GENETIC IMPROVEMENT IN FOREST TREES -- GROWTH RATE AND WOOD CHARACTERISTICS IN YOUNG LOBLOLLY PINE

Bruce Zobel, Robert Kellison and Martha Matthias

FOREWORD

Our assignment is to set the tone for the portion of the SFTIC meeting dealing with gains and improvements in forest trees through use of genetics. This could be done rather dramatically by citation of proper references, because a lot of solid information is now available. But most of you are familiar with results from the tree improvement effort and you will hear many more newer findings at this meeting. Therefore, we will only briefly summarize in general terms overall results and some of the trends for the southern pines; the bulk of this paper will describe volume and dry wood yields, wood differences and the relationship of wood density to growth rate among progeny tests of 43 families in the N. C. State Cooperative Programs. Although the progeny tests were not specifically designed to show gains over commercial planting stock, they illustrate beautifully the differences among families from selected parents for wood density, growth and their interrelationship as well as indicate moisture content and tracheid length variation.

The few generalized remarks regarding gains are drawn from work done throughout the South. They can be summarized as being most encouraging -- gains have been greater and more rapid than any of us imagined would be possible. Overall results have been so good that we no longer have difficulty in "selling" tree improvement, and it is considered operational, not research, by most organizations.

Although growth rate *per se* has been emphasized by only a few organizations, gains in volume growth have been good, even with relatively mild selection for that trait. Reported results for young plantations (up to 15 years of age) vary from 10 per cent to over 50 per cent improvement in volume growth from first-generation seed orchards. This has been true for both loblolly and slash pines. Even though reasonably good gains in volume have been achieved with relatively mild selection, the really large gains in volume will be expected in second-generation selection for use in improved seed orchards.

Most organizations have emphasized selection for bole form, especially straightness. Gains in this characteristic have been good, with heritabilities in the range of 0.5. It is hard to quantify improvements in bole form but results have been so good that selection for straightness for inclusion in second-generation seed orchards will be very minor.

Director, Associate Director, and Research Technician, respectively, Cooperative Programs

One of the earliest and most spectacular gains in tree improvement has been in production of naval stores. First- and later-generation progeny produce suitable resins at a rate several times greater than from commercial collections, and these improvements appear to be stabilized as high yield "varieties."

Another really spectacular result has been in resistance to fusiform rust *(Cronartium fusiforme).* Families have been found that are nearly completely resistant, while others are nearly completely susceptible. Heritability estimates are around 0.8, and mother trees from a given seed orchard may show differences in infection of 60 per cent or more.

Wood qualities, especially specific gravity and tracheid length, have shown high heritabilities, around 0.5 and 0.6, respectively. Although percentage gains are only about 4 per cent when based on the total weight of a cord of wood, the 150 to 300 pounds per cord gain amounts to a large amount of money for all the cords produced on each acre for a large planting program. It is difficult to put values on changes in wood quality due either to changes in specific gravity or tracheid length, but they are considerable under certain circumstances. Research results on the relationship of wood qualities to growth rate make up the bulk of this paper.

Many other tree characteristics such as the ability to survive and grow under adverse environments have responded well to genetic manipulation. "Strains" better adapted to drought, to cold, to ice, to deep peaty soils, etc. are under development and all show promise. Not the least of these is the differential ability of certain families to respond to fertilizers and intensive forest management, a genetic characteristic that must be exploited to the fullest if we are to get maximum yields from each forest acre.

INTRODUCTION

In a forest tree breeding program it is of equal importance to know how growth affects important wood properties as it is to know the inheritance patterns of growth and wood characteristics *per se*. This paper reports on inheritance of several wood properties and volume growth and their interrelationships for young but merchantable sized trees. The main emphasis of this paper is on the relationship of growth, as expressed in volume, to specific gravity and dry wood weight as produced by fast- and slow-growing families of trees.

Well over 100 papers could be cited on the relationship of growth rate to wood specific gravity. [2/] The lack of general agreement on the relationship of the variables can be partially attributed to the diverse conditions under

---

relating to conifers, were chosen for inclusion in the "Literature Cited" section of this paper.

which the studies were conducted. Almost without exception the research results have been for stands of unrelated trees where stand history is unknown and where age, species and methodology used have been confounding factors. For example, the growth rate-wood specific gravity relationship may be quite different for species of Picea and Abies than it is for the hard (Diploxylon) Pinus species, and direct transposition of results from one group to the other cannot be made.

From recent studies it is generally agreed that there is little or no relationship between growth rate and wood specific gravity of merchantable southern pine trees. In direct contrast, weak to strong negative genetic correlations have been reported for young southern pines that have not encountered intraspecific or interspecific competition (Stonecypher and Zobel, 1966; van Buijtenen, 1963; Squillace, et al., 1962). As these authors have cautioned, such correlations indicate that trees with low specific gravity will be obtained if rapid growth rate is exclusively favored; and, similarly, slower growing trees may result if there is a strong selection for high wood specific gravity. Negative genetic correlations found on young trees have led some authors such as Namkoong, et al. (1967) to suggest that inclusion of wood properties in a breeding program may not be advantageous and may even be deleterious. Such conclusions foster the generally believed but unacceptable concept that wood of low density is synonymous with rapid tree growth, irrespective of the stage of development of the tree. As the trees become older the strong negative genetic correlations become insignificant or disappear completely at about the same time as competition among trees starts. 3/ These findings are in agreement with conditions commonly observed in merchantable stands, i. e., one cannot predict wood specific gravity of a tree from an even-aged stand of harvestable southern pines by mere observation of tree size.

