42nd

NORTH CAROLINA STATE UNIVERSITY - INDUSTRY COOPERATIVE TREE IMPROVEMENT PROGRAM

1998 ANNUAL REPORT

Department of Forestry
College of Forest Resources
N.C. State University
Raleigh, North Carolina

EXECUTIVE SUMMARY

REPORTS OF RESEARCH:

Plantations grown from rogued second-generation orchard seed have an estimated gain of 14% to 23% volume per acre at 25 years over plantations grown from seed from first generation seed orchards.

A collaborative project is underway with the Forest Biotechnology Group to integrate the available breeding database with genetic marker analysis to detect and locate the loblolly pine genes with major effects and breeding significance.

Age nine results of the inbreeding study show reductions in growth on average of 4%-5% for matings among half-sibs to 16%-18% for selfs.

At age five, the grafted inbreeding study showed no meaningful difference between the growth and crown development of outcrosses, half-sib matings and full-sib matings. Selfed trees exhibited a 10% reduction in growth at age five.

A Clonal Selection Study has been established to develop information to guide organizations to efficient selection and propagation of superior clones and to develop methods for selecting and bulking up superior clones within families based on rooting ability and early shoot growth.

Results from the Scion Maturation Study at ages 5 and 6 indicate that the crown volume of the juvenile clones (ages 2 and 10) was 85% greater than for first-generation clones.

SELECTION, BREEDING, AND TESTING:

Forty-one percent of the diallel tests have been screened for third generation selections, resulting in the identification of 447 third generation selections.

Population II Hybrid families in the Piedmont Elite Population were established in replicated trials in 1997 and 1998 across a range of sites.

Pollen mix tests for the Lower Gulf Elite Population were established at 15 sites this year. The diallel crossing was to have been completed this spring.

SEED ORCHARD PRODUCTION:

Due to a freeze in the spring of 1996, the 1997 seed collection was the lowest since 1980. The only significant collections last year were in the northern regions.

ASSOCIATED ACTIVITIES:

The Cooperative has seven graduate students working on degrees and conducting research in support of the activities of the Cooperative.

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INTRODUCTION

The North Carolina State University - Industry Cooperative Tree Improvement Program has completed 42 years of continuous operation. Our mission: "To Economically Increase Forest Productivity Through Genetic Manipulation of Pine Populations" encompasses both forest genetics research and development of genetic resources for practical forestry. We have experienced a very successful and productive year for the program. Highlights of the activities and accomplishments of our 42nd year are presented in this annual progress report.

Recent data analysis from our extensive open pollinated progeny testing database concludes that plantations grown from rogued second-generation orchard seed have an estimated gain of 14% to 23 % volume per acre at 25 years over plantations grown from first generation seed orchard seed. We have estimated that these fast growing plantations will also have as much as 25% less rust infection where rust is a serious problem -- infection equal to 50%. Driven by the opportunity to capture even larger genetic gains in the future, Cooperative members have begun 2.5 generation and third-cycle seed orchard establishment. This will be a major activity for many members over the next 5 to 7 years. Selection of the best parents for these orchards will be based on the breeding value estimates currently available and those just released from the very large diallel breeding and testing program.

The Cooperative was pleased to welcome two new members to the Program during the past year. Gulf States Paper Corporation joined the Cooperative on July 1, 1997 and Temple Inland Forest, Inc. joined effective January 1, 1998. A brief profile of each new member is included in this report. Gulf States timberlands are located in northwest Alabama in the general vicinity of Tuscaloosa while Temple Inland operates in northwest Georgia and northeast Alabama in the vicinity of Rome, GA. Both members will participate in the upper gulf / Piedmont improvement zones. In each case the justification for their membership request was based on the need to increase productivity of pine plantations and the fact that an aggressive tree improvement program is a key component of this initiative. A new member can begin their program with the establishment of a third-cycle seed orchard.

The Tree Improvement Cooperative continues to make long-term investments in forest genetics research and development. Similar investments in the past are providing information today to optimize the selection of outstanding parent trees. We have located 447 third-generation selections to date. This investment will also provide the foundation for a fourth round of selection and gain. We have new breeding strategies in place that will capture genetic gains at a faster rate and at a lower cost than previous efforts allowed. Investment in research to improve and implement new technologies for evaluating genetic test data, and for capturing more gain is intensifying. Several current graduate student research projects, summarized in this report, are focused directly on providing such improvements for the future.

These developments are expected to make a substantial difference in the trees we grow and the way we grow trees in the next century. Our Cooperative Program has made a substantial impact in the past and is poised to continue this progress in the future.

RESEARCH

Impact of Forest Genetics on Productivity - Genetic Gains from Two Cycles of Loblolly Pine Breeding

Investment in genetic improvement offers increased forest productivity and an enhanced timber supply. Members of the Cooperative, currently 17 industries and five states, annually plant more than 600,000,000 trees on 900,000 acres, accounting for 37% of the tree planting in the nation. The impact of tree improvement on forest productivity has been substantial through two cycles of breeding, testing and selection. Trees grown from seeds of first-generation seed orchards have produced 7-12% more volume per acre at harvest than trees grown from wild seed. With additional improvement in value from quality traits (stem straightness, disease resistance, wood density), the estimated genetic gain in value from first-generation breeding is about 20%. Second-generation seed orchards are now producing more than 50% of the seed harvest in the region. Progeny test data from second-generation seed orchards are now available to provide genetic gain estimates.

Below is a summary of the genetic gains from two cycles of loblolly pine breeding by the N. C. State Tree Improvement Program and a discussion of it's impact on stand productivity.

BACKGROUND

First-generation genetic tests were established with full-sib families generated from an incomplete factorial mating design. Row plots were used to evaluate family variation and to compare the improved stock with unimproved check lots. Tests were measured at ages 4, 8 and 12 to estimate average percent gains in height growth over unimproved check lots. Second-generation selections were made in first-generation progeny tests and grafted to establish second-generation seed orchards. Open-pollinated progeny tests from those second-generation seed orchards were established throughout the Southeast. The number of families in each test series ranged from 19 to 44, including several unimproved check lots. Each test series generally included 4 tests established at two locations in each of two years. The experimental design was a randomized complete block with six blocks and 6-tree row plots. Tree height was assessed in all tests. Diameter, stem straightness and rust infec-

A 13 year-old plantation established by Union Camp Corporation. The outstanding productivity depicted results from the combination of good silviculture and good genetics.

tion were measured in some of the tests. The tests were grouped into four general geographic regions for genetic gain estimates: Virginia and northern North Carolina, Atlantic Coastal plain, Piedmont, and Lower Gulf. The number of families represented in the open-pollinated tests ranged from 83 to 285 per region.

The best linear unbiased prediction method was used to estimate parental breeding values for 8-year height. Percent genetic gain over local checklots was calculated from the predicted breeding values for height. Breeding values for rust infection at a 50% infection level (R-50) were also calculated to facilitate ranking parents for rust resistance. Percent height gains at age 8 years were assumed to equate to percentage gains at age 12, thus the 8-year differences in height were assumed to equal site index value changes at stand age 12. The site index values were then used with the growth and yield model first developed by Hafley et al. (1982) to estimate the volume in unthinned plantations at age 25 years. The simplifying assumption was that the shape of the height over age curves are essentially equivalent for all families and that selection has little impact on other parameters of stand growth and yield such as mortality functions and height-diameter relationships, which were found to be reasonable assumptions in most situations (Buford and Burkhart 1987, For. Sci. 33:707-724).

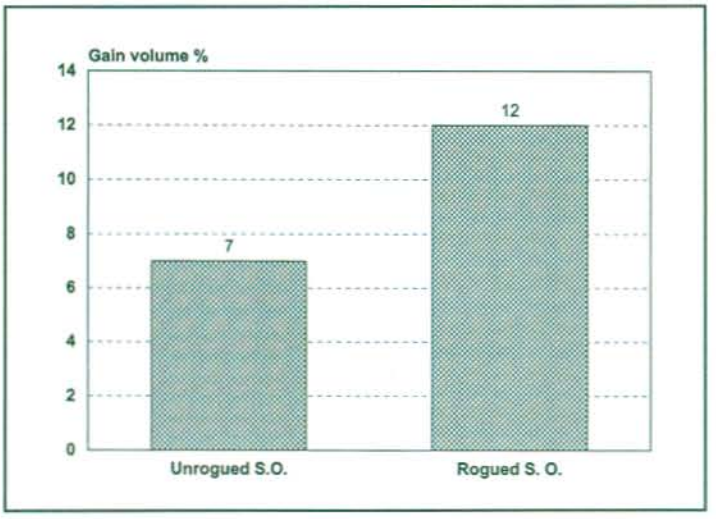


Figure 1. Twenty-five year volume gains from the first-generation over unimproved checklots.

