THE RELATIONSHIP BETWEEN SEEDLING DIAMETER AT PLANTING AND LONG TERM VOLUME GROWTH OF LOBLOLLY PINE SEEDLINGS IN EAST TEXAS

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Abstract.-- Results from a seed source study show that survival and long-term volume production could be related to ground-line diameter after planting. Average survival at age 2 was 83% for 2 mm seedlings, 94% for 3 mm seedlings and 96-100% for 4-7 mm seedlings. After 10 years of field growth, average tree volume was 21.2, 23.7, 27.2, 28.4, 33.4, and 32.0 cubic decimeters for 2, 3, 4, 5, 6, and 7 mm seedlings (n= 115, 606, 346, 85, 16, 7). There was a 20% volume increase between 3 mm seedlings and 5 mm seedlings. Thinnings were conducted after measurement at age 10 and again at age 18. After 30 years in the field, average tree volume was 290.4, 292.5, 314.3, 311.7, 333.0, and 315.3 cubic decimeters for 2, 3, 4, 5, 6, and 7 mm seedlings (n= 41, 187, 102, 34, 9, 2). At this age, the average volume difference between 3 mm seedlings and 5 mm seedlings was 6.5%. Incremental gains in volume were calculated for each mm increase in ground-line diameter at planting. Linear regression analyses (weighted by the number of seedlings per diameter class) indicate the incremental gains in mean tree volume at ages 5, 10, 15, 20, and 30 were 0.6, 2.7, 5.8, 5.5, and 10.9 cubic decimeters/mm. The relative growth patterns appear to be the same for seedlings with different diameter classes.

Additional keywords: Survival, seedling quality, seedling grade, relative growth rate, incremental growth analysis, *Pinus taeda* L.

There have been only a few long-term studies with the southern pines that have examined the effects of seedling size on volume growth. Most were established by separating seedlings into different grades and planting each grade in either row-plots (Wakeley 1969; Blair and Cech 1974; Grisby 1975; Hunt 1967) or block-plots (Hatchell et al. 1972; Bacon 1979; Sluder 1979; South et al. 1985). In studies conducted for 9 to 15 years, plantable seedlings with larger diameters produced up to 240% more volume than plantable seedlings with small diameters. For the study reporting 30 year results from row plots, volume production of Grade 1 seedlings was 26% to 59% greater than Grade 2 seedlings (Wakeley 1969). However, volume differences among grades can be accentuated by unequal competition resulting from use of row plots (Wakeley 1969).

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Although it is generally accepted that planting seedlings with large diameters and more roots will often result in more volume production, the reasons for the greater production are not fully known. In some cases, the greater production results from better survival of seedlings that have more roots. However, even with greater survival, the larger caliper seedlings may produce more growth on an individual tree basis (Blair and Cech 1974; Grigsby 1975). It has not been determined if the larger caliper seedlings actually grow faster, for a given size, or just start out ahead, on the same growth curve, and therefore remain ahead of the smaller seedlings. It would be biologically meaningful to determine the correct relationship.

A well documented seed source test provided an opportunity to examine the relationship between seedling diameter and outplanting performance. Although the study was not established with the intent of examining the effects of seedling size on survival and tree growth, the researchers did measure each seedling after planting. This provided an opportunity to examine the relationship between seedling size at planting and subsequent survival and volume growth.

METHODS

Open-pollinated seed were collected in 1951 from 12 seed sources. Seeds were sown in the spring of 1952 at the Texas Forest Service Nursery at Alto, Texas. Seedlings were lifted on December 30, 1952 and were planted on January 2, 1953. The planting site was a cultivated field located in Robertson County with a site index (base age 25) of 16 meters. The 12 seed sources were planted in a randomized complete block design with 53-tree-row plots and 2 replications (for a total of 24 measurement rows). Seedlings were planted 1.83 meters apart within each row and 2.44 meters between rows. A border row was planted between replications as well as on either side of the test. Each tree was measured (to the nearest mm for ground-line diameter and to the nearest cm for height) on February 23, 1953.

