens as well as soil factors. Symptoms of littleleaf disease rarely occur before age 20. Trees expressing littleleaf disease symptoms often die prematurely or are at high risk to attack by the southern pine beetle (*Dendroctonus frontalis* Zimmermann) (Oak and Tainter 1988).

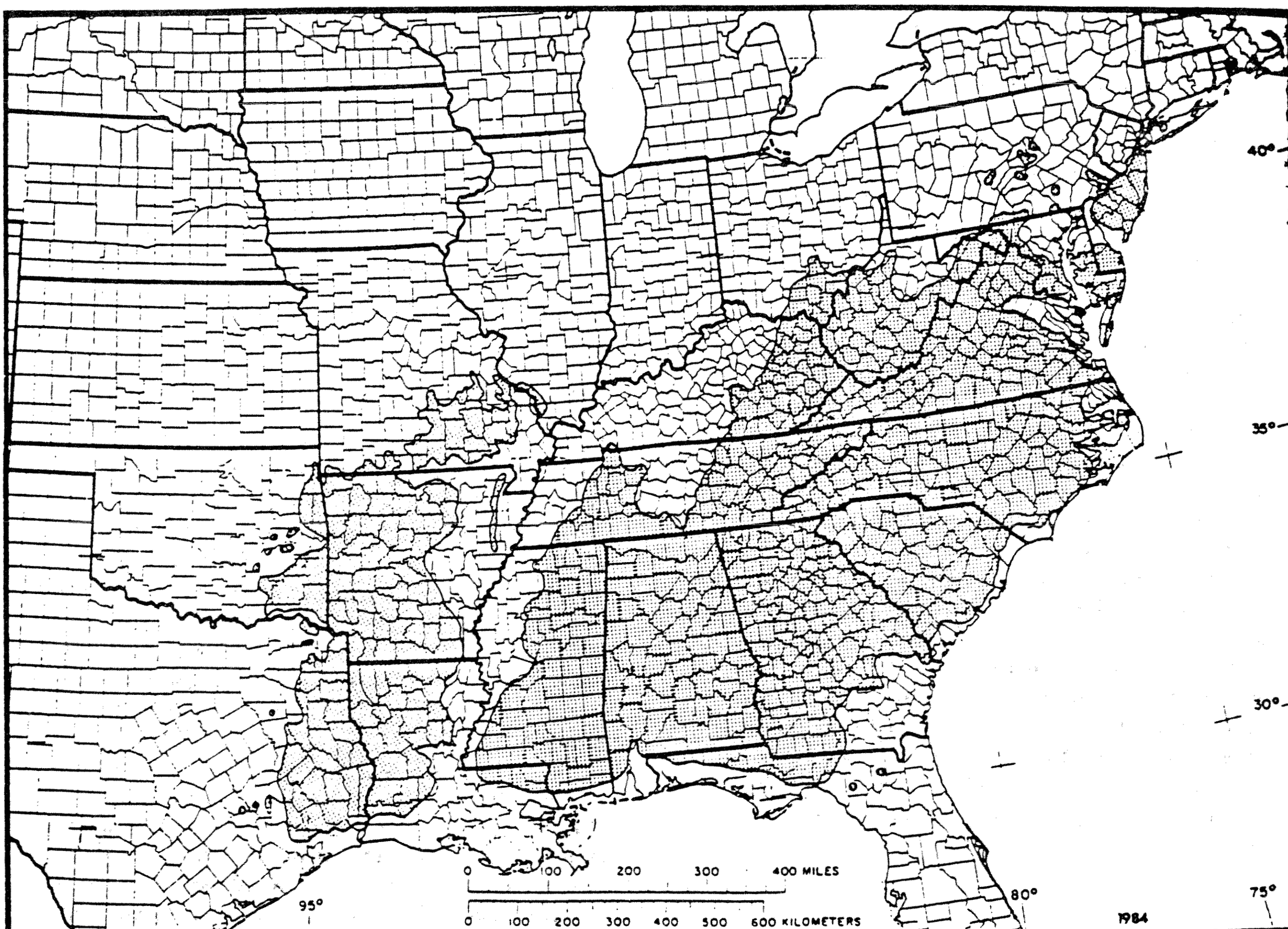

Figure 1—Natural distribution of shortleaf pine.

Campbell and Copeland (1954) found that even where disease incidence was high, not all shortleaf pines on the site died. Trees that remained healthy were judged to be resistant to the disease or better adapted to associated site conditions. A long-term research study was initiated to test the performance of selected crosses made between these healthy trees.

Symptom-free trees of good form and vigor were selected on severely affected littleleaf disease areas at Hamilton, GA, and Union, SC (Zak 1955). Scions from selected trees were grafted onto shortleaf and loblolly *(P. taeda* L.) rootstocks, and the clones were planted during the winter of 1953-54 at Whitehall, GA. Sixteen different selections were successfully grown to seed-bearing size in this breeding orchard. In 1965, a field experiment was installed on a littleleaf disease site in Union, SC, to test F-1 progenies from controlled crosses between these selections (Bryan 1965). The planting was assessed at age 17 to identify progenies with disease resistance and superior growth (Ruehle and others 1984). Among the 30 progenies in the experiment, 6 were rated superior in height, d.b.h., and tree volume growth. Since few individuals showed symptoms of littleleaf disease at this time, it was concluded that the stand was too young for proper evaluation of disease resistance.

