Table 1. — Analysis of variance for arithmetic average fiber length.

Source	d. f.	SS	MS	EMS
Total	59	.9226	—	—
Clones	4	.5408	.1352	$\sigma^2 + 3\sigma^2_T + 12\sigma^2_C$
Trees (within clones)	15	.2272	.0152	$\sigma^2 + 3\sigma^2_T$
Determinations (within trees)	40	.1546	.0039	σ^2
S^2_T			.0038	
S^2_C			.01	
$S^2_C/(S^2_T + S^2_C)$			.727	

and from 2.7 to 5.8 inches in diameter at breast height. The trees were 5 years old and represented 5 clones which were grafted and field planted in 1957 in a Union Bag-Camp Paper Corporation seed orchard near Egypt, Georgia. The scions used were from trees originally selected on the basis of growth and morphological characteristics. Upgrading of selection standards resulted in the decision to rogue out a number of the earlier selected trees with the result that the clones described were available for this wood quality study.

Table 1 illustrates the method of analysis of the data and *Table 2* (columns 1 and 2) lists the clones and tree numbers and indicates the number of grafted individuals available in each clone. The original number of 24 trees was reduced to 20 with the dropping of trees number 4, 14, 15, and 20 because of excessive levels of compression wood.

Samples taken from each tree consisted of a single bolt of wood 15 to 16 inches long, containing five annual rings, and located 30 to 54 inches above the ground. Variation in

Table 2. — Summary of wood characteristics.

Clone no.	Tree no.	Bolt[1]) diam., in.	Summer-wood, %	Com-pression wood, %	Specific gravity, g./cc. Wood-free compress. wood U. Fla.	IPC	Whole disk	Fiber length, mm. Weighted av.	Arithmetic av.
2—57	1	3.50	10.4	4.3	.323	.313	.333	2.07	1.72
	2	4.25	10.6	7.9	.300	.290	.315	2.19	1.76
	3	3.35	5.5	12.2	.283	.272	.289	1.96	1.58
	4	2.35	8.1	58.7	.338	.326	.377	—	—
	5	4.20	7.6	21.5	.324	.307	.328	1.99	1.65
21—57	6	4.50	6.0	58.5	.377	.387	.466	2.30	1 88
	7	4.85	6.5	21.8	.327	.322	.375	2.23	1.81
	8	3.15	11.5	58.0	.380	.339	.380	2.18	1.85
	9	4.30	7.2	20.4	.352	.365	.385	2.24	1.83
25—57	10	4.50	10.3	51.9	.342	.329	.402	2.37	1.94
	11	4.30	13.2	30.1	.307	.304	.328	2.21	1.85
	12	3.20	14.6	29.6	.332	.321	.347	2.37	1.89
	13	4.10	17.6	27.2	.346	.328	.372	2.48	2.08
	14	3.75	7.8	35.2	—	.333	.377	—	—
37—57	15	4.60	8.0	39.5	.336	.322	.353	—	—
	16	4.15	9.2	27.6	.320	.298	.331	2.28	1.80
	17	4.50	10.2	32.2	.307	.305	.368	2.33	1.88
	18	5.10	9.0	17.5	.318	.301	.329	2.30	1.86
	19	4.25	9.8	19.0	.305	.308	.337	2.32	1.89
41—57	20	3.55	13.6	43.4	.339	.314	.346	—	—
	21	3.60	12.2	14.4	.341	.318	.350	2.16	1.83
	22	2.90	11.0	33.8	.355	.353	.368	1.92	1.64
	23	3.80	8.6	31.7	.326	.327	.379	2.10	1.72
	24	3.55	6.4	20.1	.334	.316	.336	2.03	1.71

[1]) Bolt diameter large end inside bark.

Table 3. — Summary of chemical and micropulping work.

