NORTH CAROLINA STATE UNIVERSITY
INDUSTRY COOPERATIVE TREE IMPROVEMENT PROGRAM

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

35th
A.N.N.U.A.L R.E.P.O.R.T

MAY 1991

EXECUTIVE SUMMARY

Progress reports for research studies indicate:

- The ability to use first and second-year stem elongation traits to predict later field growth seems to differ among provenances.
- In an analysis of age trends from the 25 year old heritability study, neither length of breeding cycle or production cycle, nor the family or within family selection intensity affected the optimum selection age, but interest rates did. Lower interest rates pushed selection toward older ages and higher interest rates favored selection at younger ages.
- Two year measurements of the Cooperative's rootstock study suggest that a clone used as a scion has greater effect than the rootstock family on the growth and physiology of the graft.
- Investigations of sand pine, pitch pine and Virginia pine hybrids suggest that sand and Virginia pine may be subspecies of the same species rather than separate species.

Two other important research projects were initiated this year:

- The Scion Maturation Study is designed to determine if clones of different ages can be established together in advanced generation seed orchard blocks.
- The Inbreeding Grafting Study will determine the effects of related matings on the health and vigor of orchard trees as measured by grafting success, flower initiation, and filled seed yields.

Good progress was made in breeding and testing the Cooperative's nearly 4,000 plantation and second generation selections. Currently 80% of the crossing and 28% of the plantings are complete.

The 1990 cone crop increased 89% over 1989 production.

- Cooperative seed orchards harvested 30.4 tons of improved loblolly seed as compared to 16.1 tons in 1989.
- Second generation orchards produced 4.3 tons of seed, almost twice as much as in 1989. The second generation orchard harvest comprises 14.1% of the Cooperative total.
- Yields in pounds per bushel were relatively poor this year. The 1.19 pounds per bushel was the lowest in 11 years. Insect damage and adverse weather are suspect in this poor result.
- One orchard, Georgia-Pacific's second generation orchard in Moselle, MS, exceeded 2.0 pounds of seed per bushel of cones harvested. Despite low average yields, several Cooperators reported individual orchard clones that produced above 2.0 pounds per bushel.

During the past year, 12 graduate student programs were conducted in association with the Tree Improvement Cooperative. Of special note was the completion of degree programs by six students in 1990-1991.

The Cooperative staff and associates continue to produce a significant number of publications which impact the progress of forest tree improvement and will ultimately have important effects on forest productivity.

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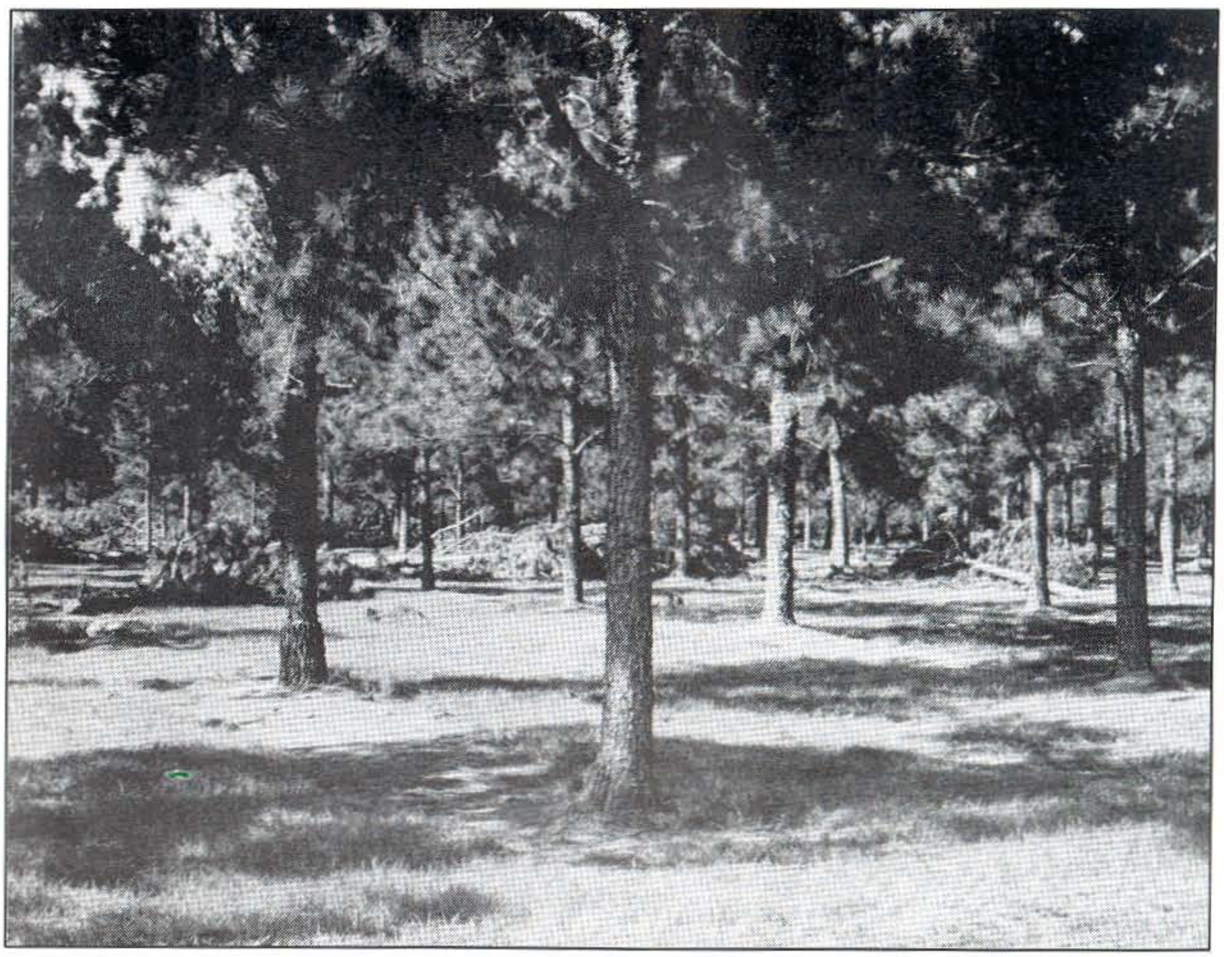
INTRODUCTION

The North Carolina State University-Industry Cooperative Tree Improvement Program has completed 35 years of continuous operation. Starting with 11 forest industries as charter members, membership now includes 20 industries and 5 state forestry agencies that operate more than 40 centers of tree improvement in the southeastern region of the United States. With a firm foundation of cooperation, the member organizations and the University have, in partnership, maintained a forest genetics research and resource development program that has substantially enhanced forest productivity in the region.

Once again we find a difficult economic environment in which to conduct our activities. The forest products industry is known to experience cyclical prosperity interrupted by periods of financial struggle. State forestry agencies, which currently comprise twenty percent of the Cooperative membership, are under severe financial strain at this time. Everyone hopes and most expect that the current downturn associated with a weak economy can be reversed in the year ahead. Despite this difficult period we are pleased that core support for Cooperative activities has been sustained allowing progress to continue.

Our research program has maintained good momentum, cone and seed production increased 89% over 1989, and advanced generation breeding and testing work has progressed well. During the next year the Breeding And Testing Task Force will complete work on plans for the Cooperative's third cycle of breeding and testing. We are poised on the threshold of a new cycle of genetic improvement, a cycle which promises to produce benefits surpassing those of the first 35 years. New technology is emerging and we are building on experience and knowledge gained from past research, thus the pace of accomplishment is accelerating. We eagerly anticipate the challenges and the opportunities that lie ahead in the 1990's.



Second Generation Orchards produced 14% of the 1990 seed harvest and wind pollinated progeny test data are now being used to genetically upgrade these orchards through intensive roguing.

RESEARCH

During the past year, results were obtained from several Cooperative research studies. An investigation of genotype by environment interaction effects in family response to silvicultural treatments in loblolly pine was conducted. Two year results from the Early Selection Verification Study are reported. Additionally, three graduate student research projects were completed: Claudio Balocchi completed his Ph.D. dissertation on Age Trends in Genetic Parameters and Selection Efficiency in Loblolly Pine; Keith Jayawickrama investigated the contributions of site, rootstocks, and scion clones to scion growth and physiology; and David Porterfield examined three interspecific pine control crosses to verify individual F_1 hybrids. Two other studies which the Cooperative staff recently initiated are described: the Scion Maturation Study and the Inbreeding Grafting Study.