In this Research Paper, we report results of measurements and evaluations at 25 years. We paid particular attention to visual crown characteristics. The recent interest in the effects of atmospheric deposition and global climate change on forest health has emphasized the need to document growth rates of important tree species and develop field methods and indicators of growth decline. Several crown characteristics have been employed in forest health monitoring programs to indicate the relative condition and/or susceptibility of a tree to specific insect and disease problems. In addition, dendrochronology has been used to detect abnormal changes in radial or basal area growth caused by environmental factors. The present study planting presented a first-time opportunity to document growth rates, observe crown conditions, and analyze tree-ring chronologies for a wide range of shortleaf pine progenies growing on a littleleaf disease site.

Specific objectives of this research were:

- To evaluate height, d.b.h., volume, and crown vigor of shortleaf pine progenies on a littleleaf disease site at age 25 years.
- To evaluate the periodic growth of these progenies from age 17 to age 25.
- To evaluate the relationships between growth from ages 17 to 25 and crown characteristics at age 25.
- To evaluate annual growth rates using tree-ring chronologies for the best, intermediate, and worst progenies based on total volume at age 25.

Study Description

Parent Selections and Progenies

The families selected for this study were crosses between five Georgia parents (Z7, Z13, Z14, Z15, and Z17) and eight South Carolina parents (Y1, Y2, Y3, Y4, Y5, Y6, Y8, and Y9). In all, there were 27 F-1 progenies and 2 selfed progenies. Table 1 shows these progenies and their parents. An open-pollinated, mixed seedlot collected in Georgia served as the check. Seeds were sown in flats in June 1964. Three months later, seedlings were transplanted into 6-inch clay pots filled with forest soil. These were grown in a greenhouse until April 1965 when they were planted in the field.

Study Site

An area in the Sumter National Forest approximately 10 miles south of Union, SC, was selected for planting. This area had supported 25- to 30-year-old shortleaf pines with moderate littleleaf disease symptoms. The area had been cut and cleared in 1959. The cleared area, about 10 acres, extends lengthwise in an east-west direction along a ridge with elevation ranging from 500 to 510 feet. The soil type is Helena/Vance sandy loam; years of erosion have removed 50 to 75 percent of the topsoil. Soil samples collected from 15 random locations over the 10 acres were assayed for soil characteristics and the presence of *Phytophthora cinnamomi*. The apple technique (Campbell and Copeland 1954) revealed the presence of *P. cinnamomi* in over 65 percent of the samples. Sampling also showed that the fungus was uniformly distributed over the area. The soil contained 1.7 percent organic matter and had a pH of 5.9. See Ruehle and others (1984) for further site information.

Table 1—Average bole dimensions and crown vigor ratings of shortleaf pine progenies at age 17 on a littleleaf disease site in Union, SC (1982 data from Ruehle and others (1984))[1]

Progeny	Parents Female	Parents Male	Volume[2]	Height	D.b.h.	Crown vigor[3]
			Cubic feet	*Feet*	*Inches*	
15	Z15	Z7	5.41 a	42.8 a	8.0 a	5.94 abc
25	Z15	Y8	5.09 ab	42.2 ab	7.9 ab	6.00 a
21	Z15	Z15	4.87 abc	42.2 ab	7.7 a-e	5.92 abc
31	Y5	Y8	4.74 a-d	40.5 a-d	7.8 abc	6.00 a
11	Y5	Z7	4.68 a-e	40.6 a-d	7.8 a-d	5.96 abc
6	Y1	Z15	4.64 a-e	40.0 a-e	7.8 a-d	5.96 abc
14	Y2	Z13	4.38 a-f	38.9 b-g	7.7 a-e	5.90 abc
10	Y9	Z7	4.29 a-f	41.2 abc	7.5 a-g	6.00 a
20	Y5	Y5	4.29 a-f	39.8 a-e	7.6 a-f	6.00 a
8	Y1	Z7	4.03 b-h	[4]4.04 a-d	7.3 a-g	5.98 ab
1	Y2	Z7	3.99 b-i	40.3 a-d	7.3 a-h	5.90 abc
16	Y2	Z14	3.86 c-j	40.0 a-e	7.2 b-h	5.66 bcd
27	Z15	Y4	3.76 c-j	40.4 a-d	7.1 c-i	5.92 abc
19	Y9	Z13	3.76 c-j	39.0 b-f	7.2 b-h	5.96 abc
33	Z15	Z13	3.75 c-j	38.3 c-g	7.3 a-h	5.96 abc
12	Y6	Y8	3.75 c-j	40.3 a-d	7.1 c-i	6.00 a
5	Y9	Z15	3.65 c-j	38.9 b-g	7.1 b-i	5.94 abc
7	Y5	Y4	3.55 d-k	38.3 c-g	7.1 b-i	5.88 abc
32	Z15	Y3	3.50 e-k	38.4 c-g	7.1 c-i	5.88 abc
9	Z15	Y6	3.49 e-k	38.9 b-g	7.0 d-i	5.86 abc
3	Y2	Y6	3.35 f-k	39.0 b-f	6.9 f-j	5.96 abc
CK	Check		3.33 f-k	38.1 c-g	7.0 e-j	5.44 d
18	Y9	Y4	3.07 g-l	38.8 b-g	6.7 g-k	6.00 a
13	Z17	Z13	2.99 h-l	37.2 d-g	6.8 g-k	5.64 cd
23	Y1	Y8	2.81 h-l	36.8 efg	6.6 h-l	5.92 abc
29	Y5	Y3	2.76 i-l	36.2 fg	6.7 h-l	5.68 a-d
2	Y9	Y8	2.63 jkl	37.6 d-g	6.4 i-l	5.90 bc
4	Y1	Y6	2.42 kl	37.2 d-g	6.3 jkl	5.88 abc
17	Z17	Y3	2.14 l	35.6 g	6.1 kl	5.42 d
22	Y9	Y6	2.12 l	36.3 g	6.0 l	5.66 bcd