Clone no.	Tree no.	Extrac-tives, %	Lignin, %	Yield, %	Lignin-free yield, %	Perman-ganate no., 25-cc. basis	For-mation	Handsheet density, g./cc.	Basis wt., g./sq. m.	Zero-span tensile, lb./in.
2—57	1	3.65	31.14	40.2	36.6	17.2	37.8	.609	54.7	48.0
	2	3.22	31.32	40.2	36.4	17.7	35.8	.614	54.3	48.7
	3	3.38	31.80	39.2	35.5	17.2	38.8	.648	54.0	46 9
	5	2.32	31.75	39.9	36.1	17.9	37.6	.625	54.0	46.7
21—57	6	1.87	30.14	41.6	38.2	16.3	41.0	.554	56.1	53.7
	7	2.00	30.27	40.8	37.3	16.6	40.4	.576	54.8	55.5
	8	3.04	30.50	40.5	36.9	16.9	41.4	.587	55.3	54.6
	9	2.40	30.44	40.7	37.2	16.8	38.4	.570	56.0	55.3
25—57	10	2.96	30.62	40.2	36.5	17.3	41.2	.576	55.3	50.4
	11	2.37	30.84	40.8	37.3	16.7	38.3	.614	55.5	49.0
	12	2.41	30.41	40.5	36.8	17.5	38.8	.609	56.4	53.6
	13	2.76	30.24	41.4	37.7	17.3	36.6	.565	56.1	55.1
37—57	16	2.26	29.49	41.2	37.9	15.8	40.5	.576	55.5	55.0
	17	3.36	30.46	40.7	37.2	16.5	38.2	.598	53.4	52.8
	18	2.60	30.31	41.1	37.4	17.2	39.3	.587	55.8	52.5
	19	3 00	29.64	41.3	37.8	16.6	36.7	.587	54.0	50.9
41—57	21	2.72	29.64	40.7	37.3	16.2	40.8	.609	54.6	48.0
	22	2.29	30.61	40.6	36.5	18.5	40.0	.637	54.7	47.5
	23	2.60	29.77	41.5	37.6	17.8	39.9	.642	54.7	47.8
	24	2.66	30.60	40.7	37.0	17.6	40.1	.637	54.7	45.4

sampling height resulted from the presence of branch whorls and variation in the height of the graft union above the ground. A single, moist, 1-inch thick disk was supplied to the University of Florida for specific gravity determinations and the remainder of the sample was shipped moist to The Institute of Paper Chemistry. This latter sample was used as a source of additional specific gravity measurements as well as measurements on summerwood, compression wood, rate of growth, lignin, extractives, pulp yield, fiber strength (zero-span tensile strength), and fiber length.

The standard micropulping technique previously described by VAN BUIJTENEN, *et al.* (1961) was used to isolate the fibers employed in fiber strength and fiber dimension determinations. This procedure, which employs a battery of seven microdigesters that are slowly rotated end over end in an electrically heated oil bath, makes it possible to evaluate six trees and a control sample at one time. TAPPI standard handsheets were prepared[4]) from the pulp produced by the individual tree "microcooks" and information on pulp yield, permanganate number[5]), basis weight, caliper, density, formation, zero-span tensile strength, and fiber length were determined either on the pulp or handsheets[6]). The zero-span tensile strength values were determined according to the procedures described by WINK and VAN EPEREN (1961) and are interpreted as a measure of fiber strength.

Sampling and chipping the wood sample from each tree was complicated by excessive levels of compression wood. With the discovery of excessive amounts of compression wood, the decision was made that: (1) specific gravity would be run in duplicate using "whole disk" samples having variable amounts of compression wood, (2) specific gravity would be run on wood samples free of compression wood, and (3) the pulping and chemical studies would be made on wood free of compression wood. The University of Florida specific gravity determinations were run independently and were made upon wood free of compression wood. Both the University of Florida and The Institute of Paper Chemistry specific gravity determinations were run using the "maximum moisture" method.

Representative samples of wood free of compression wood were obtained by cutting the bolts into a series of disks 11 to 12 mm. thick, outlining the compression wood area using the light box technique, and then splitting out wedge-shaped sections free of compression wood. The wedge-shaped sections were further subdivided into chips, 1/8-inch thick and approximately ½-inch wide. The chips from a single tree were thoroughly mixed and three samples of 20 grams each were selected for further study. Triplicate pulpings were made on each tree to provide three separate pulps for determinations of fiber length, fiber strength, and the other chemical and pulp handsheet characteristics.

Fiber length determinations were made on small samples of pulp produced by the "micropulping" procedure and were handled by the Fiber Microscopy Section using standard Institute methods. The arithmetic average and the weighted average fiber length data presented are based upon the measurement of 800 to 900 fibers for each tree and include measurements on all fibers (cut, broken, and intact) that were encountered. The University of Florida ortet (original selected tree) fiber length and specific gravity measurements were based upon data obtained from three 8-mm. increment cores per tree taken at breast height. The outer one-half of the summerwood portion of the 19th, 20th, and 21st annual rings were macerated for tracheid measurements and a total of 90 intact tracheids were measured per tree. Ortet specific gravity was based on the 10 annual rings produced during the 15th through 24th years.