Research results reported in this paper are presented to document the inheritance and relationship of growth rate and wood properties for families of trees of known genetic stock. Data are from 3,000 trees, 1,500 of which were felled, and represent actual volume and dry wood weight yields produced in the plantations involved.

MATERIALS

In applied tree improvement programs it is necessary to evaluate the parents used in seed orchards by means of progeny tests. The results from this study are tests for which growth rate and wood properties were accurately determined for trees growing under relatively uniform conditions.

3/ Manuscript in preparation by Stonecypher and Zobel

Four separate plantations supply the data used in this paper.[4/] All were thinned at 7.0 **or** 7.5 years of age, when full crown closure occurred and wood samples were obtained. In the study reported here, growth is reported by family,[5/] in cubic volume expressed as cords and in tons of dry wood per acre (Table 1). The same volume table (Goebel and Warner, 1962) was used for all plantations. The trees were fast grown, averaging more than five inches in diameter five feet above ground level at 7.5 years of age. Although growth rate of these young plantations is impressive, they are only beginning the period during which maximum average annual yield will be obtained; at culmination there is reason to believe that yield will increase by one-half or greater.

Wood properties were obtained from disks of approximately one inch thickness taken five feet and ten feet above stump height. Specific gravity of the disk was determined in the usual manner, i. e., ratio of dry weight to green volume. For better understanding by the industrialist, specific gravity was converted to pounds per cubic foot and tons of dry wood, and volume was converted to cords of unpeeled wood. A constant factor was used to convert cubic volume to cords, so results of all plantations are comparable. Moisture content of the green wood of trees 7.5 years old and tracheid length of the springwood of the last annual ring were determined from two of the open-pollinated plantations.

The open-pollinated families were represented by four replications of 25 trees (square plots) each from which growth data were obtained. An attempt was made to obtain disks from ten trees of each replication, for a total of 40 trees from each family on which family wood characteristics are based.

The control-pollinated families were in eight-tree rows, with four to six replications (total of 32 to 48 trees per family); approximately one-fourth of these were cut to obtain wood data. Of special interest in the control-pollinated plantation was that all families had the same mother (tree 11-2) but different fathers. The large differences in growth rate and wood properties are attributable to the different fathers, since all came from the same tree, with the only differences being the pollen used.

4/ All plantations are in South Carolina; two are from progeny tests of West Virginia Pulp and Paper Company in the Coastal Plain, one being control-pollinated and one open-pollinated; the open-pollinated Piedmont plantation is owned by U. S. Plywood-Champion Papers, Inc. The other Coastal Plain open-pollinated test is owned by International Paper Company.

5/ A "family" consists of trees from a common parent or parents. An open-pollinated family has a common known mother, whereas a control-pollinated family has both mother and father known.

