38th

NORTH CAROLINA STATE UNIVERSITY- INDUSTRY COOPERATIVE TREE IMPROVEMENT PROGRAM

1 9 9 4

ANNUAL REPORT

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

Front Cover

Dr. J.B. Jett, Associate Director of the Cooperative Tree Improvement Program, stepped up to the position of Associate Dean of Research and Outreach, College of Forest Resources, N. C. State University, effective April 15, 1994. All of us congratulate J.B. on his promotion, wish him the very best in his new role with the College, and look forward to working with him in his capacity as Associate Dean.

For nearly 26 years J.B. has made an enormous contribution to the success of the Tree Improvement Cooperative. His diverse experience and unique mix of skills have contributed in many, many ways to the accomplishment of the program. Above all has been J.B.'s extraordinary ability to work with people. He has been equally comfortable with detailed technical deliberations among scientists, problem solving sessions with field personnel, or planning and strategy sessions with vice presidents, state foresters, and woodland managers. J.B.'s technical ability, practical sense, and unquestionable integrity quickly earn him the confidence and trust of all with whom he interacts, both personally and professionally. We have benefited enormously from our association with J.B.. While a successor will be chosen it is unlikely that a "replacement" can be found.

Best wishes to you Associate Dean Jett, and thank you for all that you have done for the Tree Improvement Cooperative from all of us. You have measurably contributed to the forest productivity in our region.

EXECUTIVE SUMMARY

PROGRESS REPORTS FOR RESEARCH:

Twelve year results for one location of the Intergenotypic Competition Study showed loblolly families performed basically the same in mixed versus pure plots.

Ten year results of the Florida Loblolly Provenance Trial indicate that the Southern Atlantic Coastal Plain, Marion County and Gulf Hammock sources can be combined for advanced generation breeding.

Early results from verification trials being conducted at the Rust Screening Center suggest that under the standard inoculum level (50,000 spores/ml), percent galled seedlings at 3 months is as effective at predicting field performance as any trait or combination of traits at 7 months.

The computer-based simulation model indicates it will be possible to enrich elite populations from the mainline population for 3-4 generations without reducing gains in the elite breeding program.

Updates on nine research studies indicate the intensity of research efforts underway in support of resource development and utilization.

ACTIVITY IN THE BREEDING, TESTING, AND SELECTION PHASE OF THE PROGRAM CONTINUES TO INCREASE.

After the current planting season (1994), 84% of the progeny tests will be established.

To date, 116 third cycle selections have been made from 65 tests; another 42 tests will be examined this fall.

An economic analysis of the third cycle breeding strategy shows elite populations to be an exceptionally good investment.

The Cooperative's Database Management System is under development and should be operational in the summer of 1995 providing Cooperators with immediate access to the Cooperative database stored in Raleigh.

The Cooperative's 1993 seed collection was slightly smaller than in 1992 but still produced 28.3 tons of highly selected loblolly pine seed. Second generation seed accounted for 38% of the total collection.

The Cooperative presently has 4 graduate students working on degrees and conducting research important to the program.

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INTRODUCTION

The North Carolina State University – Industry Cooperative Tree Improvement Program has completed 38 years of continuous operation. Second cycle seed orchards are producing, in fact they are producing nearly half of current seed harvests; the breeding is complete, and a majority of the tests have been established that form the foundation for our third cycle seed orchards, which will be grafted by the end of this decade; a breeding plan has been approved that, when implemented, will develop the resource base for a fourth cycle of genetic improvement for loblolly pine. In the last dozen years alone, sufficient genetically improved seeds have been produced to provide seedlings for reforestation of over 17 million acres. This is a record of accomplishment for which members and Program staff can be justly proud.

Tree improvement has been and continues to be a very beneficial and cost effective technology. In partnership with effective silviculture, we have contributed to substantial increases in forest productivity in the region. Yet now, more than at any time in the past four decades, our efforts are important. The pressures for producing more wood raw material on less land at a lower cost increase daily. Because of environmental concerns for endangered species, major cut–backs in timber production in the Pacific Northwest have occurred. Important set asides for wetland conservation and endangered species have occurred in the Southeast. Urban sprawl continues to reduce the commercial timberland acreage in the region. One industry executive has estimated that by the end of this century 40% of the land on which we now grow commercial timber will be removed from production. Yet, the demand for wood products is growing and global competition intensifies as other regions of the world, e.g. Latin America and Asia with their inherently fast growing species and favorable climates, bring more wood and wood products to market.

The future competitiveness of the extensive southeastern forest based industry depends on the success of our past work and the realization of the potential for achieving even greater gains in the future. Tree improvement must and is changing as we learn to squeeze more genetic gain from our intensively managed populations at a faster rate and with lower costs. Our third–cycle breeding system, if aggressively implemented, offers great potential for making a key contribution. Our growing collaboration with biotechnology offers similar promise.

It is an exciting time to be involved with the development of such a critical technology. We look forward to the activities of our 39th and succeeding years with enthusiasm.

RESEARCH

NCSU INTERGENOTYPIC COMPETITION STUDY

Intergenotypic competition can have an important effect on selection and deployment options in a tree improvement program. The Cooperative uses single row plots in genetic tests which serve as the base populations for advanced generation selections. As a consequence, each family is neighbored by two different families. As cooperators began to use block plantings of pure families on a large scale, there existed the possibility that families chosen as winners in progeny tests (mixed plantings) would not be the best to use in reforestation programs under a different competitive situation if a family x competition type interaction existed.

The objectives of this study are:

1. To determine the effect of inter–family competition in the yield of plantations composed of selected open–pollinated loblolly pine families.

2. To assess the impact of family x competition type interaction on the relative performance of loblolly pine families.

The study consists of two experiments. Experiment 1 (established by Scott Paper and MacMillan–Bloedel) is designed to determine the influence of inter–family competition in plantation yields. Experiment 2 (established by Champion) tests for family x competition interactions as well as supplements the information on plantation yields obtained in Experiment 1. Both experiments utilized 16 seed orchard derived open–pollinated loblolly pine families from the Atlantic Coastal Plain, Florida, and Lower Gulf regions of the cooperative. Results from Experiment 2 at Champion International are presented here. Results of Experiment 1 are pending.

A split–plot design was used in Experiment 2. Main plot treatments are families, and subplots represent the two different competition types. Each subplot is a 25 tree square block, established at 8' x 8' spacing. The inner nine trees serve as measurement trees; with the outer sixteen trees acting as a border row. The mixed subplot was planted in the following manner:

x	x	x	x	x
x	o	x	o	x
x	x	x	x	x
x	o	x	o	x
x	x	x	x	x

Trees designated with an x are individuals from families chosen at random and trees designated as o are representatives of the family of interest in the main plot. Each mixed plot contains four members of a specific family, with each member surrounded by trees from random families. Of the original six replications, three have survived.