Genotype by Environment Effects in Family Response to Silvicultural Treatments

Results of recent genetic analyses suggests a high degree of stability among families of loblolly pine. Breeders have not been concerned with the need to develop multiple breeding populations for different environments within a geographic area. Data from the breeding and testing program indicate that superior families for growth traits, stem quality, and wood properties will display their superiority in virtually any well-designed, properly established and well maintained genetic test. The lack of rank change for families in genetic tests in different environments does not, however, imply that genotype by environment interaction should be ignored in operational forestry. The differential response that families display to improvements in site quality can have major implications for the efficient deployment of families to certain sites as well as for maximizing the return on silvicultural treatments.

There is tremendous variation in the quality of sites on which loblolly pine plantations are established. For example, in the upper coastal plain of the Gulf Coast region, site indexes for loblolly pine (base age 25 years) will typically vary from 50 feet to as high as 80 feet. Site variation occurs for numerous reasons including climatic variation such as temperature and rainfall (both amount and distribution), soil texture and structure, internal drainage, and nutrition. Additionally, there are tremendous opportunities to increase site quality on many sites by managing weed competition, water, and nutrition. Such silvicultural treatments can dramatically affect soil, water and nutrient availability and can be expected to accelerate the rate of stand development.

With such variation in site quality and the opportunity to impact site quality through silvicultural treatments, the variation in family response to changes in site quality is an important factor in forest management decisions. Using data from the North Carolina State University Tree Improvement Cooperative and the Forest Nutrition Cooperative, the practical importance of genotype by environment interaction to a variety of silvicultural treatments can be illustrated.

For volume at age 8, the vast majority (35 of 43) of the loblolly pine families tested over 21 sites in the Good General Combiner Test Series had average stability. In other words, if these 35 families are planted over many sites, an average site quality change of ten units would be expected to improve family performance by ten units. The stability or slope of family productivity over a range of site quality would be 1.0. Six families (07002, 07056, 08001, 08061, 10005, and 11009) had stability values significantly greater than $b = 1.0$ while two families (01064 and 06022) had stability values below $b = 1.0$. The six families with b significantly greater than 1.0 were sensitive to site quality changes and showed increased adaptation to favorable sites. Only two families (b significantly less than 1.0) did not respond as much to changes in site quality as average stability families.

There was a relatively strong, positive correlation ($r = 0.75$) between the stability parameters (b values) and stem volume at age 8 years. Better performing families tended to be those that were most responsive to site changes. Those families that did not respond to site improvements, such as 01064 and 06022, were also poor performers.

Silvicultural research results indicate that the combination of intensive site preparation, fertilization, and weed control had a major impact on eight-year stand volume compared to the control plots in two study installations in Clarke Co. and Butler Co. Alabama. At Clarke Co., the response was 439 ft^3/acre (314 vs 753), and at the Butler Co. installation, the response was 544 ft^3/acre (356 vs 900). Volume production was more than doubled when the most intensive treatments were applied (Table 1).

The site preparation, fertilization, and weed control treatments most likely affected water and nutrient availability to the crop trees. Since site quality differences are also likely due to differences in water and nutrient availability, an assumption was made that loblolly pine families will respond to silvicultural treatments the same as they responded to changes in site quality. The response of any family to intensive site preparation, fertilization, and weed control can be predicted by multiplying the average response from the silvicultural studies by the stability value for each family. Two families in numerous genotype by environment interaction trials that had stability values at the two extremes are used to illustrate the potential response of different families (Figure 1). Family 01064 would be expected to have a relatively small response to the site preparation, fertilization, and weed control treatments with an additional 246 and 305 ft^3/acre at age 8 years at the Clarke Co. and Butler Co. sites respectively.

TABLE 1. Treatment means for 8-year volume for two silvicultural studies in Alabama

Treatment	Volume (ft^3/acre) Clark Co.	Butler Co.
Low site prep., no fert., no herb[1].	314	356
Low site prep., no fert, hexazinone	524	506
Low site prep., DAP, no herb.	254	435
Low site prep., DAP, hexazinone	701	661
High site prep., no fert., no herb.	279	640
High site prep., no fert, hexazinone	581	741
High site prep., DAP, no herb.	473	702
High site prep., DAP, hexazinone	753	900

[1] This treatment served as the control treatment

Conversely, family 07056 would respond 34% better than the average of the mix of families with 588 and 729 ft^3/acre at age 8 years in the intensive site prepared, fertilized, and weed control plots (Figure 1). Simply by deploying a very good performing family that responds to site quality changes, an additional 149 and 185 ft^3/acre could be realized from the silvicultural treatments at the Clarke Co. and Butler Co. sites, respectively.

The most important implications of these results is in the deployment of certain families to specific sites and silvicultural systems. Even without significant family rank changes on different sites, foresters are better off planting the best families on the best sites.

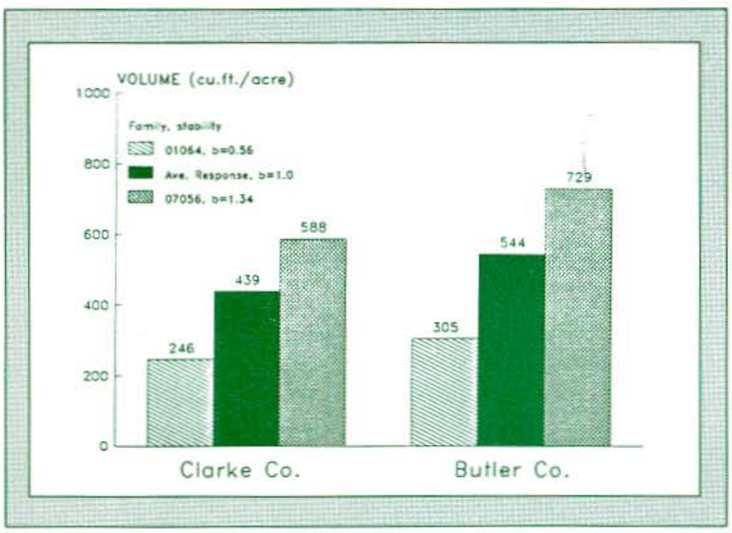


Figure 1. *Comparison of potential response of two families with extreme stability values.*

Results suggest that greater volume gains can be realized since the response of families like 07056 does not parallel the response of average families but diverge as site productivity increases. Likewise, when silvicultural prescriptions are being considered, sites that have the best families planted on them should receive the highest priority since the response will be greatest.

One possible complication could arise if silvicultural research studies are conducted with only the best families. While results would be applicable to those specific families, if inferences are drawn to families of average stability (i.e., 81% of the families studied in the genetic analysis), treatment responses would likely be exaggerated. For example, the additional 185 ft^3 per acre at the Butler Co. site from using family 07056 plus intensive site preparation, fertilization, and weed control would not be realized for less responsive families. If investment decisions are based on the economic benefit of exaggerated responses, then silvicultural prescriptions that are too costly could be recommended.

Verification Trial for Early Selection of Loblolly Pine

As the Cooperative prepares to enter the third-generation of breeding and testing, the ability to identify selections which could be culled from the breeding population before expensive controlled crossing begins could be very valuable. A reliable and repeatable early selection system for the breeding and testing program would be useful in the mid to late 1990's.

In previous research, stem elongation in first and second-year loblolly pine (Pinus taeda L.) seedlings has reliably predicted 8 to 12-year heights in eastern North Carolina and South Carolina provenances. However, it is possible that stem elongation traits will not be reliable for early selection with other provenances. In the Western Gulf Cooperative, total stem dry weight at 4-6 months is used to predict field performance, but dry weight has not been a good predictor in studies of the eastern North Carolina provenance.

A Cooperative study in conjunction with the USFS was established in southwest Georgia with 13 to 16 OP families from each of five provenances to evaluate the use of stem elongation traits for early selection among families within each provenance. The following provenances were used: South Atlantic Coastal Plain; Marion County, FL; Gulf Hammock, FL; Lower Gulf Coastal Plain; Middle and Upper Gulf Coastal Plain. The first four provenances were also growing in the Florida Loblolly Provenance-Progeny Tests established in 1982 and 1983 by members of the University of Florida and the NCSU Cooperatives. The Middle and Upper Gulf

TABLE 2. Provenance means for total height, stem elongation, and number of growth cycles.

Trait	Marion Co. FL	Gulf Ham. FL	Atl. Coast Plain	Lower Gulf	Upper Gulf
Height (cm)					
Yr 1	85.3	85.2	70.4	61.3	54.0
Yr 2	241.2	242.8	211.2	190.9	175.6
Stem Elong.(cm)					
Yr 0-1	53.2	52.5	39.1	30.6	26.3
Yr 0-2	209.1	210.0	179.9	160.2	148.0
Yr 1-2	155.5	157.1	140.3	129.3	121.4
# Growth Cycles					
Yr 1	3.9	3.9	2.8	2.1	1.8
Yr 2	4.9	5.0	4.6	4.4	4.1

families were growing in the Cooperative's Intensive Culture Study planted in 1984. The use of the different provenances allowed for determination of variation among provenances for early selection based on juvenile shoot elongation traits.