[1] Means in the same column followed by the same letter are not significantly different at the 0.05 level. Progenies are ranked by volume.
[2] $V = -0.98284 + 0.00230 (D^2H)$ where V = volume to 4-inch d.o.b. top, D = d.b.h. in inches, H = total height in feet.
[3] Most of these are included in the 25-year remeasurement; however, mortality did eliminate some.
[4] The value 4.04 is a typographical error in Ruehle and others (1984).

Study Installation

In the spring of 1964, a year before study installation, the site was intensively prepared and the large pieces of slash and brush were raked into piles and burned. On the cleared site, a 2.4-acre area was selected and divided into five irregularly shaped blocks. Seedlings were planted in April 1965 on a 12- by 12-foot spacing (302 trees/acre). Within each block, four seedlings of each progeny were randomly assigned to planting spots. Amitrol -T (3-amino-1,2,4 triazole) was sprayed for weed control. For initial control of pales weevils and tip moths, 1 teaspoon of 5-percent granular aldrin and 1 teaspoon of 10-percent granular Thimet were spread on the soil around the base of each tree. In addition, the trees were sprayed with 0.5-percent water emulsion of aldrin. A double border row of ordinary shortleaf planting stock from the North Carolina State Forestry Commission Nursery at Morganton was planted around the five blocks.

In September 1982 at plantation age 17, progeny performance was evaluated. The d.b.h. and height of all surviving trees were measured and crown characteristics were rated. Since very few trees were showing typical littleleaf symptoms, a crown vigor rating was used instead of a disease rating because few trees had littleleaf symptoms. Crowns were assigned a rating of 1 through 6:

Rating	Definition
1	Tree dead; root disease rather than injury or suppression probable cause of death.
2	Poor vigor; extensive twig mortality, obvious decline, foliage tufted and yellow.
3	Fair vigor; thin crown, some twig mortality, lower branches dying, foliage yellow-green.
4	Medium vigor; growth reduction evident, yellow-green foliage in lower half of crown.
5	Good vigor; appearance good, but foliage in crown thin, green foliage.
6	Excellent vigor; foliage and crown dense, good foliage growth, foliage dark-green.

Tree volume was calculated using equations developed by Saucier and others (1981). Breeding values of each parent (2 × the general combining ability value (GCA) + the general mean) were calculated for all growth parameters to gain an indication of the performance expected from the offspring of a selected parent when it is crossed with other parents of equal genetic quality.

These preliminary results were reported by Ruehle and others (1984 and are shown in table 1). Generally, only a few trees showed symptoms of littleleaf disease. Six progenies exhibited superior growth in height, d.b.h., and volume. Based on stem volume of the progenies, two Georgia parents (Z7 and Z15) and two South Carolina parents (Y5 and Y8) were identified as good candidates for future tree-improvement programs.

At age 25, the variables observed at age 17 plus several others were measured. Total height (ft) and d.b.h. (in) of each tree were measured. Individual-tree basal area (ft^2) was calculated in the typical manner, and volume (ft^3) to a 4-inch top d.o.b. was computed using the volume equation of Saucier and others (1981). The percentage growth in height, d.b.h., volume, and basal area between ages 17 and 25 was computed. The crown vigor rating already described (1=tree dead,..., 6=excellent vigor) was applied to each tree. In addition, four crown measures currently used in forest health monitoring (Belanger and Anderson 1992) were obtained by averaging estimates from four observers. These were:

1. **Crown Density**. Estimated to the nearest 5 percent (Belanger and Anderson 1992).

2. **Needle Retention**. The longer a tree retains its needles, the more vigorous growth is expected. Recorded as 1, 2, or 3 years.

3. **Dwarfing**. The reduction in the average length of all needles in relation to lengths on nearby healthy shortleaf pines. Estimated to the nearest 5 percent.

4. **Discoloration**. Degree of yellowing. Estimated to the nearest 5 percent.

In addition, tree-ring chronologies were developed to illustrate the growth rates of the five best, five intermediate, and five worst progenies. The progenies were ranked based on total volume at age 25. Generally, two trees were randomly selected from each block from each of these progenies for tree coring. Results were contrasted with those for the check progeny (13 trees) and other trees with crown density ratings less than 50 percent (21 trees). Tree cores were read on both sides of the pith where possible; mean ring widths were computed from 1975 to 1990 and annual basal area increments were calculated.

Statistical Analysis

The randomized block design consisted of 30 progenies replicated in 5 blocks. There were 27 F-1 progenies, 2 selfed progenies, and a check. Originally there were four additional progenies installed in the field design but since they were identical to other crosses already in the study except that the seed was crossed a year later, they were eliminated from this study. Each progeny was originally represented by four trees in each block. Of the 600 trees planted in 1965, 544 survived to age 25. Of these, 14 were suppressed, 16 had ice damage, 1 was suppressed and had ice damage, and 1 was inadvertently bypassed during crown observations. These atypical trees were excluded from the statistical analysis, leaving a sample size of 512.

