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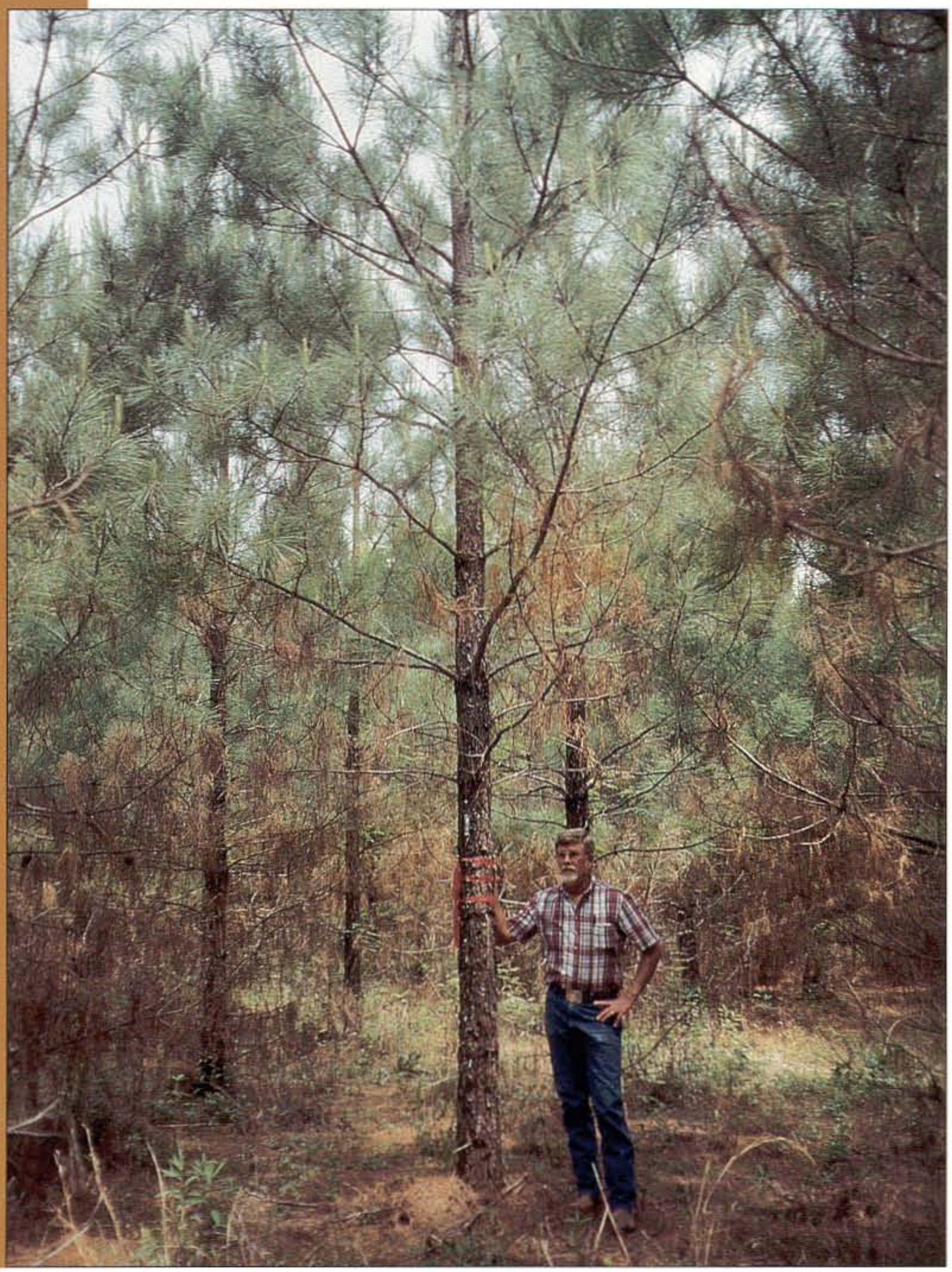
NORTH CAROLINA STATE UNIVERSITY – INDUSTRY COOPERATIVE TREE IMPROVEMENT PROGRAM



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ANNUAL
REPORT

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INTRODUCTION

The North Carolina State University - Industry Cooperative Tree Improvement Program has completed 40 years of continuous operation. Our mission through these past four decades has been to "Economically Increase Forest Productivity Through Genetic Manipulation of Pine Populations". This mission is in essence the working definition of Tree Improvement which encompasses both research in forest genetics and development of genetic resources for practical forestry. As we begin our fifth decade of cooperative work we can build on the strong foundation developed through the first 40 years of effort.

The members of the Cooperative have bred 3,834 plantation and second-generation loblolly pine selections in 639 six-parent disconnected half-diallels. The progeny grown from these 9,585 controlled-pollinations have been planted in 1,278 progeny tests. The last progeny test for this cycle of breeding and testing was established in the spring of 1996. To date we have graded 257 new third-cycle selections from the first 190 progeny tests established. Third-cycle selection work will be completed in the year 2003, as the last of the established progeny tests reach age-six. Each third-cycle selection is being grafted into at least three breeding orchards and implementation of the 3rd-cycle breeding plan will soon be initiated.

First generation seed orchards have produced well beyond early expectations. We have produced sufficient seed to meet all the planting needs of program members since 1980. In the last five years 40 percent of the seed produced has come from second-generation seed orchards. Genetic gains are substantial, with realized volume improvement from first-generation orchards ranging from 8% to 12%. Plantations grown from second-generation orchard seed have a predicted gain of 16% over the productivity of plantations grown from wild seed. Genetic gains in excess of 40% have been predicted from use of full-sib technologies such as control mass pollination and/or vegetative propagation.

On forest land that will continue to be intensively managed, it is essential that we use the best technology. The Tree Improvement Cooperative has made long-term investments in forest genetics research which is important to the successful development and implementation of improved technology. Continued support of a strong research program offers great promise.

Tree improvement must and is meeting the challenge of the next century as we learn to extract more genetic gain from the genetic populations we are intensively developing. We have breeding strategies in place that will capture genetic gains at a faster rate and at a lower cost than previous efforts allowed. New genetic technologies will make a difference in the way trees grow. It is a rewarding time to be involved with tree improvement !!!

RESEARCH

Selection Criterion and Age for Rotation Volume

Based on generalized prediction models of young 1st generation progeny tests, six-year tree height has been recommended for selection in the Cooperative's second-generation breeding program. With these tests approaching rotation age (20-years), data were analyzed again to determine optimum selection age for rotation volume. Since the data also included periodic DBH measurements, both height and DBH were evaluated for selection efficiency on rotation volume.

Eleven 20-year-old first-generation tests were used to examine the genetic control of traits at juvenile and mature ages and juvenile-mature family mean correlations. The average intraclass correlation coefficients (analogs for heritabilities) peaked at age eight for height and at age 12 for DBH (Figure 1). Tree height had a slightly higher degree of genetic control than both DBH and volume at earlier ages but DBH had the highest value at age 12.

The average family mean age-age correlations showed that juvenile DBH and volume were significantly better predictors than height for 20-year tree volume (Figure 2). The average correlation coefficients for height, DBH and volume at age eight with 20-year volume were 0.57, 0.72 and 0.75, respectively. Combining both the intraclass correlation coefficients and age-age correlations, the selection efficiencies for gain per year were estimated as the ratio of the correlated gain per year expected from juvenile selection to the gain per year expected from direct selection at 20-years. With most efficiency values above 1.0 from ages 4 to 16, Figure 3 showed that early selection at most ages was more efficient than selection at age 20. The results basically confirmed early results that the optimum age for family selection for rotation volume was about age six. However, DBH may be a slightly more efficient selection criterion than height for 20-year volume. Selection based on early height (age 4-8) was relatively more efficient than that based on juvenile volume but decreased significantly after age eight. Higher selection efficiency for DBH than

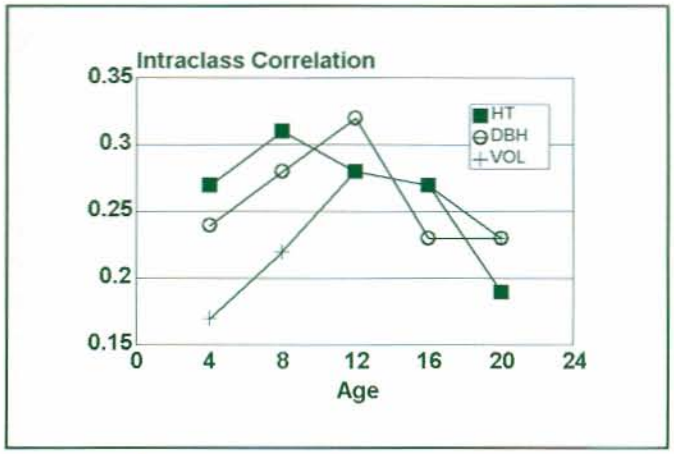


Figure 1. Intraclass correlations over time for height, DBH and volume based on eleven 20-year-old first generation tests.