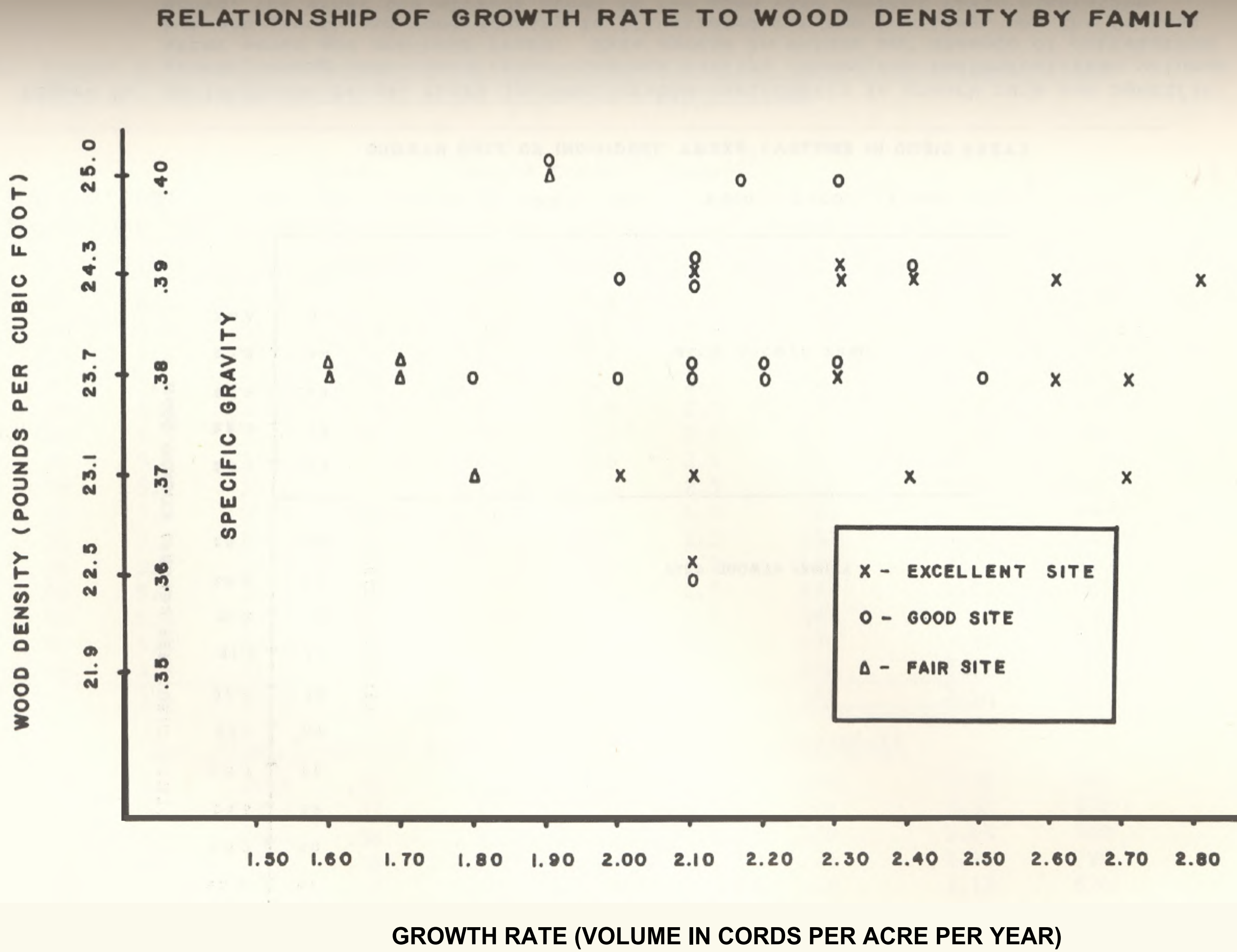
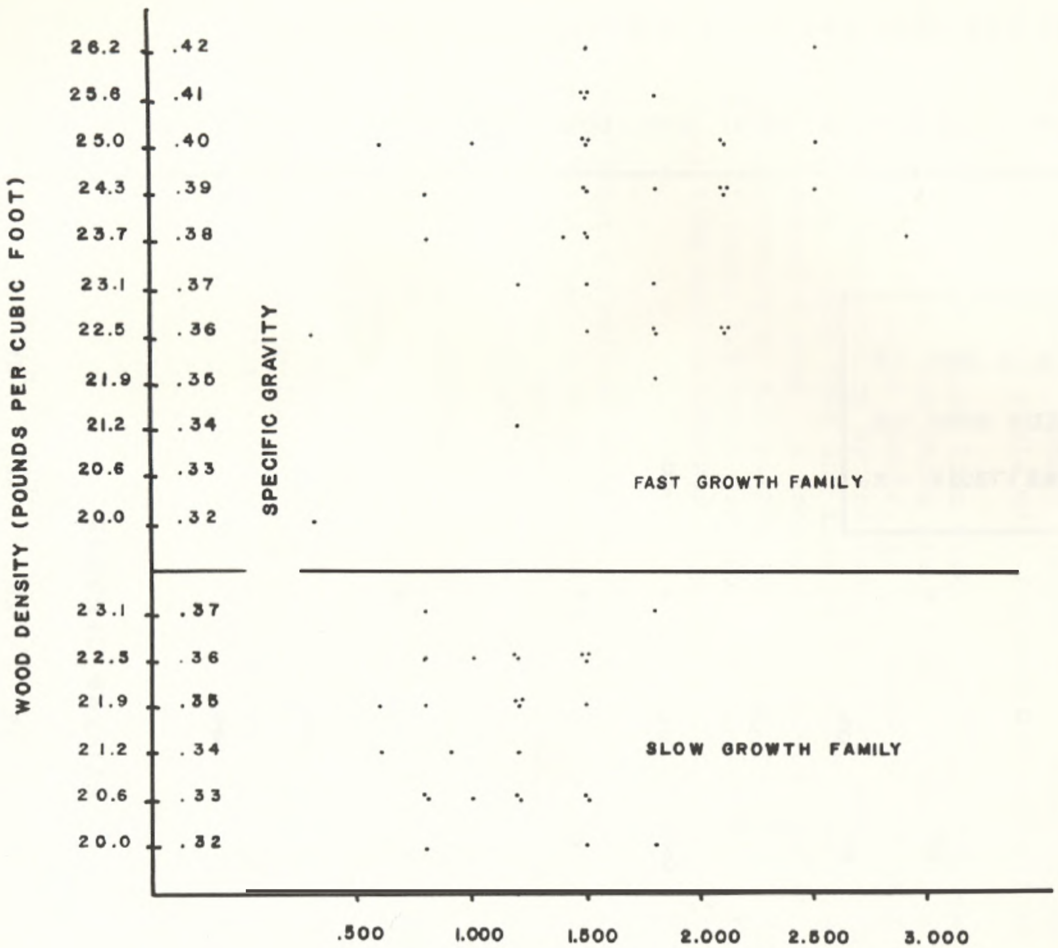


Figure 1. The relationship between growth rate and wood weight (expressed both as specific gravity and pounds per cubic foot) is shown for 43 families from the four plantations under study. There is no obvious relationship between growth rate, expressed either as cords per acre per year or average tree size and wood weight.

RELATIONSHIP OF GROWTH RATE TO WOOD DENSITY BY INDIVIDUAL TREES WITHIN A FAST AND A SLOW GROWTH FAMILY



GROWTH RATE OF INDIVIDUAL TREES (VOLUME IN CUBIC FEET)

Figure 2. As is always found, there is considerable variability in growth rate and specific gravity among individual trees within a family. Shown are individual tree volumes after seven and one-half years. This spread in values and absence of correlation between growth and wood density is illustrated for two families, one the fastest grown, the other the slowest grown in the good site Coastal Plain Plantation.

Table 1. Growth Rate and Wood Properties of Three Open-Pollinated Loblolly Pine Plantations. Data are family averages for trees 7.0 and 7.5 years of age.