In the statistical analysis, the block mean for each progeny was used as the variate. Thus, each mean was usually based on four trees. Overall F-tests were performed with PROC GLM; Tukey's test was used for pairwise comparisons at the 0.05 level (SAS Institute, Inc. 1988). Relationships between growth and crown characteristics were analyzed with PROC STEPWISE.

Results

Progeny Performance

Performance at 25 years. Growth and crown vigor of individual progenies at age 25 are shown in table 2, where the progenies are ranked in order by volume. Volume of progenies averaged 9.24 cubic feet and ranged from 13.65 cubic feet for progeny 15 to 5.21 cubic feet for progeny 22. Although volume growth for the check was low (7.02 ft^3 = 26 in ranking), only two progenies produced significantly greater volume than the check. Both these progenies had Z15 as one parent. The four progenies that grew less than the check had selections from South Carolina for both parents. The rankings in volume growth at age 25 are quite similar to those at age 17 (table 1) reported by Ruehle and others (1984). The 10 progenies with the greatest total volume at age 17 were also the top 10 performers at age 25. The largest change in ranking was for progeny 21, which fell from third at age 17 to eighth at age 25. Similarly, 8 of the 10 poorest performers at age 17 continued to grow slowly through age 25.

The most significant distinctions in progeny performance were for total height growth (see table 2). Tree height averaged 54.0 feet and ranged from 57.5 feet for progeny 10 to 49.4 feet for the check. A total of 10 progenies were significantly taller than the check. The rankings for d.b.h. at age 25 are quite similar to those for volume growth. This result was expected because tree diameter is the most heavily weighted component of volume growth. There were few differences in the crown vigor ratings among progenies.

Performance from age 17 to age 25. Since the effects of littleleaf disease on tree growth are usually more pronounced after age 20, we were particularly interested in performance since age 17. Table 3 gives percentage growth in height, d.b.h., volume, and basal area from age 17 through age 25. It also gives the four crown characteristics. Except for the check, there was no significant difference among progenies in percentage growth in height, d.b.h., volume, or basal area. Also, there was little association between these growth variables and crown characteristics at age 25. Average values for crown characteristics showed that the general visual appearance of the progenies was excellent. The crown density was 59 percent or better for all progenies. Average needle retention was at least 2 years. Dwarfing was less than 20 percent and discoloration was minimal. The exception was the check trees, which had relatively sparse crowns, poor needle retention, short needles, and a high degree of discoloration.

Individual-Tree Performance

Relationship between growth and crown characteristics. STEPWISE regression was used to model percentage growth in height, d.b.h., basal area, and volume from ages 17 to 25 as functions of the crown variables at age 25. Good crowns should reflect high growth rates, while poor crowns should show declining growth. The results are shown in table 4.

Table 2—Average bole dimensions and crown vigor ratings of shortleaf pine progenies at age 25 on a littleleaf disease site in Union, SC [1,2]

Progeny[3]	Parents: Female	Parents: Male	Volume	Height	D.b.h.	Crown vigor
			Cubic feet	*Feet*	*Inches*	
15	Z15	Z7	13.65 a	57.3 a	10.3 a	5.95 ab
6	Y1	Z15	12.57 ab	56.8 ab	10.1 ab	6.00 a
11	Y5	Z7	11.48 abc	56.0 abc	9.7 abc	5.95 ab
25	Z15	Y8	11.35 abc	56.2 abc	9.7 abc	6.00 a
31	Y5	Y8	11.26 a-d	57.0 ab	9.6 abc	6.00 a
8	Y1	Z7	11.12 a-e	54.9 a-e	9.7 abc	6.00 a
10	Y9	Z7	11.06 a-e	57.5 a	9.5 a-d	6.00 a
21	Z15	Z15	10.76 a-f	56.2 abc	9.4 a-d	5.93 abc
20	Y5	Y5	10.67 a-f	56.0 abc	9.4 a-d	6.00 a
14	Y2	Z13	10.56 a-f	55.5 a-d	9.4 a-d	5.90 abc
1	Y2	Z7	10.43 a-f	56.7 abc	9.2 a-e	5.90 abc
33	Z15	Z13	10.16 a-f	53.1 a-e	9.4 a-d	5.95 ab
16	Y2	Z14	9.46 a-g	55.3 a-e	8.8 a-f	5.58 c
5	Y9	Z15	9.18 a-g	52.9 a-e	9.0 a-e	5.93 abc
7	Y5	Y4	8.93 b-g	52.9 a-e	8.9 a-e	6.00 a
19	Y9	Z13	8.80 b-g	52.6 a-e	8.8 a-f	6.00 a
27	Z15	Y4	8.76 b-g	54.0 a-e	8.6 b-f	5.90 abc
9	Z15	Y6	8.68 b-g	53.9 a-e	8.7 a-f	5.95 ab
13	Z17	Z13	8.44 b-g	53.2 a-e	8.6 b-f	5.95 ab
3	Y2	Y6	8.34 b-g	53.4 a-e	8.6 b-f	5.93 abc
12	Y6	Y8	8.26 b-g	53.8 a-e	8.5 b-f	6.00 a
32	Z15	Y3	8.16 b-g	53.7 a-e	8.5 b-f	5.82 abc
29	Y5	Y3	7.93 c-g	51.9 a-e	8.5 b-f	5.85 abc
18	Y9	Y4	7.76 c-g	53.2 a-e	8.3 c-f	6.00 a
17	Z17	Y3	7.56 c-g	52.8 a-e	8.2 c-f	5.83 abc
CK	Check		7.02 c-g	49.4 e	8.3 c-f	5.73 abc
23	Y1	Y8	6.77 d-g	51.0 b-e	8.0 def	5.90 abc
2	Y9	Y8	6.66 efg	51.5 a-e	7.9 def	6.00 a
4	Y1	Y6	6.19 fg	50.8 cde	7.7 ef	5.88 abc
22	Y9	Y6	5.21 g	49.6 de	7.2 f	5.63 bc
p-value[4]			0.0001	0.0001	0.0001	0.0002