Statistical Procedures

The comparison of clonal materials was the method used in estimating broad sense heritability[7]). This method involves the comparison of the variation between clones with the variation that is encountered between trees within clones (genetically identical individuals). To make such a comparison, an analysis of variance of the form shown in *Table 1* was used (SNEDECOR, 1956). A similar, but slightly modified, method of analysis was used when a single determination was made for each tree. S^2_T is an estimate of the variation between trees within clones and S^2_C is an estimate of the variation between clones. The variance ratio, which is the ratio of the variation between clones (S^2_C) and the over-all variance ($S^2_C + S^2_T$), can be considered as an indication of the degree of genetic control that exists over the characteristic under consideration. Because the broad sense heritability contains both additive and nonadditive genetic factors, the heritability estimates are higher than normally obtained from progeny and parent tree-progeny comparisons.

In addition to the heritability information, a standard "F" test was used to determine if significant differences existed between trees within clones or between the clones being studied. Correlations were also run between all possible combinations of wood, fiber, pulping, and chemical data obtained.

Results

Tables 2 and 3 present a summary of the measurement data taken on the trees employed in this study. Triplicate determinations were made on a large portion of the wood, fiber, and handsheet characteristics and the values given in these two tables are average values. The per cent summerwood and the whole disk specific gravity data, which were determined in duplicate and the University of Florida and Institute of Paper Chemistry compression-free specific gravity information, which were based on single determinations, were the only measurements not made in triplicate. *Table 4* contains the specific gravity and fiber length information on the original selected trees (ortets) from which the clones were derived and the average value of the ramets which make up the clone. Also included in *Table 4* are the ortet-ramet correlation coefficients which, when squared, provide an additional estimate of gross heritability. *Table 5* summarizes the broad sense heritability estimates obtained from the analysis of variance calculations. Heritability values normally are expressed either as decimals or as percentages and high heritability estimates (values greater than 0.7 to 0.8) indicate strong genetic

[4]) TAPPI, T 205 m-58.

[5]) TAPPI, T 214 m-50. Permanganate number provides a measure of the lignin remaining in the pulp after cooking.

[6]) Basis weight, caliper, apparent density, and formation refer to properties of test handsheets. Basis weight is the weight of the test sheet in grams per square meter, caliper is the thickness in thousandths of an inch, density is weight per unit volume (g./cc.) and formation provides information on handsheet uniformity and is measured by a light-transmission technique.

[7]) Ortet-ramet correlations were also examined for specific gravity and fiber length.

Table 4. — Ortet-Ramet specific gravity and fiber length comparison.

Ortet no.	Specific gravity, g./cc. [1]		Fiber length, mm.	
	Ortet	Ramet	Ortet	Ramet
2−57	.590	.314	3.73	1.68
21−57	.597	.359	4.22	1.84
25−57	.579	.332	4.35	1.94
37−57	.581	.317	4.15	1.86
41−57	.582	.339	3.68	1.72
Ortet-Ramet correlation coefficients[2])				
Specific gravity	.50			
Fiber length, arithmetic av.	.97			

[1]) University of Florida specific gravity data.
[2]) The correlation coefficients are highly significant (1% level) if they exceed .959 and significant (5% level) if they are between .878 and .959.

Table 5. — Summary of heritability estimates for wood and fiber characteristics of slash pine.

Characteristic	Broad sense heritability
Specific gravity, I. P. C.	.49
Specific gravity, U. of Fla.	.44
Fiber length, arithmetic av.	.73
Fiber length, weighted av.	.75
Summerwood	.53
Compression wood	.34
Fiber strength[1])	.84
Pulp yield	.53
Lignin-free pulp yield	.59
Alcohol-benzene extractives	.25
Lignin	.72

[1]) Zero-span tensile strength.

control. Broad sense heritability values provide information on the transfer of gains by vegetative propagation. Because they include nonadditive genetic variation, they should be viewed as indicating maximum values with the true value being something less than the value presented.

Interest in wood, fiber, and handsheet property interrelations prompted the calculation of all possible correlations between the characteristics listed in *Tables 2 and 3*. Space does not permit the publication of all of the correlation coefficients obtained (total of 136) in this study and *Table 6* provides only selected significant and highly significant correlations[8]) believed to be pertinent to this investigation.