Family	# Trees Sampled	DBH (inches)	Height (feet)	Wood Specific Gravity	Wood Weight Lbs./ Cu.Ft.	Cords/ Acre/ Year [1]	Tons/ Acre Year [2]	Moisture-Content [3]	Tracheid-Length [4]	Trees/ Acre
(Excellent Site, Old Peanut Field, South Carolina Coastal Plain)										
11-2	40	5.8	33.8	.39	24.3	2.3	2.3	147	3.42	610
11-3	40	5.9	33.4	.39	24.3	2.8	2.7	159	3.58	610
11-7	39	5.8	34.9	.38	23.7	2.6	2.5	166	3.64	550
11-8	36	5.9	32.4	.38	23.7	2.7	2.6	162	3.36	580
11-9	40	6.0	33.4	.36	22.5	2.8	2.5	169	3.40	670
11-10	30	5.9	32.4	.37	23.1	2.1	2.0	168	3.36	540
11-11	40	5.8	35.1	.39	24.3	2.6	2.5	157	3.71	490
11-13	39	5.9	33.1	.37	23.1	2.7	2.5	156	3.47	680
11-14	40	5.7	32.1	.36	22.5	2.1	1.9	171	3.39	600
11-16	39	5.6	34.0	.39	24.3	2.4	2.3	162	3.58	640
11-18	38	5.8	34.9	.39	24.3	2.3	2.2	157	3.71	610
11-19	40	5.7	32.5	.38	23.7	2.3	2.2	157	3.47	650
11-20	40	5.4	32.5	.39	24.3	2.1	2.1	163	3.63	530
11-41	40	5.8	32.2	.37	23.1	2.4	2.3	170	3.28	650
11-51	39	5.6	31.7	.37	23.1	2.0	1.8	170	3.53	580
MEAN		5.8	33.2	.38	23.6	2.4	2.3	162	3.50	600
(Fair Site, Partially Eroded Hill, South Carolina Piedmont)										
3-2	33	4.9	26.8	.38	23.7	1.7	1.6	166	3.29	860
3-4	39	5.2	27.6	.37	23.1	1.8	1.7	171	3.30	830
3-7	38	4.9	26.9	.38	23.7	1.6	1.6	159	3.43	840
3-14	40	5.1	27.0	.38	23.7	1.6	1.5	161	3.29	790
3-16	40	5.3	29.2	.40	25.0	1.9	1.9	149	3.17	820
3-20	40	5.1	26.1	.38	23.7	1.7	1.6	159	3.09	820
MEAN		5.1	27.3	.38	23.7	1.7	1.6	161	3.26	830

(Good Site, Abandoned Field, South Carolina Coastal Plain) 5/

7-2	38	5.2	32.0	.38	23.7	2.1	2.0	720
7-18	40	5.5	31.5	.38	23.7	2.5	2.3	810
7-22	39	4.9	30.3	.38	23.7	2.0	1.9	800
7-29	37	5.1	31.5	.39	24.3	2.1	2.1	780
7-33	40	5.2	32.1	.38	23.7	2.3	2.2	810
7-34	40	5.1	33.2	.40	25.0	2.2	2.2	840
7-43	40	5.2	30.7	.36	22.5	2.1	1.9	820
7-52	40	5.1	31.7	.39	24.3	2.1	2.0	780
7-56	40	5.1	33.7	.39	24.3	2.4	2.3	850
7-58	40	5.1	31.2	.38	23.7	2.2	2.1	850
7-59	37	5.2	30.8	.39	24.3	2.0	1.9	740
7-62	40	4.7	30.3	.38	23.7	1.8	1.7	830
7-67	38	5.0	31.5	.38	23.7	2.2	2.0	850
7-70	39	4.9	30.7	.38	23.7	2.1	2.0	850
7-71	39	5.2	32.2	.40	25.0	2.3	2.3	780
7-72	39	4.8	30.8	.40	25.0	1.9	109	830
MEAN		5.1	31.6	.39	24.3	2.1	2.0	810

0N

1/ Volumes are actual for trees 7.0 and 7.5 years of age: the excellent and fair sites, 7.5 years; the good site, 7.0 years of age. Therefore, yields are affected by survival (number of trees per acre), disease attack and other items. Apparent discrepancies in volume for families having similar diameters and heights are accounted for by the dissimilar sized distributions within families; volume was determined by individual tree within family, not family mean.

2/ Tons of dry wood. 3/ Based on weight of dry wood. 4/ For the last annual ring.

5/ Moisture content and tracheid lengths were not obtained for these 7-year-old trees.

RESULTS AND DISCUSSION

Growth Rate and Dry Wood Weight

Yield and wood property data have been summarized by open-pollinated families (Table 1) and by control-pollinated families (Table 2). It is obvious from both the open-pollinated and control-pollinated families that growth rate, whether rated by tree diameter or cords per acre per year, was not closely related to wood specific gravity or dry weight per unit volume (Figure 1). For example, family 7-62 had the smallest trees (slowest growth) of the 16 families in its test and had below average specific gravity while family 7-72, nearly as slow-growing, had high specific gravity. Family 7-18, with the largest diameter trees, had below average specific gravity, while family 7-71, which grew nearly as rapidly, produced high specific gravity wood (Figure 2). There were no differences in tons produced per acre per year by these two families (2.3 tons/acre/year) because the lower gravity family survived better, having 30 trees more per acre at time of thinning (Table 1).