[1] The means for these characteristics for a given progeny were based on the mean of the five block means since the block means were used as the variates in the statistical analyses. Generally, the blocks contained four trees but occasionally less due to mortality.
[2] Means in the same column followed by the same letter are not significantly different at the 0.05 level using Tukey's test.
[3] Progenies 24, 26, 28, and 34 were identical to other progenies and were deleted from this study. Progeny 30 was not a shortleaf cross and, thus, was never used.
[4] The p-value obtained from an analysis of variance.

Table 3—Growth and crown characteristics under early littleleaf disease complex[1,2]

Progeny[5]	Percentage growth (age 17 to 25)[3,4] in— Height	D.b.h.	Volume	Basal area	Crown characteristics (age 25) Crown density	Needle retention	Dwarfing	Discoloration
	Feet	*Inches*	*Cubic feet*	*Square feet*				
15	31 ab	22 ab	112 a	49 a	62 bcd	2.0 ab	13 ab	16 abcd
6	41 a	27 ab	155 a	60 a	77 ab	2.8 a	9 ab	13 bcd
11	37 ab	25 ab	143 a	57 a	77 ab	2.7 ab	11 ab	12 bcd
25	33 ab	24 ab	128 a	54 a	76 ab	2.6 ab	13 ab	11 bcd
31	40 a	25 ab	148 a	56 a	76 abc	2.6 ab	10 ab	5 d
8	36 ab	25 ab	139 a	56 a	77 ab	2.8 a	2 b	11 bcd
10	38 a	24 ab	137 a	53 a	82 a	2.8 a	5 ab	10 bcd
21	35 ab	28 ab	[6] 468 a	72 a	59 cd	2.2 ab	13 ab	17 abcd
20	41 a	25 ab	154 a	57 a	84 a	2.8 a	5 ab	6 cd
14	37 ab	22 ab	132 a	50 a	78 ab	2.8 a	11 ab	12 bcd
1	41 a	31 a	234 a	76 a	78 ab	2.5 ab	3 b	13 bcd
33	36 ab	28 ab	191 a	69 a	69 abcd	2.6 ab	10 ab	22 ab
16	38 ab	23 ab	148 a	52 a	72 abc	2.4 ab	17 ab	14 bcd
5	35 ab	25 ab	154 a	57 a	75 abc	2.7 a	9 ab	11 bcd
7	37 ab	25 ab	156 a	57 a	77 ab	2.6 ab	13 ab	12 bcd
19	34 ab	21 ab	130 a	48 a	78 ab	2.7 ab	9 ab	7 cd
27	34 ab	22 ab	139 a	49 a	74 abc	2.5 ab	13 ab	17 abcd
9	36 ab	21 ab	132 a	47 a	75 abc	2.4 ab	7 ab	15 bcd
13	38 ab	19 ab	125 a	43 a	75 abc	2.6 ab	4 b	7 cd
3	35 ab	24 ab	143 a	54 a	81 a	2.6 ab	9 ab	13 bcd
12	34 ab	21 ab	127 a	46 a	80 a	2.7 ab	12 ab	8 cd
32	35 ab	19 ab	123 a	43 a	61 bcd	2.3 ab	13 ab	19 abc
29	37 ab	22 ab	142 a	48 a	71 abcd	2.3 ab	15 ab	14 bcd
18	36 ab	22 ab	140 a	50 a	82 a	2.7 a	15 ab	8 cd
17	34 ab	17 ab	112 a	38 a	69 abcd	2.5 ab	8 ab	15 bcd
CK	27 b	16 b	96 a	35 a	55 d	1.8 b	22 a	30 a
23	39 a	21 ab	160 a	47 a	76 ab	2.5 ab	19 ab	8 bcd
2	34 ab	20 ab	134 a	44 a	77 ab	2.6 ab	19 ab	6 cd
4	35 ab	22 ab	146 a	48 a	76 abc	2.5 ab	12 ab	7 cd
22	33 ab	20 ab	154 a	44 a	75 abc	2.7 ab	15 ab	6 cd
p-value[7]	0.0023	0.0710	0.6530	0.1934	0.0001	0.0030	0.0013	0.0001