GENETIC GAINS

Genetic gains for 25-year volume from an unthinned plantation are approximately 7% on average for unrogued first-generation seed orchards and 12% on average for rogued first-generation seed orchards (Figure 1). Genetic gains over unimproved checklots from second-generation seed orchards for growth are substantially higher than those from the first-generation seed orchards. The genetic gains for all families in a region are representative of the gains from unrogued seed orchards, while gains for the top 30% of families are representative of the gains from intensively rogued second-generation seed orchards. The estimated gains in rotation volume (25-year) over unimproved checklots ranged from 13% to 21% for unrogued orchards and 26% to 35% for the top 30% of families in rogued orchards (Figure 2). Since these

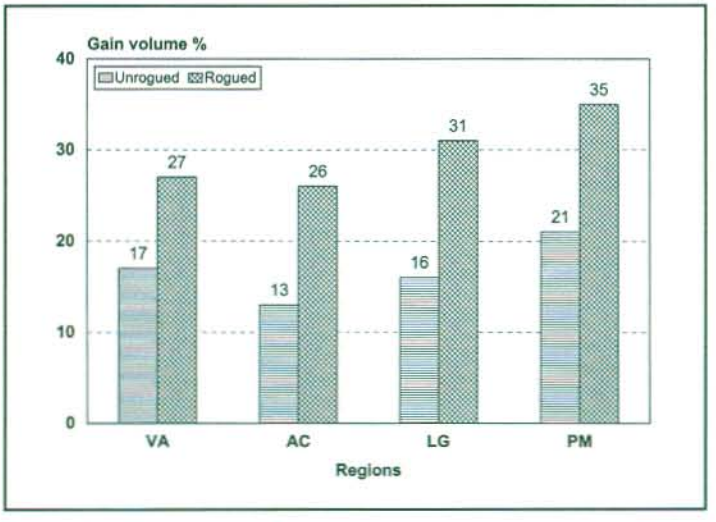


Figure 2. Second-cycle 25-year volume gains over unimproved checklots for unrogued and rogued seed orchards.

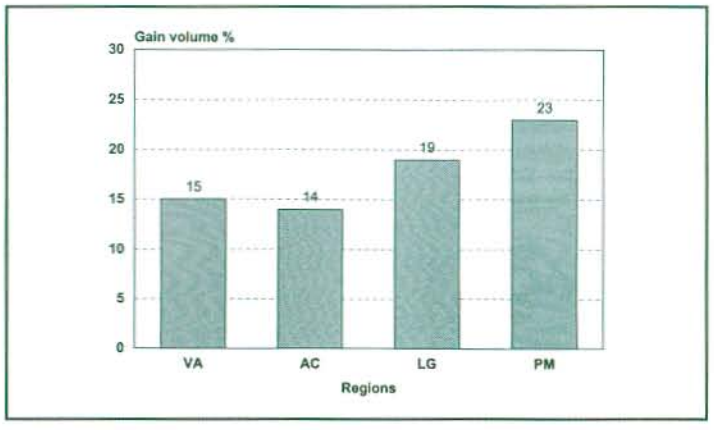


Figure 3. Twenty-five year volume gains over first-cycle for rogued second-generation orchards.

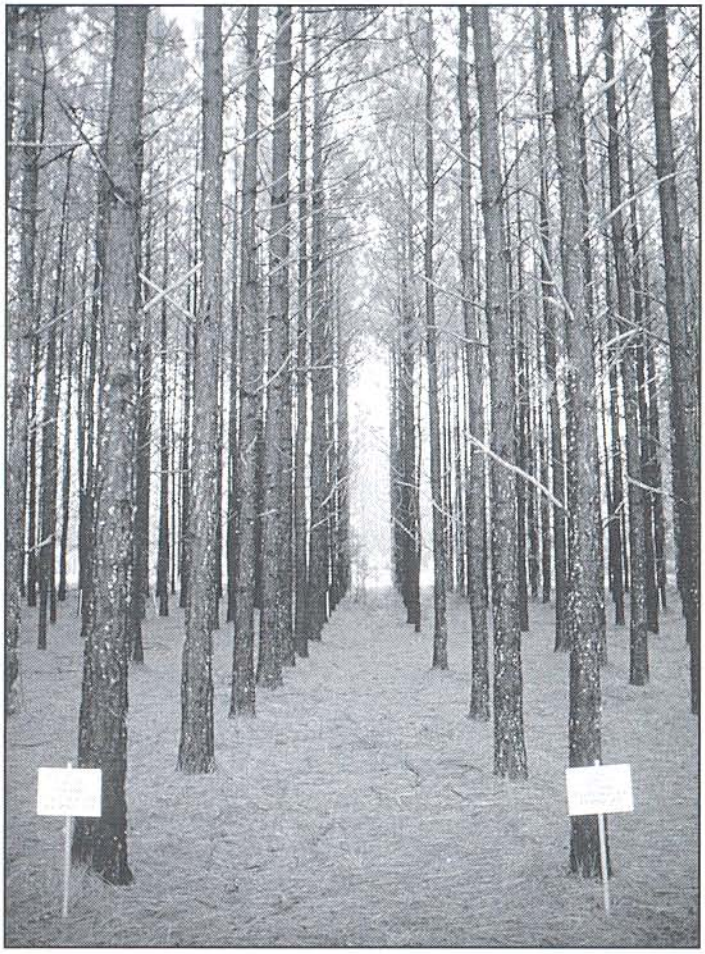
estimates represent genetic gains from two cycles of breeding, it is clear that, by subtracting the first-generation gains, second-generation breeding and selection has produced an average across regions of an additional 14% to 23% volume gain for rogued seed orchards over first-generation seed orchards (Figure 3).

Improvement in resistance to fusiform rust is apparent based on the significantly lower R-50 values for second-generation families than for unimproved checklots (Li et al. 1997). For example, in the Atlantic Coastal plain, about 80% of the families had lower R-50 breeding values than the checklots. The top ranked 30% of families for rust in this region had an R-50 of 29.6%, significantly lower than the checklot average (over 63%). Similar differences in R-50 values were observed for the Piedmont population which averaged 28% for the better families and 56% for checklots.

Much greater genetic gain can be expected from utilizing the best families since large differences were observed among second-generation families. The best Atlantic Coastal family had 38% volume gain over the unimproved checks, while the best Piedmont family had 66.2% volume gain over the unimproved checks. Although genetic gain for stem straightness is difficult to quantify since a subjective scoring system was utilized in assessing this trait, it is evident that most of the second-generation families had much better stem/crown quality than the unimproved checks. The unimproved checklots are usually ranked at or near the bottom for stem straightness.

THE IMPACT ON PRODUCTIVITY

Considering the large scale tree planting program in the South, the impact of tree improvement on forest productivity has been substantial through the two cycles of breeding in loblolly pine. Loblolly pine, already the most significant commercial tree species in the South, will become an increasingly important source for softwood fiber for pulp and timber. To meet future demands without increasing pressures on old-growth and ecologically sensitive forests, timber productivity per acre must increase. Intensively managed plantations of loblolly pine, employing the best genetically improved planting stock and best silvicultual practices, are the best strategies to meet these demands. With the 7-12% more volume per acre at harvest from first-generation and 17-30% more volume per acre at harvest from second-generation over trees grown from wild seed, the impact of tree improvement on forest productivity has been substantial. Genetically improved stock has not only demonstrated outstanding growth, but also has lower fusiform rust infection, typically 20%-25% below the unimproved checklots. With additional improvements in value from quality traits (stem straightness and wood quality), the realized genetic gains in value should be even greater. Although only 15 percent of the commercial forests are currently in plantations (28 million acres), almost 50 percent of the South's timber supply will soon come from these plantations. Improved wood production on limited commercial lands will reduce the logging pressures on natural forests and provide better opportunities for the use of natural forests and forest lands for conservation and other recreational purposes. Future impact will be even more dramatic as the tree improvement program moves to the 3rd generation of breeding. Together with intensive silvicultural practices, tree improvement will continue to contribute significantly to sustainable forestry in the future.



A dramatic demonstration of genetic gain on lands of Bowater, Carolina Woodlands Operations in SC. The gain in volume per tree for the genetically improved trees (left) over the commercial check is 51%.