Table 2. Growth Rate and Wood Properties for Control-Pollinated Families[1] -- Loblolly Pine, 7.5 Years of Age[2] (South Carolina Coastal Plain)

Family	# Trees Sampled (reps.)	DBH (in.)	Hts.	Sp. Gr.	Lbs./ cu. ft.	Cords/ Acre/ Year	Tons/ Acre/ Year	Moist. Cont.	Tracheid Length
11-2 x 11-9	12(4)	5.5	29.2	.35	21.9	2.2	1.9	150	2.93
11-2 x 11-14	8(4)	4.7	27.6	.38	23.7	1.6	1.5	142	2.89
11-2 x 11-18	8(4)	6.1	32.0	.39	24.3	2.9	2.8	136	3.37
11-2 x 11-20	10(4)	5.4	31.2	.40	25.0	2.1	2.2	133	3.36
11-2 x 11-41	18(6)	6.1	32.1	.38	23.7	2.8	2.6	155	3.05
11-2 x 7-34	12(6)	5.9	31.7	.39	24.3	2.4	2.3	141	3.15
MEAN		5.6	30.6	.38	23.8	2.3	2.2	143	3.13

1/ All families had a common mother, with different but known fathers.

2/ The per acre yields are maximum, i. e., with the assumption of full stocking of 680 trees per acre. The field layout did not allow an accurate assessment of the actual wood per acre as was done for the open-pollinated families.

Many similar comparisons could be made. For example, on an excellent site, one of the fastest growing families, 11-2 x 11-41, produced exactly the same specific gravity as the slower growing family, 11-2 x 11-14 (Table 2). In contrast, families 11-9 and 11-14 (Table 1), with the lowest wood specific gravity for their test, 0.36, represent fast and slow growing families, respectively. Based on average tree diameter of families, rather than cubic volume, no obvious relationship between DBH and pounds per cubic foot is shown, the correlation coefficient being r = 0.240 for the good Coastal Plain site and -.309 for the excellent site. These nonsignificant relationships are indicated by family 7-71 which had a tree diameter of 5.2 inches and wood weighing 25.0 pounds per cubic foot and family 7-62 which had a tree diameter of 4.7 inches and wood that weighed 23.7 pounds per cubic foot. Family 11-20 had small trees (diameter 5.4 inches), while family 11-11 averaged 5.8 inches, but both had exactly the same dry wood weight per unit volume.

To further test growth rate and wood specific gravity, correlation coefficients were calculated using individual trees from five families of one open-pollinated progeny test, which represented the fastest, slowest and intermediate growth families. No significant relationship was found between individual tree growth rate and its wood specific gravity for four families, whereas the fifth showed a significant positive correlation (summarized in Table 3). These results support the family mean data based on 40 trees per family, indicating that the fastest growing trees do not necessarily have the lowest specific gravity.

Table 3. Relationship between growth rate and wood specific gravity of individual trees within families

Family	No. of Trees Within the Family	Correlation Coefficient Between Growth Rate and Specific Gravity of Tree	Statistical Significance
7-59	37	+.143	N.S.
7-18	40	+.184	N.S.
7-2	38	+.151	N.S.
7-62	40	+.007	N.S.
7-29	37	+.447	**
All 5 families combined	192	+.014	N.S.

** Significant at the 1% level

Although only **six** families were involved in the control-pollinated progeny test (total of 68 trees harvested of the 262 measured), the variation in wood properties and growth rate and the lack of relationship of growth rate to wood specific gravity is very pronounced (Table 2). The fastest growing cross (11-2 x 11-18) produced 1.3 cords per acre per year more than the slowest growing cross (11-2 x 11-14) while still producing somewhat more dense wood, 24.3 versus 23.7 pounds per cubic foot.

Yield of Dry Wood Substance

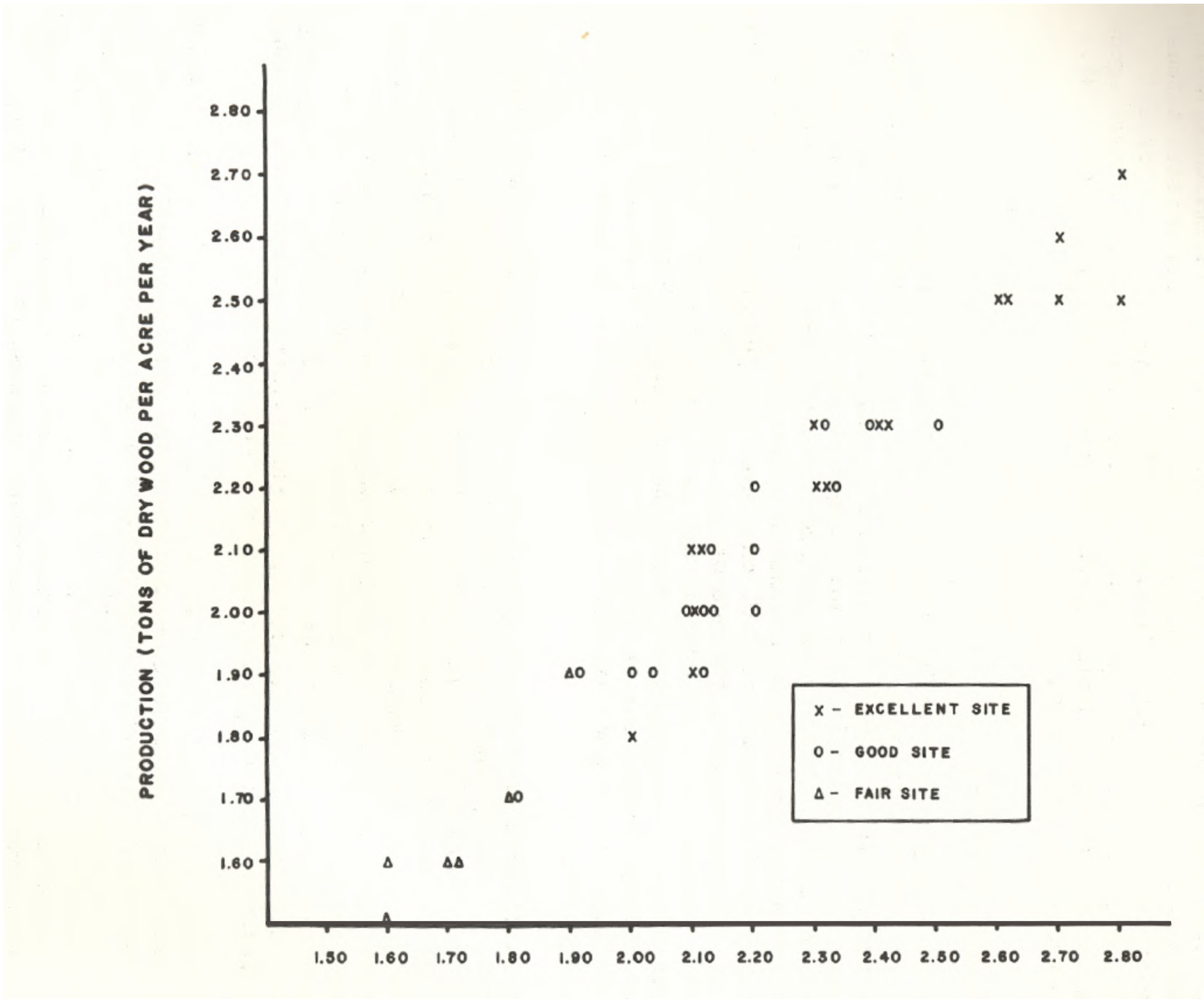
When discussing dry wood weight yields **it is** necessary to keep the proper perspective. An increase in wood specific gravity will improve yields in tons per acre but much greater tonnage yields can be obtained by increasing volume growth. We as plant breeders look at any change we can obtain in specific gravity as "cream on the milk" but we all recognize the best way to increase total production is to increase the amount of volume (Figure 3). In general, a difference in specific gravity of 0.02 on a two cord per acre per year volume production will mean a weight difference of 0.1 ton of dry wood per acre per year. However, an increase of 0.2 cords per acre per year will mean a difference of 0.25 tons per acre per year of wood produced (See Table 1). For this study, maximum family differences in wood specific gravity were 0.04 but it is not unusual to have growth rate differences among families as great as 0.6 cords per acre per year.