Measurements, taken after the 12th growing season, showed no significant ($P \leq .05$) differences between the competition treatments for any of the traits assessed (Table 1). For growth traits, rust levels, and survival there were no significant family x competitive effects, indicating that a family's performance in mixed plots is indicative of its performance in pure plots. For height, the correlation between family means in the pure versus

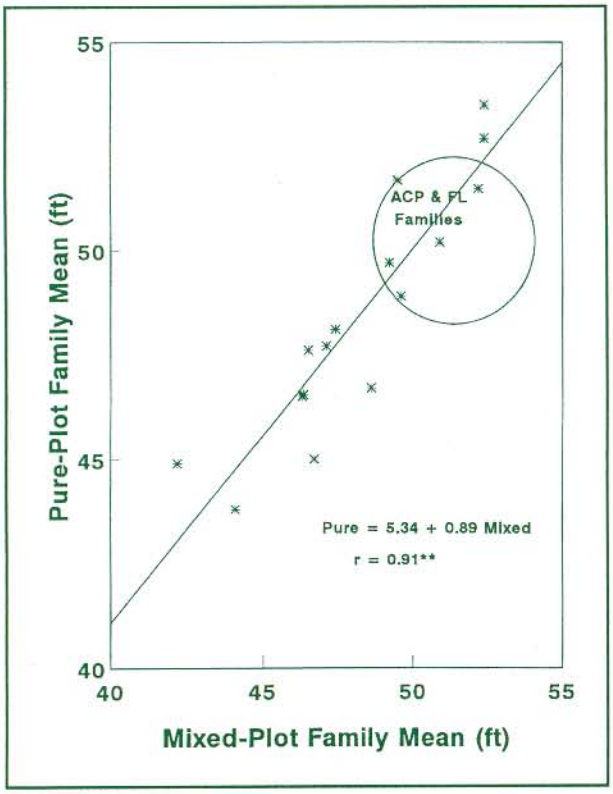
Table 1. Trait averages of two competition types.

TRAITS	PURE PLOTS	MIXED PLOTS
Height (ft)	48.4	48.2
DBH (in)	6.7	6.8
Volume (ft^3)	4.6	4.6
Rust (%)	13.9	13.2
Straightness	3.5	3.8
Survival (%)	93.2	93.2

mixed plots (Figure 1) was very high (r = 0.91**), and the slope did not differ significantly from b = 1.0 and, as expected, the intercept was not different from a = 0. The same was true for DBH and volume, but the correlations were lower between family performance in pure vs. mixed plots. For straightness score, there was a significant competition x family interaction and a negative correlation (r = –0.54*) between a family's performance in pure versus mixed plots. Without further investigation, this interaction is difficult to explain.

The stability of loblolly pine families across different environments (competition type in this study) is once again demonstrated. Families that do well in one environment, whether it be a particular type of competition, nutrient level, soil moisture regime, or other site productivity indicator will typically do well under other levels of the same factor. There is little evidence that deploying the best families based on row–plot progeny test results will be a problem for forest managers. This does not imply that per acre yields can be accurately predicted from row–plot trials, but it does imply that rankings of families will not change.

Figure 1. *1981 NCSU Competition Study (Champion International) 12-year results: Height in pure vs. mixed plots.*



A final comment about the source of origin of the 16 families is in order. The 5 best growing families are all from the Atlantic Coastal Plain and Florida provenances; the other 11 are from the Lower Gulf (Figure 1). This is yet another piece of evidence for the growth superiority of Atlantic Coastal Plain and Florida Loblolly over Lower Gulf trees.

FLORIDA LOBLOLLY PROVENANCE TRIAL (10–YEAR–RESULTS)

In 1982 and 1983 the Florida Loblolly Provenance/Progeny trials were established by members of the Cooperative and by members of the University of Florida Cooperative Forest Genetics Research program. An objective of this study was to thoroughly evaluate the potential of the Marion County (MC) and Gulf Hammock (GH) (from Levy Co.) sources of loblolly pine in the southern Atlantic Coastal Plain and Lower Gulf regions of the Southeast.

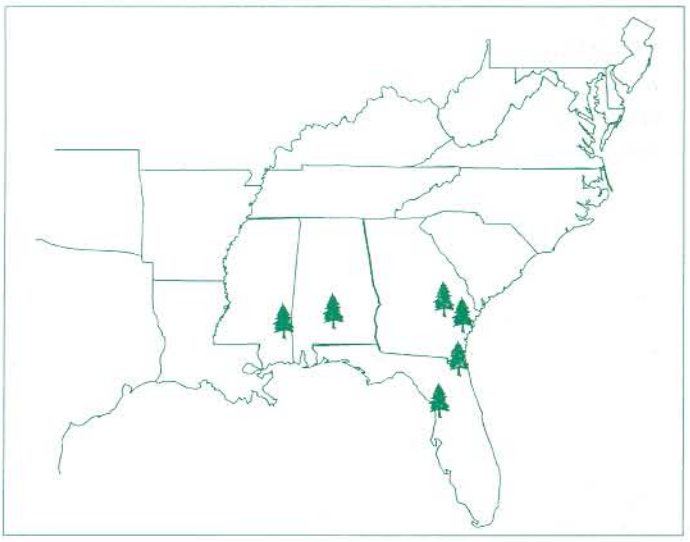
There are several unique aspects to the Florida sources of oblolly pine. The first is the relatively small base population of selections in both Cooperatives. There also seems to be little opportunity to expand the breeding base by acquiring new selections from the Florida sources. One objective of the study was to determine if improved sources of loblolly pine from the Florida sources could be included in the advanced generation improvement program with the Lower Gulf and South Atlantic Coastal Plain sources.

A second complexity of the Florida source is that despite a very restricted range in peninsular Florida, the MC and GH sources evolved on very different soil types. Marion County is typified by sandy soils (Quartzipsamments) in the inland areas while Levy County has wet, marl type soils (Aqualfs) with high pH's nearer the Gulf Coast. Differences such as these are ideal for the formation of edaphic races of loblolly pine which might respond to different soil types. A second objective of the trials was to determine if differences existed between the MC and GH sources.

A total of six trials (Figure 2) have been retained in the study through age 10. Each trial was established with open–pollinated families from the following sources of loblolly pine:

- Marion County, FL
- Lower Gulf Coastal Plain (LG)
- Gulf Hammock, FL
- Southern Atlantic Coastal Plain (ACP)

Figure 2. Location of Florida Loblolly Provenance/Progeny Trials.



A total of 15 families represented each source in the study, although not every family was planted in each trial. Based on the 10–year results (Table 2), the Southern Atlantic Coastal Plain, Marion County, and Gulf Hammock sources are very comparable for growth, rust resistance and survival. The straightness of the Marion County and Gulf Hammock sources was inferior to the Southern Atlantic Coastal Plain and Lower Gulf sources. Based on these results, it appears that the Southern Atlantic Coastal Plain, Marion County and Gulf Hammock sources could be combined into one region for advanced generation breeding. This breeding population would be restricted to the deep South. We have seen from the Cooperative's Good General Combiner tests (1986 Annual Report) that Marion County and Gulf Hammock sources perform very poorly when moved north of coastal Georgia and the Lower Gulf.

There appears to be a slight growth advantage (especially for height) of the Gulf Hammock source (wet, marl soil origin) compared to the Marion County source (sandy soil origin) (Table 2). The two Florida sources were essentially equal for the other traits.

The poor growth and rust performance of the 15 Lower Gulf families were surprising. They averaged about 3.5 feet shorter and had about 10% more fusiform rust than the other three sources. The inferior growth of these families suggests that use of non–local sources such as Atlantic Coastal Plain families is preferred for the Lower Gulf region. Fortunately, seed orchards in this region of the Cooperative were established with many clones from the Atlantic Coastal Plain. As orchards are rogued, the Lower Gulf clones have been removed in greater frequency, and the genetic quality of the orchards have increased.

Table 2. Source means for different traits at age 10 years combined over six test locations in the Florida Loblolly Provenance/Progeny Trials [1].