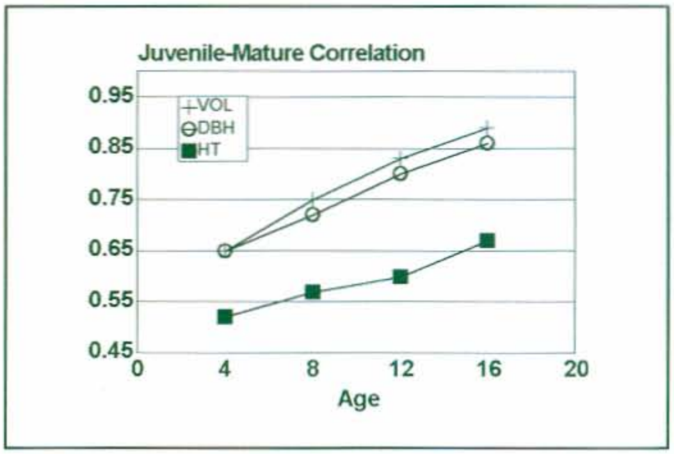


Figure 2. Correlations of juvenile height, DBH and volume with 20-year rotation volume (based on eleven 20-year-old first generation tests).

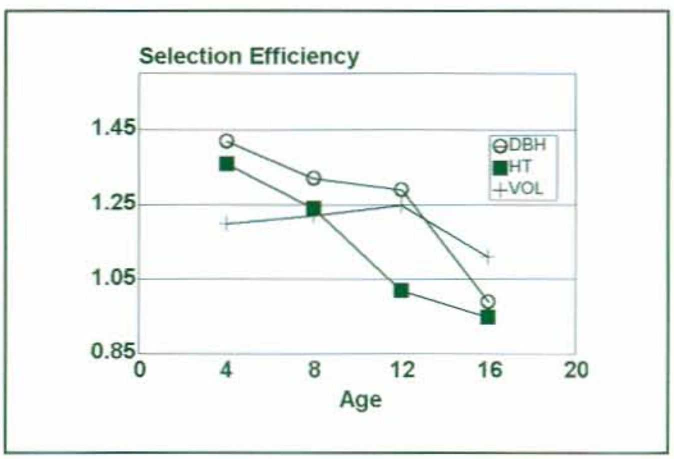


Figure 3. Efficiency of Selection—based on juvenile traits for 20-year volume (based on eleven 20-year-old first generation tests).

for height was mainly the result of strong juvenile-mature correlations for DBH with 20-year volume.

The correlation of test survival and heritability of DBH was calculated to examine the common concern that DBH is more sensitive to test spacing and survival. With a range of test survivals from 75% to 98%, the correlation of survival with DBH heritability (r=0.51) was not different than the correlation with height heritability (r=0.54). When the tests below 80% survival were eliminated, no important correlation could be detected between survival and DBH heritability.

Results from 30 test series of the 2nd generation diallels also confirmed that the heritability estimates for DBH were very comparable to those for height at age six (Table 1). Similar to the first generation data, the correlation of test survival with DBH heritability (r=0.21) was not any higher than the correlation with height heritability (r=0.30), with a range of test survivals from 73% to 98%. These results suggest that selection efficiency could be improved by including DBH for selection.

Preliminary Results from Early Diallel Measurement Study

The Early Diallel Measurement Study (EDMS), was established from second generation and plantation

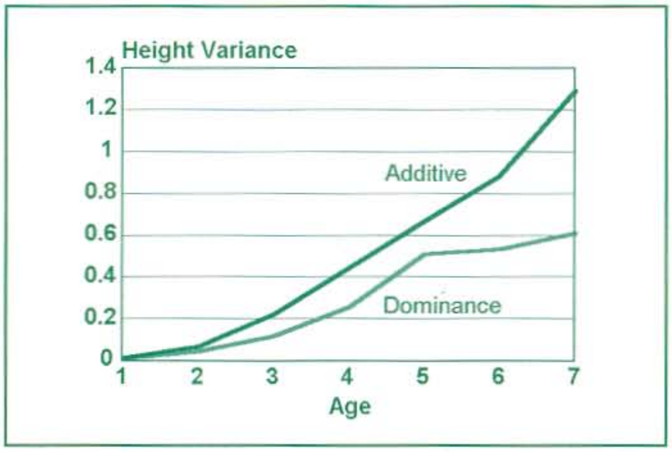


Figure 4. Variance components over time for tree height based on 15 diallel test series.

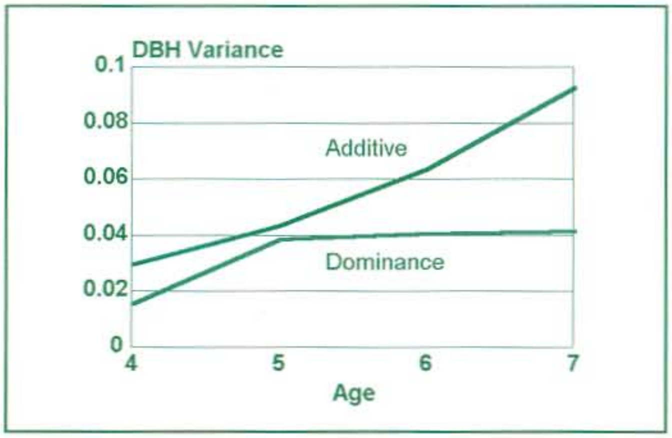


Figure 5. Variance components over time for DHB based on 15 diallel test series.

Table 1. Average heritability estimates for height and DBH from 30 diallel test series at age 6

Heritability estimates	Height	DBH
Narrow-sense individual heritability	0.17	0.13
Broad-sense individual heritability	0.27	0.21
Half-sib family mean heritability	0.73	0.68
Full-sib family mean heritability	0.84	0.78
Within full-sib family heritability	0.09	0.10

selection breeding. These tests have better genetic balance, test management and growth rate than first generation progeny tests. The EDMS included several test series (four tests over a two year period in two locations) in each of seven Cooperative test areas. All tests were measured for annual tree height, DBH and stem straightness starting at age four, and rust infection was assessed in tests with sufficient rust infection levels. Data from 15 test series with six-year data (eight of which have seven-year data) are being analyzed to provide more accurate information for optimizing the selection and breeding strategies for the Cooperative's third-cycle breeding program.

Preliminary results from these tests confirmed that the additive genetic variance was more important for height and diameter growth than the dominance genetic variance, but the relative proportion changed over time (Figures 4 & 5). The additive variance increased with age for both height and DBH. The dominance variance increased rapidly before age five and then leveled off. The trend was surprisingly similar between height and DBH. The ratios of dominance to additive genetic variance were relatively high at early ages (0.78 and 0.88 at age five for height and DBH, respectively) but decreased thereafter. This indicated that the dominance variance was relatively more important at early ages but the additive genetic variance becomes increasingly more important after age five, which confirmed previous results from the NCSU-International Paper Heritability Study.

Heritability estimates for height, DBH, rust infection and stem straightness generally increased over time for the measurement period from age one to age

The EDMS trial established by Tenneco Packaging exhibits good growth on a very uniform site. These tests, measured annually through age 8, are providing a most valuable data base.

seven (Table 2). However, this was based on a few young tests, and only 8 of 15 test series had seven-year data. The true time trend will be determined with more EDMS tests and with later age measurement data.

Family means based on early height measurements were strongly correlated with later heights as shown for the two test series with eight-year data (Figure 6). The age-age correlation increased significantly in the first three years and then leveled off after age four. This indicated that family height performance at age four was a good indicator of family performance at age eight (r=0.90). The high correlation and the general time trend of heritability suggest that the optimum selection age could be earlier than the age six recommended from the first generation data analysis. Further analyses will incorporate economic parameters to determine the optimum selection age.

The genetic correlations estimated from the EDMS tests showed a strong but not perfect correlation between height and DBH (Table 3). All other correlations were very weak and thus can be considered as independent traits. This suggests that both growth rate and quality traits can be improved simultaneously through selection

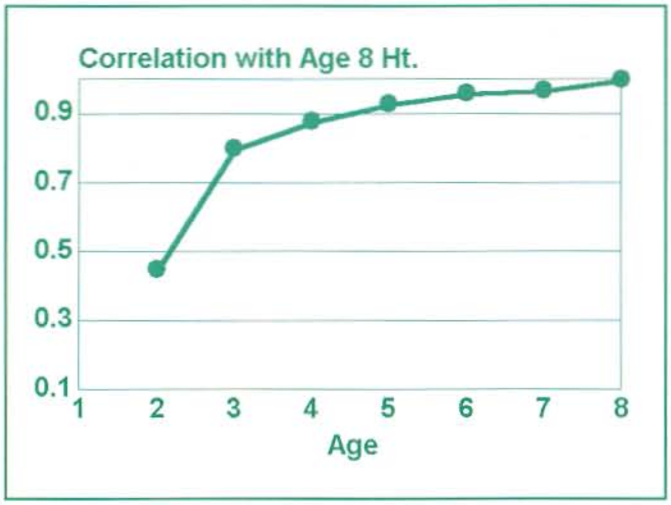


Figure 6. Age-age correlations for early height with eight-year height.