Discussion of Results

The average fiber, wood and handsheet values presented in *Tables 2 and 3* provide an opportunity to compare the variation between individuals within clones with the variation between clones. These data, and the data in *Table 4*, also afford the opportunity of comparing the specific gravity and fiber length of the grafted individuals (ramets) with the specific gravity and fiber length of the mature trees (ortets) from which the scions were taken.

The range of specific gravity values for the ortets was quite low and this, apparently, was a contributing factor to the low ortet-ramet correlation presented in *Table 4*. The highly significant ortet-ramet fiber length correlation indicates fairly strong genetic control of this property. Squaring the ortet-ramet correlation coefficient provides an estimate of gross heritability. Employing this procedure

[8]) Significant and highly significant as used in this study indicates the values which are significant at the 5 and 1% levels of probability, respectively.

Table 6. — Significant correlations between wood, fiber, and handsheet characteristics.

Variables		Correlation coefficient[1])
Specific gravity (IPC compression-free wood)	Compression wood	.615
	Extractives	−.513
	Pulp yield	.459
	Handsheet density	−.454
	Basis weight	.502
Fiber length (arithmetic average)	Summerwood	.592
	Lignin	−.512
	Pulp yield	.559
	Pulp yield, lignin free	.609
	Handsheet density	−.777
	Basis weight	.528
	Zero-span tensile	.683
Lignin (level in wood)	Fiber length, weighted average	−.501
	Fiber length, arithmetic	−.512
	Pulp yield	−.832
	Pulp yield, lignin free	−.855
	Permanganate number	.513
	Handsheet density	.454
	Zero-span tensile	−.461
Pulp yield (lignin free)	Fiber length, arithmetic average	.609
	Extractives	−.451
	Lignin, level in wood	−.855
	Permanganate number	−.574
	Handsheet density	−.614
Fiber strength (zero-span tensile strength)	Fiber length, weighted average	.750
	Fiber length, arithmetic average	.683
	Lignin	−.461
	Pulp yield	.454
	Permanganate number	−.534
	Handsheet density	−.849
	Basis weight	.572

[1]) The correlation coefficients are highly significant (1% level) if they exceed .561 and significant (5% level) if they are between .444 and .561. The negative sign indicates a negative correlation and has no influence on the level of significance.

results in heritability values of 0.93 for fiber length and 0.25 for specific gravity.

Particularly encouraging were the satisfactory heritability values obtained for such important properties as fiber strength, fiber length, per cent lignin, and pulp yield. To point up the usefulness of the heritability information in deciding the wood and fiber properties that should be used in selecting parent trees, tentative[9]) estimates of genetic wood property gains were calculated.

As broad sense heritability values are directly applicable only in predictions of gains with vegetative propagation and slash pine reforestation is a seedling planting situation, adjustment of the broad sense heritability information was required. Several instances where both narrow and broad sense values are available suggest that narrow sense values run approximately 60 per cent of broad sense heritability. Therefore, to obtain a very rough approximation of genetic gains in seedling population, 60 per cent of the broad sense heritability values obtained in this study were used in estimating expected genetic gains. In addition, information on natural variation available from a previous

[9]) The gains are specified as tentative because, as the heritability calculations cited in the Introduction indicate, considerable variation in heritability values can be expected depending upon age, type of material used in making the estimate, and the methods used in selecting the trees and making the wood property measurements.

study of slash pine growing in southeast Georgia was used[10]). Also used in these calculations was the assumption that parent trees could be obtained, by intensive selection, which were two standard deviations above or below the population mean.

Table 7 summarizes expected gains and indicates that genetic improvement of several properties, including fiber length and fiber strength, look quite promising. The reader is cautioned regarding the tentative nature of the expected gains and also cautioned against mentally adding the expected gains for the several characteristics listed. Correlations between the several wood and fiber properties (fiber length and fiber strength, specific gravity and per cent summerwood, pulp yield and lignin and extractives) indicate that the expected gains presented are not independent and are not entirely additive.

The existence of the above-described correlations has both advantages and disadvantages. One disadvantage is that such correlations make impossible the independent selection and improvement of the correlated wood and fiber properties. An illustration of such a situation is the adverse fiber properties (high proportion of summerwood fibers and reduced zero-span tensile strength, bursting strength and tensile strength[11]) which apparently will accompany rigorous selection for specific gravity.