Search for Major Genes Using Progeny Test Data

Traditional tree improvement has produced significant genetic gains from two cycles of loblolly pine breeding (see the previous section). To accelerate the realization of genetic gains, new approaches integrating biotechnology with traditional tree improvement need to be developed and implemented. Recent developments in molecular biology and genomic mapping offer potentials to alter traditional tree improvement processes and accelerate genetic gains. For these techniques to be useful for practical tree breeding, it is essential that existing breeding populations and genetic information be used. The extensive breeding materials and progeny test data of the Tree Improvement Program can provide a valuable database for developing such new techniques.

The Tree Improvement Program is working collaboratively with the Forest Biotechnology Group at N. C. State University on a project searching for major genes. The project proposes to integrate the available breeding materials/database with genetic modeling/marker analysis to detect and locate the loblolly pine genes with major effects and breeding significance. If statistical methods can be developed to screen crosses of parents with desirable traits for segregation of major genes in these populations, it would significantly increase the chance of detecting major genes with economic value. It should also reduce the time required for major gene detection since data on the traits of interest have already been collected from progeny tests and are available for molecular analysis. Additionally, by working only with targeted pedigrees, it should reduce the cost of gene mapping and increase the likelihood of success. For example, the fusiform rust resistant gene that was detected in loblolly pine by the Forest Biotechnology Group was first noted by the strong segregation pattern of the family from greenhouse and field tests.

Preliminary analyses conducted with two selected six-parent half diallels showed that a 2-gene genetic model can explain 81% of the among family variation and 45% of the within family variation. Needle samples collected from these materials led to confirmation of a strong association between tree height growth and DNA markers. One DNA marker found was significantly associated with tree height and explained 10% of the variation within the full-sib family. More data analyses and molecular confirmation are under way to validate these results.

This research project will develop an approach that fully utilizes the current breeding materials and

genetic test information available to identify major segregating genes that control loblolly pine growth, disease/insect resistance and wood quality. If major genes can be identified in the existing breeding population, they can be utilized directly in the conventional loblolly pine breeding program. With the putative genotypes of parents identified, tree breeders can make effective decisions on management of breeding populations and operational deployment of genetically superior trees. Forest productivity will be significantly enhanced if genetically superior genotypes with major genes for economically important traits could be deployed in an operational plantation program.

Inbreeding Study - Age Nine Results

Two Inbreeding Studies were established in field trials in the spring of 1988--one for Piedmont Loblolly and one for Coastal Plain Loblolly. The Piedmont trials were established by Bowater(SDW), Procter and Gamble, Bowater(CWD), International Paper, and S. C. Commission of Forestry. The Procter and Gamble study was abandoned due to poor survival. The Coastal Loblolly trials were established by Union Camp(VA), Weyerhaeuser, The Timber Company, the N. C. Division of Forest Resources and International Paper. The N. C. Division of Forest Resources and

South Carolina Comm. of Forestry's Planting of the Inbreeding Study on the Manchester State Forest. The selfed lot being measured at age 8 is "puny" in contrast to the adjacent outcross plot.

International Paper trials were abandoned due to poor survival. The remaining trials were measured at ages 3, 6 and 9.

The objectives of the Inbreeding Studies were:

- To determine the response to related matings in improved loblolly pine.

- To characterize family differences in sensitivity to inbreeding.

Parents used in the study were all second-generation selections. Four levels of inbreeding were created from matings of selfs (F=.50), full-sibs (F=.25), half-sibs (F=.125) and unrelated selections (F=0). For all matings, except selfs, parents were mated to two individuals to reduce the bias caused by the breeding value of the other parent in the cross.

Inbreeding resulted in a significant reduction in height growth at all three ages (Figures 4 and 5). At age nine, in the Coastal Plain Inbreeding Study, half-sib matings resulted in a height reduction of 4.7%, full-sib matings resulted in a height reduction of 11.6% and selfs resulted in a height reduction of 16.7%. Age nine results in the Piedmont Study showed reductions in height growth equal to 4% for half-sib matings, 5.3% for full-sib matings and 18.5% for selfs. While the percent reduction in height growth has declined slightly as the trials have aged, the absolute differences have increased. Parents differed significantly in their response to inbreeding. Figure 6 displays the response of seven parents at each level of inbreeding. Parent 1-1069 showed a positive response at each level of inbreeding. Parent 3-1008 showed a negative response at each level of inbreeding. These significant interactions suggest that no general prescription can be made for use of related individuals in seed orchards.

More detailed analyses, including summaries of volume, are currently underway and should be completed by the fall of 1998.

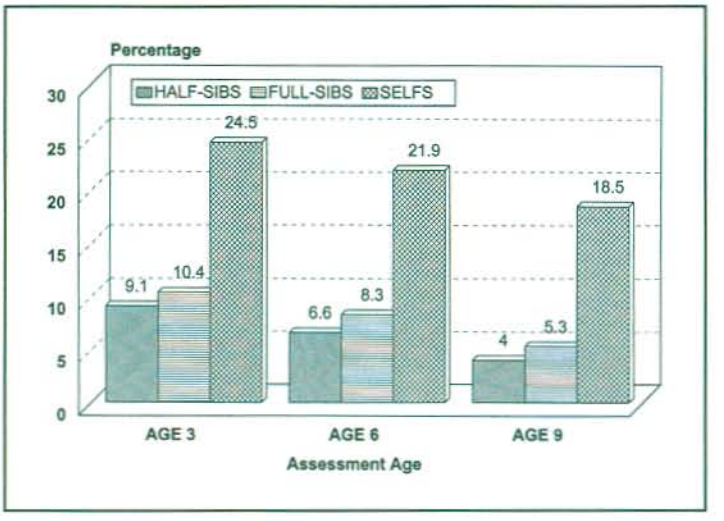


Figure 4. Percent reduction in height for three levels of inbreeding in the Piedmont Loblolly Inbreeding Study.

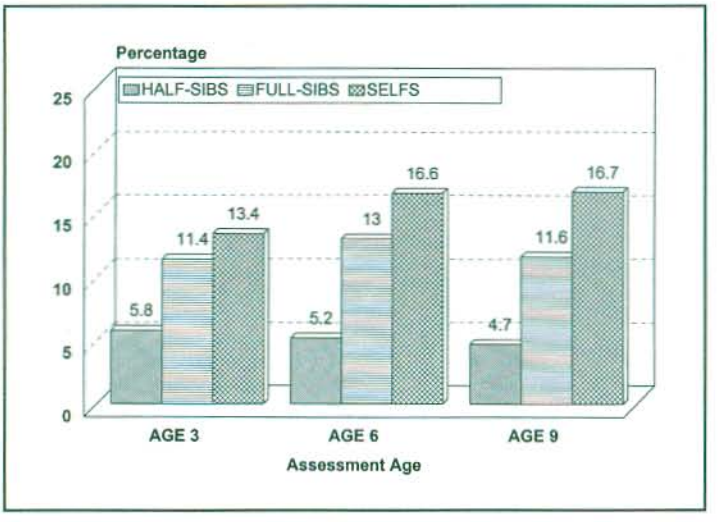


Figure 5. Percent reduction in height for three levels of inbreeding in the Coastal Loblolly Inbreeding Study.

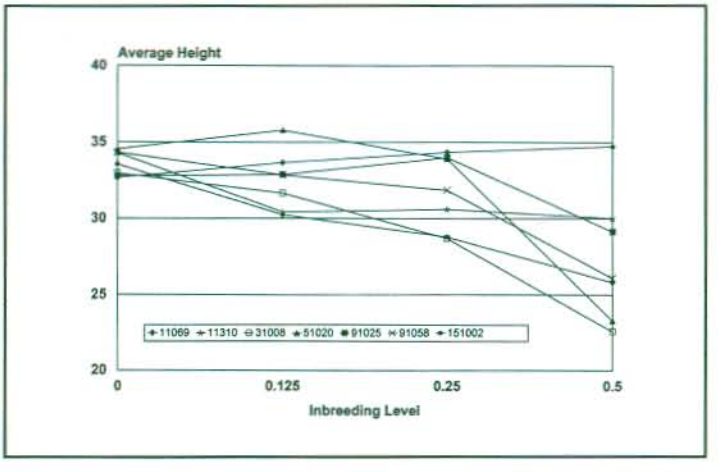


Figure 6. Growth response of seven clones in the Piedmont Loblolly Inbreeding Study at each of four levels of inbreeding.