Seedlings were remeasured for heights and ground-line diameters in November of 1953 and 1954. Trees were measured for height and diameter at breast height (DBH) at age 5, 10, 15, 20 and 30. After measurement at age 10, 28% of the trees were removed in a thinning (which left about 35 trees per row). Another thinning was conducted at age 18 when 51% of the remaining stand was removed. This resulted in leaving about 17 trees per row.

Survival at age 2 was calculated on a seed source basis and subjected to analysis of variance. A separate analysis (disregarding seed source) was conducted to determine the effect of diameter on survival. Survival percentages by diameter class were calculated for each replication.

A volume index (D^2H) was calculated for seedlings at time of planting and for ages 1 and 2. At age 5 and greater, individual tree volumes were calculated using total height and DBH measurements. For each diameter class, average tree volumes were calculated using all seedlings regardless of replication or seed source. Mean relative growth rates (Redford 1967) and mean relative production rates (Brand et al. 1987) were calculated in an attempt to compare growth of seedlings with different initial sizes.

RESULTS AND DISCUSSION

Survival - age 2

Average survival for this test was 93.6%. Survival by seed source ranged from 90 to 99 percent. As a result, no significant differences among seed sources were detected for survival (Table 1). However, as expected, seedling size was strongly related to early survival. The average survival of 2 mm seedlings was about 14 percentage points lower than for 4 mm seedlings. For this study, the relationship between seedling diameter and initial survival is curvilinear (Figure 1).

Table 1. --Analysis of variance for survival at plantation age 2 years

Source of variation	d.f.	Sum of squares	F Value	P > F
Block	1	59.3	4.04	0.0695
Seed source	11	220.1	1.36	0.3078
error	11	161.4		
Block	1	6.2	6.6	0.0503
Diameter class	5	413.3	87.3	0.0001
error	5	4.7		