The advantages of wood property correlations, when in the desirable direction, become evident when one considers that selection, from the practical point of view, becomes increasingly difficult with each additional characteristic that is considered.

When, as in the case of fiber length, the property in question is correlated with several other desirable properties, the choice of the single wood or fiber characteristic that should be emphasized is greatly simplified. Using the appropriate regression coefficients and the data and the assumptions employed in establishing *Tables 6 and 7*, it appears that selection for fiber length will result in an expected gain in the progeny of approximately 10.6%. Accompanying this increase in fiber length, the data in this study indicate that improvements approaching 9% in fiber strength, 1.2% in pulp yield, and 2% in reduced levels of lignin can be expected. A 3.5% increase in summerwood is also indicated. Selection for fiber strength will result in fiber strength increases of 10.7% and these expected gains apparently will be acompanied by a 7% increase in fiber length, a 1% increase in pulp yield, and a 1.5% decrease in lignin.

Space does not permit discussing each of the correlation coefficients listed in *Table 7* but, because of the importance of the correlations, those which require interpretation are considered. The correlation between specific gravity (compression-free wood) and compression wood in the tree, is interpreted as indicating that not all the compression wood was removed from the samples used in determining specific gravity. The negative correlation between specific gravity and extractives is what would be expected when specific gravity determinations are made on wood that has not been extracted prior to making the specific gravity determination. The correlations between fiber length and lignin and fiber length and pulp yield are as expected if increased fiber length results in fewer fibers per gram and this in turn means less intercellular material and less lignin. Density of the handsheets was correlated with more properties than one would have predicted from the small range of values obtained in density (.554 to .648). High handsheet density in this study is associated with shorter fiber length and shorter fiber length is in turn associated with lower fiber strength. This reasoning accounts for the observations which indicate that handsheets having similar weight of cellulosic material exhibited variation in density and this variation was negatively correlated with fiber length and fiber strength.

Also worthy of additional emphasis is the positive, highly significant correlation between fiber length and zero-span tensile strength. This correlation, as described by Einspahr (1963), has been encountered in a number of the earlier studies and substantiates the usefulness of fiber length and/or fiber strength in tree improvement work. Although not adequately investigated, the above correlation seems to be related to variation in fibril angle. Another correlation, the highly significant correlation between lignin and pulp yield suggests that this measurement might provide a suitable way of predicting the pulp yield of immature trees.

Acknowledgements

The authors are indebted to the co-operating companies and in particular to Mr. J. W. Johnson and Mr. Edward Hinkle of Union Bag-Camp Paper Corporation for their assistance in measuring and sampling the trees used in this study. Also to be acknowledged is the valulable assistance of Mr. John Peckham for his supervision of the pulping work. Thanks also go to Mr. John Hankey and Mrs. Marguerite Davis for carrying out the fiber measurements, Mr. Harold Grady and Mr. Robert Kilgas for carrying out the pulping

[10]) Unpublished data, The Institute of Paper Chemistry, 1962.
[11]) Einspahr, *et al.*, 1962.

Table 7. — Calculation of expected gains in slash pine through genetic improvement of wood quality.

Wood or fiber characteristics	Av. values	Parental increase by selection [1]) Actual	Parental increase by selection [1]) %	Gross herita-bility	Tentative estimates of expected gains [2]) Veg. pro-pagated individ-uals, %	Tentative estimates of expected gains [2]) Pro-geny, %
Specific gravity, g./cc.	.560	.07	12.5	.49	6.1	3.7
Fiber length						
Weighted av., mm.	2.46	.58	23.6	.75	17.7	10.6
Fiber strength						
Zero-span tensile, lb./in.	54.1	11.5	21.2	.84	17.9	10.7
Pulp yield, %	39.4	3.1	7.9	.53	4.3	2.5
Lignin, %	28.1	−1.6	−5.7	.72	−4.1	−2.5
Extractives, %	6.2	−4.3	−69	.25	−17.0	−10.1
Summerwood, %	49.1	11.0	22.4	.53	11.9	7.1

[1]) Expected increase if only those individuals two standard deviation above the mean are selected.
[2]) Tentative gains expected using gross heritability figures for vegetatively propagated individuals and assuming narrow sense heritability equal to approximately 60% of the gross heritability.

work, Mr. W. A. Wink and members of the Paper Evaluation Section, and to Mr. John Bachhuber and Mrs. Lea Pellett for their assistance with statistical and computer problems.