Seeds were sown in the greenhouse in Raleigh in early November, 1988 and were grown in RL Super Cells until they were outplanted at Georgia Pacific's (GP) Nursery near Cedar Springs, GA and at International Paper Company's (IPCo) Southlands Experiment Forest near Bainbridge, GA, March 13- 15, 1989.

After the first growing season, height to the end of the free growth cycle and total stem height were measured. After two growing seasons, total height was again measured. Stem elongations from the free growth to the end of the first and second year heights and from the first year height to the end of the second year height were determined. The number of growth cycles or flushes were counted following both growing seasons.

Family and provenance means combined across the two planting sites were calculated for each trait. Variance components (both genetic and environmental) were estimated for each provenance, and individual tree heritabilities were calculated. Family mean correlations with the five-year field data from the Florida Loblolly Provenance-Progeny Trial and the Intensive Culture Trial were calculated for each provenance.

TABLE 3. Individual tree heritability estimates for different provenances for total height, stem elongation, and number of growth cycles.

Trait	Marion Co. FL	Gulf Ham. FL	Atl. Coast Plain	Lower Gulf	Upper Gulf
Height					
Yr 1	0.09	0.44	0.44	0.42	0.93
Yr 2	0.11	0.49	0.58	0.45	0.80
Stem Elong.					
Yr 0-1	0.15	0.40	0.53	0.35	0.75
Yr 0-2	0.10	0.49	0.64	0.42	0.71
Yr 1-2	0.11	0.32	0.37	0.21	0.44
# Growth Cycles					
Yr 1	0.46	0.55	0.59	0.33	0.84
Yr 2	0.30	0.37	0.47	0.10	0.53
% Rust					
Yr 2	0.10	0.07	0.23	0.05	0.13

The growth and survival (97%) at both locations was excellent after two growing seasons. Provenances ranked as expected for total height, stem elongation, and number of growth cycles (Table 2) based on other provenance studies with loblolly pine. The Florida provenances grew the most and had the most flushes in both years followed by the Atlantic Coastal, Lower Gulf, and the Middle-Upper Gulf provenances.

There were some very large differences in the degree of genetic control for each of the traits among provenances (Table 3). Individual tree heritabilities were very high for the Middle-Upper Gulf provenance and were intermediate for most of the other provenances. There were very small differences in growth among the families in the Marion Co. provenance with heritability values ranging from 0.09 to 0.15 for total height and stem elongation, in both the first and second year.

There was an interesting trend in the heritability values for the annual height increment in the first and second years. The heritability estimates for stem elongation from year 1 to year 2 decreased an average of 0.15 for each provenance compared to the heritability for stem elongation in the first year. Apparently, the environmental noise for cyclic growth in the second year was larger than in the first year. This is also demonstrated by the lower heritability values (average decrease = 0.20) for the number of growth cycles in the second year.

The correlations with the 5-year field data were also variable (Table 4). Total height, stem elongation, and the number of growth cycles were moderately to strongly correlated with 5-year heights for the Atlantic Coastal and Middle-Upper Gulf families in both the first and second year. The family means in the other provenances were less well correlated. There was a strong trend for the second-year heights to be more strongly correlated to 5-year field data than first-year heights, but there was little advantage in using stem elongation versus total height. Apparently the "noise" from the free-growth cycle at the time of planting had little influence on the correlations, especially after two growing seasons.

The ability to use stem elongation traits to predict later field growth does seem to differ among provenances. In the Atlantic Coastal Plain and Upper Gulf provenances, the relatively high heritabilities and age-age correlations for height indicate that early selection for families will be effective. In the two Florida provenances, the age-age correlations improved in the second year but were not nearly as strong as the correlations for the Atlantic Coastal and Middle-Upper Gulf provenances. The low heritabilities for height and stem elongation for the Marion County, FL provenance also suggest that early selection among families in this provenance will be only marginally effective. For the Lower Gulf families, both the heritabilities and age-age correlations were moderate to low also indicating that early selection will not be as great as for other provenances.

No firm decisions about the use of early selection for the Cooperative's breeding program can be made until we have older "mature" data from the Florida Loblolly Provenance-Progeny Test and the Intensive Culture Test. The older field trials will be measured through rotation age and the long-term relationships with these juvenile measures will be evaluated.

TABLE 4. Family mean correlations with 5-year field data for different provenances for total height, stem elongation, and number of growth cycles.

Trait	Marion Co. FL	Gulf Ham. FL	Atl. Coast Plain	Lower Gulf	Upper Gulf
Height					
Yr 1	0.38	0.34	0.56⁺	0.34	0.87*
Yr 2	0.59*	0.44⁺	0.65*	0.37	0.90*
Stem Elong.					
Yr 0-1	0.10	0.26	0.61*	0.36	0.86*
Yr 0-2	0.50⁺	0.40	0.65*	0.38	0.90*
Yr 1-2	0.54*	0.47⁺	0.65*	0.36	0.83*
# Growth Cycles					
Yr 1	-0.01	0.00	0.66*	0.35	0.84*
Yr 2	-0.11	0.12	0.40	0.43	0.65*

*, ⁺: Significant at $p \leq .05$ and $p \leq .10$, respectively.

Age Trends in Genetic Parameters and Selection Efficiency in Loblolly Pine

Graduate student Claudio Balocchi reported on the estimated selection efficiencies for family and within family selection based on both the additive and total genetic component for tree height of loblolly pine. Data used for the analyses were collected in the N.C. State University - International Paper Company Heritability Study near Bainbridge, Georgia which was established in 1963, 1964, and 1965. Each of three plantings of the Heritability Study were measured annually after establishment through age 16 with the exception of ages 11 and 12. The trial was last measured in 1989 at ages 24, 25, and 26 for the 1965, 1964, and 1963 plantings, respectively.

Selection efficiency was estimated by the present value (PV) of correlated responses between selection age and the final measurement age for tree height. The analyses showed that neither the length of breeding or production cycle nor the family or within family selection intensity had an effect on the optimum selection age, even though there was an impact on expected gain. In contrast, interest rate directly affected selection age. Lower interest rates pushed selection toward older ages and higher interest rates pushed selection toward younger ages.

Optimum selection ages for an interest rate of 8% were found to be 7 and 10 years for full-sib families based on the total genetic and additive components, respectively; 9 years for half-sib families; 6 years for within full- and half-sib families based on the total genetic component; 13 and 10 years for within full-sib and half-sib families based on the additive component, respectively; and 6 and 7 years for simultaneous selection of family and within family for the total genetic component of full-sib and half-sib, respectively. Finally, the optimum selection age for family plus within family selection for the additive component was found to be 10 years for both full-sib and half-sib families. The sensitivity of selection age to interest rate and the difference in optimum selection age resulting from selection on the total genetic component vs. the additive genetic component are illustrated in Figure 2.

Thus, selection for a production system that can capture all, or part, of the non-additive genetic variation can be made 3 to 4 years earlier than for systems that can only capitalize on additive genetic variance. Production systems such as mass controlled or supplemental pollination, "bulking-up" full-sib families using vegetative propagation, or vegetatively propagating selected individual genotypes, not only promise greater genetic gain but a shorter interval than seed orchards for realization of those gains.

A Packaging Corporation plantation diallel progeny test that is included in the Cooperative's Early Diallel Measurement Study. This project will provide estimates of genetic parameter differences among geographic areas.