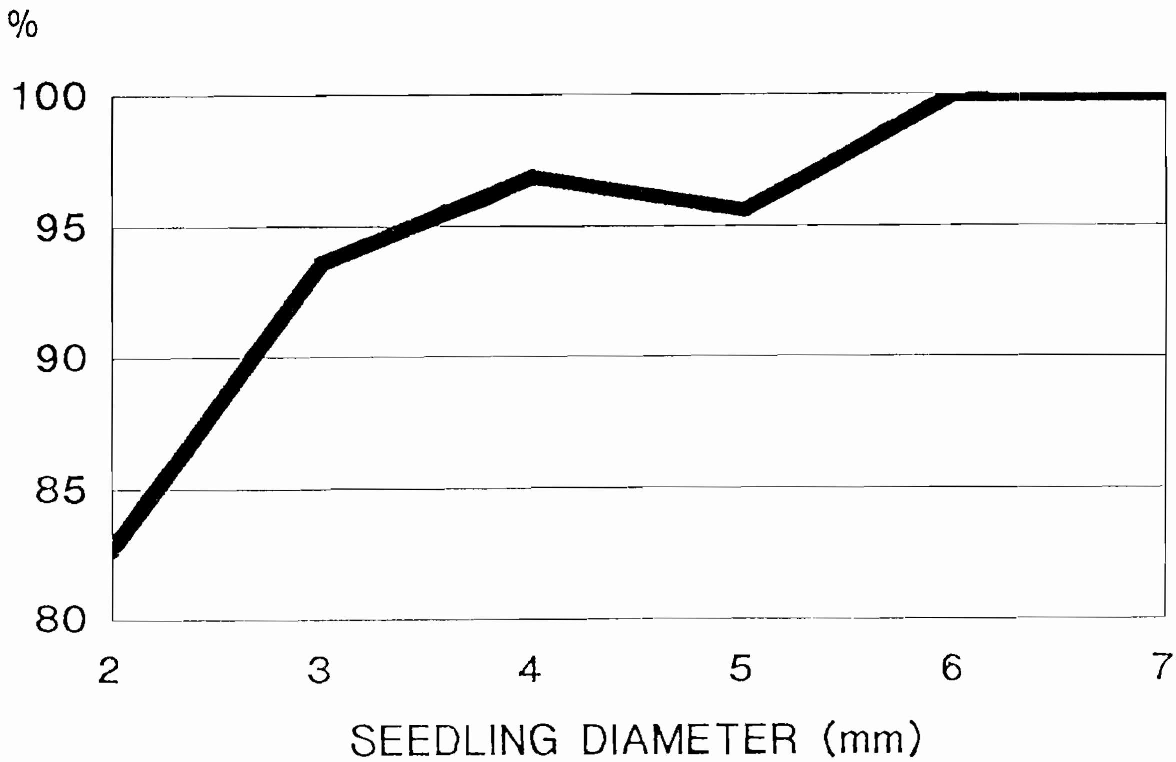

Figure 1. --Survival of loblolly pine by seedling diameter class.

Survival differences between seedlings of different diameter classes can be larger when seedlings undergo droughts following planting. For example, for a study planted in Cherokee County, Texas in December of 1952, survival of small seedlings (average diameter of 2 mm) was 28 percentage points lower than for seedlings that averaged 4 mm in diameter (14% vs. 42%). The largest seedlings (average diameter of 7 mm) had 73% survival even after undergoing the moderately dry summer of 1953 and the severe drought of 1954 (Zobel, Goddard and Cech 1957).

Average tree volumes

There was a positive relationship between seedling diameter at planting and average tree volume. At all ages, the average volumes of 2 and 3 mm seedlings were lower than those of 4, 5, 6, or 7 mm seedlings (Table 2).

Table 2. Average volume index (year 0-2), average tree volume (year 5-30) and number of trees per mean by seedling diameter class.

Year after planting	Seedling diameter at planting (mm)					
	2	3	4	5	6	7
	----------- D^2H - cubic centimeters (standard error of mean) --------					
0	0.4 (.008)	1.1 (.009)	2.3 (.028)	4.2 (.102)	6.9 (.327)	10.3 (.400)
1	18 (1.00)	30 (0.69)	50 (1.35)	79 (4.44)	126 (13.5)	112 (19.6)
2	444 (30.4)	635 (19.0)	921 (33.7)	1228 (92.0)	1560 (268)	1204 (202)
	------------------ cubic decimeters (standard error of mean)--------					
5	2.7 (.17)	3.1 (.08)	3.9 (.12)	4.3 (.25)	5.7 (.78)	4.7 (.54)
10	21.2 (.84)	23.7 (.44)	27.2 (.59)	28.4 (1.1)	33.4 (2.2)	32.0 (3.5)
15	49.0 (2.5)	54.5 (1.3)	62.2 (1.7)	65.7 (3.4)	73.1 (5.1)	65.5 (6.9)
20	105.3 (5.8)	108.2 (3.7)	115.9 (4.2)	120.0 (9.2)	129.7 (9.8)	113.3 (35)
30	290.4 (19)	292.5 (10)	314.3 (12)	311.7 (26)	333.0 (28)	315.3 (80)
	-------------------- number of trees per mean ---------------------					
0	141	656	360	92	16	7
1	116	618	349	88	16	7
2	116	614	349	88	16	7
5	115	610	349	88	16	7
10	115	606	346	85	16	7
15	90	421	246	54	14	6
20	49	208	111	35	9	2
30	41	187	102	34	9	2

The slopes of the fitted regression lines represent the differential increase in tree volume that could be related to a 1 mm increase in seedling diameter (Table 3). Since the slope appears to increase with time, the absolute volume difference between seedlings of different sizes also increases with time. The apparent lack of an increase from age 15 to age 20 may be a result of how the thinning was done at age 18.