Summary

Twenty-four five year old grafted slash pine trees, 11 to 24 feet tall and 2.7 to 5.8 inches in diameter were cut and used in studying the heritability of a number of wood and fiber characteristics. A single sample of wood approximately 16 inches long was removed from each tree and a portion of this sample used to determine the percentages of summerwood and compression wood and the specific gravity.

Wood free of compression wood from twenty of the trees, four trees each from five clones, was reduced to chips and micropulped. Measurements on the fibers and pulp isolated by the micropulping procedure included fiber length, zero-span tensile strength, pulp yield, and permanganate number. Alcohol-benzene extractives and lignin were also determined on representative wood samples from the above trees. Broad sense heritability values were calculated for the wood and fiber properties measured. Fiber strength, fiber length, and per cent lignin (heritabilities of 0.84, 0.73, and 0.72) were the properties having the highest heritability. Specific gravity, per cent summerwood, and pulp yield all had broad sense heritabilities of approximately 0.50.

Correlations were calculated for a number of wood, fiber, and handsheet strength properties. Of particular interest were the previously reported highly significant correlations between fiber length and fiber strength and between pulp yield and levels of lignin. Tentative estimates of expected gains through genetic improvement of wood quality were calculated. These estimates indicate that of the wood properties studied, fiber strength and fiber length are the properties most amenable to genetic improvement.

Résumé

Titre de l'article: *Etude de l'héritabilité des caractères du bois et des fibres de Pinus elliottii.*

Vingt quatre individus greffés de cinq ans de *Pinus elliottii,* de 3,3 m à 7,3 m de haut et 6,8 à 14,7 cm de diamètre ont été coupés pour étudier l'héritabilité d'un certain nombre de caractères du bois et des fibres. Sur chaque arbre, on a prélevé un échantillon d'environ 40 cm de longueur et utilisé une partie de cet échantillon pour déterminer les pourcentages de bois d'été et de bois de compression, et la densité.

Le bois dépourvu de bois de compression de vingt de ces arbres, provenant de cinq clones dont chacun était représenté par 4 arbres, fut réduit en copeaux et défibré.

Les mesures effectuées sur les fibres et la pâte obtenue par défibrage portaient sur la longueur des fibres, la résistance à la tension «zero-span», le rendement en pâte et l'indice de permanganate. Les extraits à l'alcool-benzène et la lignine furent aussi déterminés sur des échantillons représentatifs des arbres en question. Les valeurs de l'héritabilité au sens large furent calculées pour les propriétés mesurées du bois et des fibres. La résistance des fibres, leur longueur et la teneur en lignine sont les propriétés présentant la plus forte héritabilité: 0,84, 0,73 et 0,72. La densité, le pourcentage de bois d'été, et le rendement en pâte avaient tous des héritabilités au sens large d'environ 0,50.

On a calculé des corrélations pour un certain nombre de propriétés du bois, des fibres et de résistance des feuilles, faites à la main en laboratoire. Se sont révélées particulièrement intéressantes les corrélations hautement significatives citées précédemment entre la longueur des fibres et leur résistance et entre le rendement en pâte et les teneurs en lignine. A titre d'essai, on a fait des estimations des gains attendus par suite de l'amélioration génétique de la qualité du bois. Ces estimations indiquent que parmi les propriétés du bois étudiées, la résistance des fibres et leur longueur sont les propriétés les plus susceptibles d'amélioration génétique.

Zusammenfassung

Titel der Arbeit: *Heritabilitätsuntersuchung an Holz- und Fasereigenschaften bei Pinus elliottii.*

Vierundzwanzig Pfropflinge von *Pinus elliottii,* welche 11—24 Fuß hoch waren und Durchmesser von 2,7 bis 5,8 Zoll besaßen, wurden gefällt und zum Studium der Heritabilität einer Reihe von Holz- und Fasereigenschaften benutzt. Eine einzige Stichprobe von etwa 16 Zoll Länge wurde von jedem Baum entnommen, und ein Teil dieser Probe diente zur Bestimmung des Spätholzprozents, des Druckholzprozents und der Raumdichte.