SOURCE	HEIGHT (FT)	VOLUME/ TREE (FT^3)	STRT. SCORE [2]	% RUST	% SURVIVAL
Southern Atlantic Coastal	39.5 [b]	3.2 [b]	3.0 [b]	45 [b]	79 [a]
Gulf Hammock, FL	40.9 [a]	3.6 [a]	3.3 [a]	46 [b]	75 [a]
Marion County, FL	40.1 [b]	3.4 [a]	3.5 [a]	43 [b]	75 [a]
Lower Gulf	36.7 [c]	2.7 [b]	3.1 [b]	54 [a]	77 [a]

[1] *Trait means followed by the same letter are not significantly different at $p \leq .05$.*
[2] *Straightness measured on a 1-6 scale; 1 = straight and 6 = crooked.*

VALIDATION OF RESISTANCE SCREENING CENTER RESULTS

The Resistance Screening Center is operated by the Forest Pest Management staff of the USDA Forest Service's Southern Region, State and Private Forestry. The Center is located near Asheville, NC at the Bent Creek Experimental Forest. The Resistance Screening Center evaluates pine seedlings for resistance to fusiform rust. Potential benefits of utilizing the Screening Center include:

Reduced Evaluation Time

Field tests require 4+ years to develop adequate infection levels for rust evaluation. Evaluations through the Screening Center currently require 9 months.

Availability of Rust Evaluations for All Clones

Some field tests have low infection levels and thus provide inadequate information for parental assessment. Evaluations of all clones for rust performance are possible through the Screening Center.

Optimize Site Selection for Evaluation of Other Traits

In order to maximize the opportunity to obtain meaningful rust evaluations from progeny tests, high rust hazard sites must be utilized to insure moderate to high infection levels. The use of such sites can, however, reduce the precision of genetic evaluations for other traits of interest (i.e., growth, form).

Three verification trials, consisting of three diallel test series, are being processed at the Screening Center to provide a database for development of a loblolly pine index to predict field performance. The three test series being used for verification are:

- Diallel Test Series 121 (MacMillan Bloedel) – field tests established in 1988–89 in Wilcox County, AL.
- Diallel Test Series 102 (Mead Corporation) – field tests established in 1988–89 in Dooly County and Sumter County, Georgia.
- Diallel Test Series 157 (MacMillan Bloedel) – fieldtests established in Wilcox County, AL in 1989–90.

Field infection levels in the tests listed above range from 30% to 60%.

The Resistance Screening Center has completed the processing of Test Series 121. The remaining two Test Series (102 and 157) are currently being processed and results should be available in the Spring of 1995.

Two complete screening tests were run on Series 121 – one test at the standard inoculum level of 50,000 spores/ml and one test at a reduced inoculum level of 20,000 spores/ml. Each test consisted of 120 seedlings per seedlot. Traits assessed included:

- Percent Galled Seedlings at 3 months.
- Percent Galled Seedlings at 7 months.
- Percent Fat Galls at 7 months. (Galls are classified as fat when the stem is twice the diameter of a normal seedling).
- Percent Smooth Galls at 7 months. (Proportion of galled seedlings with smooth bark on the gall).

Preliminary results, shown in Table 3, are very encouraging. Preliminary findings include:

- Under the standard inoculum level (50,000 spores/ml), percent galled seedlings at 3 months was as effective at predicting field performance as any trait or combination of traits at 7 months.
- Under the reduced inoculum level (20,000 spores/ml), inclusion in the model of percent fat galls at 7 months with percent galled significantly improved the model over only using percent galled at 3 or 7 months.
- Percent smooth galls added little to the effectiveness of the model at either inoculum level.

TABLE 3. Preliminary Results from Resistance Screening Center for Test Series 121.

MODELS	STANDARD INOCULUM	REDUCED INOCULUM
	R^2 (Full-Sibs)	
% Galled (3 mo.)	.52	.49
% Galled (7 mo.)	.40	.36
% Galled, % Fat Galls (7 mo.)	.52	.61
% Galled, % Fat Galls, % Smooth Galls (7 mo.)	.52	.62
	R^2 (Half—Sibs)	
% Galled (3 mo.)	.54	.58
% Galled (7 mo.)	.37	.41
% Galled, % Fat Galls (7 mo.)	.53	.69
% Galled, % Fat Galls, % Smooth Galls (7 mo.)	.53	.71

- Under both inoculum levels, percent galled at 7 months was less predictive of field performance than percent galled at 3 months.

The same inoculum levels and traits are being assessed on the two test series currently being processed. In addition, percent galled seedlings will also be assessed at 5 months.

COMPUTER MODELING OF BREEDING STRATEGIES

The North Carolina State University-Industry Cooperative Tree Improvement Program adopted a breeding strategy in 1992 for the third cycle of selection and breeding. The strategy aims to provide maximum genetic gains in the short term as well as to maintain genetic diversity to ensure the viability of breeding populations in the long term. The details of the strategy may be found elsewhere (McKeand and Bridgwater 1992), but the fundamental population structure is a hierarchy of three populations. A **mainline breeding population** will have about 160 parents available for each Cooperative member and will be maintained in small sublines (size 4 in the plan) primarily to provide for long term genetic gains. The most intensively selected and managed level in the hierarchy will be **elite populations** of about 40 parents. The elite populations will be bred as rapidly as possible to provide maximum short-term genetic gains. A third level in the population hierarchy will be extreme genotypes maintained as a **genetic diversity archive.**

The goal is to cycle elite populations as rapidly as possible. Since production populations will be derived from these, genetic gains will be realized from plantations sooner than if larger populations, requiring more time and effort, were used. Elite populations may be managed in a variety of ways and will be structured to meet the needs of individual or groups of cooperative members. One option under evaluation is to subdivide elitepopulations into sublines as small as 4 parents each and to mate these in diallels which will include self-fertilization. This action will result in inbreeding and an increase in homozygosity at a rate that depends on the method of selection employed. When inbreeding reaches levels that require reduction, the plan is to enrich the elite populations from the much larger mainline population which will have been bred at a slower rate. The greater selection intensity possible in the larger mainline populations is expected to provide material suitable for inclusion in the elite populations. Introductions from the mainline populations will reduce coancestry in elite populations.

There are risks inherent in adopting the strategy described above. One way to reduce the risks of adopting an untested strategy is to model aspects of the strategy. Such a model was developed and is being used to help choose among alternatives as the strategy is implemented. The basic structure and assumptions of the computer–based simulation model are described in Bridgwater, Woodbridge and Mahalovich, 1993.

Alternatives addressed to date indicate that:

- Selecting the best individual from the four best families (self or outcross) ranked on expected breeding values is an alternative that will give good genetic gains and result in relatively moderate rates of increase in coancestry within sublines;

- Assigning parents to sublines at random, or disassortatively, rather than by positive assortment will increase within-subline genetic variance and result in greater increases in breeding value for the first generation of selection and mating;

- It will be possible to enrich elite populations from the mainline population for 3–4 generations without reducing gains in the elite breeding program.

RESEARCH STUDY UPDATES

Inbreeding Study

Age six assessments are currently being completed on the Inbreeding Study. Four levels of inbreeding, created from matings among selfs (F = .50), full–sibs (F = .25), half– sibs (F = .125) and unrelated matings, are being compared for growth, rust infection, form and survival. Analysis of the six–year data should be completed this summer.

Virginia Pine Model Population

Working in conjunction with Bowater (CWD), Floyd Bridgwater (USFS) has completed the grafting of a model Virginia Pine population. The population consists of three 6–parent diallels. Breeding is being initiated this spring.