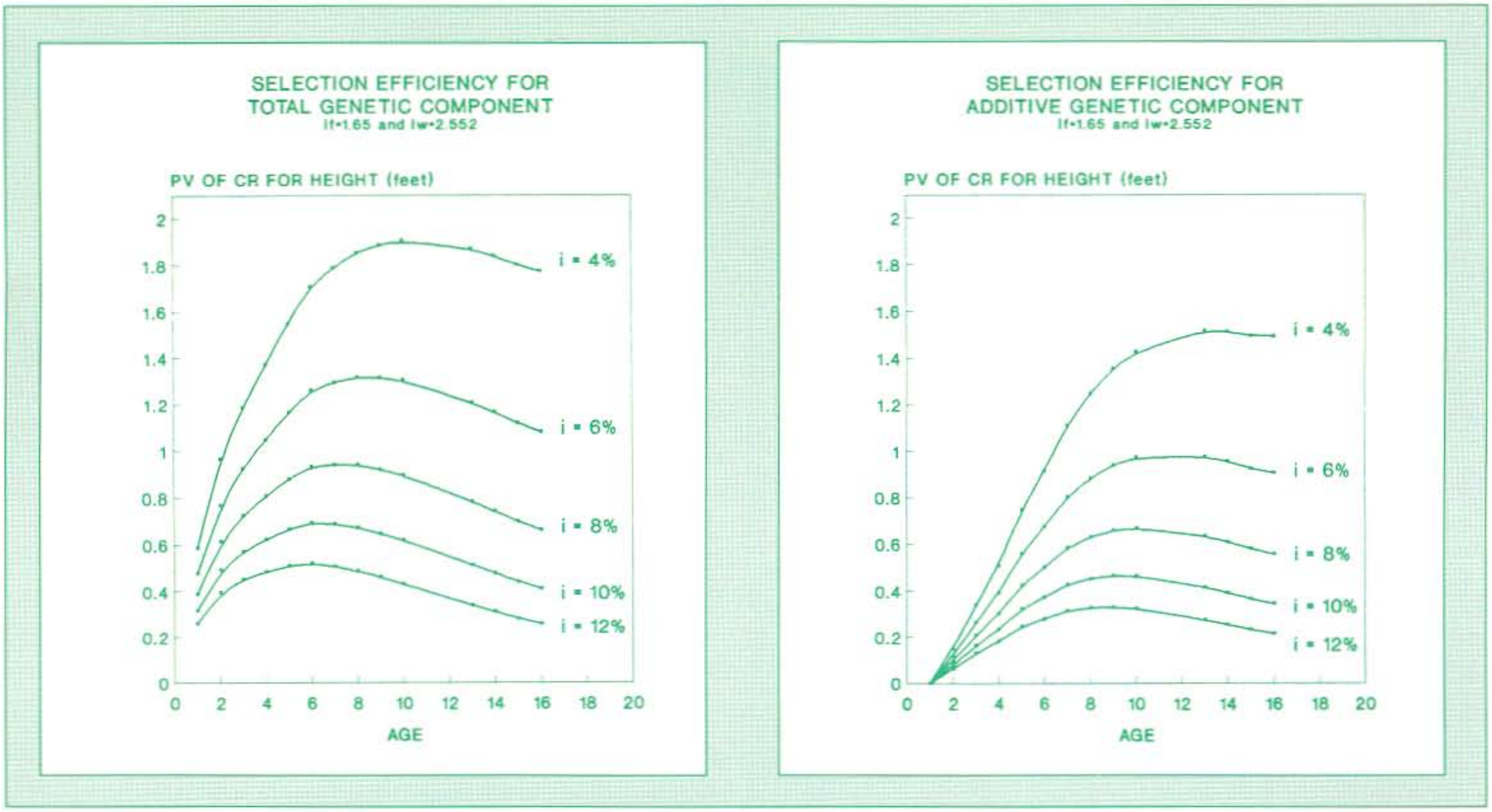


Figure 2. *Effect of interest rate on selection efficiency for half-sib family plus within family selection, based on the total genetic component and on the additive component in loblolly pine.*

Rootstock Study Results

The choice of rootstocks can influence graft success, compatibility, scion elongation and sexual reproduction in grafted conifers. Effects on disease resistance, needles and crown characters have also been reported. While graft success and compatibility tend to increase with closer relationship between the scion and rootstock, it is difficult to predict a rootstocks's influence on other traits for a specific scion.

In this study, conducted by graduate student Keith Jayawickrama, contributions of sites, rootstocks, scion clones (and the interactions between these factors) to scion growth and physiology were investigated in loblolly pine. Six second generation clones were used as scions and 25 full-sib families (20 fast-growing and 5 slow-growing) as rootstocks. The study was established on four sites but data only from the three sites grafted in 1988 are summarized. Significant differences ($p<.05$) were found between scion clones for all traits measured: two-year scion elongation, number of flushes in the second year, crown diameter, dbh and number of male and female strobili. Significant differences among rootstock families were shown for crown diameter and number of flushes.

Additional measurements were taken on the South Carolina Forestry Commission site at the Niederhof seed orchard, located in Jasper County, SC. Heights were measured through the 1989 season (on nine occasions), and predawn needle water potentials were measured four times. Needle samples were taken in September, 1989, to assess carbohydrate and mineral nutrient levels at the end of the growing season, and at the beginning of March 1990 for the start of the growing season. Significant differences were found ($p<.05$) between scion clones for onset of dormancy (defined here as the day the tree completed 95% of scion elongation for the second growing season), predawn needle water potential, needle hexose and sucrose contents and contents of all mineral elements measured (N,P,K,Ca,Mg). The rootstock family significantly ($p<.05$) affected contents of hexoses, Ca and Mg in needles but not the other characteristics. At this age the clone used as scion appears to have a greater effect than the rootstock family on the growth and physiology of the scion.

Sand Pine, Pitch Pine, and Virginia Pine Hybrids

Graduate student David Porterfield recently completed his Master of Science thesis research examining three interspecific pine control crosses of sand pine (Pinus clausa (Chapm. ex Engelm.) Vasey ex Sarg.), pitch pine (Pinus rigida Mill.) and Virginia pine (Pinus virginiana Mill.). The objectives of the study were to: 1) verify individual F^1 hybrids and to describe each of the crosses taxonomically; 2) determine the mode of inheritance of individual traits as to whether intermediate or dominant for P. virginiana x P. clausa and P. clausa x P. virginiana; 3) determine whether there are significant reciprocal hybrid differences for these traits.

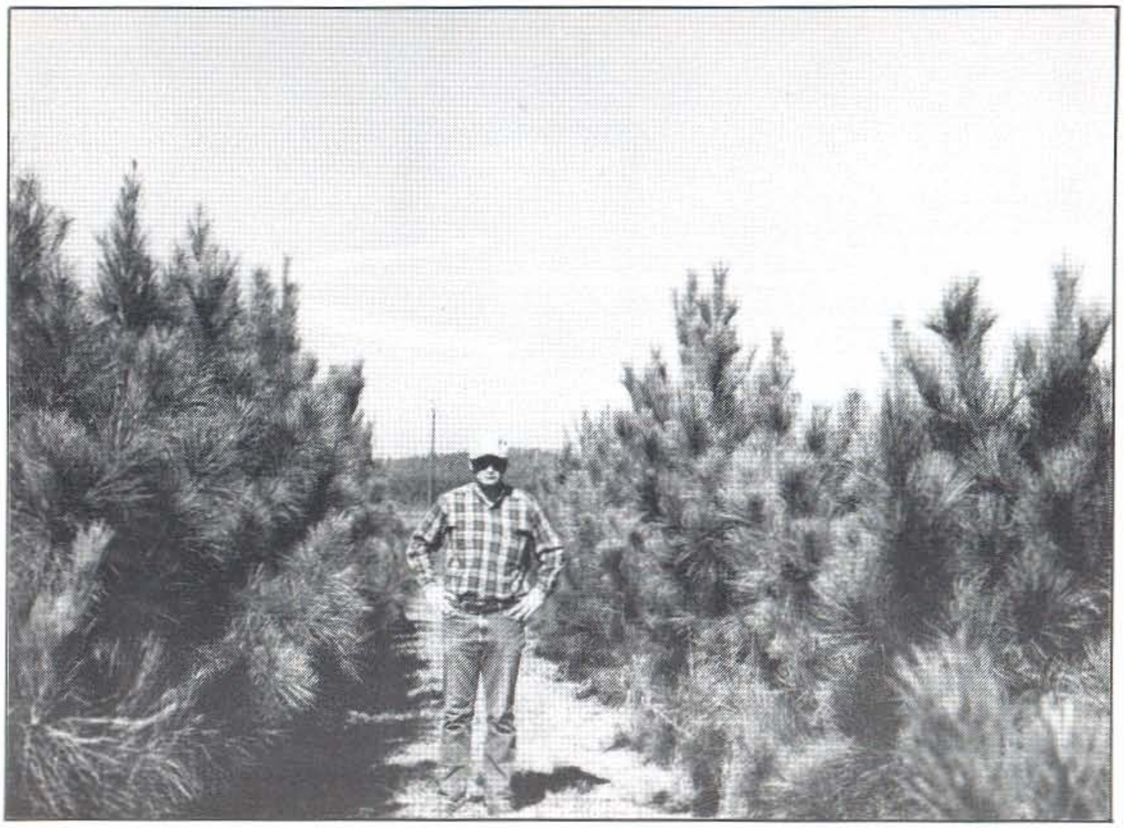
Thirty-three different morphological, anatomical, biochemical, and phenological characters were chosen for evaluation and description of parental species and hybrids. Analysis of putative hybrids of P. rigida x P. clausa was done by use of a five variable weighted hybrid index and comparison of individual trait means. Analysis of putative hybrids of P. virginiana x P. clausa and P. clausa x P. virginiana was done using a weighted hybrid index, several canonical discriminant analyses, and a comparison of trait means.

Several good discriminating characters were found between the parental species. The pollen shedding stage was by far the best and is recommended for future interspecific pine hybrid verification studies.