Mit Holz von 20 der Bäume, welches kein Druckholz enthielt, wurden nach Zerteilung in Späne in einer Mikroapparatur Kochungen durchgeführt; je 4 dieser Bäume gehörten zu 5 Klonen. Messungen an den Fasern und am Zellstoff, der durch die Mikrokochung entstand, umfaßten die Faserlänge, Zugfestigkeit von Einzelfasern bei Einspannlänge Null, Zellstoffausbeute und Permanganatzahl. In Alkohol-Benzin lösliche Stoffe wurden ebenfalls an repräsentativen Holzproben obiger Bäume bestimmt. Werte der Heritabilität i. w. S. wurden für die gemessenen Holz- und Fasereigenschaften berechnet. Faserfestigkeit, Faserlänge und Ligninanteil (Heritabilitäten von 0,84, 0,73 und 0,72) waren die Eigenschaften mit der höchsten Heritabilität. Raumdichte, Spätholzprozent und Zellstoffausbeute besaßen Heritabilitäten von etwa 0,50.

Für eine Reihe von Merkmalen von Holz, Fasern und Papierprobeblättern wurden die Korrelationen berechnet. Von besonderem Interesse waren die hochsignifikanten Korrelationen zwischen Faserlänge und Faserfestigkeit und zwischen Zellstoffausbeute und Ligningehalt, über welche bereits früher berichtet wurde. Versuchsweise Schätzungen der zu erwartenden Fortschritte bei Züchtung auf Holzqualität wurden unternommen. Die Schätzwerte zeigen, daß von den untersuchten Holzmerkmalen Faserlänge und Faserfestigkeit am stärksten auf Züchtung reagieren.

Literature Cited

(1) Dadswell, H. E., Fielding, F. M., Nicholls, J. W. P., and Brown, A. G.: Tree to tree variation and the gross heritability of wood characteristics of *Pinus radiata.* Tappi 44: 174—179 (1961). — (2) Einspahr, D. W.: Correlations between fiber dimensions and fiber and handsheet strength properties. Paper presented at Tappi Forest Biology Conference, November, 1963. To appear in Tappi in 1964. — (3) Einspahr, D. W., Peckham, J. R., and Mathes, M. C.: Base-lines for judging wood quality of loblolly pine. Accepted for publication in Forest Science. — (4) Einspahr, D. W., van Buijtenen, J. P., and Thode, E. F.: Wood and pulp properties as determined from slash pine increment core and whole tree measurements. Silvae Genetica 11: 68—77 (1962). — (5) Goddard, R. E., and Strickland, R. K.: Geographic variation in wood specific gravity of slash pine. Tappi 45: 606-608 (1962). — (6) Goggans, James F.: The correlation, variation, and inheritance of wood properties in loblolly pine. North Carolina State College, School of Forestry

Tech. Report 14, 155 p. (1962). — (7) SNEDECOR, G. W.: Statistical methods. 5th Edition. Ames, Iowa, Iowa State University Press. 534 p. (1956). — (8) SQUILLACE, A. E., ECHOLS, R. M., and DORMAN, K. M.: Heritability of specific gravity and summerwood per cent and relation to other factors in slash pine. Tappi 45: 599—601 (1962). — (9) VAN BUIJTENEN, J. P., JORANSON, P. N., and MACLAURIN, D. J.: Pulping southern pine increment cores by means of a small-scale kraft procedure. Tappi 44: 166—169 (1961). — (10) VAN BUIJTENEN, J. P., ZOBEL, B. J., and JORANSON, P. N.: Variation of some wood and pulp properties in an even-age loblolly pine stand. Tappi 44: 141—144 (1961). — (11) VAN BUIJTENEN, J. P.: Heritability estimates of wood density in loblolly pine. Tappi 45: 602—605 (1962). — (12) WINK, W. A., and VAN EPEREN, R. H.: The development of an improved zero-span tensile test. Tappi 45: 10—24 (1962). — (13) ZOBEL, B., THORBJORNSEN, E., and HENSON, F.: Geographic site and individual tree variation in wood properties of loblolly pine. Silvae Genetica 9: 149—176 (1960). — (14) ZOBEL, BRUCE, COLE, DONALD, and STONECYPHER, ROY.: Wood properties of clones of slash pine. Proc. Forest Genetics Workshop, p. 32—39., SAF, Macon, Georgia, October 26, 1962.