Inbreeding Grafting Study - Age Five Results

In any long term breeding program, concerns exist as to the level of inbreeding that can be tolerated before fecundity is adversely affected. This concern exists both for the breeding population and for the orchard populations. Fecundity has two components: (1) the initiation and development of strobili or "flowers" and (2) the production of filled seeds. The impact of inbreeding on filled seed is better understood than the impact on strobili initiation and development. Filled seed yield in selfs is typically much lower than for outcrossed families.

While information exists relating filled seed yields to inbreeding, information is lacking as to how various inbreeding levels influence the initiation of strobili. The consequence of reduced plant vigor and tree sizes, and the resulting effect on crown size, due to inbreeding may be a reduction in strobili initiation. Reduced plant vigor may also result in lowered strobili retention. In 1992, the Cooperative initiated the Grafted Inbreeding Study to determine the impact of various inbreeding levels on growth and reproduction in seed orchards. Scions were collected from good phenotypes (selection was minimal) from 3-year-old trees in the Cooperative's Inbreeding Study in both the Piedmont and Atlantic Coastal Plain trials. Grafts were established at three sites in the Atlantic Coastal Plain and three sites in the Piedmont, with five replications at each site. Each provenance was represented by nine family lines at four inbreeding levels (selfs F=0.5, full-sibs F=0.25, half-sibs F=0.125, and outcrosses F=0). In 1997, height, DBH, crown diameter and number of female strobili were measured at age five. Only the Piedmont results will be summarized here, but similar trends were found in the Coastal Plain trials.

There was no meaningful difference between the growth and crown development of outcrosses, half-sib matings and full-sib matings (Table 1). Selfed trees sustained about a 10% reduction in growth through age five. While similar trends for inbreeding effects for number of female strobili were found, these differences (Table 1) were not significant. There was tremendous variation in flowering within each inbreeding level, so differences among the means were not significant.

Based on these early assessments, it appears that the penalty for mild inbreeding is rather minimal. The performance of selfs is more questionable and will require assessment at later ages to ascertain the full effect of selfing. These trials will be maintained through age 10 for assessment of growth and reproductive performance.

Table 1. Trait means for different inbreeding levels

Inbreeding Level	Height(ft.)	DBH(in.)	Crown Diameter(ft.)	#Female Strobili
F=0, outcross	17.7	4.7	10.3	54
F=0.125, half-sib	17.0	4.5	10.0	47
F=0.250, full-sib	17.6	4.6	9.9	41
F=0.500, self	16.0	4.1	8.9	19

Clonal Selection Study

The Clonal Selection Study is a joint project between the NCSU Rooted Cutting Program and the NCSU Cooperative Tree Improvement Program. The objectives of the study are:

- To develop information that will enable individual organizations to efficiently select and propagate superior clones.

- To develop methods for selecting superior clones within families based on rooting ability and early shoot growth.

- To produce clones for evaluation in long-term trials.

The project was initiated in the fall of 1996. Eight full-sib crosses from the South Atlantic Coastal Plain region were chosen from diallel tests on the basis of rapid growth, good rust resistance, acceptable form, availability of seed, and non-relatedness. One hundred seedling hedges were established from each cross. In February of this year, fifteen cuttings from each of the 100 hedges of all eight families were stuck for rooting. Clones yielding an acceptable number of rooted cuttings will be established in field trials in November. Height growth will be assessed annually through age 3. Based on clonal means, a proportion of the clones will be culled each year. Multiplication of selected clones will occur simultaneously with progressive culling each year. Final selection of clones for long-term studies will occur after the third growing season.

The study will provide estimates of the proportion of clones culled for rooting ability, the efficiency of selection at different ages, the multiplication rates for clones, and the magnitude of genetic gain for the best clones in each cross. Information generated from this study will significantly increase the base of knowledge necessary for the implementation of clonal forestry using rooted cuttings.

Rooting cuttings for The Clonal Selection Study which is designed to provide information leading to the development of an efficient, cost effective early selection - clonal multiplication system.

Scion Maturation Study

In 1991 and 1992, the Scion Maturation Study was established to determine if seed orchard parents grafted from different aged trees can be established together in advanced generation seed orchard blocks. Will parents that are considerably older (e.g. 35-45 years old) be able to compete with younger ones (e.g. 10 years old) and produce comparable amounts of seed? Cooperators establishing third-cycle production seed orchards would ideally select those parents with the highest breeding values, regardless of age. It is likely that parents with the highest breeding values will be a mixture from plantation selections, second-generation selections, third-generation selections, and even a few first-generation parents. The problem with establishing seed orchards with grafts of scions of vastly different ages is that as loblolly pine and other trees mature, several growth, morphological, and physiological changes occur. One of the more important changes for a seed orchard manager is the reduction in growth rate. If the large growth differences observed between second-generation orchard trees and first-generation parents in previous orchards also occur among trees with less difference in age, then third-cycle orchards may well need to be established differently. Either clones of different ages will be established separately, or only clones of a similar age will be used in the entire orchard, or the seed orchard design will need to be altered to accommodate selections of vastly different growth rates.

Scions from the following five age groups were used in the Scion Maturation Study: first generation selections (75 years), selections from the plantation selection population (40 years), second generation selections (21 years), third generation selections (8 years), and juvenile selections (2 years). In each age group, 20 selections were used to ensure inclusion of a broad range of genotypes. Three trials were established in the Atlantic Coastal Plain and three in the Piedmont, but only two trials in each have 5- and 6-year data. At each site, a randomized complete block design with three replications was used for a total of 300 grafts per study. In the spring of 1997, height, DBH, crown diameter, and number of female strobili per tree were assessed. Crown volume was estimated for each tree based on crown length and width.

The maturation effect was large and highly significant for growth traits. As expected, the growth of older trees was much slower than for the more juvenile clones. The most dramatic illustration of this is for crown volume. For both the Piedmont and Coastal Plain trials, the differences between the juvenile clones (ages 2 and 10) and the first-generation clones was about 85% (Figure 7). If clones with such large differences were grown together at fairly close spacing, competition effects would severely impact the grafts from older scions. At wider spacings, these growth differences may be manageable.

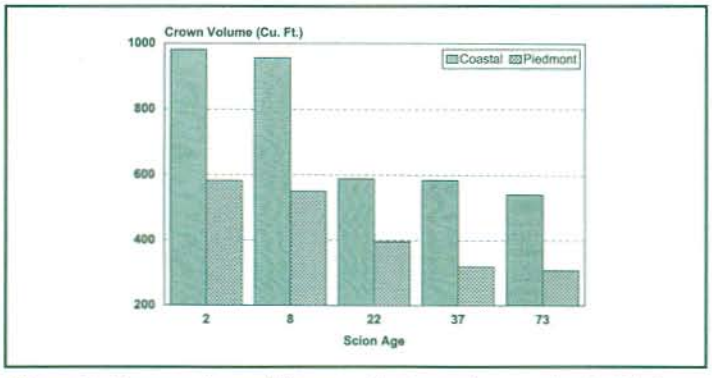


Figure 7. Crown volume differences for five scion ages in the Piedmont and Coastal Plain trials of the Scion Maturation Study.

Scion maturation effects for female strobilus production were not as clear-cut. Age differences were only significant (p .05) in the Coastal trials where the 2-year-old scions had almost twice as many females compared to all other age groups. In the Piedmont trials, the number of female strobili were variable, and the differences among the different aged trees were small and not significant. Effects on female strobili production should be better defined as the study ages.

The most valuable data from these trials will come over the next 5-10 years as competition effects increase. In the interim, orchard managers need to be cautious when establishing clones of vastly different ages in production orchards.

SELECTION, BREEDING, AND TESTING

Third Generation Selection - A Progress Report

Members of the Cooperative have made a major investment in future forest productivity through their breeding, testing and selection work. Collectively, members have bred 3,834 plantation and second-generation loblolly pine selections in 639 disconnected 6-parent half-diallels. Over 1,300,000 progeny seedlings have been produced from 9,585 controlled-pollinations and these seedlings have been planted in 1,278 progeny tests. It has been estimated that this effort represents an investment by the membership of over $35,000,000. While that is an enormous investment, the projected value of the "extra" wood grown in highly productive plantations established with this genetic material is expected to exceed 2 billion dollars over 20 years. Clearly, this has been an investment worth making.

