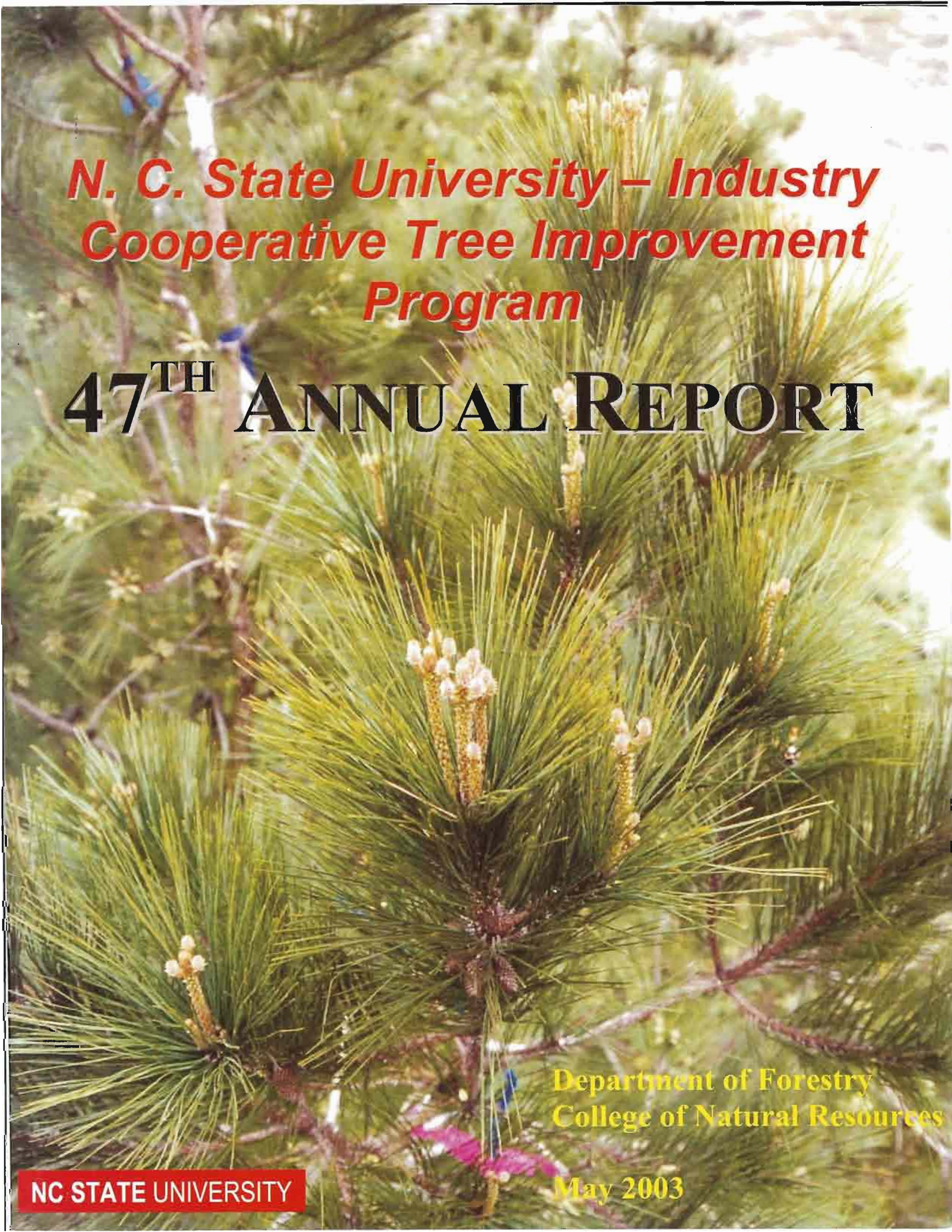
N. C. State University – Industry Cooperative Tree Improvement Program

47TH ANNUAL REPORT



Department of Forestry
College of Natural Resources

NC STATE UNIVERSITY

May 2003

Front Cover:

Top-grafting is now the standard technique used by Coop members to accelerate breeding in the third cycle. Here, Weyerhaeuser's loblolly seed orchard at Lyons, Georgia, several grafts of third-cycle selections established in the top of a mature tree are loaded with female strobili and ready for breeding just two years after grafting (photo courtesy of Patrick Cumbie, Weyerhaeuser Corp.)

EXECUTIVE SUMMARY

BREEDING, TESTING, AND SELECTION

The Coop reached a major milestone this year by completing selection of the 3rd-cycle breeding population. The final 106 progeny tests from the second cycle were screened and 73 new selections made. This brings the total to 968. Most of these selections have now been assigned to breeding sublines. Currently, we have 32 sublines with 350 selections in the Coastal zone, 31 sublines with 362 selections in the Piedmont zone, and 13 sublines with 164 selections in the Northern zone.

Pollen is now available for polycross breeding in all zones and a substantial amount was shipped to cooperators for this season's breeding. More members participated in this year's breeding, with priority being given to the generation of checklot seed for the next round of progeny testing. A limited number of full-sib crosses for 4th-cycle selection were also made.