Inheritance of Needle and Bud Characteristics of Slash Pine

By FRANK C. SORENSEN

(Received for publication December 3, 1963)

The purpose of this investigation was to analyze the extent of gene control of several variable needle and bud characteristics in slash pine (*Pinus elliottii* ENGELM.). Variation in needle and bud characteristics, particularly needle length, has often been used as a tool in investigations of geographic variation and of interspecific hybridization in pine species. Only rarely, however, have the observations and studies included determination of an approximate degree of genetic control of variation, or compared different characteristics on this basis.

Review of Literature

DENGLER (1938), in studying a number of pines, found that different races still varied in needle length in the second generation. In another European investigation, BURGER (1941) found that Scots pines (*P. sylvestris* L.) of different origins, but grown on the same site, required different amounts of needles to produce the same wood volume increment.

Three pertinent observations have been made in ponderosa pine (*P. ponderosa* LAWS.) in this country. LORENZ (1949), in a seed source study, reported major differences in color and texture of needles of trees of different sources when grown on the same site. In a similar study, MUNGER (1947) noted that progeny from some seed sources were bushier than others and that variation existed in needle color, duration of needle retention, and angle of the needle with the twig. Average needle length ranged from 4 inches for one source to 7½ inches for another. WEIDMAN (1939) showed that 22- to 26-year-old ponderosa pine progenies from different geographic sources differed in the number of needles per fascicle, length of needles, and general appearance of foliage. These differences corresponded to differences between trees of the various parent localities, and the conclusion was drawn that the characteristics were strongly inherited.

Several needle characteristics of slash pine and some of its hybrids were investigated by MERGEN (1958). The number of resin ducts per needle and the number of stomata per millimeter of length showed a pattern which could be correlated with the geographic distribution of the species. The number of teeth on the needle margin, however, did not appear to be so correlated.

Procedure

Description of Material

The plant materials used in this study were: 1) 15-year-old rooted cuttings obtained from a group of slash pine trees selected for their high gum-yielding ability, and 2) 15-year-old progenies produced by controlled pollinations among the same high-gum-yielding selections. Both of the plantations were situated near Olustee, Florida. The material was made available to the author by the Lake City Research Center of the U. S. Forest Service.

The clones were growing in an informal plantation about 3/4 acre in size, containing varying numbers of ramets from each clone. The ramets of some clones were planted in unreplicated row plots while those of other clones were located more or less at random. Five of the clones were chosen for study (*Table 1*).

The progeny plantation was about 6 acres in size. In it, varying numbers of trees of most progenies were planted randomly within seven blocks. A few progenies were represented only in replacement blocks where the trees were planted in unreplicated row plots. Seven of the progeny

Table 1. — Clonal and progeny averages for all traits measured.

Clone or progeny	Trees per clone or progeny	Needle length	Needle-bundle volume	Needles per bundle	Fascicle sheath length	Needle divergence	Bud scale length
	Number	*mm.*	*cc.*	*Number*	*mm.*	*mm.*	*mm.*
			CLONES				
G-1	6	263	.785	2.17	14.1	11.4	14.1
G-2	8	239	.520	2.04	10.5	15.2	11.5
G-3	2	248	.667	2.00	13.5	5.7	13.1
G-4	6	264	.632	2.05	16.0	17.8	15.2
G-7	1	297	.786	2.30	17.0	9.9	—[1]
			PROGENIES				
1 × 2	14	244	.515	2.13	11.6	16.3	—[1]
1 × 7	14	248	.509	2.14	13.3	14.9	—[1]
3 × 2	14	227	.472	2.04	11.2	12.6	14.0
4 × 1	14	252	.557	2.31	13.0	19.6	15.7
2 × 7[2]	7	252	.505	2.12	—[1]	15.8	—[1]
3 × 4[2]	7	—[1]	—[1]	2.14	—[1]	16.9	15.9
4 × 2[2]	4	240	.454	2.05	12.3	17.3	—[1]

[1]) Not measured.

[2]) Progenies represented in the replacement blocks only.

[1]) Based upon a thesis presented by the author in partial fulfillment of the degree of Master of Science in Forestry at the University of Florida, 1960. The investigation was conducted in cooperation with the Southeastern Forest Experiment Station, Lake City, Florida, which supplied the plant material. Acknowledgements are due to Dr. T. O. PERRY for suggesting the problem and to Mr. A. E. SQUILLACE for much helpful advice. Further acknowledgements are made to Drs. R. R. SILEN and H. IRGENS-MÖLLER for reviewing the paper. The author is presently a Research Forester with the Pacific Northwest Forest & Range Experiment Station at Corvallis, Oregon, USA.