Table 3. Genetic correlations among traits at age six for several EDMS tests

	DBH	Rust	Straightness
Height	0.79	-0.27	0.27
DBH		-0.13	0.41
Rust%			0.16

Table 2. Estimates for narrow-sense individual-tree heritabilities for height and DBH and half-sib family mean heritabilities for rust infection and stem straightness.

	Individual-tree narrow-sense heritability		Half-sib family mean narrow-sense heritability	
Age	Height	DBH	Rust%	Straightness
1	0.14	-	-	-
2	0.11	-	0.39	-
3	0.14	-	0.12	0.80
4	0.16	0.12	0.51	0.86
5	0.17	0.12	0.57	0.80
6	0.17	0.15	0.73	0.81
7*	0.22	0.19	0.78	0.80

** only 8 test series had 7-year data*

and breeding. Based on additional estimates of variance and covariance components from other diallel tests, a selection index will be developed to improve rotation volume by assessments of early height, DBH, rust and straightness.

Age Trends for Genetic Parameters of Some Loblolly Pine Wood Density Traits[1].

To undertake this project, a direct scanning x-ray densitometer was assembled in a temperature-humidity control room associated with the Cooperative's Laboratory. A direct-scanning densitometer measures the attenuation of an x-ray beam as it passes through a wood sample. Calibration is required to convert raw results to density estimates for the material scanned.

Calibration studies were undertaken to establish whether x-ray attenuation characteristics changed over the range of densities likely to be encountered in different ages of loblolly pine. If high density mature wood produced a significantly different result than low density juvenile wood, then specific calibration relationships would need to be developed to convert x-ray results to gravimetric density for different ages or density classes of loblolly pine. The studies used radial increment core samples from trees covering a large age range, 7 - 55 years, and selected trees from known high density families.

The calibration relationships developed were close to identical using samples which were juvenile wood or mature wood, as well as for mixtures of juvenile, intermediate and mature wood samples. Consequently, future recalibration of the x-ray densitometer can be somewhat simplified for studies within the normal range of loblolly pine material likely to be investigated in tree improvement projects. Comparable results can be achieved between studies, independent of the age or density of the material used.

To make informed decisions on selection age(s) chosen to minimize the length of breeding cycles, and to optimize potential genetic gains and financial returns from a breeding program, tree breeders should ideally have knowledge of:

(a) the significance of age trends for genetic variation,

(b) the extent of juvenile/mature genotypic and phenotypic correlations among the economically important trait(s) of interest.

Reliable estimates of the genetic parameters needed to address each of these concerns require mature progeny trials which are well designed and maintained. This study was possible due to the availability of such a loblolly pine genetic trial planted in 1963-65 near Bainbridge, Georgia by the personnel of the Southlands Experiment Forest of International Paper Company and the North Carolina State University - Industry Cooperative Tree Improvement Program.

Age trends in genetic parameters of loblolly pine wood density traits were investigated using the direct scanning x-ray densitometer to assess 180 control-pollinated families from the Heritability Study from which wood samples were collected in 1992. Individual tree narrow-sense heritability estimates and genetic and phenotypic correlations for individual growth rings, core

[1]Excerpt from Ph. D. Thesis of Kevin J. Harding, Wood Quality Improvement Lab., Timber Research, Queensland, Australia. Thesis research under the direction of J.B. Jett and Robert J. Weir

segment means and whole core means were estimated (Table 4). Traits assessed included mean growth ring densities and the mean density of the earlywood (readings <480 kg/m3) and latewood (readings >480 kg/m3) within each growth ring.

Heritability estimates peaked for average growth ring density at growth ring 12 with a heritability estimate of 0.56 ± .07 (Figure 7) and for the core segment spanning rings 11-15 ($h^2 = 0.68 \pm .08$, Table 4). These compared to $h^2 = 0.75 \pm .08$ (Table 4) for the whole core weighted average density. Genetic correlations between mean density of individual growth rings 4, 5, 6 and 8 and mature wood density (assessed as weighted mean density of rings 15-20) and whole core density traits ranged from 0.73 ± .23 to 0.91 ± .14 (Table 5) and were therefore

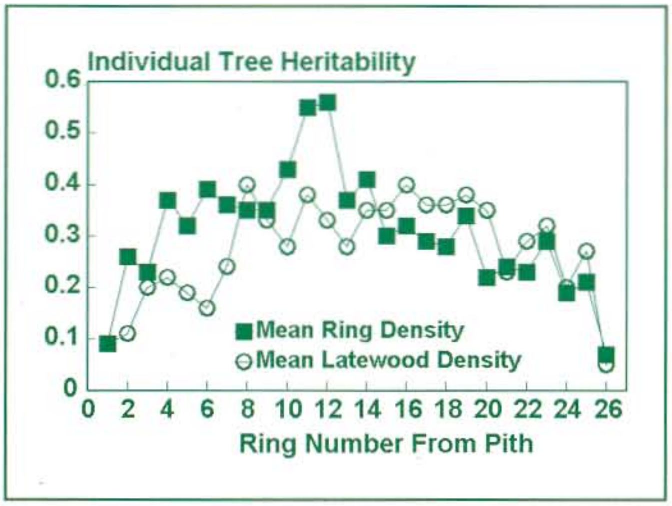


Figure 7. Heritability estimates for average growth ring densities and latewood densities.

Table 4. Individual tree narrow-sense heritability estimates for individual ring, core segment and whole core wood traits.

Trait	Growth Ring Segments	Narrow Sense Heritability	Estimated Additive Variance	Phenotypic Variance
DENSITY	1-5	0.39	399.96	1026.44
	6-10	0.55	963.12	1738.08
	11-15	0.68	1291.40	1911.51
	16-20	0.46	981.48	2127.80
	21-25	0.37	1017.48	2736.12
	3-5	0.15	252.84	1733.80
	15-20	0.33	1707.96	5157.56
	Whole Core	0.75	1078.68	1429.89
	Latewood	0.71	803.16	1134.08
	Earlywood	0.42	127.08	306.16
	Mean Max.	0.67	1011.93	1517.52
	Mean Min.	0.44	157.24	356.55
MEAN LATEWOOD %	3-5	0.21	108.84	522.09
	6-10	0.36	614.00	1685.04
	1-10	0.31	1251.84	4002.23
	11-15	0.26	1225.32	4641.18
	11=20	0.30	3147.32	8820.00
	21-27	0.15	1445.28	9365.34
	Whole Core	0.46	14.28	31.10

generally strong. However, consistently stronger correlations were found for the growth rings 3-5 weighted mean density and mature wood and whole core densities for density traits (>0.84 ± .19). Some moderately negative genetic correlations between density and radial increment were found in the juvenile wood (< 10 years) but these were non-existent for correlations between juvenile density and either complete juvenile (growth rings 1-10) or mature wood (growth rings 11-20) radial increments. These results suggest that early selection for density in loblolly pine would be effective in increasing dry wood weight yields, particularly of mature wood. However, further work to combine the wealth of data available from densitometer studies of wood variation to volume models would greatly enhance the value of gain estimates by balancing the demands for improved growth and density in a breeding program.

Work is continuing to establish the most efficient parameters to use to predict transition age from juvenile to mature wood production and to then investigate the heritability of this transition age. This will enable us to critically evaluate the potential of improving wood uniformity by breeding for a lower juvenile-mature transition age. Breeding to reduce the differential between mean juvenile and mean mature wood densities, or within growth ring density extremes, can also be investigated as a potential avenue for improving overall within-tree wood uniformity.

Table 5. Genotypic correlation estimates among individual growth ring and growth ring segment mean densities and whole core traits and core segment lengths.

Growth Ring or Segment Density[a]	Average Density (kg/m³)		Whole Core Density (kg/m³)[b] (Growth rings 1-25, 1-26 or 1-27)			Whole Core Mean Latewood %	Core Segment Length (mm) Growth Rings		
	(Growth Rings 11-15)	(Growth Rings 15-20)	Core Mean	Latewood Mean	Earlywood Mean		6-10	1-10	11-20
4	0.84	0.73	0.86	0.62	0.82	0.85	-0.07	0.45	0.04
5	0.87	0.89	0.90	0.75	0.71	0.93	-0.71	-0.63	0.13
6	0.83	0.84	0.86	0.60	0.85	0.93	-1.12	-0.94	-0.03
8	1.01	0.91	1.01	0.80	0.86	1.02	-0.68	-0.69	-0.01
1-5	0.78	0.80	0.82	0.73	0.69	0.77	-0.47	0.08	0.08
3-5 Juvenile	0.91	1.05	0.97	0.95	0.61	0.88	-0.87	0.26	0.05
6-10	0.96	0.99	0.98	0.80	0.80	0.95	-0.70	-0.42	0.15

[a] Segment mean densities proportionately weighted by growth ring basal area.
[b] Core mean density proportionately weighted by growth ring basal area.
Latewood density and earlywood density means (> or < 480 kg/m3 respectively) proportionately weighted by growth ring basal area.