Plantation Selection Seed Source Study

Breeding has been completed for the Plantation Selection Seed Source Study and the first field test was established by Westvaco Corporation in the spring of 1994. Several additional field trials will be established in the fall of 1994 and spring of 1995. Results from this study will be used to evaluate the patterns of variation among and within sources of the plantation selection population.

Wide Crosses Among Southern Sources of Loblolly Pine

Establishment of the field trials for the Wide Cross Study has been completed by Container Corporation. The study will determine if hybrid vigor exists in interprovenance crosses of loblolly pine in the southern Atlantic Coastal Plain and Lower Gulf Coastal areas. Three tests were established in 1992 and three in 1993. The trials are located in Nassau Co., FL, Escambia Co., AL, Conecuk Co., AL and Ware Co., GA.

Site selection is underway for the Plantation Selection Seed Source Study. Pictured is a Georgia Forestry Commission test site.

Scion Maturation Study

The Scion Maturation Study has been established to determine if clones of different ages, established together in advanced generation orchards, will grow and compete with equal effectiveness. Grafting was completed in the Spring of 1992. The three piedmont locations were established by Bowater (SDW), Bowater (CWD), and Federal Paper Board. Three coastal trials were established by South Carolina Commission of Forestry, Georgia Forestry Commission, and Container Corporation of America. The studies are scheduled for first assessment at age 5.

Inbreeding Grafting Study

The Inbreeding Grafting Study has been established to determine whether a loss of vigor in inbred selections will occur and result in a decline in seed production that would effect seed orchard or breeding orchard efficiencies. Six locations have been successfully established. Organizations participating in the study are: International Paper Company, Kimberly–Clark Corporation, South Carolina Commission of Forestry, Scott Paper Company, Packaging Corp. of America, and Procter and Gamble (now Weyerhaeuser). The first assessment has been scheduled for the fall of 1997.

Age Trends of Genetic Parameters of Wood Properties for Loblolly Pine

The study of age trends for genetic parameters of wood properties in loblolly pine being conducted by graduate student Kevin Harding continues to make progress. Since the initiation of the study in 1992 approximately 1800 cores have been collected, processed and scanned with the x–ray densitometer. Current work centers on editing of the raw data and the assembly of the final data sets for statistical analyses. Anticipated completion of the study is early 1995.

Phenological Variation in Shoot Elongation and Diameter Growth and Their Relationships to Latewood Formation and Wood Specific Gravity in Loblolly Pine

This research study supported by Georgia Pacific will intensively sample 5–year–old trees from 8 families from each of four provenances in the Early Selection Verification Trial. The study will determine how wood properties are affected by the timing of the initiation and cessation of height and diameter growth of trees. Results will indicate if provenances and families can be selected that exhibit both rapid growth and favorable characteristics for wood products. Detailed height and diameter measurements were taken throughout the 1993 growing season. These measurements will be repeated during the 1994 growing season and wood samples will be collected in the fall of 1994.

Provenance and Family Variation in Wood Properties in Loblolly Pine

This study is a supplement to the research study "Phenological Variation in Shoot Elongation and Diameter Growth and Their Relationships to Latewood Formation and Wood Specific Gravity in Loblolly Pine." This supplemental study is being jointly funded by Container Corp., Rayonier, Scott Paper Company and Union Camp Corporation. The study will evaluate provenance and family variation in the wood properties of older trees from four of the Florida Loblolly Provenance/Progeny Trials established in 1982 and 1983. Traits being assessed include wood specific gravity, within ring and between ring specific gravity, tracheid lengths and percent extractives. Bark to bark increment cores were taken from trees in all four trials this spring. Analysis of the samples will begin this summer.

BREEDING, TESTING, AND SELECTION

STATUS OF PROGENY OUTPLANTINGS

Breeding of the Cooperative's nearly 4000 plantation and second generation selections has been completed and Cooperators are now aggressively pursuing completion of the outplantings. A record number of tests (164) were established in 1993. The current establishment year (1994) should be the peak year with 195 tests planned for outplanting. In 1995, the outplanting workload should drop to 120 tests. Currently, sixty–eight tests are scheduled for outplanting in 1996, completing test establishment for the current breeding and testing cycle.

The distribution of progeny tests for the current cycle is shown in Figure 3.

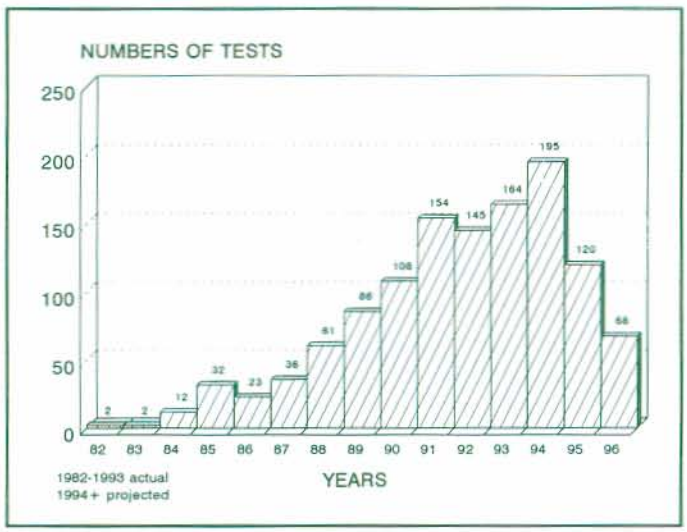
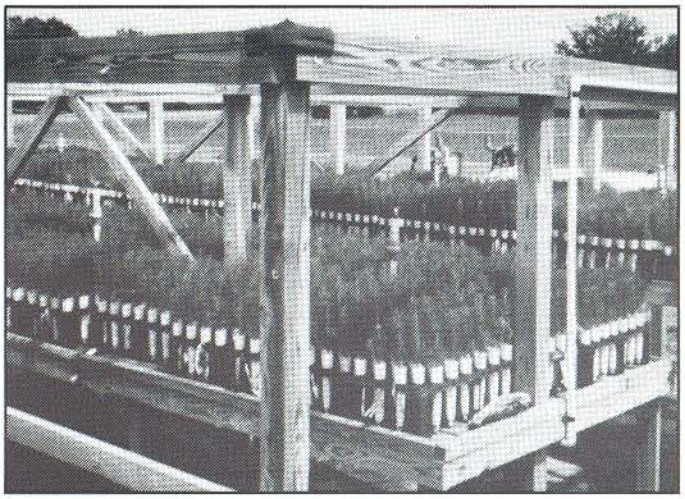


Figure 3. *Distribution of progeny test establishment.*

Progeny test establishment is currently a major activity of Cooperative members. Bill Mueller proudly shows off one of Packaging Corporation's outstanding 1992 tests.

THIRD GENERATION SELECTIONS

The first third generation selection was identified and graded for Westvaco in February, 1990. Since then a total of 116 selections have been made for 8 organizations. At this stage it is difficult to know the range of quality in diallels since the base of comparison is quite small. Therefore, a conservative approach is being taken and more selections are probably being made than will actually be needed. As more diallels are selected from, there will probably be fewer trees selected from any given test series. At present 116 selections have been made in 65 tests. This fall, an additional 42 tests will be ready for selection followed by 80 more tests in the fall of 1995. A big push in the next 5–7 years will be making selections from the second generation and plantation diallel tests.



Kimberly Clark's progeny test seedlings growing in their very functional shadehouse.