[1] The means for these characteristics for a given progeny were based on the mean of the five block means since the block means were used as the variates in the statistical analyses. Generally, the blocks contained four trees but occasionally less due to mortality.
[2] Means in the same column followed by the same letter are not significantly different at the 0.05 level using Tukey's test.
[3] Percent growth of a characteristic is defined as $100(X_{25} - X_{17})/X_{17}$ where X_{17} and X_{25} are the values of the characteristic at age 17 and 25 years, respectively, based only on the trees alive at both times.
[4] Due to the calculation method (footnote 1) and the sample of trees (footnote 3), the percent growth characteristics cannot be computed exactly from tables 1 and 2.
[5] Progenies 24, 26, 28, and 34 were identical to other progenies and were deleted from this study. Progeny 30 was not a shortleaf cross and, thus, was never used.
[6] This high value for volume is due to one tree that had a very low volume (0.23 ft^3) at age 17 and grew considerably to a moderately high volume (13.14 ft^3), which resulted in a very high percent growth (5506%) due to the very low volume used in the denominator of the percent growth calculation (footnote 3).
[7] The p-value obtained from an analysis of variance.

Table 4—Models developed to describe the relationship between several growth variables and the crown variables[1,2]

Eight-Year Periodic Growth Models (17-25 years)

HTPG = 21.5 + 0.19 CDR - 0.07 DWAF + 0.07 DCOL	$R^2 = 0.09$
DBHPG = 13.6 - 0.20 DWAF + 0.17 DCOL + 0.13 CDR	$R^2 = 0.10$
BAPG = 34.1 - 0.58 DWAF + 0.51 DCOL + 0.25 CDR	$R^2 = 0.07$
VPG = 146.6 - 2.18 DWAF + 2.54 DCOL	$R^2 = 0.02$

Previous-Year Periodic Growth Models (24-25 years)

DBHI = -0.00651 - 0.00192 DWAF + 0.00196 CDR + 0.000900 DCOL	$R^2 = 0.35$
DBHPG = 0.705 - 0.0198 DWAF + 0.0154 CDR	$R^2 = 0.32$
BAI = -0.00441 - 0.000193 DWAF + 0.000223 CDR + 0.000125 DCOL	$R^2 = 0.33$
BAPG = 1.42 - 0.0403 DWAF + 0.0312 CDR	$R^2 = 0.31$

[1] HTPG = Percent height growth
DBHPG = Percent d.b.h. growth
BAPG = Percent basal area growth
VPG = Percent volume growth
CDR = Crown density rating (%) at age 25 years
DWAF = Dwarfing (%) at age 25 years
DCOL = Discoloration (%) at age 25 years
DBHI = Diameter increment (in)
BAI = Basal area increment (ft^2)

[2] The variables entered the stepwise regression models in the order in which they are in the equation.

The associations between crown characteristics and percentage growth from age 17 to age 25 were poor; R^2 values were less than or equal to 0.10. Radial growth at age 24 was obtained from the tree-ring chronologies and regressed on the crown variables at age 25. These relationships had higher R^2 's (0.31 to 0.35) for diameter and basal area increment and percent growth. Therefore, current crown conditions such as those observed in this study cannot be used to predict the previous 8-year periodic growth rate, but may be useful in explaining the previous year's growth.

Tree-ring chronologies. Dendrochronologies permitted us to study long-term annual growth in a representative sample of the progenies. When the progenies were ranked based on individual tree total volume at age 25, the Best progenies were 6, 11, 15, 25, and 31; the Intermediate were 5, 7, 9, 16, 19; and the Worst were 2, 4, 17, 22, and 23. The trees to be cored were randomly selected from each of these progenies. Generally two trees were selected per progeny from each of the five blocks. All 13 check trees were also cored.

In order to examine trees in obvious decline, trees with a crown density rating of less than 50 were also selected. These 21 trees were in the following progenies (the number in parentheses indicates the number of trees in that progeny): 1(1), 5(1), 6(1), 15(3), 21(4), 23(1), 29(1), 32(3), 33(2), and check(4).

Mean annual basal area increment from age 10 through 25 years averaged 0.022 square foot for the Best, 0.016 square foot for the Intermediate, and 0.012 square foot for the Worst progenies (table 5). These values corroborate the rankings of the progenies into these groups based on total volume at age 25. The check had a growth rate of 0.014 square foot, which was between

Table 5—Basal area increment (BAI) for the Best, Intermediate, Worst, Check, and CDR < 50 progenies based on tree-ring chronologies

Progeny group	Number of trees	Progenies	Mean annual BAI (1975-90)	6-yr periodic BAI (1985-90)
			Square foot[1]	*Square foot*[1]
Best	[2]53	6,11,15,25,31	0.022 a	0.110 a
Intermediate	50	5,7,9,16,19	.016 b	.073 b
Worst	[3]50	2,4,17,22,23	.012 c	.051 c
Check	13	CK	.014 bc	.054 bc
CDR < 50	21	1,5,6,15,21, 23,29,32,33,CK	.015	.048

[1] Means in the same column followed by the same letter are not significantly different at the 0.05 level using Tukey's test.
Since the CDR <50 progeny group contained trees from each of the other progeny groups, it was not included in any statistical tests.
[2] Progeny 15 had 13 trees cored.
[3] Progeny 17 had 9 trees cored, and progeny 23 had 11 trees cored.

the Intermediate and Worst. Trees with poor crowns (crown density rating < 50) had a similar low growth rate of 0.015 square foot.