Use of Resistance Screening Center for Rust Evaluations

The Resistance Screening Center, located at the Bent Creek Experimental Forest near Asheville, NC, is operated by the Forest Health Staff of the USDA Forest Service's Southern Region, State and Private Forestry. The Screening Center evaluates loblolly seedlings for resistance to fusiform rust. Benefits of utilizing the Screening Center for rust evaluations include:

- Reduced Evaluation Time

  Field tests generally require 4+ years to develop infection levels high enough for a meaningful evaluation. The Screening Center process takes about seven months.

- Availability of Rust Evaluations for All Parents

  Field tests need a minimum of twenty percent infection to provide an evaluation of a parent's rust resistance. Many field tests never have infection levels high enough to obtain an evaluation.

- Optimizing Site Selection for Evaluation of Other Traits of Interest

  To increase the likelihood of obtaining rust infection levels high enough to ensure a meaningful evaluation for rust resistance, progeny tests are often planted on high hazard sites. The use of high hazard sites can, however, reduce the precision of genetic evaluations for other traits of interest (i.e., growth, form). Use of the Screening Center allows site selection to be optimized for evaluation of other traits.

Seedlings inoculated with fusiform rust are grown for several months to allow symptoms of infection to develop. Family plots are scored for rust infection at five months of age.

Three trials, consisting of three diallel test series, were processed at the Screening Center to provide a database for determining the reliability of Screening Center evaluations. The three test series used were:

- Series 121 (MacMillan Bloedel).
  Field tests established in 1988-89 in Wilcox Co, Alabama.

- Series 102 (Mead Corporation).
  Field tests were established in 1988-89 in Dooly County and Sumter County, Georgia.

- Series 157 (MacMillan Bloedel)
  Field tests were established in Wilcox County, Alabama in 1989-90.

Infection levels in the field tests ranged from 30 to 60 percent.

Two complete Screening Center tests were processed for each test series -- one at an inoculum level of 50,000 spores/ml and one at an inoculum level of 20,000 spores/ml. Each test consisted of 120 seedlings per seedlot. Traits assessed included:

- Percent galled seedlings at 3, 5 and 7 months. (The five month assessment was not made on Series 121)

- Percent smooth galls at 5 and 7 months

- Percent fat galls at 5 and 7 months.

Results showed that the Screening Center assessments were extremely repeatable, even when comparing tests at different inoculum levels. Family mean correlations from test to test at the Screening Center ranged from .87 (Series 121) to .95 (Series 157). Correlations from field test to field test within these three series ranged from .54 to .91. Family mean correlations (Table 6) between Screening Center tests and field tests showed little difference in: (1) Standard inoculum and reduced inoculum tests, (2) percent galled assessments at 3, 5 and 7 months, and (3) assessments based on a three trait (percent galled, percent fat galls,

Table 6. Family Mean Correlations Screening Center to Field

	Series 121	Series 102	Series 157
Standard Inoculum			
% Galled-3 Mo.	.68	.68	.71
% Galled-5 Mo.		.69	.69
% Galled-7 Mo.	.58	.72	.71
Index-5 Mo.		.70	.72
Index-7 mo.	.65	.72	.73
Reduced Inoculum			
% Galled-3 Mo.	.65	.64	.72
% Galled-5 Mo.		.70	.68
% Galled-7 Mo.	.55	.70	.70
Index-5 Mo.		.65	.69
Index-7 Mo.	.65	.70	.70

INDEX = 176 - 104(% Galled) - 44.4(% Smooth Galls) - 26.1(% Fat Galls) percent smooth galls) index value and assessments based on the single trait, percent galled. Based on these results, the Screening Center has adopted as standard procedure, use of an inoculum level of 20,000 sp/ml and assessment of the single trait, percent galled, at 5 months.

Potential uses of the Screening Center by the Cooperative include:

- Screening good growing parents for rust resistance to aid selection for seed orchard and/or rust resistant populations.

- Screening parents in current orchards to obtain rust information for use in roguing.

- Screening specific crosses being considered for use in supplemental mass pollinations or vegetative propagation programs for rust resistance.

Slash Pine Rooting Improved from Genetic Culling of Families and Individuals

The Loblolly and Slash Pine Rooted Cutting Project has, during the past four years, been developing information that is intended to improve the success and cost effectiveness of rooted cutting technology. The project has worked on a wide array of research topics, e.g. stock plant physiology, optimizing the rooting environment, root system morphology, process control of root initiation and tree maturation, and genetic influence on rooting percent. Success of this project will provide a technology that can lead to capturing more genetic gain.

Genetic variation for rooting percent has been demonstrated for several tree species so it followed that a strategy of culling poor rooting families and poor rooting individuals within family could increase overall rooting percent. What was not well known for loblolly or slash pines was how much improvement in rooting was possible from genetic culling, and if culling would adversely impact opportunities for capturing gain in other economically important traits such as growth rate and/or rust resistance.

Studies were initiated in 1992 using 38 slash pine open-pollinated families. These families have been extensively field tested by the University of Florida Cooperative Forest Genetics Research Program and their breeding values (BV's) encompassed the full range of good to poor for volume and rust infection. Percent rooting data for these 38 slash pine families were averaged over two studies established in the winter of 1994 and the summer of 1995, respectively. The overall average rooting of these families was 51% and the half-sib family means ranged from a low of 9 % rooting to a high of 82 %.

The family means for rooting percentage are not correlated with breeding values for volume or rust infection (Figures 8 and 9). While greatest value improvement can be achieved with traits that are positively correlated, the zero or nonexistent correlations will allow for simultaneous selection of these three traits. The amount of improvement possible was estimated by selecting eight families that had high breeding values for volume and rust and were good rooters. The selection differential for the group of eight families with respect to rooting percent was 15% (66% minus 51%, the overall mean). The family mean heritability for rooting percent was estimated to be .69. The predicted response to culling 38 families to eight is determined by the product of the family mean heritability and the selection differential or in this case .69 x 15% = 10.3%. The opportunity exists to achieve even greater gains in rooting percent by selecting the best rooting individuals within the best rooting families. The variation among individuals within each of these eight families for rooting percent was enormous (Figure 10). Rooting only the best 1 to 3 individuals within each of these eight families could increase the rooting percent by 38%. This is an upper limit (or over estimate) of the gain that is possible. It should be adjusted by the appropriate heritability estimates for family and within family selection, since not all of the differences in rooting are the result of gene action.

An additional within family rooting study was conducted that included seedling hedges from four good rooting families and two poor rooting families. A

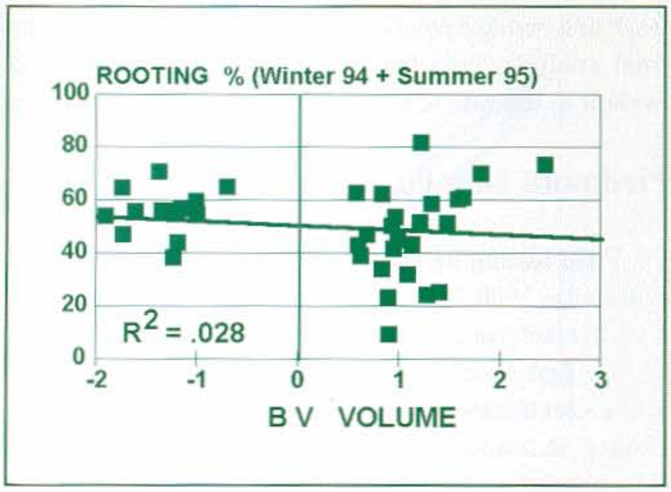


Figure 8. Relationship of rooting percentage and breeding values for volume.

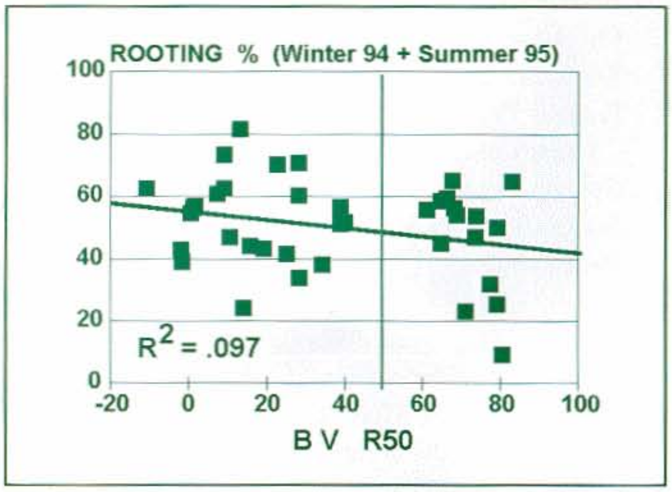


Figure 9. Relationship of rooting percentage and breeding values for rust.