The hybrid, P. rigida x P. clausa, was identified and is likely a true intergroup cross between subsections Australes and Contortae and suggests a close taxonomic relationship between these subsections.

The reciprocal crosses, P. virginiana x P. clausa and P. clausa x P. virginiana were verified and indicate a very close taxonomic relationship between these two species. The reciprocal hybrids of Virginia with sand pine were healthier and better adapted to the site at Tillery, NC, than sand pine and performed as well if not better than Virginia pine based on observations of survival, height and diameter. This hybrid might be useful on other sites in the southeastern United States.

Although generally recognized as distinct species, the taxonomic status of sand and Virginia pines as species is questioned by this and other studies which suggest that they are really subspecies of the same species. Further crossing and taxonomic studies are needed to resolve this question as well as the relationships of the other species in subsections Australes and Contortae.

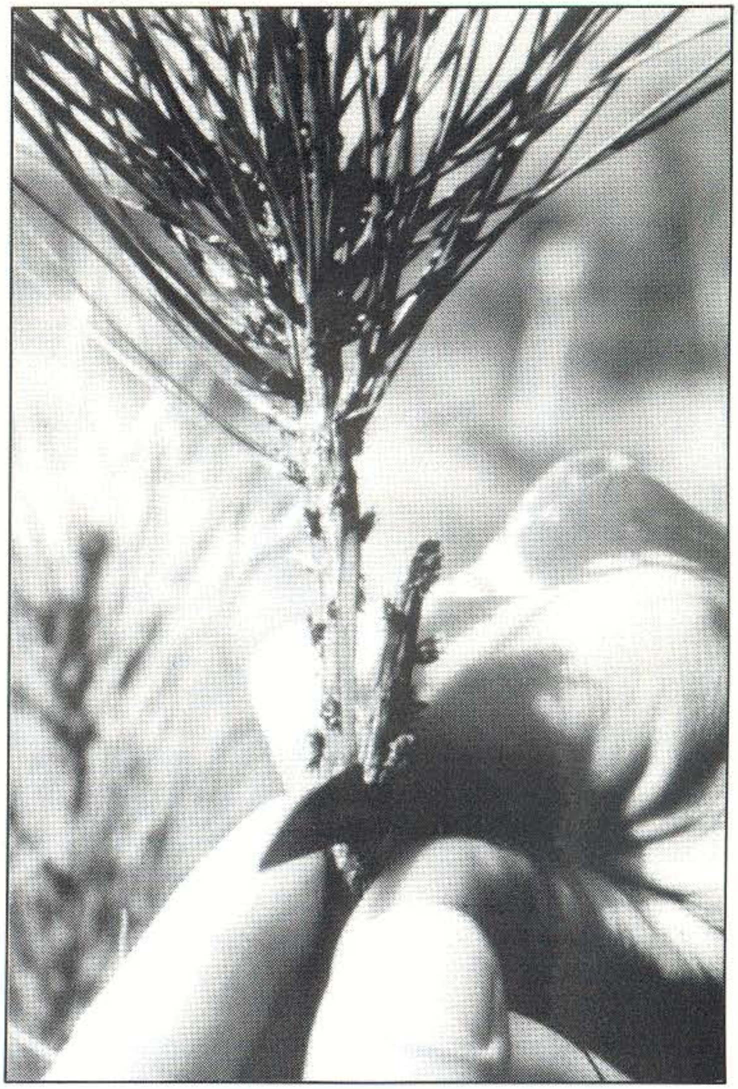


A three-year-old Kimberly Clark Corp. plantation diallel progeny test. The trees on the left are from a cross of plantation selections, right are unimproved commercial check trees.

Scion Maturation Study

The purpose of this study is to determine if clones of different ages can be established together in advanced generation seed orchard blocks. Will clones that are much older (e.g., 70+ years old) be able to grow as vigorously and thus successfully compete with younger clones (e.g., 10 years old from seed) and produce comparable amounts of seed? There are numerous examples with vegetative propagules where significant growth reduction is evident when grafted juvenile trees are compared to grafts of older trees. When second generation orchards were first established in the Cooperative, a few first generation clones were grafted in the orchards to serve as pollen parents. In a study of four such orchards, first generation clones averaged 24.8 ft. in height and second generation clones averaged 27.8 ft. Since these data were reported, we have observed even greater differences between the very mature clones and the more juvenile second generation clones. Virtually none of the pollen parent clones were able to grow and compete with the younger clones, and most have been rogued from the orchards.

In the late 1990's, Cooperators will be establishing third-cycle production seed orchards. Ideally, clones with the highest breeding values, regardless of age, should be established in these new orchards. It is very likely that some clones from the plantation selections (avg. age 45 yrs.) and the second generation selections (avg. age 30 yrs.) will have breeding values comparable to third generation selections (avg. age 7-10 yrs.) and could, therefore, be established in orchards together. If the large growth differences experienced previously between second generation clones (avg. age 15 yrs.) and first generation clones (avg. age 70 yrs.) also occur for the scion age differences anticipated for the newer orchards, then the new third cycle orchards will need to be established differently. Either clones of different ages will be established in separate blocks, or only clones of similar ages will be used in the orchards.



Grafting for the scion maturation study was completed in the spring of 1991.

This study is to be grafted in the spring of 1991. Presently, Piedmont locations will be established by Bowater (SDW), Bowater (CWD), and Federal Paper Board. Coastal locations will be at the S.C. Comm. Forestry, Georgia Forestry Commission, and Container Corp.

Inbreeding Grafting Study

Several years ago, the Inbreeding Study was initiated to determine the effects on growth rate of various levels of inbreeding derived from various types of related matings. Recently, members of the Breeding and Testing Task Force expressed concern about the effects of inbreeding on the health and vigor of the tree as it relates to grafting success, flower initiation, and filled seed yield. The reason for their concern is that sublining breeding systems under consideration by the task force often force a build up of inbreeding. These inbred trees are then established in seed orchards and outcrossing or unrelated matings occur to produce production seed crops. The concern is whether a loss of vigor in the inbred selections will cause a decline in seed production that would affect seed orchard or breeding orchard efficiencies in the generations ahead.

Therefore, the Cooperative staff is initiating a study to evaluate the effects of various inbreeding levels (outcross, half-sib, full-sib, and self) on seed production and on graft development. The study is to be established in 6 locations, 3 in the Piedmont and 3 in the Coastal Plain. Plans are to grow the rootstock in 1991 and to graft in 1992.

BREEDING, TESTING AND SELECTION

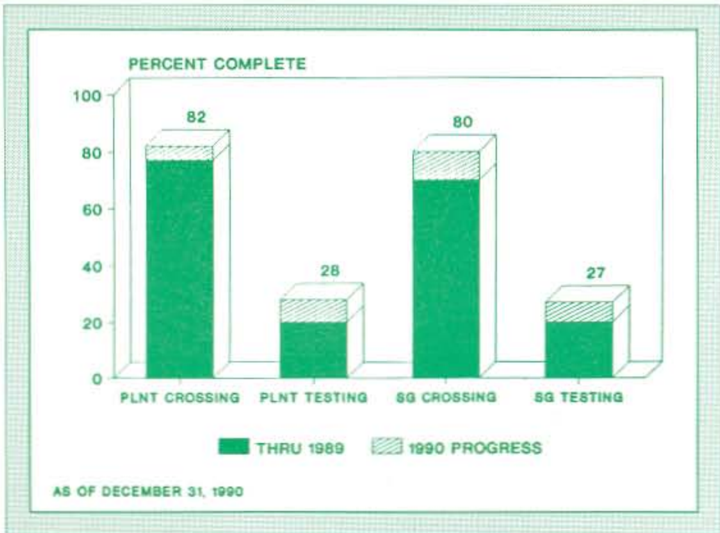


Figure 3. *Overall status of the Plantation and Second Generation Breeding and Testing Program.*

Breeding and Testing Progress Report

Significant progress was made in 1990 toward completion of the breeding and testing of nearly 4000 plantation and second generation selections. As of December 31, 1990, crossing for the plantation material was estimated at 82% complete (up from 77% last year) and 80% complete for the second generation (up from 70%). Test establishment is approximately 28% complete for both plantation and second generation tests as compared to 22% last year (Figure 3). A status report of progress by region is displayed in Figures 4 and 5.

During the 1990 planting season, an additional 108 tests were successfully established, including 99 plantation tests and 9 second generation tests. This brings the total tests established to 363 (Figure 6). The 108 tests established in 1990 were approximately equivalent in number to the tests planted in 1989. With 80% of the crossing done, the tests established per year should increase substantially in 1991 and 1992. We estimate that 1992 will be the peak year for test establishment in this cycle of breeding and testing.