THIRD–CYCLE BREEDING STRATEGY: AN ECONOMIC APPRAISAL

A third–cycle breeding strategy for loblolly pine (*Pinus taeda* L.) has been developed to provide maximum and accelerated genetic gain in the short–term and to maintain genetic diversity for long–term improvement. A hierarchy of three populations will be managed with differing levels of intensity. The mainline population will consist of 160 selections that are available to each member operating a tree improvement center in a given geographic region. These populations will be managed as subdivided breeding populations (40 sublines of 4 trees each) primarily to provide for long–term genetic gain. The most intensively selected and managed hierarchy will be elite populations. An intensively selected group of approximately 40 trees will be managed to provide maximum and accelerated short–term genetic gain for each member's program. A third hierarchy will be the genetic diversity archives managed to preserve a broad range of genotypes, including those with extreme breeding values for individual traits. These diversity populations represent insurance for environmental or selection criteria changes in an uncertain future.

This new breeding strategy has improved efficiency and lower costs resulting from reduced population sizes. The increased selection intensity used to reduce the population sizes and the increased rate of breeding made possible with fewer trees will substantially increase genetic gains and value returns in the next cycles of improvement. At the same time, the long–term well–being of the genetic resource will be maintained by judicious management of all three hierarchies.

Given the hierarchal breeding system adopted for our Cooperative, it was of interest to quantify the financial advantage the elite population strategy would provide. Clearly, a small population that is selected more intensively and bred more rapidly should provide greater economic return. The focus in the following analyses, a collaborative effort between the Cooperative Staff and David Todd of Champion International, was to determine the magnitude of this advantage and to assess the nature of any additional risk that might be encountered.

For purposes of the economic analyses, the following assumptions were used:

- A typical southern mill using 500,000 cunits of wood per year (a cunit = 100 cubic feet of solid wood).
- The typical mill manages as fee land 200,000 acres of land in pine plantations.
- Approximately 1/3 of the annual mill furnish is harvested on fee land and 2/3 of the furnish is purchased from other land owners.
- Annual planting with seedlings derived from seed orchards is 8000 acres.
- Genetic gains produced from breeding strategies are fully realized.
- All cash flows are before taxes.
- The analyses spans 6 elite cycles and 4+ mainline cycles (110 years).
- Wood values were conservatively escalated at 1% per year.
- Annual breeding costs were assumed to be equal for elite and mainline strategies with more progress being made with the smaller elite populations. This is a very conservative assumption since experience suggests that elite populations can, not only progress more rapidly, but at lower annual costs.

The expected gains for elite and mainline populations have been translated into wood volume production over cycles and shown in Figure 4. Substantially more wood is projected to be produced from the elite population breeding strategy for the period of the analyses. The stair step appearance of the wood volume gains over the firm's land base reflects the life expectantcy of each seed orchard developed from successive cycles of breeding, testing and selection. These estimates are conservative since the increments of gain to be realized from seed orchard roguing have been ignored. In reality the profile of wood volume would be expected to have several smaller steps within each cycle that would be realized following each orchard roguing.

In estimating the benefits of elite and/or mainline breeding, an economic value was assigned to the extra wood produced based on the marginal or replacement wood value. Forest economic analyses have traditionally used market stumpage prices as the wood value, however, the cost structure of wood delivered is a distribution of many cost levels (Figure 5). The real value of improving forest productivity is the ability to replace the most expensive wood with generally cheaper wood produced on company owned and managed fee land. Delivered fee wood cost in our region has been estimated by Timber Mart South to be $52.00 a cunit. The average cost of all delivered wood is $83.00 a cunit, while the most expensive 55,000 cunits purchased annually is $98.00 per cunit. Thus, the marginal or replacement wood value is estimated to be $98 – $52 = $46.

The second part of the economic appraisal includes estimates of the costs associated with achieving the projected improvement. Break–even wood values per cunit are depicted for elite and mainline breeding strategies in Figure 6. These break–even wood values are the values at which net present values approximate zero. Across several categories of site quality (site index at base age 25), the mainline breeding strategy has break–even wood values that are essentially double the values for elite breeding. Since marginal wood value for both breeding strategies is $46.00 and the break–even (no profit net present value) are in both cases equal to or less than half of $46.00, it is clear that both the mainline and elite breeding strategies are worthwhile investments. The elite breeding strategy appears to be an exceptionally good investment.

Figure 7 (page 14) shows the net present value (NPV) estimates for elite breeding and mainline breeding over a range of site index values and discount rates. NPV is an appropriate measure for this comparison since it incorporates investment costs and benefits measured as cashflows over time. NPV estimates are very sensitive to both site index, inherent land productivity

Figure 4. *Wood volume production for elite and mainline breeding strategies.*

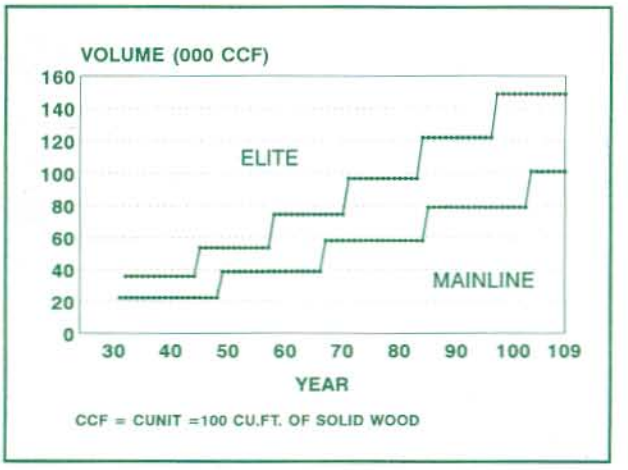


Figure 5. *Cost Distribution of purchased wood delivered to the mill.*

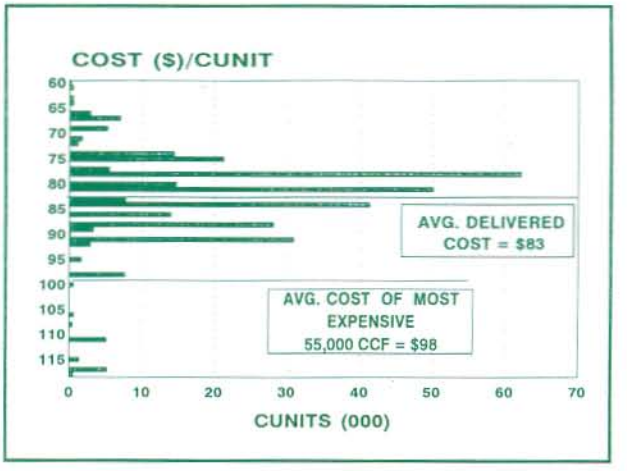


Figure 6. *Break-even wood values for elite mainline breeding at various site index levels (base age 25).*