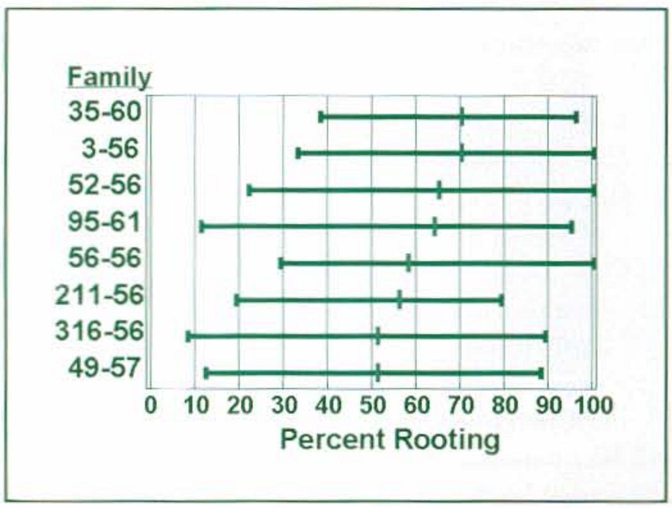


Figure 10. Within family variation for rooting percent for eight good rooting families.

total of 15 seedling hedges were rooted from each of the six open-pollinated families. It was interesting to note that the best three rooting individuals within the two otherwise poor rooting families rooted at an acceptable or near acceptable rate (50 + %) with the best rooting equal to 79%. If a genetically superior family for growth, rust, etc. turns out to be a poor rooter in general, it appears that some individuals within that family might root well enough to be chosen for a propagation program. Plans are developing to repeat this work for loblolly pine in the next several years.

Phenological Variation in Height Growth in Provenances and Families of Loblolly Pine and Its Effect on Transition to Latewood

In this study, conducted by Keith Jayawickrama and supported by Georgia-Pacific, growth phenology of five- and six-year old trees (from eight open-pollinated families from each of four different provenances) was studied in 1993 and 1994. Provenances did not vary as to when height growth started in spring, but there were very significant differences for the date of cessation of growth in fall. The fast-growing Gulf Hammock provenance had the longest growth period (till the end of August) while the slowest growing Upper Gulf source was first to stop height growth (early August). Provenances were also different for the date of cessation of diameter growth, and the order of cessation was the same as for height. The order in which provenances ceased growth was consistent in the two years. Families within provenances were different for date of cessation for both height and diameter growth. There was some indication that faster growth was associated with longer growing seasons even for families within provenances.

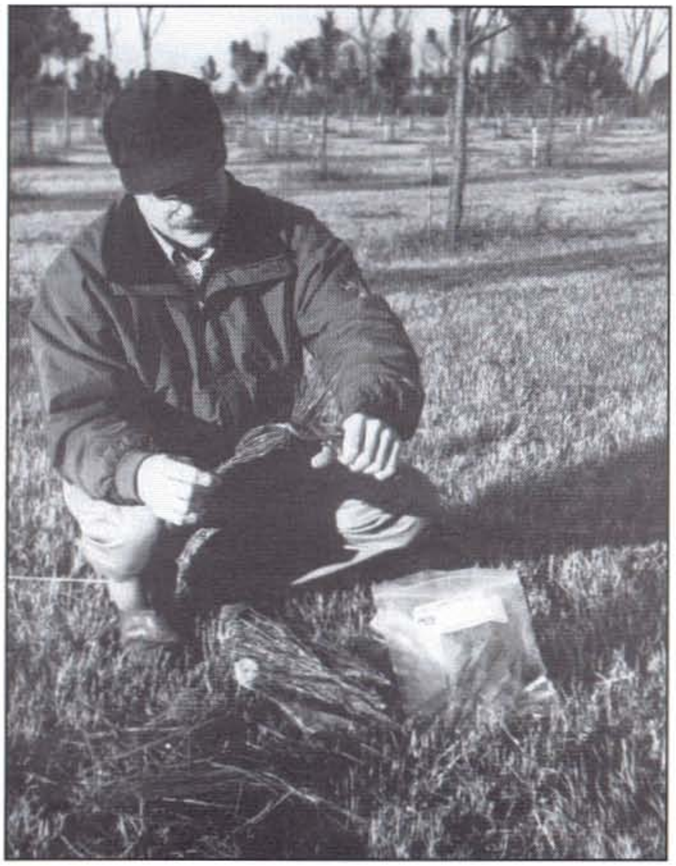
Evaluation of transition to latewood is almost complete. Preliminary results are that the response was different in the two years. There was earlier transition to latewood, and very significant differences between provenances, in 1994 (a wet year). The fast growing Gulf Hammock source was the last to undergo transition and the slow growing Upper Gulf the first. Provenances were not significantly different in 1993.

BREEDING, TESTING, SELECTION

Status of Diallel Breeding and Testing

All eight regions have completed the breeding for both the plantation and second generation populations. The final diallel tests were established in the spring of 1996. Four regions will establish open-pollinated tests of the remaining unbred and/ or untested clones this fall.

Figures 11-16 show, by testing area, the percentage of the population for which third generation selections will be available through the year 2003. Fifty percent of third generation selections will be available for breeding work and orchard establishment in 1999 or 2000. In the final analysis, very little difference among regions is evident in the rate of test establishment over time.



As third-cycle selections are made, they are immediately grafted into the breeding orchards of at least three Cooperative members. Tom Greene of Mead Coated Board prepares newly collected scions for shipment.

Piedmont Elite Population (PEP)

Field testing for the Piedmont Elite Population was initiated in 1996. Seeds from the pollen mix breeding and from the factorials are being sown in the summer and fall for the first field tests to be established in 1997. Five years after the Piedmont Elite Population was proposed, testing is underway. Credit goes to the following Cooperators who worked diligently to get the breeding completed as quickly as possible:

Bowater, Inc.
Champion International Corp.
Evergreen Timberlands Corp.
Federal Paper Board Company (now International Paper Company)
Georgia-Pacific Corp.
International Paper Company
Westvaco Corp.

The Piedmont Elite Population is based on the production of hybrids between 2.5-generation clones from the Piedmont and the Atlantic Coastal provenances. The goal is to combine the better growth of the coastal trees with the superior form and cold tolerance of the Piedmont clones. To test the performance of the hybrids, pollen mix crosses between the two provenances will be tested across a range of sites. Four tests will be planted in each of the following four physiographic regions:

Lower Piedmont or Fall Line
Middle Piedmont
Upper Piedmont at or just beyond the natural range of loblolly pine
Cold Areas - beyond the natural range of loblolly pine but where Piedmont loblolly pine is operationally deployed.

Plots designed to provide growth and yield estimates will be established for each of the four provenance x pollen mix combinations so that adaptability can be assessed through rotation.

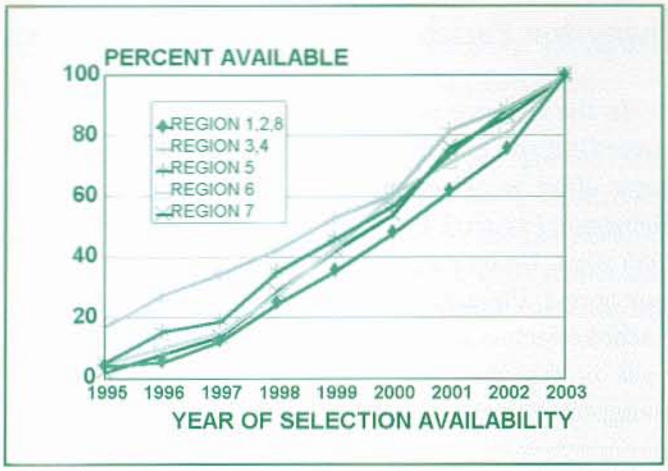


Figure 11. Percent of population with test establishment completed by region.

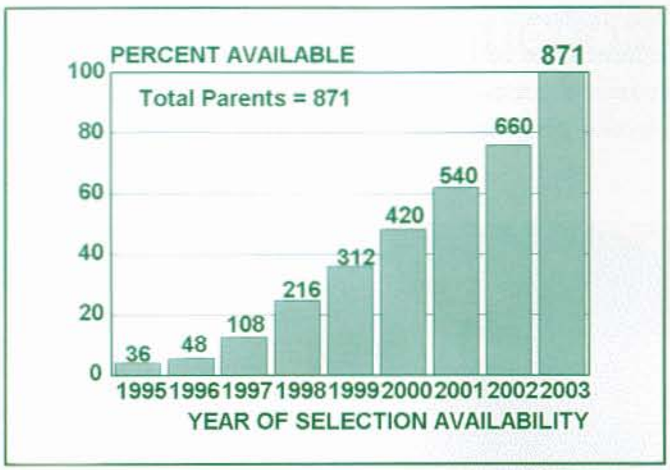


Figure 12. Percent of population with third generation selections available for regions 1, 2, and 8 combined.