Volume production is controlled by growth rate of the **individual trees**, by per cent stocking, and by the number of destructive agents present. For example, in the good Coastal Plain plantation, family 7-62 with good stocking gave low tonnage yields because it grew slowly, whereas family 7-18 produced 0.6 tons more wood per acre per year because it was a faster grower even though it had twenty less trees per acre. As another example, family 11-8, with 580 trees per acre, produced an equal volume of wood on an acre, as did family 11-13 which retained a stocking of 680 trees per acre. The prevalence of Cronartium fusiforme and other destructive agents will reduce yields considerably although this is not readily indicated by the number of trees per acre.

It is obvious from the 37 open-pollinated and 6 control-pollinated families studied here that individual tree growth rate, wood specific gravity, or survival cannot alone be a good predictor of dry wood weight yields. The only uncontested result is a direct measurement of dry wood weight on the plantation, which requires accurate determination of both volume and weight of wood per unit volume. No matter how it is obtained, the largest quantity of most desirable fiber is the objective of tree improvement programs, and this can be achieved best by improving growth and wood qualities simultaneously, as seen by the 43 families in the four plantations studied.

Under current conditions, loblolly pine of either low or high specific gravity wood may be preferred, depending on the product produced. To attain this objective the breeder must aim for fast growth plus control of the kind of wood desired. Because of the lack of relationship between growth and specific gravity on either a family or individual tree basis, the breeder should

GROWTH RATE RELATED TO TONS OF DRY WOOD



GROWTH RATE (VOLUME IN CORDS PER ACRE PER YEAR)

Figure 3. Growth rate in cords per acre year year is plotted against production rate in tons per acre per year, illustrating the close relationship between tonnage yields and increasing volume growth.

attempt to obtain gains in both, and neither wood quality nor growth rate need be sacrificed for the other.

Moisture Content and Tracheid Length

Differences in amount of water per unit of dry wood in different families are quite outstanding. For example, family 11-2 had 1.5 pounds of water per pound of dry wood while family 11-14 had 1.7 pounds of water per pound of dry wood. Both families were the same age, both slow growing, but the former had high gravity, the latter low gravity. A similar range of moisture contents by family was found even among the six families in the fair Piedmont site. In the control-pollinated test (all families which had the same mother) there was a strikingly high difference of 133 to 155 per cent moisture content among the six families.

To the authors' knowledge this is the only time that inheritance of oisture content per se by family has been reported. The differences found at this young age (7.5 years) will probably increase as specific gravity and moisture contents diverge as the trees become older.

It has been commonly observed that within a species, higher specific gravity is associated with a lower moisture content. This relationship, plotted in Figure 4, is quite good, the trees having the highest dry weight of wood per unit volume having the lowest moisture contents.

Tracheid lengths varied considerably by family but were not related to growth rate. In the open-pollinated families from the excellent site, tracheid lengths varied nearly 0.5 mm, a greater spread than one would expect from families of trees of this young age growing on the same site. Approximately the same range of lengths was found among the six control-pollinated families.

As an aid to those proposing short rotations or use of young thinnings, complete summary data from this study are reported below (Table 4). This is a good idea of the kind of wood to be expected from young loblolly pine.

Table 4. Wood properties for 7.0- and 7.5-year-old loblolly pine are summarized by plantation to help give an idea of the kind of wood obtained from young thinnings.