We examined 6-year periodic growth from age 20 to age 25 to determine the effect of early littleleaf disease. The ordering for periodic growth (see table 5) was similar to that found for mean annual basal area increment. Analysis of variance and Tukey's test showed significant differences between the Best, Intermediate, and Worst. Only the Best was significantly different from the check.

The annual basal area growth increments are shown in figure 2. The Best progenies have always been the fastest growers, the Worst have always been the slowest, and the Intermediate in between. No evidence of littleleaf disease was found in selected progenies, and growth did not taper off unexpectedly for any group around age 20 as it would if the disease was progressing. In contrast, however, performance of the check was similar to that of the Intermediate at early ages but began to slow down and approach the Worst starting at age 19. The check trees may be reflecting susceptibility to littleleaf disease or an inability to grow well on littleleaf disease sites. A quadratic equation was fitted to each of these sets to smooth out the annual fluctuations (fig. 3).

The results from the 21 poor-crown trees are shown in figure 2, while the quadratic equation smoothing results are in figure 3. In these trees, annual basal area growth started to decrease drastically at age 18. Before that, growth of trees with poor crowns was similar to that of the Intermediates. Oak and Tainter (1988) noted similar growth responses for loblolly pine with light and severe littleleaf disease symptoms. It is noteworthy that four of the shortleaf pine trees in decline belonged to the Best progeny group, while only one came from the Intermediate and one from the Worst groups. Thus, it seems that progenies with generally excellent growth have certain individuals with poor crowns and slow growth. The average 6-year periodic basal area growth of these four trees was 0.066 square foot, which is between the Intermediate and Worst groups. Thus, progenies that exhibit excellent growth do have individuals that are susceptible to growth decline, possibly from littleleaf disease. Of further interest is the genetic composition of trees with poor crown density ratings. Of these 21 trees, 17 had known genetic composition, of which 14 (82 percent) had at least one Z15 parent. Generally, in the population of progenies studied here, only 9 of 29 had at least one Z15 parent (31 percent). This is ironic since it was formerly believed that Z15 was resistant to littleleaf disease (Zak 1955). If Z15 is resistant, then the poor crown density ratings may well be genetically controlled and do not reflect littleleaf disease symptoms.

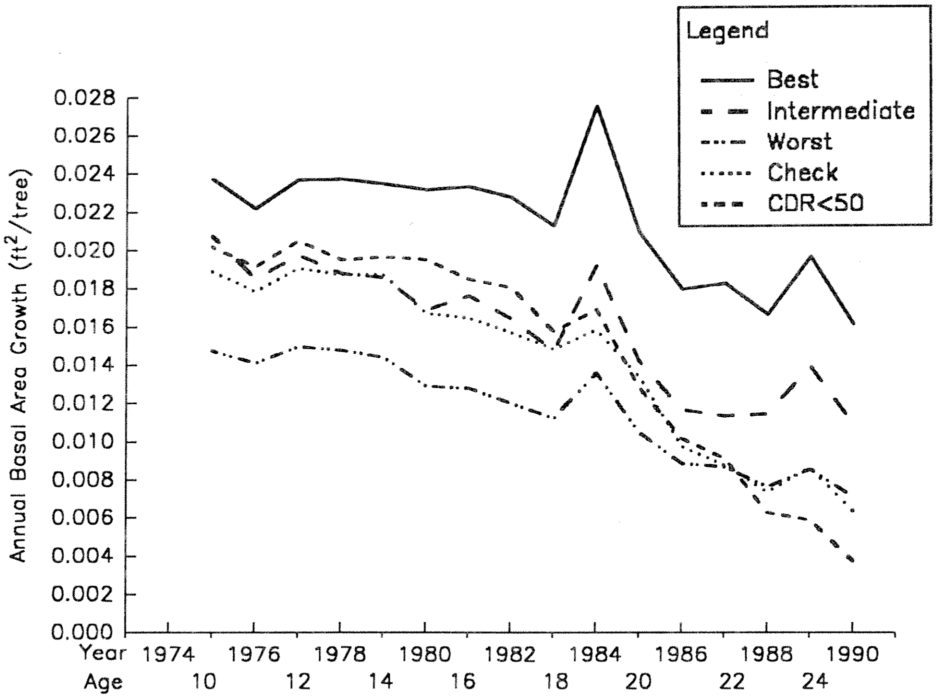

Figure 2—Annual basal area growth (ft^2/tree) for the Best, Intermediate, and Worst progenies based on tree-ring chronologies. The check progeny and the CDR < 50 trees from certain progenies are included for comparison.