To date, 13 programs (Table 5) are 100% complete on crossing and are in the process of heavy test establishment. One organization, Weyerhaeuser, is 100% complete in test planting. Though 1991 was suppose to be the last year for breeding work, several organizations will require an additional year or two of crossing to complete their diallels. Variation in the rate of progress among programs has developed in the

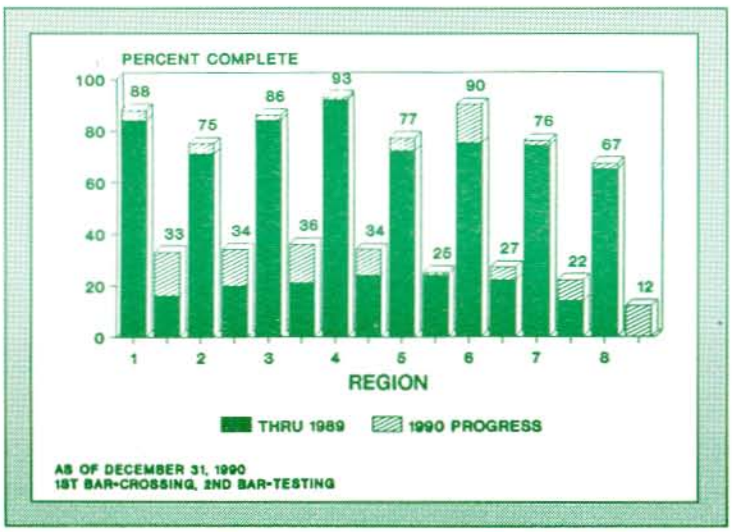


Figure 4. *Plantation testing status by region.*

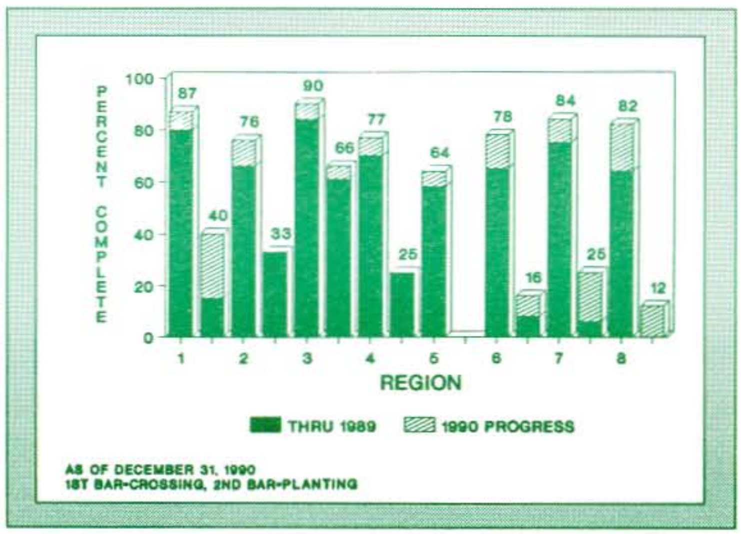


Figure 5. *Second generation testing status by region.*

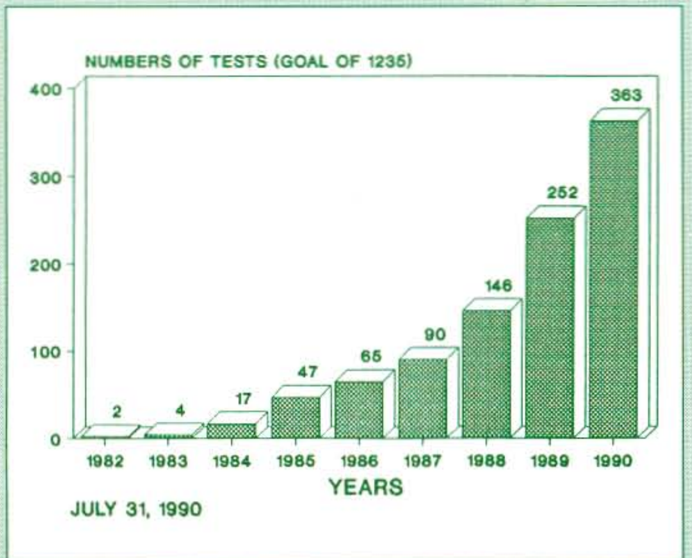


Figure 6. *Cumulative number of advanced generation progeny tests established.*

breeding phase for several reasons including: (1) utilization of poor sites for establishment of some early clone banks, (2) late establishment of clone banks thus delaying flower production, and (3) poor flower crops in one or more years in several breeding regions. Most cooperators have reported excellent flower crops in the current year so we are optimistic that breeding will be completed very shortly.

Progeny test establishment has been very successful to date. Though there have been some problems—mice and squirrel damage in the greenhouses, rabbits and tipmoth in the field, and a few droughts—overall we have experienced a high success rate in test establishment. Of the advanced generation tests established to date, only 16 have been abandoned due to poor survival and/or unacceptable field layout.

Members continue to cooperate effectively in sharing the testing work load. Those with an excessive number of tests ready to plant in a given year give some to those members who presently have few tests ready. In future years, the donor will become the recipient for an equal number of tests. Such sharing on the part of cooperative members results in a more balanced distribution of tests over years for a given member and faster completion of the testing program than would otherwise be possible.

Plantation Selection Seed Source Study

Progress on the Plantation Selection Seed Source Study (PSSSS) continues and with a little luck and good weather, 1991 will be the last year of pollination work. If so, the first field plantings will be in 1994. This spring, Cooperators will be pollinating 8451 flowers for this study. Overall, crossing is about 52% complete. Crossing status by region is shown in Table 6. As with most studies involving control pollinations, we had hoped to be finished by now but Mother Nature does not always share our priorities. With 52% of the crossing completed and most everyone reporting good flower crops this spring, the crossing should be over soon and test establishment can begin.

TABLE 5. Leaders of the pack: Programs who have completed crossing and are well on the way in testing.

Crossing Complete		% Planting Completed
Weyerhaeuser, NC	(16)	100
Bowaters CWD	(17)	56
Union Camp, GA	(15)	53
Packaging Corp.	(14)	50
Union Camp, VA	(12)	50
Westvaco, SC	(18)	48
International Paper, SC	(11)	45
Scott	(8)	38
Kimberly Clark	(15)	34
Macmillan Bloedel	(14)	31
Bowater SDW	(19)	29
Ga. Pacific, SC	(17)	18
Westvaco, VA	(4)	16

Note: parenthesis ( ) represents number of diallels bred.

TABLE 6. Status of the Plantation Selection Seed Source Study.

Area	% Crossing Complete		# Flowers to Pollinate in 1991
1. Virginia	64		935
2. Coastal, NC	33		1,265
3. Coastal, SC	30		2,292
4. Coastal, Ga. & Fl.	58		1,044
5. Lower Gulf	66		584
6. Upper Gulf	67		814
7. Pied. Ga. & SC	43		1,517
Avg.	52	Total	8,451

SEED ORCHARD PRODUCTION

Cone and Seed Yields

The 1990 cone crop brought good news for cooperative seed production with 30.4 tons of genetically improved loblolly pine seed produced, a 89% increase over the extremely low crop of 1989 (16.1 tons) (Table 7). It is interesting to note that while the 1990 crop produced twice as many bushels of cones as the 1989 crop, only 89% more seed were produced, reflecting considerably poorer seed yields than in the previous year. Yields for 1989 averaged 1.38 pounds of seeds per bushel of cones harvested. The 1990 yields fell to only 1.19 pounds per bushel, the lowest yield in the past 10 years. Table 7 shows a steady decline in pounds per bushel since 1987. Several factors could influence the yields including less effective insect control or adverse weather patterns. It is believed that the low 1990 yields was affected by the drought in 1990. Also, with an abundance of seed in storage some organizations may not be as intensively managing the old 1.0 orchards which still account for 85% of the Cooperative's seed production.

Table 8 compares yields in bushels and pounds of seed for the 1989 and 1990 harvests for seven species. Slash pine was up substantially with 12,816 pounds of seeds produced in 1990 as compared to 687 pounds in 1989. Minor species collections were almost nonexistent this year as only Virginia pine (47 pounds) and white pine (2847 pounds) collections were reported.

While the 1990 crop was historically a low harvest, it is becoming increasingly more difficult to assess the success of a harvest. Various harvest strategies contribute more significantly each year to reported production figures. With an abundance of seed in storage, some organizations choose not to collect in poor years. Other organizations collect from only the genetically best parents. This year we had reports of "no collection" from at least 17 orchards.

Will this downward trend continue? It appears the 1991 crop will be fairly good but we may never see another 93 ton year as we did in 1987 because of changes in harvest strategies. This is not cause for concern, since additional genetic gains are being realized by collecting more selectively. The 1987 crop reflected a year when organizations were collecting all they could from both 1.0 and 2.0 orchards. In the

TABLE 7. Ten year cone and seed yields from loblolly orchards.