	No. of Trees	Lbs/cu.ft. (Dry Weight)	Moisture Content (Based on Dry Weight)	Tracheid Length (7th ring)
Excellent Site (Coastal)	581	23.6	162	3.50
Good Site (Coastal)	626	24.3	-	-
Fair Site (Piedmont)	230	23.7	161	3.26
Excellent Site (Coastal) (Control-pollinated -- 1 common female parent)	68	23.8	143	3.13

RELATIONSHIP OF MOISTURE CONTENT TO DENSITY

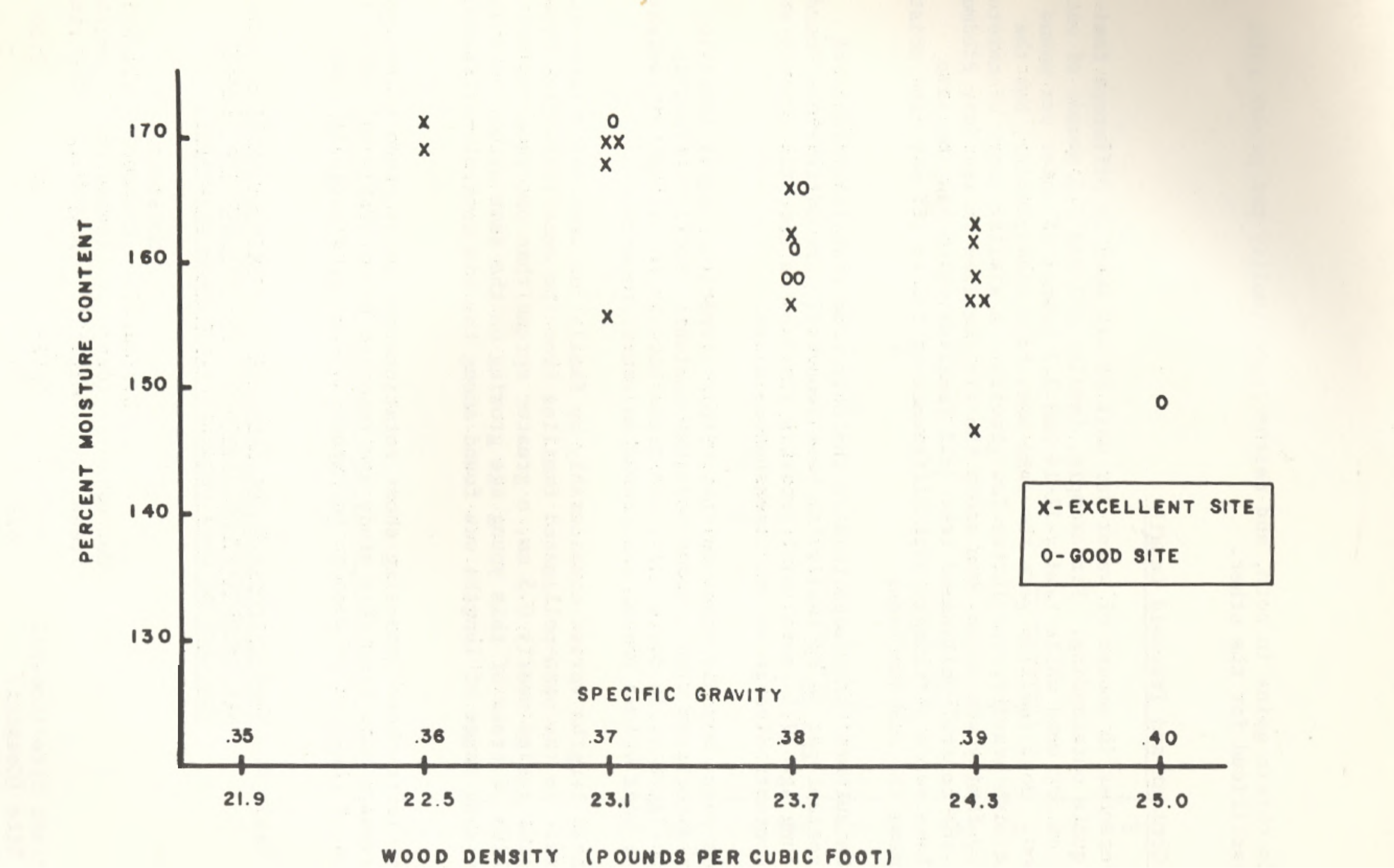


Figure 4. There usually is a good (negative) relationship between wood density (specific gravity) and moisture content. Averages of wood weight are plotted against moisture content (based on dry wood) for 21 families analyzed. Note the lower moisture contents for the families with higher wood densities.

Inheritance of Wood Weight and Moisture Content

Wood qualities among families were constantly and statistically different, indicating that trees of the same age growing at the same spacing produce quite different kinds of wood. Although the six families are too few from which to draw sound conclusions in the control-pollinated test, it appears to be more than chance that the very low gravity family (11-2 x 11-9) has inherited light wood from parent 11-9, which produced a very low gravity open-pollinated family. Conversely, 11-2 x 11-20 had high wood specific gravity, which might be expected since 11-20 was one of the highest of the open-pollinated families. The common parent in both crosses (11-2) had slightly higher than average specific gravity when tested as an open-pollinated family.

Parent 11-2 used as the mother of all families in the control-pollinated test had low moisture content and all crosses with this tree had low moisture (143 per cent compared to 162 per cent for the average of all open-pollinated families of the excellent Coastal Plain site with which it occupied adjacent plantations). There are too few data for absolute proof but it would be difficult to explain the low moisture content of the control-pollinated families if it were not that the one common parent 11-2 had the lowest moisture content of all open-pollinated families, and this was reflected in control-pollinated families.