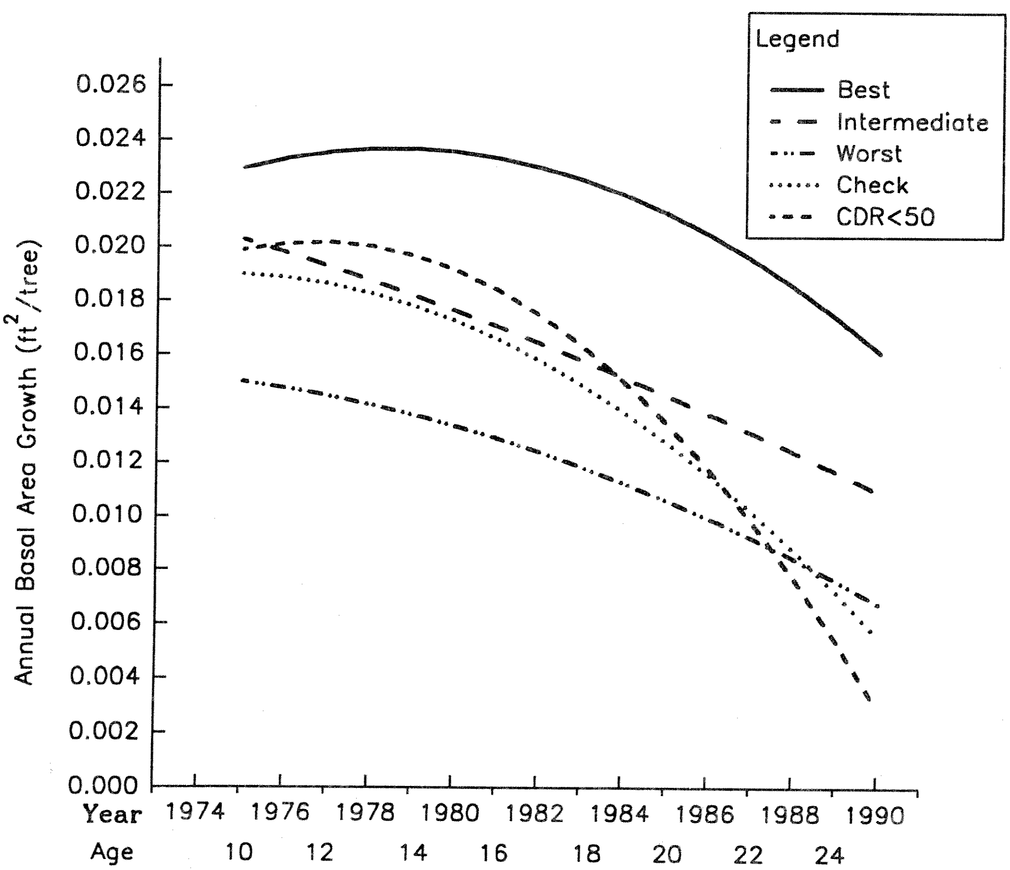

Figure 3—A quadratic model fit to the annual basal area growth (ft^2/tree) for the Best, Intermediate, and Worst progenies based on tree-ring chronologies. The check progeny and individual CDR < 50 trees from certain progenies are included for comparison.

Discussion

The wide range in average volume growth among progenies indicates that selective breeding can improve growth of shortleaf pine on littleleaf disease sites. Only two progenies grew significantly better than an ordinary check, but the general vigor and recent growth of the check were poor. Unhealthy crowns and a reduction in periodic volume growth indicate that growth of the check will continue to decline. We therefore expect some of the selected progenies to perform much better than the check in the next few years.

The most significant differences among progenies were in height growth. A total of 10 progenies were significantly taller than the check. The check ranked last of 30 in total height at age 25 and in periodic height growth between ages 17 and 25. Height growth of individual trees may be the most sensitive growth variable affected by site conditions conducive to littleleaf disease. Once crown position in the stand canopy is lowered, a reduction in crown vigor, d.b.h., and volume growth may follow. Alternatively, height growth rate may simply be an inherited characteristic. Height growth and crown position need to be examined more closely in assessing stand and individual-tree health.

The average vigor rating of all the progenies was high, indicating that stand health in general was good. The high vigor ratings were substantiated by favorable values for crown density, needle retention, dwarfing, and discoloration. The high vigor ratings may reflect the initial selection of parents that performed well on severe littleleaf disease sites. Again, the ordinary nursery-selected check had the poorest visual crown ratings. Thus, choosing trees that perform well on littleleaf disease sites may be an effective form of selection.

There was a close association between rankings for total volume, height, and d.b.h. growth at ages 17 and 25 years. The 10 progenies that produced the most total volume at age 17 were also the top performers at age 25. That finding suggests that performance could be assessed at age 17, lowering the time and administrative expense associated with a 25-year progeny test. The tree-core chronologies show that current annual basal area growth of the Best, Intermediate, and Worst progenies is closely related to past volume growth. Growth curves for selected progeny show no evidence of a decline due to littleleaf disease. However, in the check—which was originally intermediate in annual basal growth rate—there has been a recent decline. Many of the check trees show advanced symptoms of littleleaf disease. In contrast, the progenies from parents selected for apparent resistance may be exhibiting a degree of resistance to problems associated with littleleaf disease sites.

Trees with poor crowns (CDR < 50) exhibited a drastic decrease in annual basal area growth at age 18. It is of more interest, however, that many of these trees were from the Best progenies. Thus, progenies that generally show excellent growth include individual trees that have poor crowns and slow growth.

Although trends indicate a direct relationship between crown vigor and tree growth, it appears that the visual characteristics of crowns are indicative only of growth in the recent past. Perhaps a stronger association would be found by regressing current crown conditions on future tree growth. The detailed tree and crown measures taken in this study at age 25 will allow us to test these relationships over extended periods of time. Findings may be critical for developing biological and statistical techniques needed to evaluate individual tree, stand, and forest health.

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On a littleleaf disease site in South Carolina, most of the control-pollinated progeny of shortleaf pines that appeared to be resistant to the disease outperformed a check seedlot through age 25. Rankings of progeny based on volume changed little between ages 17 and 25.

Keywords: Tree decline, forest health, tree-ring chronologies, *Pinus echinata.*

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