A critical step toward realizing the payoff of this investment is currently underway, as third-generation selections are identified in this test population. To date, Cooperative members, working with the program staff, have screened 41%, or more than 500 of the 1,278 progeny tests established (Figure 8). This work has resulted in 447 third-generation selections being graded thus far. Photographs on the back cover of this report show the outstanding quality of the selections being located.

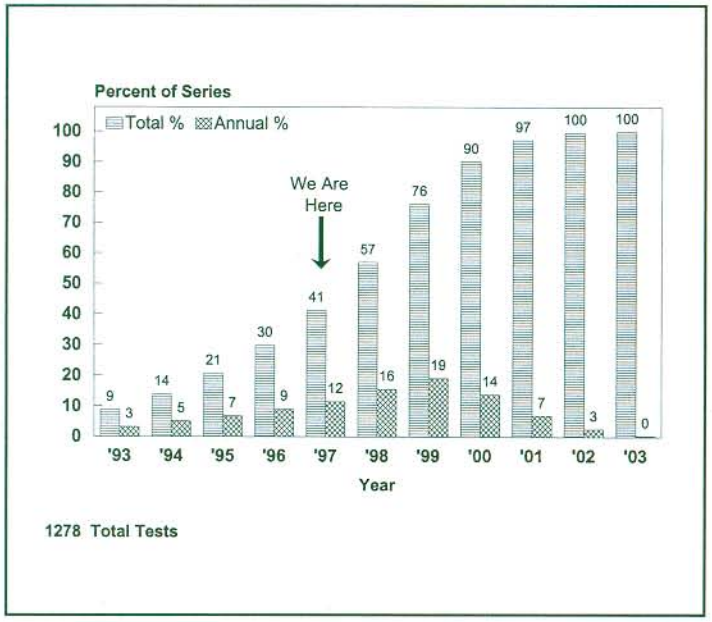


Figure 8. Time line for third-cyle selections with current progress highlighted.

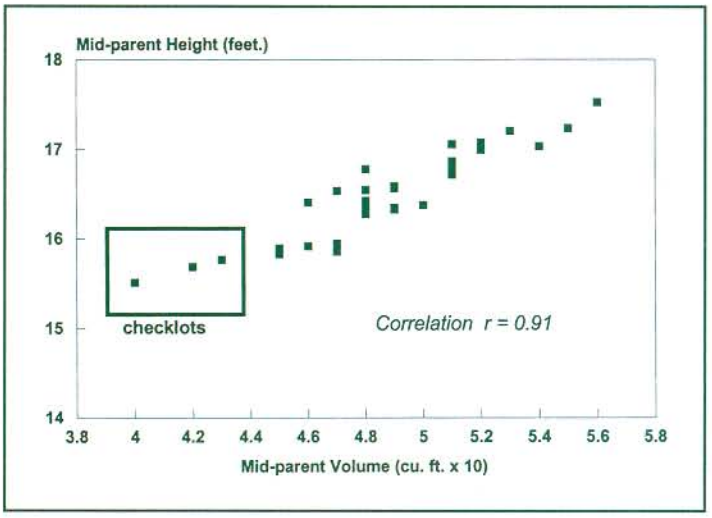


Figure 9. A comparison of midparent heights and volumes for full-sib families in a diallel test to that of the standard checklots.

In general, the genetic superiority of loblolly pine families developed from controlled-crossing of second generation and plantation selections (diallel-breeding) is high. An example of the genetic superiority in one test series is shown in Figure 9. The slower growing standard checklots are from seeds collected in wild or unimproved forest stands in the localized area of the testing program. An average (all crosses in a test) genetic gain of 25% for volume at age 6 is common. Genetic gain for height is often in the range of 12% - 16%. Third-generation selections are the best individual trees in the very best families. It is not uncommon to find age-6 mid-parent volume superiority in excess of 50% for the best families . Some of the individual trees selected in these families are indeed "super trees".

A recent analysis by Bailian Li has provided more accurate estimates of genetic parameters for use in

prediction of rotation age volume. This analysis also produced better estimates of juvenile-mature correlations for diameter and volume. Heritability estimates for juvenile diameter and volume were similar to height, but were significantly better predictors than height alone for tree-volume at rotation age (25 years). Thus, the selection efficiencies for rotation volume (gain per year) were much higher when using volume and height than when using only height. Based on these results tree-volume is now being used along with height in identifying third-generation selections.

Piedmont Elite Population - A Status Report

The Piedmont Elite Population (PEP), which is the first of the Cooperative's elite breeding programs, is a very focused intensive effort at developing the potential of an intensively selected, high value Coastal Plain by Piedmont hybrid breeding population. Twelve members, including both industries and state forestry agencies, have collaborated over the past six years to initiate the most intensive breeding, testing, and selection program ever for the Piedmont region. We anticipate big payoffs when the results of this work are deployed operationally.

Plans for PEP began to take shape in 1992 - 93, and by 1998 the initial test establishment phase is just about complete. There are two separate populations in PEP, and both involve hybrids between Atlantic Coastal Plain and Piedmont parents. Population I is comprised of second-generation selections that are hybrids between first-generation Atlantic Coastal Plain and Piedmont parents. While population II was designed to create additional hybrid families by crossing outstanding second-generation selections from the Atlantic Coastal Plain with Piedmont second-generation selections, all of which are proven winners based on progeny performance.

Breeding for Population II - making new hybrid combinations - began first. The Population II full-sib families, derived from factorial matings, were established in 1997 and 1998. These replicated trials will be used to determine which full-sibs perform well across a range of sites and would be candidates for deployment. Recent emphasis on Control Mass Pollination and Vegetative Propagation prompted a redesign of these tests, so not only the best individuals for the breeding program, but also the best families for deployment could be identified. Pollen mix tests of Population II parents have been established across environments from the fall line to cold regions beyond the natural range of loblolly pine. These long-term trials, designed to test the adaptability of hybrids compared to within provenance crosses, are now in their second growing season. First year height and survival data were collected as part of Angelia Kegley's graduate research project.

Pollen mix tests for Population I parents (second-generation selections that are hybrids) were established this spring. The objectives are to identify hybrid parents with the highest breeding values so that individuals from within crosses among these parents can be selected (4-tree diallels have been bred). Full-sib block plots of these diallel crosses will be planted soon , so the best individuals from within the crosses with the highest breeding value can be selected.

Status of Lower Gulf Elite Population

Members of the NC State University, University of Florida, and Western Gulf tree improvement cooperatives, are all collaborating on this breeding program. The best 75 coastal plain families from all three programs are being tested together to determine which are the best genotypes for the Lower Gulf region. This is the first time such a comprehensive and direct comparison of families from these diverse areas will be made. Pollen mix tests for the Lower Gulf Elite Population were established across 15 different sites this year.

Diallel breeding of the different parents was delayed because of the freeze damage in 1996. We are optimistic that the diallels were all completed in the 1998 breeding season. These crosses and a few remaining pollen mix families will be established in trials by 2000 or 2001.

SEED ORCHARD PRODUCTION

The 1997 seed collection was the lowest since 1980 when only 15,800 lbs. of loblolly seed were collected. The fall 1997 collection produced 25,890 lbs. of seed. Due to a freeze in the spring of 1996, most cooperators collected no seed. Collections were better in the northern region of the Cooperative. One organization which had a great year was the Virginia Department of Forestry who collected 12,200 lbs. of seed, representing 47% of the total collection for 1997. Average yield for 1997 was 1.35 lbs. per bushel, down from 1.57 last year. The 2.0 lbs. per bushel mark was not reached in 1997 by any cooperative member.