Wood weight, moisture content and tracheid length, plus rate of volume growth, were determined for 1,500 young (7.0- and 7.5-year-old) progeny from seed orchard parents, grown on three different sites. Wood specimens were obtained as thinnings from 43 families from the three open-pollinated and one control-pollinated plantations.

1. Relationship between growth rate and wood specific gravity was nonexistent. Some fast growth families had heavy wood, some light. The fear that fast growing families will produce only low gravity wood is unfounded; it is possible to breed for rapid growth without sacrificing high wood specific gravity. In fact, the nonsignificant correlations between wood specific gravity and growth rate for trees harvested would indicate the necessity of making simultaneous selections for both growth and wood density.

2. A worthwhile increase in wood production per acre can be obtained by increasing wood specific gravity, but increased tonnage yields can be more easily produced by **an** increase in volume growth.

3. Differences among families growing under uniform conditions within plantations were considerable for both wood moisture content and tracheid length. Low moisture content parents produced low moisture

in both open- and control-pollinated progeny. A strong relationship exists between low wood density and high moisture content. No relationship was evident between wood density and tracheid length.

4. Growth rate and dry wood production were remarkably high for plantations only 7.0 or 7.5 years old; the best family grew at the rate of 2.8 cords per acre per year or 2.7 tons of dry wood per acre per year. Although all families were from selected trees used in seed orchards, wood yield differences were very great. For example, in the plantation on the best sites, dry wood produced varied from 1.8 to 2.7 tons per acre per year for the best and poorest families.

LITERATURE CITED

Echols, R. M. 1960. Effects of growing space on wood specific gravity in loblolly pine. Proc. Amer. For. 1959-60:140-3. For. Abs. 21(3):3727. July, 1960.

Fukazawa, K. and Aoki, A. 1960. Studies on the relation between physical properties and growth condition for planted SUGI (*Cryptomeria japonica* D. Don) in central district of Japan (IV) on the hardness test. Res. Bull. Faculty of Agri., Gifu University, No. 12:109-117.

Geyer, W. A. and Gilmore, A. R. 1965. Effect of spacing on wood specific gravity in loblolly pine in southern Illinois. U. Illinois, Agri. Expt. Sta. For. Note No. 113. pp. 1-5.

Goebel, N. B. and Warner, J. R. 1962. Volume tables for small diameter loblolly, shortleaf and Virginia pine in the upper South Carolina Piedmont. For. Res. Ser. #7, S. C. Agri. Expt. Sta., Dept. of For.

Goggans, J. F. 1961. The interplay of environment and heredity as factors controlling wood properties in conifers with special emphasis on their effects on specific gravity. Tech. Rept. No. 11, For. Tree Impr. Program, School of Forest Resources, N. C. State University, Raleigh.

Harris, J. M. 1963. The influence of environment on the wood density of radiata pine grown in New Zealand. World Consultation on Forest Genetics and Tree Improvement, Stockholm, Sec. 7/3. pp. 8.

Huang, T. C. and Liu, Y. J. 1959. The effect of growth and development on the timber quality of fast-grown *Pinus koraiensis* S. et Z. grown in Tsaohokow (Liaoning Prov. N. E. China). For. Sci. Peking 1959 (6):489-96. For. Abs. 21(3):3722. July, 1960.

Keith, C. T. 1961. Characteristics of annual rings in relation to wood quality. For. Prod. Jour. 11(3):122-126. For. Abs. 22(4):642.

Knigge, W. 1962. Untersuchungen uber die Abhangigkeit der mattleren Rohdichte nordamerikanischer Douglasienstamme von unterschiedlichen Wuchsbedingungen. (Investigations on the dependency of the average density of North American Douglas fir stems of different conditions.) "Holz als Roh- and Werkstoff" Bd. 20, S. 352-360.

Namkoong, G., Barefoot, A. C., and Hitchings, R. G. 1967. Problems in evaluating control of wood characteristics through breeding. Proc. Fourth Forest Biology Conference, TAPPI. pp. 131-139.

Nicholls, J. W. P. and Fielding, J. M. 1964. The effect of growth rate on wood characteristics. Commonwealth Scientific and Industrial Research Organization (Rep.), 19(1):24-30.

Paul, B. H. 1959. The effect of environmental factors on wood quality. U. S. Forest Service, Forest Products Laboratory, Madison, Wis. Rept. 2170.

Pechmann, H. von, 1964. Influence of growth rate on structure and physical properties of certain tree species (in part). Repr. from Schweiz Z. Forstw. 109:615-647.

Sellers, T., Jr. 1962. Factors influencing the wood quality of plantation-grown slash pine. For. Prod. Jour. 12(9):443-6. For. Abs. 24(2):313.

Squillace, A. E., Echols, R. M., and Dorman, K. W. 1962. Heritability of specific gravity and summerwood per cent and relation to other factors in slash pine. Tappi 45(7):599-601.

Stonecypher, R. W. and Zobel, B. J. 1966. Inheritance of specific gravity in five-year-old seedlings of loblolly pine. Tappi 49(7):303-305.

van Buijtenen, J. P. 1963. Heritability of wood properties and their relation to growth rate in Pinus taeda. World Consultation on Forest Genetics and Tree Improvement, Stockholm. Sec. 7/2. pp. 13.

Zobel, B. J., Thorbjornsen, Eyvind, and Henson, F. 1960. Geographic, site and individual tree variation in wood properties of loblolly pine. Sit. Gen. 9(6):149-176.