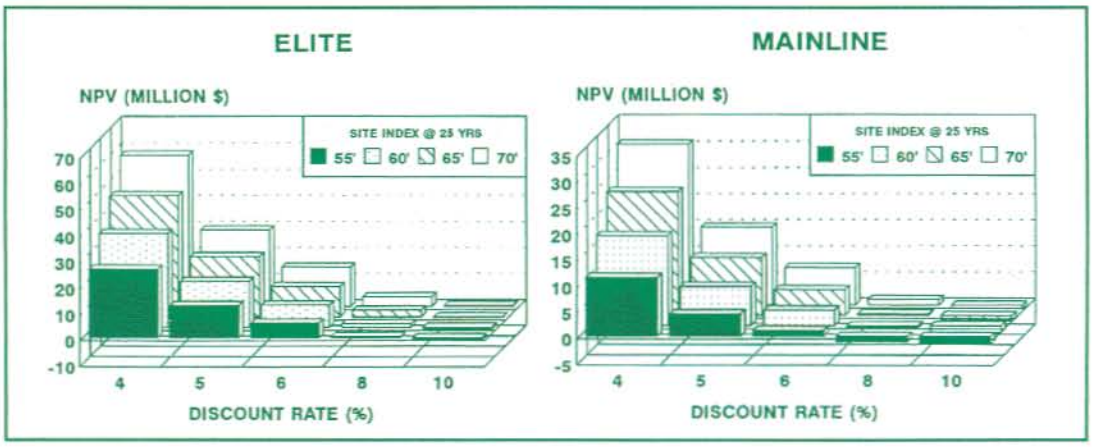
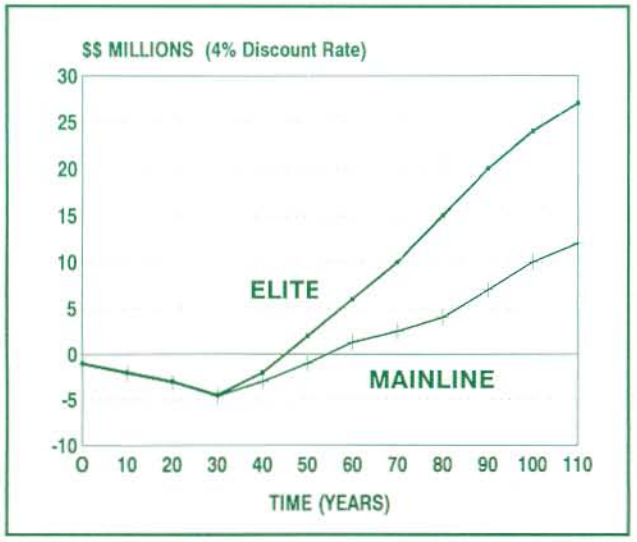


Figure 7. *The effect of site index and discount rate on the net present value (NPV) for the elite and mainline breeding strategies.*

potential, and to discount rates. NPV estimates show a large drop as discount rates increase, they are more sensitive to variation in discount rates than to site index.

Figure 8. *Cumulative discounted cash flows for both elite and mainline breeding strategies.*



The final chart developed from the analyses shows the cumulative cash flows for elite and mainline breeding over a 110–year–period (Figure 8). This is the accumulated net effect of all costs and benefits over time. Figure 8 shows higher and diverging cash accumulation for the elite population compared to the mainline. The elite breeding system will make more money faster than the mainline alternative. It is a relatively low risk investment that has high value. The divergence of cash flows is due to gain from a one time selection intensity increase and more rapid turn–over of breeding, testing and selection cycles.

The N. C. State University – Industry Cooperative Tree Improvement Program is pleased with the economic appraisal of the new breeding plan. It is anticipated that elite population strategies will be aggressively pursued by members of the program and that the results of more gain realized at a faster rate than systems used in the past, will provide for continued support of tree improvement investments for several additional cycles of improvement of loblolly pine.

COOPERATIVE DATABASE MANAGEMENT SYSTEM

Traditionally, information distribution within the N. C. State University–Industry Cooperative Tree Improvement Program has consisted of printed reports and summaries. While this method of distribution was perhaps adequate during the initial cycle of breeding and testing, it does not possess the flexibility required to provide the membership with the information necessary in a more complex advanced generation breeding program while meeting the specific information needs of each member. To better meet the needs of the membership, an information system, possessing the following characteristics, is being developed:

- Immediate access to all current information at all times.
- Easy access.
- Flexible enough to meet the specific needs of each member.

The database management system is being developed and will be maintained and managed using Microsoft Access. Access is a relational database management system used to enter, retrieve, update, manipulate and report information. Access operates

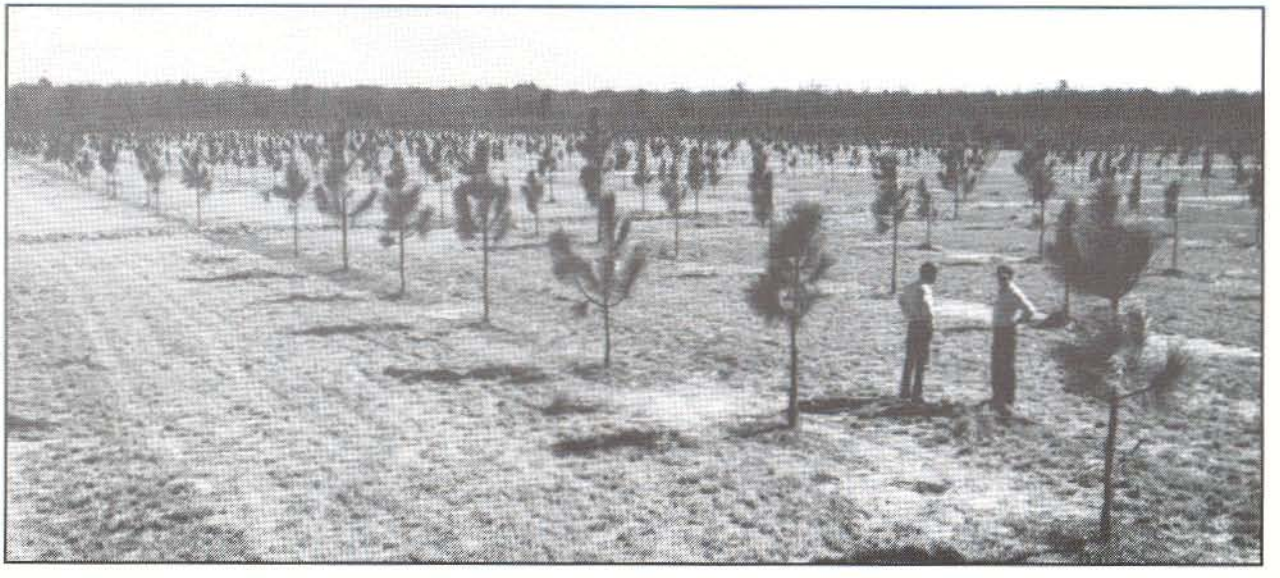
under Microsoft Windows version 3.1. The user interface is designed to provide quick and easy access to the full–range of database features. Reporting capabilities are extensive, with built–in sorting, grouping and calculated fields. Access provides almost instantaneous results even for queries involving operations on the entire database. Members will be able to carry out any of the following operations with relative ease:

- Retrieve data based on various search criteria.
- Select subsets of the data based on various selection criteria.
- Perform calculations on selected elements in the database.
- Rearrange the data as desired.
- Produce reports and summaries that include all or selected elements of the database in desired order and format.
- Export data files in numerous formats for transfer to members internal information management systems.

Norton pcAnywhere will provide PC–to–PC remote computing and general communications capability. Use of pcAnywhere will allow remote users (cooperative members) to control the host PC (Database Management computer) from any PC, PS/2 or compatible via a modem. The remote user will assume control of the host PC allowing the remote to run applications on the host machine and transfer files between the host and the remote PC.

The database management system is being developed on a 486DX–50MHz PC. The modem used on the Host PC will support data transmission rates up to 14.4K. Each member will require a PC, PS/2, or compatible operating MS–DOS version 3.1 or later with at least 320K RAM available for Norton pcAnywhere. The system must be equipped with a modem, a Microsoft or compatible mouse and either an EGA or VGA monitor. The only software required on each member's system will be Norton pcAnywhere/Remote Only.