Table 2. Twenty-nine years of seed production from Cooperative orchards

Harvest Year	Bushels of Cones	Pounds of Seed	LBS. /Bushel	Millions of Acres Regenerated
1969	1,769	2,000	1.13	0.03
1970	5,146	7,000	1.36	0.10
1971	6,478	7,400	1.14	0.10
1972	6,807	6,600	0.97	0.09
1973	11,853	13,000	1.10	0.18
1974	8,816	8,800	1.00	0.12
1975	16,348	21,400	1.31	0.30
1976	14,656	17,800	1.21	0.25
1977	32,152	49,600	1.54	0.69
1978	37,977	47,000	1.24	0.65
1979	39,693	55,400	1.43	0.77
1980	15,296	15,800	1.03	0.22
1981	64,811	101,000	1.56	1.40
1982	44,761	61,000	1.36	0.84
1983	68,447	98,000	1.43	1.36
1984	105,239	160,200	1.52	2.22
1985	52,155	75,600	1.45	1.05
1986	84,953	140,200	1.65	1.94
1987	112,822	186,600	1.65	2.58
1988	56,822	85,400	1.50	1.18
1989	23,247	32,200	1.39	0.45
1990	50,944	60,750	1.19	0.84
1991	55,555	75,555	1.40	1.07
1992	44,547	63,039	1.42	0.09
1993	35,387	46,990	1.33	0.65
1994	25,529	31,104	1.22	0.43
1995	40,250	63,867	1.57	0.88
1996	96,735	151,627	1.57	2.10
1997	19,183	25,890	1.35	0.36
Totals/Avg.	**1,177,378**	**1,712,822**	**1.45**	**23.72**

ASSOCIATED ACTIVITIES

Graduate Student Research and Education

The education of graduate students and the research they conduct as part of their degree programs continues to be an important activity of the Cooperative. During the past year, seven graduate programs have been developing in association with the Tree Improvement Cooperative. Four were directed towards a Masters degree and three were involved in a course of study leading to the Ph.D. degree. Following are the graduate students working in association with the Cooperative along with a brief overview of their research projects, including any current results, and the expected completion date of their graduate program:

Paul Belonger: Paul is Forest Genetics Manager for The Timber Company, formerly Georgia Pacific Timberlands Division. Paul's research involved a study of wood properties variation among seed sources and families within seed source using data collected from four locations of the Florida Provenance - Progeny Test. Paul expects to complete his Master of Science degree in the summer of 1998. His research has been supported by Georgia Pacific, now The Timber Company, and a consortium of five Tree Improvement Cooperative members.

Thesis Research Title: *Wood Density Assessment of Diverse Families of Loblolly Pine Using X-Ray Densitometry*

Abstract:— A direct scanning x-ray densitometer was used to measure juvenile wood density characteristics for two 10-year-old plantings of a genetics trial that included 52 open-pollinated families from four provenances of loblolly pine. Both volume production and wood density differed greatly for the two sites. Genetic parameters were estimated for basal area weighted whole-core density, earlywood and latewood density, and percent latewood. All traits were under high genetic control and exhibited strong family differences. Family mean whole-core specific gravities ranged from .441 to .507. Site differences had a major influence on all the traits measured, accounting for 42% to 73% of total variation, but significant genotype by environment interaction was not detected.

Linear regression models (density = ring number) were fit for individual tree annual earlywood, latewood, and ring densities to determine the rate of change in the traits over the first 10 years. Provenance differences were marginally significant ($p<0.10$) for the slope of the regression line for earlywood density and ring density. The individual tree narrow sense heritabilities for slope ranged from 0.05 to 0.15.

(Abstract is from a paper presented at the 24th Southern Forest Tree Improvement Conf., June 1997, Orlando, Fl.)

Wen Zeng: Came to the United States for Ph.D. studies after receiving a Masters Degree in Silviculture and Forest Management from Beijing Forestry University in China. Wen served as an instructor at the Beijing Forestry University for approximately 5 years before beginning graduate work at the University of Minnesota in 1995. Wen followed Dr Bailian Li to North Carolina State University in late 1996 to continue his Ph.D. studies in association with the NCSU Tree Improvement Cooperative. He is supported with a Department of Forestry Graduate Research Assistantship.

Thesis Research Title: *Detection of Major Genes Using Phenotypic Data.*

Description of Research: Economically important traits, such as height growth, DBH, and fusiform rust resistance, may be controlled by several major genes and also have polygenic inheritance (many genes, each with small effect). Despite large genetic effects, major genes are often not immediately apparent due to obscuring effects of polygenic and environmental variations. If proper pedigree data from a mating design could be used, and progenies tested over different environments, it may be possible to develop a biometrical method for screening for major genes in the breeding population. The purpose of this research is to develop statistical methods and evaluate genetic models for major gene detection. It will also be useful to estimate gene effects and probabilities for each candidate that carries the major genes. Preliminary analyses has shown a significant segregation of major genes for tree height. Expected date of completion is August 1999.

John Mann: Following service in the U.S. Army, John received a BS degree in biology from Coastal Carolina University in Myrtle Beach, SC where he was employed as a chemistry lab instructor for one year following graduation. John enrolled in a Master of Science program at NC State Univ. in May of 1996. He has a graduate research assistantship provided by the USFS through a Cooperative Agreement with the Global Change project and a small supplement from the Tree Improvement Cooperative.

Thesis Research Title: *The Effects of Fertilization and Irrigation on Wood Quality of Loblolly Pine.*

Project Description: The study site is located in the sand hills of Scotland county, NC. The design is a randomized complete block replicated four times with fertilization and irrigation treatments applied in factorial combination. Dendrometer bands were placed around 25 trees per plot prior to the 1997 growing season. The diameter growth was taken weekly until late into the growing season. During the winter of 1997, after growth ceased, final dendrometer readings were recorded and 12mm increment cores were taken. The cores were prepared and run through a scanning x-ray densitometer for density and growth analysis. The analysis is expected to:

- determine what effect fertilization and/or irrigation has on the transition date between earlywood and latewood formation,
- to characterize treatment effects on the within ring and whole ring specific gravity,
- to determine if the treatments have an effect on the latewood percentage, and
- using the previous two results, provide information for carbon budget estimates for annual stem diameter growth.

Preliminary results: Irrigation has caused the transition date to occur one week early, while fertilizer treatments have caused the transition date to be delayed for 16 days. Treatments had no effect on latewood percent or earlywood density, but irrigation increased latewood density by 2% and fertilization decreased latewood by 8.6%. Fertilization decreased overall ring density by 5.3%, and (although not significant, $Pr > F = .12$) irrigation increased ring density by less than 2%. Finally, irrigation increased overall ring width by 16.6% and fertilization increased it by 28%. Fertilization and irrigation applied together increased ring width by 44% over the control. This information will provide forest managers an improved understanding of the effect that intensive fertilization treatments can have on overall specific gravity, and will allow them to incorporate these results into their management strategies. Expected date of completion is the summer of 1998.

Angelia Kegley: A native of southwest Alabama, Angelia received a BS degree from Mississippi State University, Department of Forestry in the summer of 1996. She enrolled in a Master of Science program in tree improvement at NCSU during August of that year and is now nearing completion of her graduate program and seeking employment as a tree improvement - technical department specialist. Angelia has been supported on a Graduate Research assistantship funded one half by the Cooperative and one half by the Department of Forestry.

Thesis Research Title: Screening Coastal and Piedmont Loblolly Pine Families and Their Hybrids for Growth and Cold Hardiness.

Project Description: Angelia is examining the growth and cold hardiness of Coastal and Piedmont sources and their hybrids under controlled environments. She will evaluate family differences in these traits, and compare these results with field trials. The focus of her research is to determine whether or not the provenance hybrids exhibit superiority over the pure Piedmont source, resulting from the combination of the faster growth of the Coastal parent with the cold hardiness of the Piedmont parent, or if the hybrids are intermediate for these traits. The trees used in the experiment were grown outside in pots, and the growth data from the 1997 growing season has been collected. Cold-temperature treatments were simulated to reflect climatic conditions in three major deployment regions, fall line climate, middle Piedmont and the cold areas (upper Piedmont). Cold-damage and growth data are being collected. If a screening procedure can be developed to mimic natural conditions and reflect the type of stress that the plants will be subjected to in the field, early selection will be possible. An added complication for developing early screening methods relates to the fact that extreme weather in the field occurs on average once every 10 years, thus it could take several years for the plants to undergo severe winter stress. Expected time of completion is August 1998.

James Grissom: Jim earned a B.S. degree in forestry from the University of Florida in 1983 and a Masters of Forest Resources and Conservation from the same University in 1986. Jim worked the next 10 years as a forest research technician with the U.S. Forest Service, Southern Institute of Forest Genetics located in Gulfport, Mississippi. He began a Ph.D. program in forest genetics at NCSU in the fall of 1996 and is supported by a Department of Forestry Graduate Research Assistantship.

Thesis Research Title: *Regulation of Biomass Partitioning in Loblolly Pine Seedlings: Influence of Root Processes Versus Shoot Processes*

Project Description: Plantation management options to enhance productivity are broadening, and now range from fertilizing to planting "off-site". Determining the suitability of particular families to these site conditions requires a full understanding of their adaptabilities. Adaptability differences may arise from characteristics of their physiological machinery, i.e., leaves and/or roots. In its broadest context, this project aims to assess the relative influence of processes in roots and shoots of loblolly pine seedlings, upon growth in relation to soil fertility. Specifically, it is planned to examine patterns of biomass partitioning in two contrasting provenances of loblolly pine by using a novel grafting method.