Table 3. Regression equations describing relationship between seedling ground-line diameter after planting and average tree volume (N=6). Y = cubic decimeters; X = ground-line diameter in mm. (Regressions are weighted by the number of trees in a diameter class)

Year	Regression equation	P>F	R^2	Standard error of estimate of slope
5	Y = 1.3 + 0.6 (X)	0.0014	0.94	0.08
10	Y = 15.7 + 2.7 (X)	0.0008	0.95	0.30
15	Y = 37.6 + 5.8 (X)	0.0020	0.93	0.81
20	Y = 92.5 + 5.5 (X)	0.0044	0.89	0.96
30	Y =263.5 + 10.9 (X)	0.0223	0.77	3.01

Gains from planting seedlings with larger diameters are often expressed as percentages. For example, South et al. (1985) reported that planting seedlings with larger diameters could increase volume production at age 13-15 by 13% to 27%. However, as the plantation ages, the percentage volume gains should decrease (even though absolute differences can be increasing). Figure 2 illustrates how the percentage difference in tree volume changes with age. Although there may be a 380% difference in volume between 3 mm and 5 mm seedlings at planting, the difference can drop to 38% during the first five years and to 6.5% after 30 years.

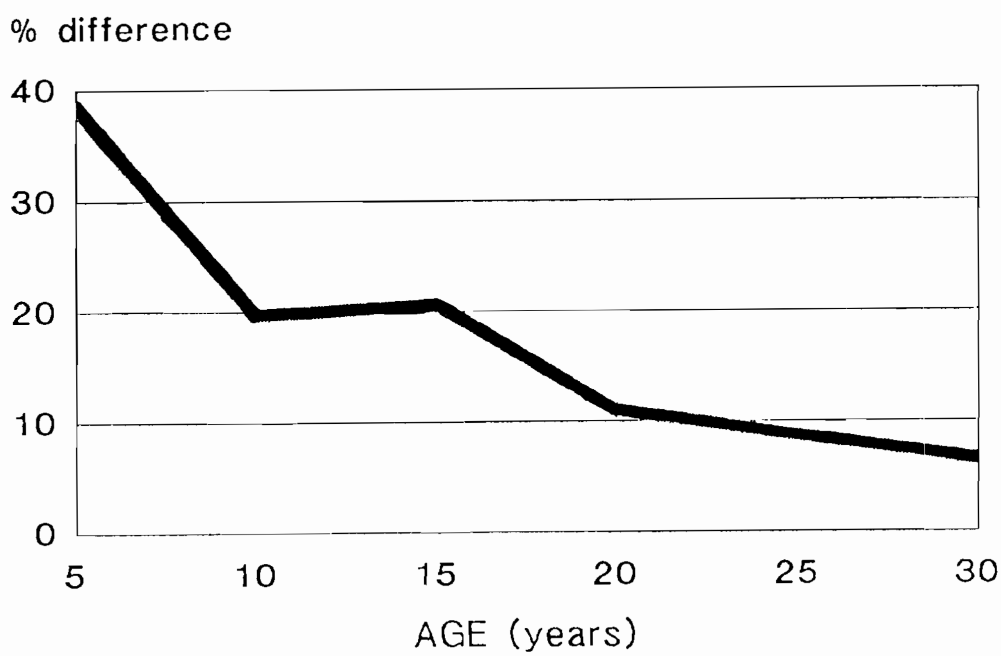

Figure 2. --Percent difference in average tree volume between 3 mm and 5 mm seedlings by plantation age.