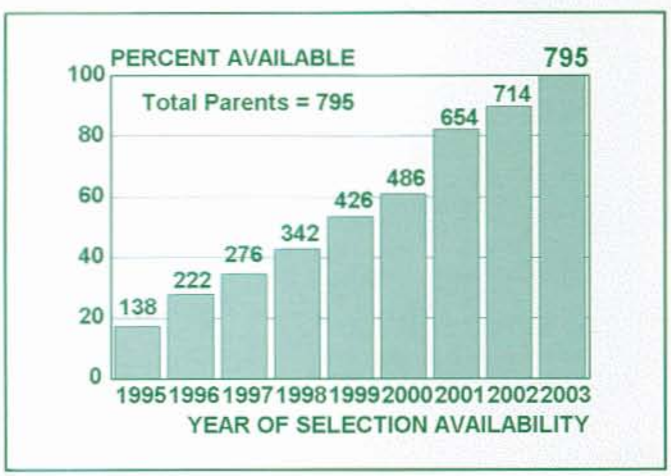


Figure 13. Percent of population with third generation selections available for regions 3 and 4 combined.

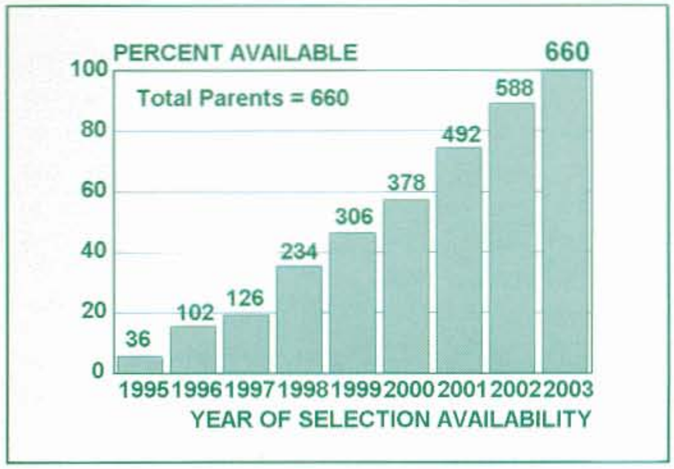


Figure 14. Percent of population with third generation selections available for region 5.

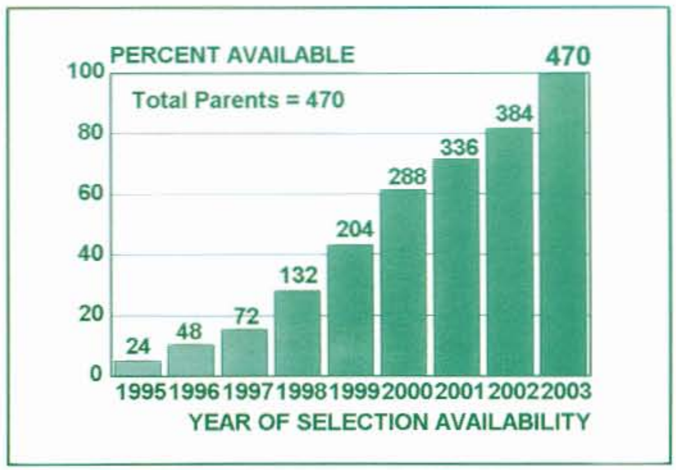


Figure 15. Percent of population with third generation selections available for region 6.

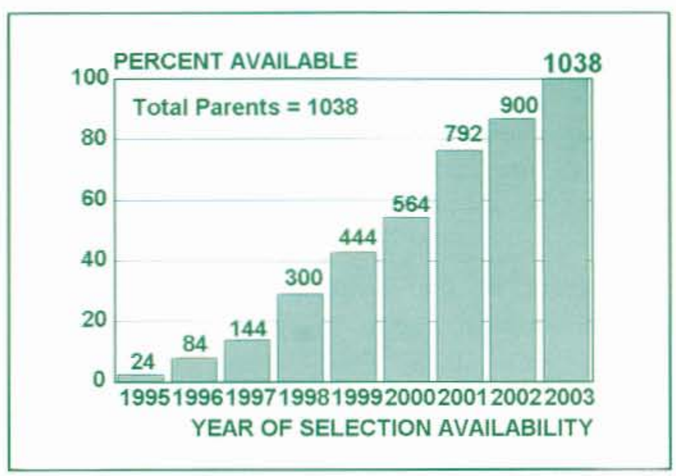


Figure 16. Percent of population with third generation selections available for region 7.

Full-sib families from factorials of Piedmont x coastal clones will also be tested across a range of sites. The original intent was to establish the full-sib families only in block plots for within family selection, but an increased interest in deployment of full-sibs has necessitated the establishment of replicated tests to determine full-sib performance. The full-sib tests will be planted in 1997 and 1998.

Breeding of the 27 Piedmont x coastal hybrids (Population I) has progressed well. The pollen mix and diallel breeding should be completed by 1997 or 1998. Bowater has done most of this breeding in their greenhouse with help from Champion.

Lower Gulf Elite Population

Progress in breeding for the Lower Gulf Elite Population was significantly impacted this spring by the extreme cold (15-20°F) in early March. Breeding orchards along the Gulf Coast and South Atlantic Coast had most of the female strobili frozen. Few cooperators were able to start any of the eight-tree diallel breeding or wrap up the pollen mix (PMX) breeding started in 1995.

Fortunately, pollen mix breeding from 1995 appears to have been very successful. Conelet counts were sufficient to consider the breeding of many selections complete. Pollen mix crossing will be necessary next spring to finish the few remaining parents. Plans were underway to start breeding six eight-tree diallels this spring. Each diallel will consist of:

4 clones from the South Atlantic Coastal Plain
3 clones from Florida
1 clone from Livingston Parish, LA or Southeast Texas

Members of the Cooperative Forest Genetics Research Program at the University of Florida are providing most of the Florida loblolly clones, and members of the Western Gulf Forest Tree Improvement Program are providing the Livingston Parish and Texas loblolly. Members of all three cooperatives will have access to clones selected from tests established in the Lower Gulf Elite Population.

Livingston Parish, LA Plantation Selections

In the summer and fall of 1995, cooperators in the Lower Gulf and South Atlantic Coastal Plain launched a major effort to select superior trees from unimproved Livingston Parish (LP) plantations. This effort began in 1985 when Union Camp made 62 selections over a four year period. Plantations of other Cooperators have now reached selection age allowing another 85 selections to be made in the past year. There is now a total of 154 Livingston Parish selections in the Cooperative.

The potential growth and rust resistance superiority of the Livingston Parish provenance has long been recognized. Many organizations used this seed source in their regeneration programs in the 1970's and 1980's. Regeneration with this seed source to date has, for many organizations, consisted of unimproved LP families. The selection program undertaken during the past year will

An outstanding Livingston Parish source plantation selection is being graded by Chris Hunt on lands of Georgia Pacific Corporation.

facilitate establishment of an improved Livingston Parish breeding population within the Cooperative .

All 85 of the new selections were grafted into breeding orchards this winter and are being intensively managed to stimulate female strobili as soon as possible. Several Cooperators have attempted to graft scions into the tops of mature orchard trees to stimulate flowering quickly (e.g., Bramlett and Burris, 1995 SFTIC paper). Pollen mix testing has begun with the Union Camp LP selections. The remaining clones will be tested as quickly as possible. When data from the pollen mix tests are available, the best clones will be identified for inclusion in the local advanced generation breeding program. Formation of a distinct Livingston Parish elite population is an option as well.

SEED ORCHARD PRODUCTION

CONE AND SEED YIELDS

The 1995 Cooperative loblolly pine seed collection was the largest in four years, nearly doubling the 1994 collection. Yields were 1.57 lbs./bushel, the third highest in Cooperative history. The total collection cooperative-wide produced 32 tons of seed, 9.4 from Piedmont sources and 22.5 from coastal sources. Over three tons of the Piedmont seed were collected from second generation orchards, representing 33% of the total Piedmont collection. Of the coastal seed collected, over 11 tons were from second generation orchards, representing 50% of the coastal collections. Overall, collection from second generation orchards accounted for 45% of the total crop (Figure 17).

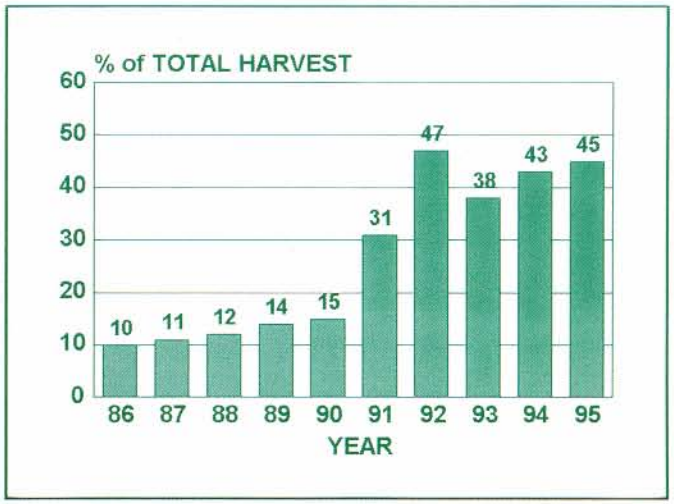


Figure 17. Percent of total seed harvest produced in second generation orchards.