The experimental work has begun; grafting has been completed and one-year-old seedlings have been planted in the field. The graduate advisory committee has met twice; research proposal has been drafted but not finalized. The project will continue through 1999, with an expected completion date of June 2000. The "Mini-grafting" technique employed was highly successful, over 95% survival rate.

In a separate preliminary experiment designed to assess distinguishing traits of the two provenances (Texas and Atlantic Coastal) several promising traits were identified. Significant differences were detected in biomass partitioning and in root architecture.

Bin Xiang: In 1996, Bin enrolled in a forest genetics Ph.D. program at NCSU after earning a masters degree in quantitative ecology from the Chinese Academy of Plant Sciences. Bin's Ph.D. studies are primarily supported by an NCSU Department of Forestry Graduate Research Assistantship, however he receives a small supplement from the Cooperative Tree Improvement Program.

Thesis Research Title: *Genetic Analysis of Diallel Tests of Loblolly Pine.*

Project Description: Previous analyses of data from first generation progeny tests indicated time trends in genetic parameters for a single trait (height) and suggested that, if a single measurement is used, measurement at age 6 and selection one year later would maximize the gains per year as well as increase the financial returns from seed orchards. The well balanced data from second- generation diallel tests are being used to develop analytical methods for estimation of genetic parameters and genetic gain prediction, to examine time trends of genetic parameters for different traits (height, DBH, volume etc.), and to determine selection efficiency and optimal ages for different selection methods, including two-stage selection and other strategies to maximize genetic gains. The selection methods under consideration include mass selection, family selection, within family selection and index selection combining family and within family. The optimal ages for different selection methods may be estimated more reliably and may not be the same as those obtained from the first-generation tests. More importantly, with new and better information, alternative selection strategies, such as index selection for multiple traits, two stage selection and their optimal selection ages can also be investigated to get maximum genetic gains per unit time. Expected time of completion for Bin's Ph.D. program is August 1999.

Paul Shannon: Graduated from Clemson University with a B.S. degree in Forest Resource Management. In August 1997 Paul enrolled at NC State University and began work toward a Master of Science degree with emphasis on genetics, tree improvement and financial analysis. Paul has a 1/4 time assistantship from the Cooperative Tree Improvement Program for one year.

Thesis Research Title: *An Evaluation of The Financial Returns for Different Seed Orchard Establishment Options.*

Objectives:

1. To do a comparative analysis of genetic gains , costs, and financial returns associated with several different seed orchard development options. The comparative analysis will primarily focus on roguing existing second generation seed orchards, establishing 2.5 generation orchards, and establishing true third-generation orchards.

2. To develop guidelines for tree improvement managers to utilize when assessing different seed orchard development strategies.

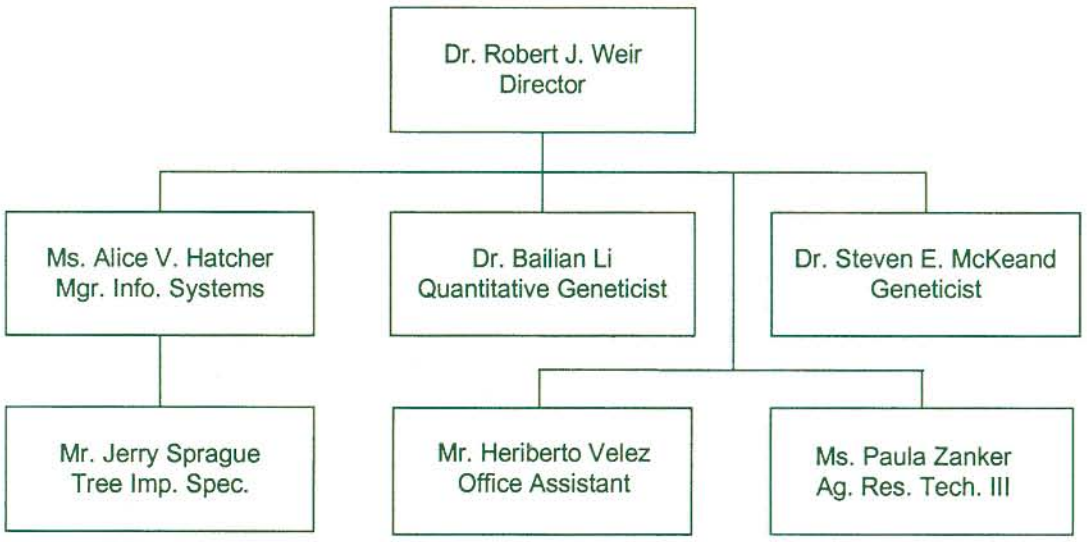
Paul is currently working to develop his research proposal and work plan. He expects to have the work plan ready for graduate committee review by the middle of June. Paul's expected date of completion is September of 1999.

Program Staff

Current program staff and areas of responsibility are depicted in the Cooperative Tree Improvement Program Organizational Chart below. During the past year, Jean Pittman resigned her position with the Tree Improvement Program and is currently employed in a similar position with the Extension Program in the Department of Forestry. We would like to thank Jean for her years of service to the program and we wish her the very best in her new position.

The position vacated by Jean was reduced from a full-time position to a part-time position (25 hrs/week). Heriberto (Eddie) Vélez assumed the part-time position as administrative assistant in August. While working for the program, Eddie will also be pursuing a degree in biochemistry. We are delighted to have Eddie on board and have already begun to rely on his many excellent skills and abilities.

Cooperative Tree Improvement Program
Organizational Chart - May, 1998



MEMBERSHIP OF THE TREE IMPROVEMENT COOPERATIVE

Alabama Forestry Commission
Champion International Corp.
Georgia Forestry Commission
International Paper Company
Jefferson Smurfit Corp.
MacMillan Bloedel Packaging, Inc.
N. C. Division of Forest Resources
S. C. Commission of Forestry
Tenneco Packaging Corp.
Union Camp Corp.
Virginia Department of Forestry
Bowater, Inc.
Chesapeake Forest Products
Gulf States Paper Corp.
Fort James Corp.
Kimberly Clark Corp.
Mead Coated Board
Rayonier, Inc.
Temple Inland Forest, Inc.
The Timber Company
U.S. Alliance Coosa Pines Corp.
Westvaco Corp.

We were pleased to welcome to the Cooperative two new members this year. Gulf States Paper Corporation joined on July 1, 1997 and Temple Inland Forest, Inc. became a member on January 1, 1998. They will be participants primarily in the Upper Gulf breeding region. We look forward to a long and rewarding association with both organizations. Below is a short profile of each organization.

NEW MEMBER PROFILES

Gulf States Paper Corporation

The company that became Gulf States Paper Corporation originated in Marseilles, Illinois in 1884 as a small mill that made wrapping paper from wheat straw. At Gulf States we are proud of our continual growth and progress through more than one hundred and thirteen years. We pride ourselves on the dedication of our associates, continual modernization of our equipment, and an abiding belief that uncompromising quality in our products and services is vital to a successful, long-term business relationship.

Gulf States employs more than 2100 people at plants in five states and sales offices in the Chicago and New York metropolitan areas. Four operating divisions--Pulp & Paperboard, Paperboard Packaging, Wood Products, and Natural Resources--make up the fully integrated Gulf States Paper Corporation. The company is the third largest U. S. Producer of solid bleached sulfate (SBS) folding boxboard and among the nation's top 10 SBS folding carton manufacturers.

The Pulp and Paperboard Division manufactures bleached kraft pulp and solid bleached sulfate(SBS) paperboard at its Demopolis, Alabama mill. This division also markets a nearly equivalent amount of paperboard at an external mill located in Crossett, Arkansas. A portion of the SBS board is used in Gulf States' own plants for food and consumer goods packaging. Pulp and paperboard are also sold on the open market.

The Paperboard Packaging Division's plants in five states--Alabama, Kentucky, North Carolina, Missouri, and Texas--manufacture consumer packaging in a variety of styles, sizes, and categories. The division produces packaging for markets such as baked goods, frozen food, dry food, fast food, health care, and consumer products.

The Wood Products Division manufactures high-quality lumber and related products from southern yellow pine at its Moundville, Alabama sawmill. This new state-of-the-art facility uses computer-controlled systems to produce the optimum yield from tree-length stems. The straightest, tallest trees become utility poles; the remaining trees are cut into log lengths and sawed into lumber. The lumber is graded and kiln-dried to produce a variety of products for domestic and international markets.