Relative volume growth

Since the absolute difference between seedling classes increases with age, it would be of value to know if this increase results from; (1) larger caliper seedlings having a greater growth rate than smaller caliper seedlings; or (2) the larger seedlings simply starting out ahead on the same growth curve and remaining ahead. In attempting to answer this question, mean relative growth rates ($\overline{RGR}$) and mean relative production rates ($\overline{RPR}$) were calculated and plotted against time. However, it was determined that when the X axis is expressed as time, neither method adequately corrects for differences in seedling size. Even when growing on the same growth curve, larger trees were found to have lower values for $\overline{RGR}$ and $\overline{RPR}$ than smaller trees for a given point in time (especially during the early years of growth). This can easily be verified by using the data in Table 2. However, both methods can be used to correct for differences in tree size if the X axis is expressed in terms of tree size (e.g. volume at beginning of the growth period).

Redford (1967) stated that if progress is to be made in growth analysis, we must avoid unnecessary assumptions and return to a closer examination of the original data. We have attempted to do this by plotting the incremental growth (Y) over the tree size at the beginning of the growth period (X). This method we refer to as Incremental Growth Analysis (IGA). We define IGA as the analysis of periodic growth as a function of plant size instead of plant age. This simple method of analysis can be useful in determining if various treatments are growing on the same growth curve.

Two IGA curves were developed for this study. One was developed using the volume index (D^2H) for early growth (Figure 3) and another was developed using volume growth (in five year increments) from age 5 until age 20 (Figure 4). In each figure, the points fell essentially on the same curve. This indicates, for this study, seedlings from larger diameter classes simply start out ahead and stay ahead on the growth curve. The data suggest neither that large caliper seedlings grow faster than small caliper seedlings, nor that small caliper seedlings catch up to large caliper seedlings. Rather, they show that small differences in diameter (volume) are maintained and expanded upon.

CONCLUSIONS

We consider this finding to be biologically and economically important. An average difference of 2 mm in seedling diameter at planting could result in a 6.5% difference in tree volume at age 30. How much of this effect is nursery effect and how much is genetic will have to be determined with further analysis. However, it is known that factors such as seed size, maternal seed effects, and time of emergence play a strong role in initial seedling size. Regardless, these results support previous studies that demonstrate long term benefits from planting larger diameter seedlings.