As in previous years, many orchards were reported as "no collections". Collections from other orchards were highly selective, with only the best 6-10 clones being harvested. Several clones produced in excess of 2.0 lbs/bushel; 10-5 was reported at 2.74 and 2.55 lbs/bushel from two different members. The highest single clone production was reported from a Champion orchard in SC; clone 8-120 produced 3.57 lbs/bushel which is a new record. The six clones harvested from this orchard averaged 2.95 lbs/bushel, an orchard record. The six clones ranged from a low of 2.49 lbs./bushel to a high of 3.57 lbs./bushel.

Champion International's orchard management and seed extraction efficiency made them the leaders for seed production in 1995. Table 7 shows the top ten Cooperative orchards for seed production efficiency. In the top ten are five Champion orchards, three Westvaco orchards, one Georgia-Pacific orchard, and one Jefferson Smurfit orchard. The top production efficiency orchard for 1995 was Champion's 1.5 Alabama loblolly orchard located in Newberry, SC and managed by George Oxner. These orchard managers are to be congratulated on their outstanding orchard management.

In this the 40th year of continuous operation for the N.C. State University - Industry Cooperative Tree Improvement Program, it is informative to reflect on past seed production and reforestation accomplishments, a history lesson if you will (Table 8). Meaningful commercial quantities of genetically improved seed were first produced by Cooperative members in 1969, 13 years following the programs inception. It took that long for selections to be made, orchards to be grafted and for early seed crops to be produced. Total harvest of genetically improved seed in the first five years of orchard production was sufficient to plant only 500,000 acres of loblolly pine. Cooperative Program seed orchards have produced enough seed in the most recent five years to regenerate 4 million acres, and of those, 1.6 million acres were planted with second-generation seed orchard seedlings.

The seed orchards owned and managed by Cooperative members have produced enough genetically improved seed in the past 27 years to establish 21.3 million acres of loblolly plantations. As the earliest genetically improved loblolly plantations reach harvest age, 40 years of long term research and development investments are beginning to pay off. The impact of tree improvement on the cash flow and the profitability of forestry investments will be substantial in the years ahead.

Table 7. Top Ten Orchards in Production Efficiency for the 1995 Cone Crop

Organization	Orchard Type	Age	Lbs./Bushel	No. of Clones	Orchard Manager
Champion, NC	1.5 Alabama	20	2.95	6	George Oxner
Westvaco, SC	1.0 Coastal	28	2.48	6	Dave Gerwig
Champion, SC	1.0 Piedmont	29	2.24	10	George Oxner
Champion, SC	Rust Resistant	26	2.24	5	George Oxner
Champion, Fl	1.5 Coastal	18	2.23	19	Homer Gresham
Champion, NC	1.0 Coastal	33	2.22	4	George Brantley
Westvaco, SC	Central 1.0	24	2.07	6	Dave Gerwig
Georgia Pacific	2.0 Coastal	13	1.95	10	Paul Belonger
Westvaco, SC	2.0 Coastal	21	1.95	9	Dave Gerwig
Jefferson Smurfit	1.5 Coastal	20	1.91	5	Fred Raley

Table 8. Seed Yields from N.C. State University-Industry Cooperative Tree Improvement Program

Harvest Year	Bushels of Cones	Tons of Seed	Lbs./Bushel	Millions of Seedlings	Millions of Acres Regenerated
1969	1,769	1.0	1.13	18	0.03
1970	5,146	3.5	1.36	63	0.10
1971	6,478	3.7	1.14	67	0.10
1972	6,807	3.3	0.97	59	0.09
1973	11,853	6.5	1.10	117	0.18
1974	8,816	4.4	1.00	79	0.12
1975	16,348	10.7	1.31	193	0.30
1976	14,656	8.9	1.21	160	0.25
1977	32,152	24.8	1.54	446	0.69
1978	37,977	23.5	1.24	423	0.65
1979	38,693	27.7	1.43	499	0.77
1980	15,296	7.9	1.03	142	0.22
1981	64,811	50.5	1.56	909	1.40
1982	44,761	30.5	1.36	549	0.84
1983	68,447	49.0	1.43	882	1.36
1984	105,239	80.1	1.52	1442	2.22
1985	52,155	37.8	1.45	680	1.05
1986	84,953	70.1	1.65	1262	1.94
1987	112,822	93.3	1.65	1679	2.58
1988	56,822	42.7	1.50	769	1.18
1989	23,247	16.1	1.39	290	0.45
1990	50,944	30.4	1.19	547	0.84
1991	55,555	38.8	1.40	698	1.07
1992	44,547	31.5	1.42	567	0.87
1993	35,387	23.5	1.33	423	0.65
1994	25,529	15.6	1.22	281	0.43
1995	40,250	31.9	1.57	574	0.88
Totals	**1, 061,460**	**767.65**		**13,818**	**21.26**

ASSOCIATED ACTIVITIES

Graduate Student Research and Education

The education of graduate students and the research they conduct as part of their degree program continues as an important activity of the Cooperative. During the past year, five graduate students have been working in association with the Tree Improvement Cooperative. The efforts of two students were directed toward a Masters degree and three were involved with Ph.D. programs of study. During the year two students, Kevin Harding and Jan Svenson, completed their degree requirements.

Student research projects encompass a broad range of topics related to the Tree Improvement Program. Financial support for students comes from a variety of sources, the Tree Improvement Cooperative, the College of Forest Resources - Department of Forestry, special project funding by industry, fellowship programs, competitive grants, and foreign governments.

During the past year we aggressively advertised available opportunities for graduate research studies in forest genetics and tree improvement at N. C. State University. We were pleased to receive applications from several outstanding prospective graduate students. As this report was being written, four had accepted

STUDENT, DEGREE RESEARCH PROJECT

Paul Belonger, M.S.
Provenance and family variation in specific gravity and tracheids of loblolly pine.

Kevin Harding, Ph.D.
Age trends in genetic parameters for wood properties of loblolly pine.

Keith Jayawickrama, Ph.D.
Phenological variation in shoot elongation and diameter growth and their relationships to latewood formation and wood specific gravity in loblolly pine.

John Mann, M.S.
The influence of water and nutrient availability on the transition from earlywood to latewood.

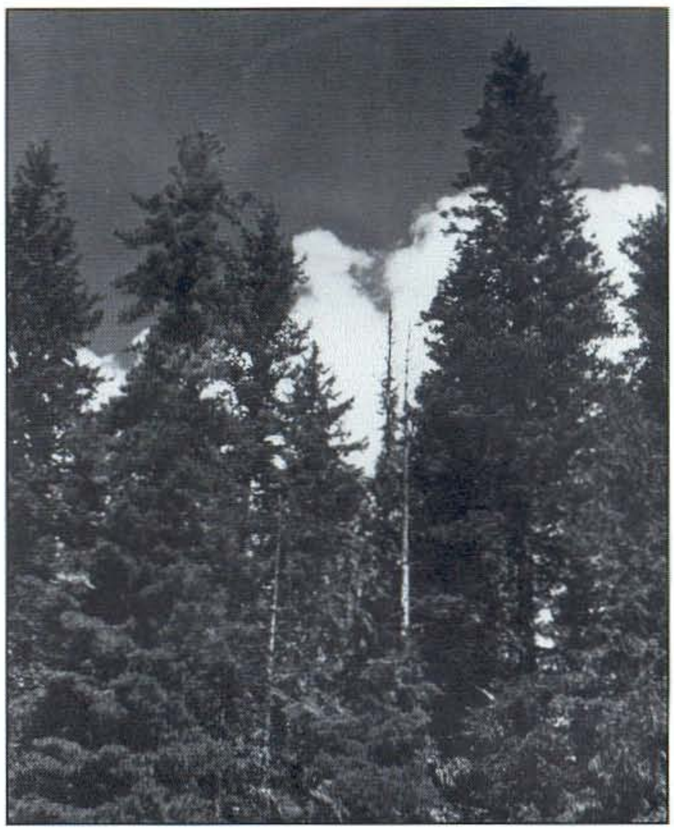
Jan Svenson, Ph.D.
Ecophysiological bases for genetic differences in growth of loblolly pine stands. (Joint Project with Forest Nutrition Coop.)

assistantship offers and three were awarded competitive departmental assistantships.

Our successful graduate education program is an accomplishment for which we are proud, and one for which the Cooperative membership deserves much credit. Members of the Cooperative have routinely contributed to graduate student research projects by contributing land, equipment, and manpower resources for the conduct of research. We wish to recognize these contributions, for without it, our graduate research and education program would not be nearly as successful.