Harvest Year	Bushels of Cones	Tons of Seed	Pounds Per Bushel	# Seedlings (Millions)	Acres Regenerated (Millions)
1981	64,811	50.5	1.56	808	1.35
1982	44,761	30.5	1.36	488	0.82
1983	68,447	49.0	1.43	784	1.31
1984	105,239	80.1	1.52	1,282	2.14
1985	52,155	37.8	1.45	605	1.01
1986	84,953	70.1	1.65	1,122	1.87
1987	112,822	93.3	1.65	1,493	2.49
1988	56,822	42.7	1.50	683	1.14
1989	23,247	16.1	1.38	257	0.43
1990	50,944	30.4	1.19	486	0.81
Totals	664,201	500.5	1.51(avg.)	8,008	13.37

TABLE 8. Cone and Seed Yield Comparisons for 1990 and 1989.

Species	Bushels of Cones 1990	Bushels of Cones 1989	Pounds of Seed 1990	Pounds of Seed 1989	Pounds of Seed per Bushel Cones 1990	Pounds of Seed per Bushel Cones 1989
Coastal 1.0	32,016	11,341	37,895	15,246	1.18	1.34
Piedmont 1.0	11,069	7,715	13,692	12,212	1.24	1.58
Coastal 2.0	4,786	2,216	5,947	2,417	1.24	1.09
Piedmont 2.0	3,073	1,975	3,216	2,242	1.05	1.14
Slash pine	11,203	912	12,816	687	1.14	0.75
Virginia pine	54	48	47	45	0.87	0.94
White pine	3,882	3,342	2,847	2,268	0.73	0.68
Totals	66,083	27,549	76,459	35,117		

future, collections will be concentrated more in the second generation orchards with collections in the first generation orchards being highly selective and ultimately phased out.

Figure 7 shows the cumulative impact of the Tree Improvement Program on regeneration since 1980. Enough seed has been harvested to plant 13 million acres which is approximately 65% of the forest land area managed by members of the Cooperative. With some 25% of the managed land dedicated to hardwood production, we have produced enough seed in 10 years to regenerate almost the entire land base of the membership dedicated to loblolly pine production. Clearly, significant amounts of improved seed are being sold or used in landowner assistance programs.

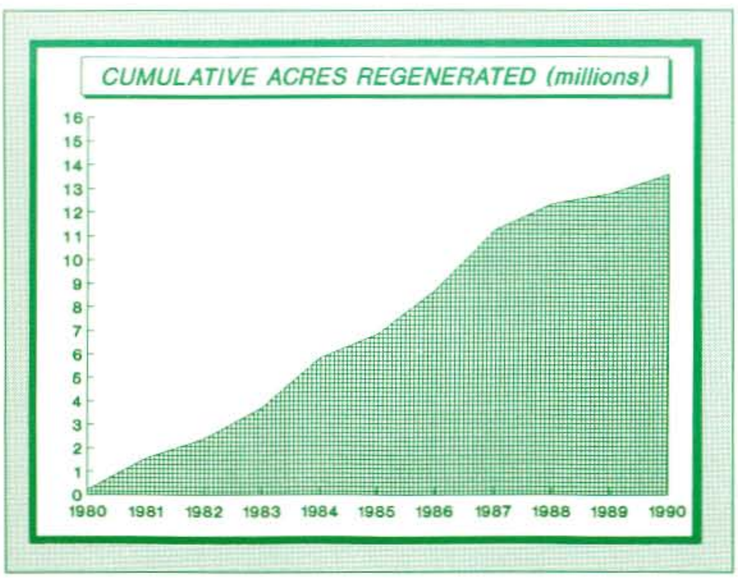


Figure 7.

Cumulative regeneration profile for the Cooperative since 1980.

Production of the second generation orchards over the last 9 years is shown in Figure 8. The 1990 crop yielded 4.3 tons of seed. While that still represents only 14% of the total crop, it is about twice what was produced in 1989 (2.3 tons).

Total production in either bushels or pounds of seed do not tell the whole story. Production efficiency is a key objective in seed orchard management; that is, how many pounds of seed per bushel of cones are produced. Production efficiency is a reflection of how well orchards have been managed in terms of site selection, general health and vigor, insect control, cone harvest and seed extraction efficiency. At one time, we thought 1.0 pound per bushel was an acceptable yield, but as management practices improved, 2.0 pounds per bushel became the expected goal. One clone in a Champion (NC) orchard produced 3.3 pounds per bushel in 1989. Since 1969, Cooperative orchards have produced on average 1.46 pounds of seed per bushel. If that time frame is separated into two periods, yields from 1981-1990 averaged 1.51 pounds per bushel while those from the previous 11 years (1969-1980) averaged only 1.28 pounds per bushel, a difference of .23 pounds per bushel. It is obvious that our overall management has improved over the years . One may ask, however, "Does .23 pounds per bushel make that much difference?" Simple calculations show that it does. During the period from 1981-1990, Cooperative orchards produced 664,201 bushels of loblolly pine cones for a total of 500 tons of seed. The same number of bushels at 1.28 pounds per bushel yields 425 tons. Increasing our yields by .23 increases by 75 tons the amount of seed produced during the 10 year period from 1981-1990. As more and more second generation seed is harvested, our goal should be to keep pounds per bushel yields as high as possible.

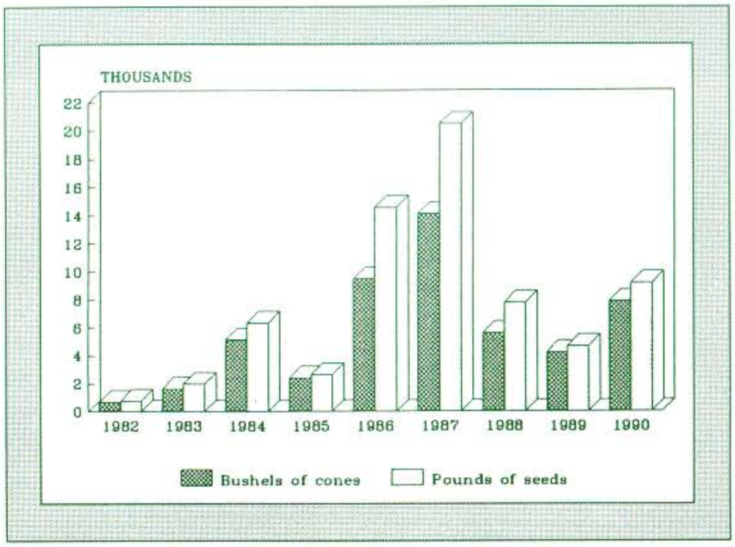
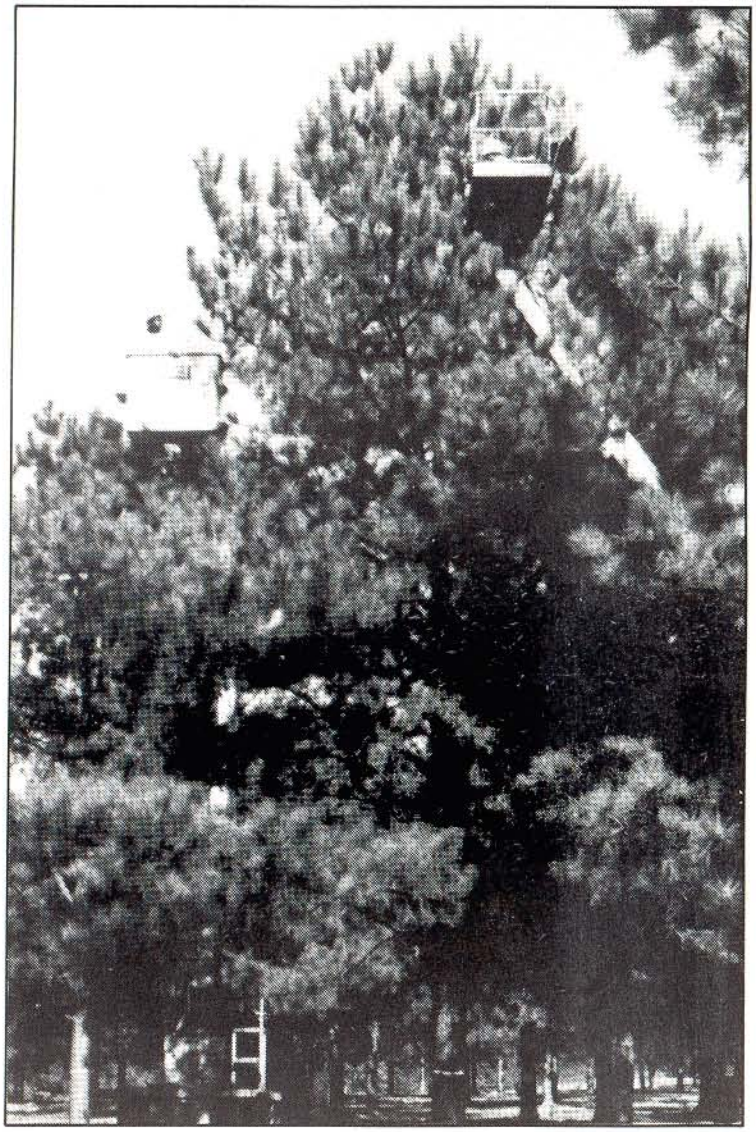


Figure 8. *Second generation seed orchard yields for the past nine years.*



Cone harvesting in James River Corporation's second generation seed orchard in southwest Alabama.