The database management system is scheduled to come on–line in the summer of 1995. During the first year of development, the staff is working with members to establish communication links with the host system and to determine each member's specific information needs. During the second year of development, workshops will be conducted for members on the use of Microsoft Windows and Microsoft Access.



While loblolly orchard establishment is minimal, some minor species establishment is underway. Pictured is North Carolina Forest Service's Longleaf expansion orchard.

SEED ORCHARD PRODUCTION

CONE AND SEED YIELDS

The 1993 loblolly pine seed collection was slightly smaller than the 1992 crop with about 3.2 tons less seed collected. Members collected 40,698 bushels for 28.3 tons of seed (Table 4). Average yield was 1.39 lbs./bushel, slightly less than the 1992 yield of 1.42. This was the second smallest collection in 10 years. Though only 28.3 tons were collected, much was left uncollected as cooperators continue to selectively harvest from only the best clones.

The collection of second generation seed was 10.6 tons, significantly less than the 1992 record of 14.4 tons. Lower collections in piedmont second generation orchards accounted for about 90% of the reduction. In all probability this is reflective of the extent of damage to orchards from the "storm of the Century" in 1993. The 1994 crop is projected to be lower as well due to flower damage from the same storm. Figure 9 shows the percent of the total crop represented by second generation collections from 1983 through 1993.

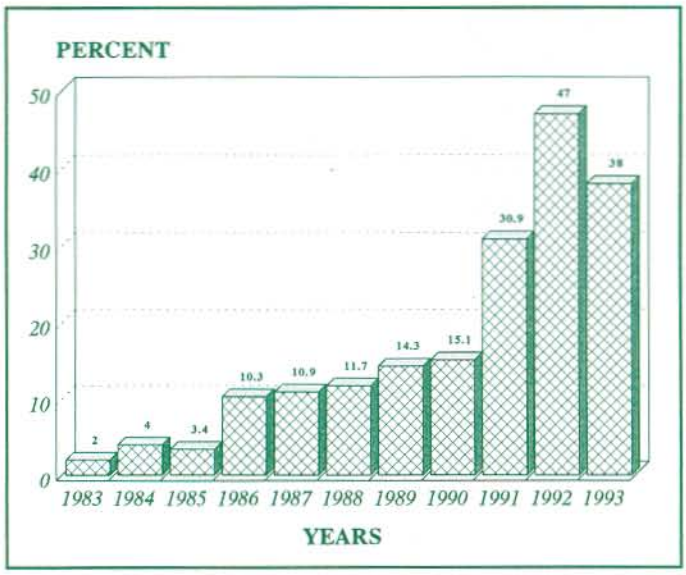


Figure 9. Percent of total crop represented by second generation seed collections from 1983-1993.

Several organizations reported clones producing in excess of 2.0 lbs./bushel. The highest yielding clone reported was 10–5 from the Champion (Florida) Santa Rosa orchard (2.92 lbs./bushel). The record high was set in 1989 when clone 8–73 yielded 3.3 lbs/bushel.

Table 4. Comparison of 1993 and 1992 Loblolly seed orchard collections for the Cooperative.

	BUSHELS OF CONES		POUNDS OF SEED		POUNDS OF SEED/BUSHEL OF CONES	
SOURCE	1993	1992	1993	1992	1993	1992
Coastal 1.0	18,744	12,020	27,153	18,249	1.45	1.52
Piedmont 1.0	5,474	9,207	8,148	14,453	1.49	1.57
Coastal 2.0	9,538	10,270	13,034	12,762	1.37	1.24
Piedmont 2.0	6,942	13,050	8,184	17,575	1.18	1.35
TOTALS	40,698	44,547	56,519	63,039	1.39	1.42

The top ten producing orchards in 1993 are shown in Table 5. Production ranged from a high of 2.21 lbs./bushel to 1.70 for the ninth and tenth place orchards. The best producing orchard was Westvaco's Central Loblolly Orchard which produced 2.21 lbs./bushel. Special congratulations to the managers of these orchards for their outstanding accomplishments in orchard management and production.

Intensive orchard roguing in Virginia Department of Forestry's white pine seed orchard.

ASANA STUDY

During the summer of 1993 the Seed Orchard Pest Management Subcommittee conducted a timing study of Asana XL to control cone and seed insects in southern pine seed orchards. Four basic time intervals between sprays were evaluated; 4, 8, 12, and 16 weeks. Also included in the study were a control treatment and a sixth spray treatment that consisted of a combination of times between sprays.

Spray treatments were applied on an individual tree basis with the initial spraying done within seven days following peak pollen flight. Some orchards sprayed with a mist blower and others used a hydraulic sprayer. The Asana XL rates employed followed label recommendations appropriate to either a hydraulic sprayer or mist blower. The study was installed in four seed orchards scattered from Texas to Virginia.

Results of the study were inconclusive. It seems that the insect populations across the southeastern U. S. were quite low in 1993. Although the study design was robust enough to detect statistically significant differences for a few variables such as total filled seed per cone, the operational or practical treatment effects were very small. There were no findings to suggest that the interval between sprays could be lengthened.

Table 5. Top ten production orchards in the Cooperative for the 1993 cone crop.

ORGANIZATION	ORCHARD TYPE	AGE	LBS./ BUSHEL	NO. OF CLONES	ORCHARD MANAGER
Westvaco, SC	Central Loblolly	22	2.21	7	Dave Gerwig
Champion, FL	1.5 E. Loblolly	16	2.03	16	Homer Gresham
Champion, SC	1.5 Piedmont	27	2.02	10	George Oxner
Champion, SC	1.5 Alabama Lob.	18	1.92	4	George Oxner
Westvaco, SC	1.0 Coastal Lob.	26	1.92	5	Dave Gerwig
Champion, SC	Rust Resist. Lob.	24	1.91	5	George Oxner
Westvaco, SC	1.0 Va. Loblolly	22	1.77	7	Dave Gerwig
Champion, SC	2.0 Piedmont Lob.	17	1.75	16	George Oxner
Chesapeake	1.5 Coastal Lob.	22	1.70	8	Mike Harbin
Rayonier	2.0 Piedmont Lob.	14	1.70	15	Ben Cazell

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, 4 graduate students have been working in association with the Tree Improvement Cooperative. The efforts of one was directed toward a Masters degree, and three were involved in Ph.D. programs of study. During the year, four students completed their degree programs which caused our student population to decline.

Student research projects encompass a 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, the North Carolina State University Agricultural Research Service, the U. S. Forest Service, industry, various fellowship programs, competitive grants, and foreign governments.

This year all graduate students were from foreign nations. This development stems from: 1) scarce employment opportunities for domestic graduate students, and 2) the strong international recognition of our tree breeding research and development success. In the past year we have seen some applications from qualified domestic applicants, but limited funding for assistantships continues to constrain our ability to accept more graduate students into the program.

Our successful graduate program is an accomplishment for which we are very proud, and one for which the Cooperative membership also deserves a pat on the back. Cooperative members have generously contributed to graduate student research projects, by contributing land, equipment, and manpower resources. We wish to recognize this outstanding contribution, for without it our graduate research and education program would be substantially reduced in scope and accomplishment.