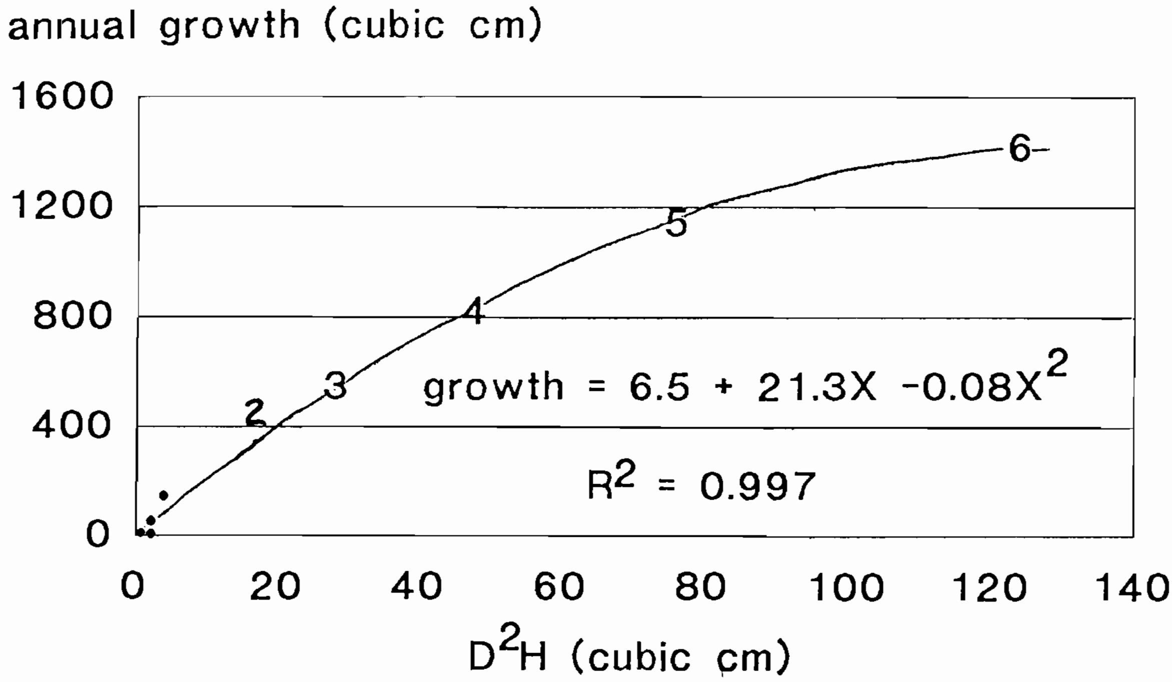

Figure 3. -- Relationship between D^2H at the beginning of the growth period (x axis) and annual growth (Y axis) for trees from 2 to 6 mm seedling classes (N=10).
(Means for X axis are listed in Table 2 for ages 0 and 1)

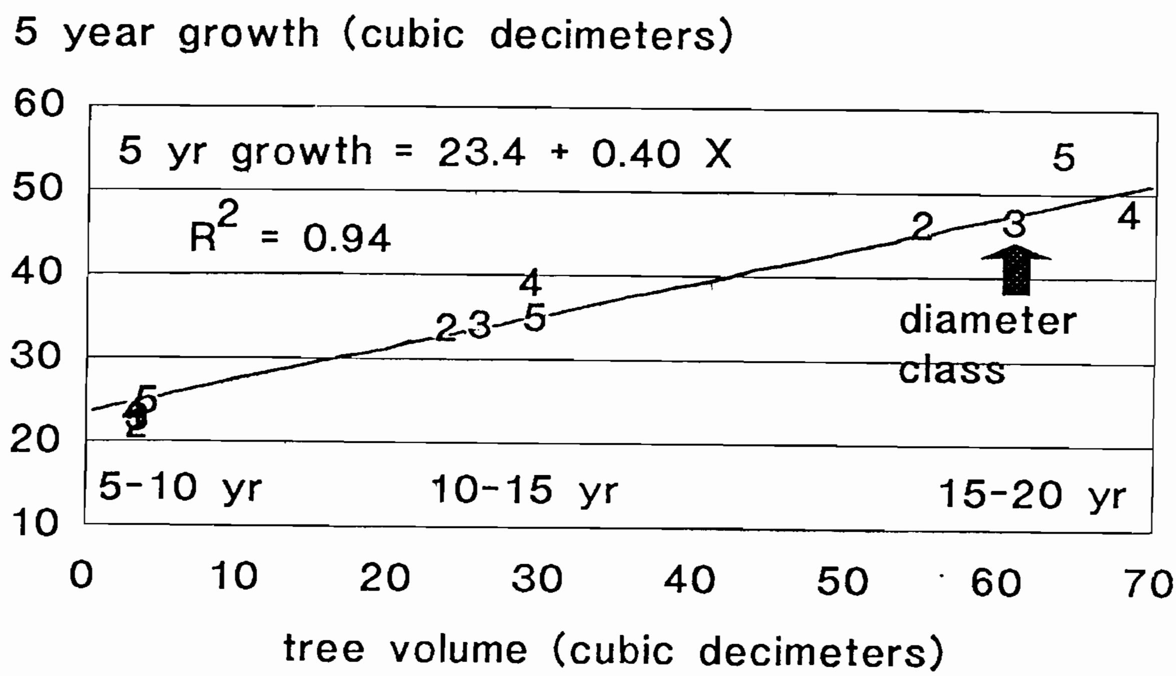

Figure 4. --Relationship between tree volume at the beginning of the growth period (x axis) and 5 year growth (y axis) for trees from 2 to 5 mm seedling classes (N=12).
(Only seedlings that remained through age 20 are included).

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