PROGRAM STAFF

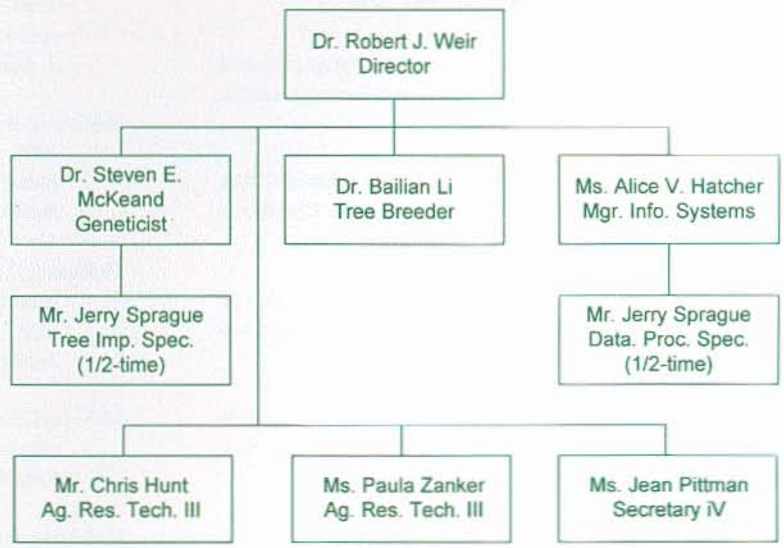
We are pleased to welcome a new addition to our Cooperative Program staff. Dr. Bailian Li began work as Tree Breeding Scientist and Assistant Professor in January of this year. Bailian, a native of the Peoples Republic of China, came to this country in 1983. He completed his Master of Science and Ph.D. at N.C. State University, worked for one year as a tree breeder/genetic analyst in the southern research division of a forest products firm and has, for the most recent five years, served as Director of the University of Minnesota Aspen/Larch Genetics Cooperative. We are fortunate to have Bailian join our team. He is a capable and experienced research scientist with extensive experience working in an industry sponsored genetics R & D program. His work to date involves analysis of the Cooperative's genetic data base. The information Bailian is developing will lead to improved selection, breeding and testing systems and will eventually provide a basis for developing improved strategies for capturing more genetic gain. Welcome Bailian! We are delighted to have you with us!



Plans are developing for The Cooperative's Annual Contact Meeting to be held in New Brunswick, Canada in August. Studying the tree improvement methods used for spruce, larch and northern pine species promises to be informative.

We also wish to note that Paula Otto was married to Alan Zanker in April and is now properly listed in the organizational chart of the Cooperative as Paula Zanker. Congratulations to Paula and Alan! We wish you much happiness. Paula's outstanding contribution to the Cooperative Tree Improvement Program was also recognized in December when she was promoted to Agricultural Research Technician III. Paula earned this recognition for her capable contribution to The Tree Improvement Program.

Cooperative Tree Improvement Program
Organizational Chart - May, 1996



MEMBERSHIP OF THE TREE IMPROVEMENT COOPERATIVE

Alabama Forestry Commission
Bowater, Inc.
Champion International Corp.
Chesapeake Forest Products
Federal Paper Board Company
Georgia Forestry Commission
Georgia-Pacific Corp.
International Paper Company
James River Corp.
Jefferson Smurfit Corp.
Kimberly Clark Corp.
MacMillan Bloedel, Inc.
Mead Coated Board
N. C. Division of Forest Resources
Rayonier, Inc.
Scott Paper Company
S.C. Commission of Forestry
Tenneco Packaging Corp.
Union Camp Corp.
Virginia Department of Forestry
Westvaco Corp.

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS OF THE COOPERATIVE

Arnold, R.J., F.E. Bridgwater, and J.B. Jett. 1994. Single- and multiple-trait index selection efficiencies in Fraser fir Christmas trees. Can. J. For. Res. 24:1487-1494.

Arnold, R.J. and J.B. Jett. 1995. Seed source variation for growth and quality traits of Fraser fir Christmas trees; rotation age results. So. J. Appl. For. 19:157-167.

Arnold, R.J., J.B. Jett and W.T. Huxster. 1995. Relationship of USDA grades to wholesale and retail values of Fraser fir Christmas trees. HortScience 30(2):369-373.

Arnold, R.J., J.B. Jett and S.E. McKeand. 1994. Natural variation in genetic parameters in Fraser fir for growth and Christmas tree traits. Can. J. For. Res. 24:1480-1486.

Balocchi, C.E., F.E. Bridgwater, and R. Bryant. 1994. Selection efficiency in a nonselected population of loblolly pine. For. Sci. 40:452-473.

Balocchi, C.E., F.E. Bridgwater, B.J. Zobel, and S. Jahromi. 1993. Age trends in genetic parameters for tree height in a nonselected population of loblolly pine. For. Sci. 39(2):231-251.

Enebak, S.A., M.E. Ostry, G.W. Wyckoff, and B. Li. 1996. Mortality of hybrid-triploid aspen in Wisconsin and upper Michigan. Can. J. For. Res. (In Press).

Enebak, S.A., B. Li, and M.E. Ostry. 1996. Seedlings response of two trembling aspen (*Populus tremuloides*) to infection by Hypoxylon mammatum. Europ. J. For. Path. (In press).

Greenwood, M.S. and Weir, R.J. 1995. Genetic variation in rooting ability of loblolly pine cuttings: Effects of auxin and family on rooting by hypocotyl cuttings. Tree Physiology. 15:41-45.

Hodge, G.R., C.J. Masters, R.S. Cameron, W.J. Lowe, and R.J. Weir. 1996. The role of the USDA Forest Service in seed orchard pest management research and development. Journal of Forestry. (In press for August 1996).

Jayawickrama, K.J.S., S.E. McKeand, and J.B. Jett. 1995. Phenological variation in height and diameter growth in provenances and families of loblolly pine. P. 33-39. In: Proc. 23rd South. For. Tree Impr. Conf., Asheville, NC.

Li, B. and G.W. Wyckoff. 1994. Breeding strategies for *Larix decidua, L. leptolepis* and their hybrids in the United States. Forest Genetics 1:(2):65-72.

Li, Bailian. 1995. Aspen improvement strategies for western Canada - Alberta and Saskatchewan. Forestry Chronicle 71(6):720-724.

Li, B. and R. Wu. 1996. Genetic causes of heterosis in juvenile aspen: a quantitative comparison across intra- and interspecific hybrids. Theo. Appl. Genetics. (In press).

Mangini, A.L., L.R. Baarger, R.S. Cameron, G.L. DeBarr, G.R. Hodge, J.B. Jett, W.S. Lowe, J.L. McConnell, J. Nord and J.W. Taylor. 1995. A southwide rate test of Azinphosmethyl (Guthion R) for cone and seed insect control in southern pine seed orchards. So. J. Appl. For. (In press).

McKeand, S., F. Bridgwater, C. McKinley, J.B. Jett, and R. Arnold. 1995. 1994 seed collection from natural stands of Fraser fir and plans for breeding and genetics research at NCSU. Limbs & Needles 22:4,6-7.

McKeand, S.E. and F.E. Bridgwater. 1995. Variance component and genetic gain estimates from 6-year-old diallel tests of loblolly pine. P. 197-203. In: Proc. 23rd South. For. Tree Impr. Conf., Asheville, NC.

McKeand, S.E., R.P. Crook, and H.L. Allen. 1996. Genetic stability effects on predicted family responses to silvicultural treatments in loblolly pine. South. J. Appl. For. (In press).

McKinley, C.R. and S.E. McKeand. 1995. Genetic improvement of Christmas trees: progress and possibilities. P. 48-54. In: Proc. 23rd South. For. Tree Impr. Conf., Asheville, NC.

O'Malley, D.M. and S.E. McKeand. 1994. Marker assisted selection for breeding value in forest trees. Forest Genetics 1:231-242.

van Buijitenen, J.P. and B.J. Zobel. 1994. Genetics and breeding of wood. In: Tree Breeding. (A.K. Mandal, ed.). International Book Distribution and Publishers. Dehra Dun, India.

Weir, R.J. 1996. The impact of genetics on forest productivity. Tree Talk (official publication of Miss. For. Assoc.). Winter 21-24.

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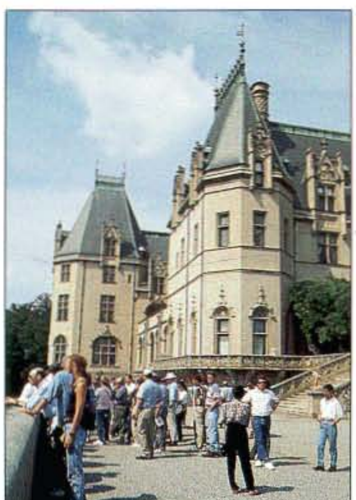
Zobel, B.J. 1994. Feasibility of establishing forest plantations in the tropics of America. Plantaciones Forestales IV Regunion National, Institute Nacional de Investigaciones Forestales y Agropecuarias. Mexico City, Mexico, p. 51-55.

Zobel, B.J. 1994. The need and potential for intensive forestry in Mexico. Second International Agribusiness Seminar. Monterrey, Mexico, 11 pp.

An improvement cut or thinning in a 45 year old white pine plantation.
Harvesting and forest management in the midst of heavy tourism on the Estate is a major challenge.

In June 1995 the N.C. State Tree Improvement Cooperative organized and hosted the 23rd Southern Forest Tree Improvement Conference in Asheville, North Carolina. A highlight for the 160 conference attendees was a tour of the Biltmore Estate where professional forestry was first practiced in the U.S. and the first forestry school in the nation was organized.



The magnificence of
The Biltmore House.

A view of the Blue Ridge Mountains and the Biltmore Estate.