STUDENT, DEGREE	RESEARCH PROJECT
Peter Althoff, M.S.	*Genetic variation in leaf area/production stand level measures (Joint project with Forest Nutrition Cooperative)*
Kevin Harding, Ph.D.	*Age trends of genetic parameters for wood properties for loblolly pine*
Keith Jayawickrama, Ph.D.	*Phenological variation in shoot elongation and diameter growth and their relationships to late wood formation and wood specific gravity in loblolly pine*
Jan Svensson, Ph.D.	*Ecophysiological bases for genetic differences in growth of loblolly pine stands (Joint project with Forest Nutrition Cooperative)*

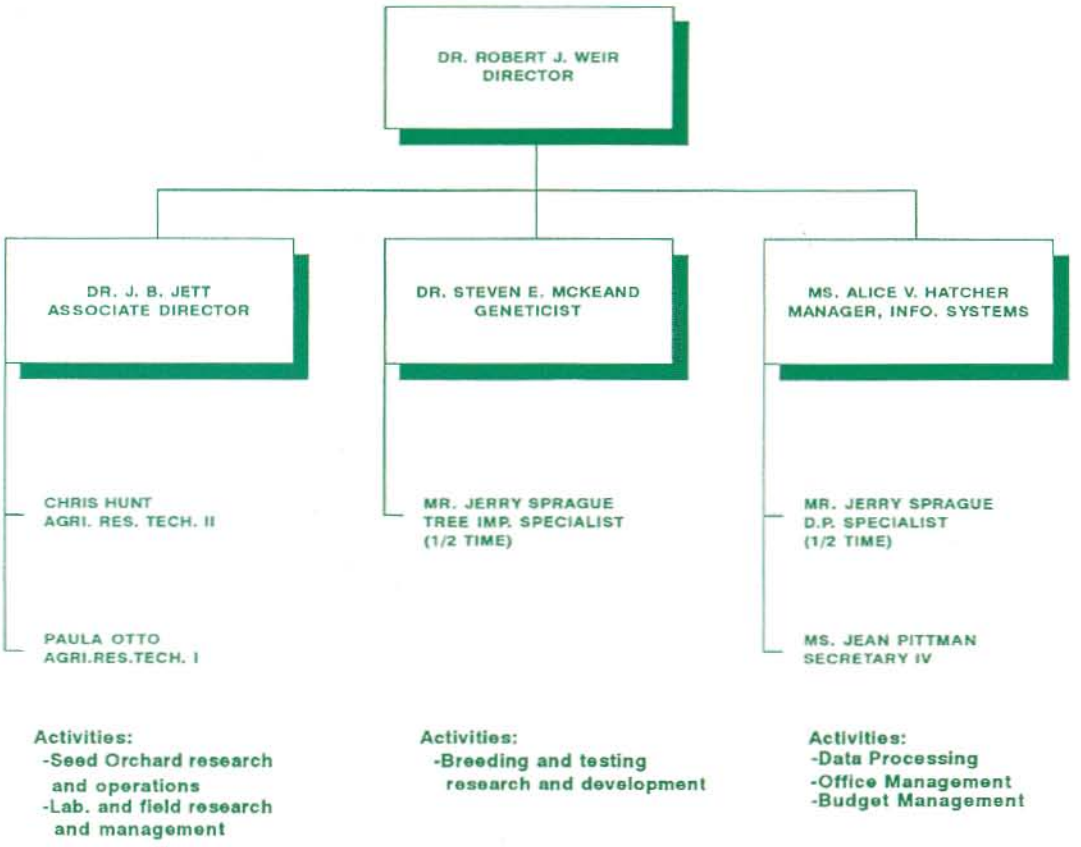
Wood sampling in Union Camp's Florida Loblolly Provenance/Progeny Trial to determine provenance and family variation in wood properties.

PROGRAM STAFF

As referenced on the cover of this report, a significant change occurred with the Tree Improvement Program staff during the late spring of 1994. Dr. J. B. Jett left the Cooperative after nearly 26 years of service with the program to become the Associate Dean for Research and Outreach in our College of Forest Resources. He will be missed a great deal!! Activities are ongoing to find his successor.

Not shown on the organizational chart, but a highly productive member of the "team", is Dr. Floyd Bridgwater, Research Geneticist and Acting Project Leader for Forest Genetics with the Southeastern Station, U. S. Department of Agriculture, Forest Service. Virtually all of the research conducted or administrated by Floyd is complementary to the Cooperative Program. Several outstanding tree improvement graduate students have worked, or are working, under Floyd's direction, and he teaches a course in genetic analyses that is well received by our graduate students. We are enthusiastic about opportunities for developing an even closer research collaboration with the USFS, Forest Genetics project in the future, especially in the area of population genetics as it relates to issues of bio–diversity in managed forests.

COOPERATIVE TREE IMPROVEMENT PROGRAM ORGANIZATIONAL CHART – MAY, 1994



MEMBERSHIP OF THE TREE IMPROVEMENT COOPERATIVE

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

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS OF THE COOPERATIVE

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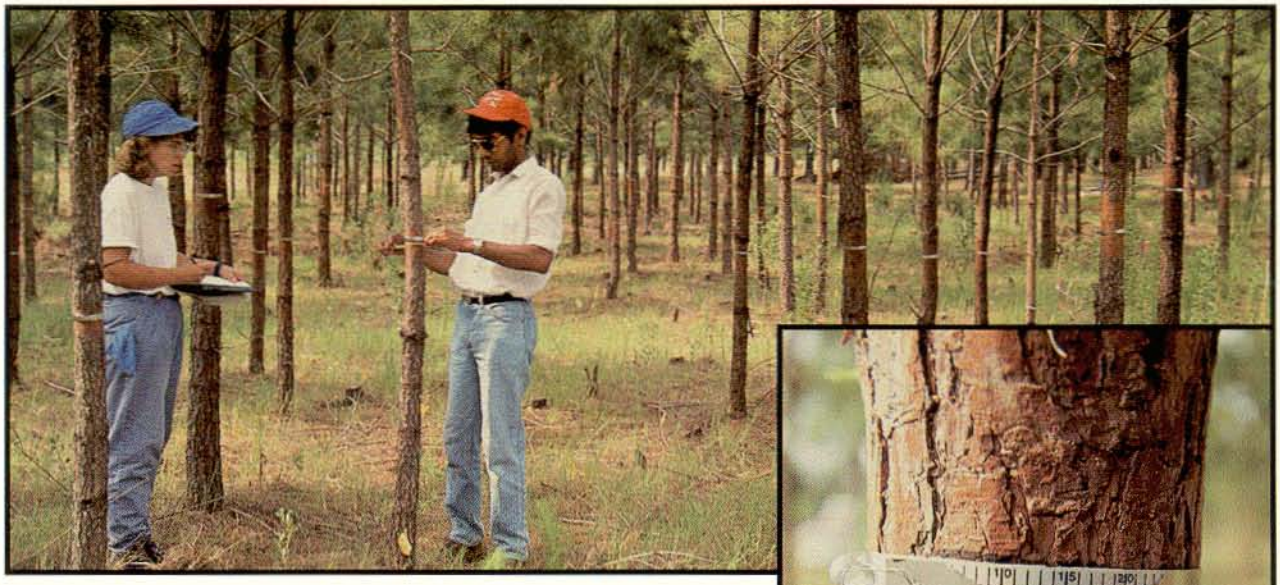

Three Major Research Studies on Wood Properties are Underway to Determine:

Age Trends For Genetic Parameters

The Effect of Growth Initiation and Cessation on Wood Formation

Family and Provenance Variation