The Natural Resources Division's timber and land resource management professionals are the stewards of Gulf States' 375,000 acres of Alabama woodlands that provide raw materials for the company's products. The goal is to produce high-quality trees that grow quickly to usable size, then scientifically replant to ensure productive forests for future generations.

A large part of Gulf States' program of land management is tied into environmental concerns. The company meets or exceeds the guidelines of the American Forestry and Paper Association's Sustainable Forestry Initiative and manages all its land with a concern for the impact on the environment.

Temple Inland Forest

Temple-Inland Forest provides the forest management, regeneration and procurement services for Temple-Inland Inc. operating subsidiaries.

Temple-Inland Inc., a Fortune 300 company with total annual revenues of over three billion dollars, is a holding company based in Diboll, Texas that conducts all of its operations through its subsidiaries. Temple-Inland's operations include corrugated container products, bleached paperboard products, building products, timber and timberlands, and financial services.

Temple-Inland's paper group is vertically integrated with four linerboard mills, three corrugating medium mills, 39 box plants and nine specialty converting plants. The bleached paperboard operation consists of one large mill located in Evadale, Texas.

The building products group manufactures a wide range of building products, including lumber, plywood, particleboard, gypsum wallboard and fiberboard.

Forest resources include approximately 2.2 million acres of timberland located in Texas, Louisiana, Georgia and Alabama.

The Financial Services group consists of savings bank activities, mortgage banking, real estate development and insurance brokerage.

Temple-Inland is a Delaware corporation that was organized in 1983. Its principle subsidiaries include Inland Paperboard and Packaging, Inc.; Temple-Inland Forest Products Corporation; Temple-Inland Financial Services Inc., Guaranty Federal Bank, F.S.B.; and Temple-Inland Mortgage Corporation.

Headquartered in Rome, Georgia, Temple-Inland Forest in Georgia and Alabama is headed by S.B. Kinne III, general manager. Leading his management team are Ron Cockrel, operations manager; Steve Raper, chief forester; and Tom Ritch, operations administrator.

Regional managers are Ted Swope, Cedartown region; John Davis, Gainesville region; Tracy Dickerson, Douglasville region; and Bill Berry, Jasper region.

Temple-Inland Forest is the largest private landowner in the following counties: in Alabama, Cherokee and St. Clair; in Georgia, Carroll, Chattooga, Cherokee, Coweta, Elbert, Haralson, Heard, Pickens, and Polk.

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS OF THE COOPERATIVE

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Belonger, P.J., S.E. McKeand, and J.B. Jett. 1997. Wood density assessment of diverse families of loblolly pine using x-ray densitometry. P. 133-142. In: Proc. 24th South. For. Tree Impr. Conf.

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Hodge, G.R., C.J. Masters, R.S. Cameron, W.J. Lowe, and R.J. Weir. 1997. Seed orchard pest management: The case for Forest Service R&D. Journal of Forestry, Vol 95, No1: pp29-32.

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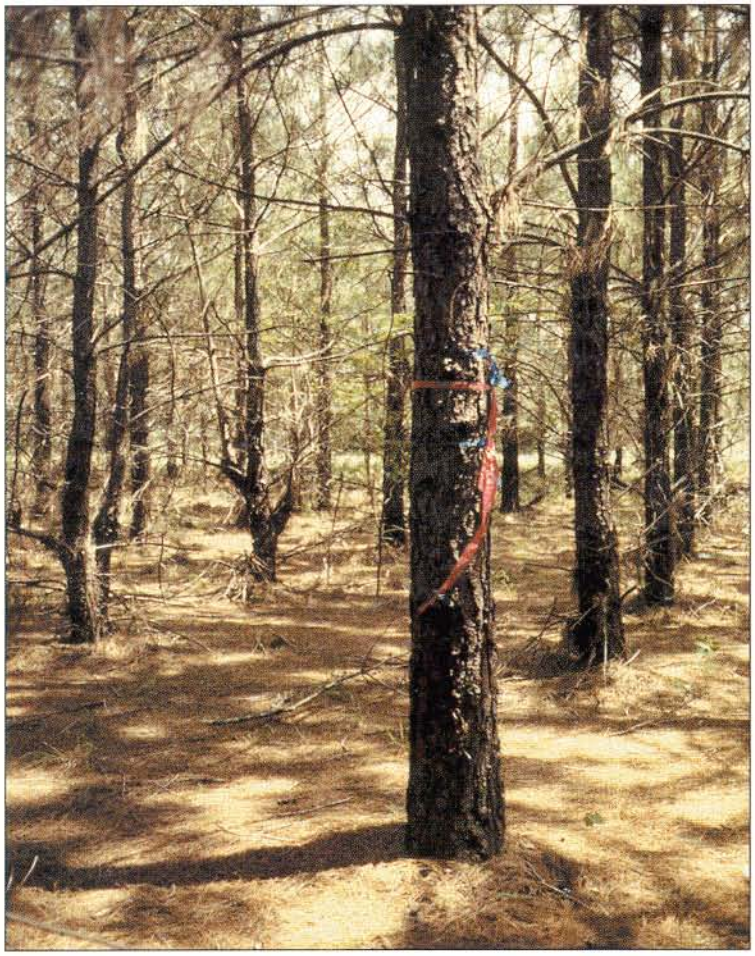

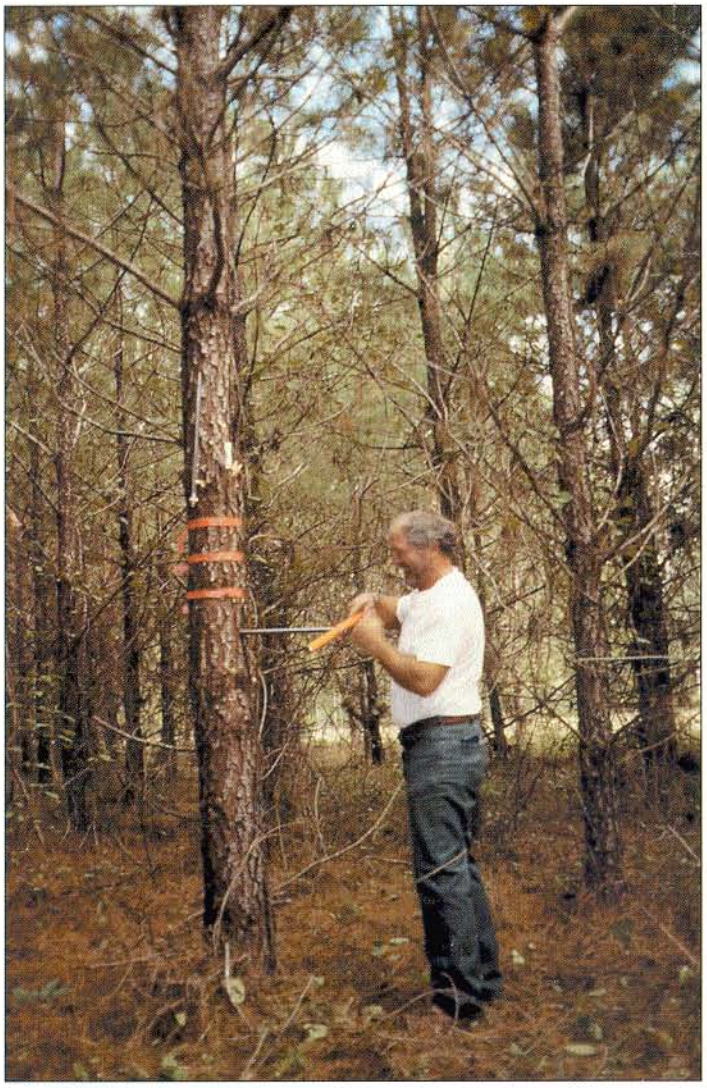

During the past year we graded 124 new 3rd generation selections in 42 Diallel Test Series. Many outstanding trees were selected, four of which are depicted here.

Top Left: Barbara McCutchan shows off a very good selection on lands of Westvaco Corp. in the coastal plain of South Carolina.

Left Middle: An outstanding selection in a progeny test established by MacMillan Bloedel Packaging, Inc. near Camden, Alabama.

Bottom Left: Ray Moody admires a six year old selection found in a South Carolina Commission of Forestry Piedmont test.

Top Right: Chuck Little extracts an increment core for wood density analysis from a selection made in a Georgia Forestry Commission test in the upper coastal plain of South Georgia.