Production Leaders

Last year, only the Champion (NC) Coastal orchard made the Honor Roll at 2.61 pounds per bushel. For the second consecutive year, a single member made the Two Pound Honor Roll. We are pleased to recognize an organization who appears on the Honor Roll for the first time—Georgia Pacific's second generation orchard (Moselle, MS) managed by Tommy Sims, produced 2.12 pounds per bushel. Congratulations go to Tommy for a superb job of seed orchard management in a year when yields were generally low.

With a single orchard on the Honor Roll, we have chosen to recognize several other production efficiency leaders for the Cooperative. The highest efficiencies, after Georgia Pacific's 2.12 pounds per bushel, ranged from 1.60 to 1.84 pounds per bushel. Champion's (SC) 1.5 Piedmont loblolly orchard was second at 1.84 pounds per bushel. Orchards in the 1.60 pounds per bushel range (in order of magnitude) include: Weyerhaeuser, NC Piedmont orchard; Weyerhaeuser, NC Coastal orchard (at Lyons, Ga.); the Champion (SC) 1.5 Alabama loblolly orchard and Weyerhaeuser (NC) Coastal tied for fifth place and finally, the Champion (SC) Disease Resistance orchard. As Table 9 depicts, production efficiency was dominated by two organizations in 1990, Champion (SC) and Weyerhaeuser. Congratulations to orchard managers George Oxner (Champion), Gary Oppenheimer (Weyerhaeuser, NC) and Franklin Brantley (Weyerhaeuser, GA) for their diligent efforts in maintaining a high level of orchard production.

It is interesting to note that even in poor production years, certain clones continue to yield at high levels. James Hodges of Champion (SC) reported 3 clones yielding above 2.0 pounds per bushel: 3-47 (2.37 pounds per bushel), 3-13 (2.25 pounds per bushel) and 8-120 (2.17 pounds per bushel). Dave Gerwig of Westvaco also reported several clones that yielded 2.0 pounds per bushel even though their orchard average was only 1.16 pounds per bushel.

TABLE 9. Production efficiency leaders for the 1990 loblolly pine cone harvest.

Cooperator	Orchard Type	Acres	Age	Lbs./ Acre	Manager
Ga. Pacific (Moselle, MS)	Coastal 2.0	14	10	2.12	Tommy Sims
Champion, SC	Piedmont 1.5	20	24	1.84	George Oxner
Weyerhaeuser (NC)	Piedmont 1.0	11	28	1.65	Gary Oppenheimer
Weyerhaeuser (GA)	Coastal 2.0 (NC)	52	14	1.64	Franklin Brantley
Champion, SC	Alabama 1.5	10	15	1.63	George Oxner
Weyerhaeuser (NC)	N. Coastal 1.0	33	30	1.63	Gary Oppenheimer
Champion, SC	Disease Resist.	10	21	1.60	George Oxner

ASSOCIATED ACTIVITIES

Graduate Student Research and Education

The education of graduate students and the research they conduct as part of their degree programs continues as a very important activity of the Cooperative. Cooperative members have generously contributed to graduate 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.

During the past year, 12 graduate students have been working in association with the Tree Improvement Cooperative. The efforts of nine were directed toward Masters of Science degrees, and three were involved in Ph. D. programs. Of special note were six students who completed their degree programs during the past year.

Following is a list of the graduate students working in association with the Cooperative, the degree to which each aspires and the subject of their research project. Student research projects encompass a wide range of subject matter related to tree improvement. 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. Many of the outstanding applicants to our graduate program are from foreign nations. This results from two primary factors, 1) the employment opportunities for domestic graduate students are scarce, and 2) the strong international recognition of our tree breeding research and development success.

STUDENT, DEGREE	*RESEARCH PROJECT*	*STUDENT, DEGREE*	*RESEARCH PROJECT*
Claudio Balocchi, Ph.D.	*Age trends of genetic parameters and selection efficiency for loblolly pine (Completed)*	*Roger Arnold, Ph.D.*	*Quantitative genetics of Fraser fir, with emphasis on a multi-trait selection index*
Ann Margaret Hughes, M.S.	*Seed quality studies in Fraser fir (Completed)*	*Mohammad Charomaini, M.S.*	*New Student - project undecided*
Keith Jayawickrama, M.S.	*Nutrient and carbohydrate variation among loblolly pine clones grafted on different rootstock families (Completed)*	*Jan Svensson, Ph.D.*	*Ecophysiological bases of genetic differences in productivity of loblolly pine*
Yecai Liu, M.S.	*Genetic variation in a four year old Fraser fir provenance study (Completed)*	*Ying-Hsuan Sun, M.S.*	*Vegetative propagation and DNA transfer in Fraser fir*
Luis Osorio, M.S.	*Vegetative propagation of Pinus maximinoi and Pinus tecunumanii (Completed)*	*Jerry Windham, M.S.*	*Variation in the number of archegonia per ovule in loblolly pine*
David Porterfield, M.S.	*An evaluation of interspecific hybrids of P. clausa x P. virginiana and P. rigida x P. clausa (Completed)*	*Youhau Zhang, M.S.*	*Genetic differences in seasonal growth patterns associated with fusiform rust resistance in loblolly pine*

PROGRAM STAFF

The 1991 Cooperative Tree Improvement Program Organizational Chart reflects little change from last year with the exception of Vernon Johnson's position which was terminated in January, 1991. Vernon had been working in a 3/5 time position since his retirement in June of 1988, but due to state budget cuts, the position had to be eliminated. Vernon served the Cooperative faithfully for 25+ years and his presence and contributions to the program will certainly be missed.

Not shown on the organizational chart, but a member of the "team", is Dr. Floyd Bridgwater, Research Geneticist with the U. S. Dept. of Agriculture, Forest Service. He is a full-time research scientist housed in the Cooperative office complex but supported by the Southeastern Experiment Station of the USFS. Virtually all of the research conducted by Dr. Bridgwater complements the Cooperative's research program. Several outstanding tree improvement graduate students have worked, or are working, under Dr. Bridgwater's direction.

MEMBERSHIP OF THE TREE IMPROVEMENT COOPERATIVE

No changes have occurred in membership since the 1990 Annual Report. Total membership remains at 25 organizations managing 45 distinct tree improvement projects. During the 1989-1990 year, Georgia Pacific purchased two other Cooperative members, Great Southern and Leaf River. Georgia Pacific will maintain both tree improvement programs but the Leaf River unit will be managed under the direction of the Western Gulf Cooperative. They will, however, complete their current plantation breeding and testing obligations to the North Carolina State 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.
Internationl Forest Seed Co.
International Paper Co.
James River Corp.
Kimberly Clark Corp.
MacMillan Bloedel, Inc.
Mead Coated Board
N.C. Division of Forest Resources
Packaging Corp. of America
Procter and Gamble Cellulose
Rayonier, Inc.
Scott Paper Co.
S.C. State Commission of Forestry
Union Camp Corp.
Virginia Department of Forestry
Westvaco Corp.
Weyerhaeuser Co.

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS OF THE COOPERATIVE

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Balocchi, C. E., F. E. Bridgwater, B. J. Zobel, and S.Jahromi. Age trends in genetic parameters for tree height in a nonselected population of loblolly pine. (In Review)

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Li, B., S.E. McKeand and H.L. Allen. 1991. Seedling shoot growth of loblolly pine families under two nitrogen levels related to 12-year height. Can. J. For. Res. 21:In press.

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Lowerts, G.A. and J.B. Jett. 1989. Seed orchard turf management with sublethal application of selected herbicides.Abst. Proc. 20th So. For. Tree Improv. Conf. June 26-30, Charleston, SC.

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Genetic resource development of loblolly pine by means of breeding, testing,and selection is proceeding aggressively within the Cooperative. Pollination, production of test seedlings, planting and maintaining quality progeny tests on uniform sites provides the foundation for a third cycle of selection and genetic improvement.