PROGRESS REPORTS FOR RESEARCH

An economic analysis of seed orchard options demonstrated that genetic improvement of loblolly pine can be VERY profitable. Net Present Values were sensitive to timber prices, but were always positive except when all timber was used for pulpwood and double-digit discount rates applied.

The laboratory analysis of wood cores from a diallel progeny test of loblolly pine demonstrated considerable genetic variation for fiber length, alpha cellulose, coarseness, lignin content and specific gravity. High positive genetic correlations between cellulose content, fiber length, and wood density suggest that simultaneous improvement of these traits is feasible.

Early results from the PEP Hybridization Study suggest that inter-specific hybridization among Atlantic Coastal and Piedmont loblolly pine sources could generate trees with growth comparable to the Coastal sources and cold adaptation similar to the Piedmont source.

A survey of agencies participating in cooperative breeding programs in the South indicated that over 1.3 billion pine seedlings are planted each year in the South, about 80% of the nation's reforestation effort. More than 1.1 billion of these are loblolly pine and virtually ALL of them are genetically improved.

Computer simulation of nucleus breeding strategies suggest that the management of an elite line can offer some potential for additional genetic gain in seed orchards, but that this may come at the expense of gene diversity and more rapid accumulation of inbreeding.

A December ice storm caused severe damage to tress at a genetics demonstration trial at the University's Schenck Memorial Forest. One particularly fast-growing family suffered much greater than average stem breakage.

SEED PRODUCTION

The 2002 seed collection provided Coop members with 13.5 tons of loblolly pine seed, down considerably from previous years. Average yields in pounds per bushel were higher than in 2001. About 83% of the harvest came from 2nd-generation orchards and 65% from Coastal sources.

ASSOCIATED ACTIVITIES

All Cooperative staff on faculty were active in teaching this year, and three graduate students completed their programs. The Coop was involved in several Technology Transfer activities, including the IEG Meeting on Silvicultural and Genetic Impacts on Productivity of Southern Forests and our Annual Contact Meeting. Workshops were presented to members on the use of our Coop Database. Coop members were active on the Seed Orchard Pest Management Committee and participated in an efficacy trial of Imidan© and Capture© for cone and seed insect control in orchards. The Coop hosted two visiting scientists: Professor Dr. Lindgren from Sweden and Dr. Evi Alizoti from Greece.

As of April 2003, membership in the Coop stood at 16, with 6 state agencies and 10 private corporations.

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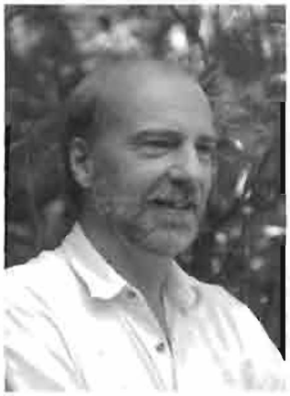
INTRODUCTION



What is it that all our members of the NCSU-Industry Cooperative Tree Improvement Program have in common? Obviously, all of them are connected in some way to forest production in the South, where forestry is BIG business: just shy of 16% of the world's timber production. Awesome!! That figure always gives me pause! While all of our members share this connection in common, the connection itself is established in many different ways, perhaps more than at any other time in the 47-year history of the Coop.

State government agencies have been with the Coop almost from the beginning. They continue to promote the forest economy in their respective jurisdictions by making genetically superior seedlings available to virtually all residents of the State. The economic spin-offs from improved forest productivity are good for landowner, manufacturer, workers and taxpayers alike.

Of course, we also have longstanding members who fall under the traditional "integrated forest industry" model. These companies operate manufacturing facilities that add value to round wood, while relying heavily on management of forest lands under their ownership as a major source of furnish for their mills.

Not so long ago, State agencies and integrated forest industry represented the two categories of members in our Coop. Each has a characteristic motivation for investment in tree improvement that has been recognized and balanced in the planning of our programs. History shows we've been successful.

Today, the landscape is more complex.

The public side of our membership appears largely unchanged, although State lawmakers are finding themselves challenged as never before to balance the public purse. Maintaining the continuity necessary for the long-term health of the State forest economy is a struggle when tax revenues are down.

It is on the private-sector side where the biggest "adjustments" have occurred. We used to refer to the phenomenon of "industry consolidation", describing a tendency for companies to seek stability through acquisition. This certainly created a challenge for our Coop. "Many hands make light work", but our hands became less numerous. Now, however, "consolidation" has evolved into "restructuring". Some of our private-sector members have adjusted their business plan, divesting themselves of forest assets to become manufacturers without land. Others now manage their forestlands as separate profit centers, competing with outside suppliers to sell wood on an open commodity market. Still others have gone to the extreme of becoming forestland managers without mills. Never before have we seen so much diversity in the way forest companies do business.

From the midst of this restructuring has emerged another important player: the timberland investor, whose business plan is to seek return from the trading of forested land. Important as it is to forest production in the US, the South is an obvious target for forestland investment and the restructuring of the industry has created opportunities for investment. This past year, we welcomed our first member in this new category: Hancock Natural Resources Group. While Hancock may have a different business model, they are acting as responsible stewards of a valuable forest resource and are highly motivated to enhance their investment. Hancock recently received certification under the 2002-2004 Sustainable Forestry Initiative®, and their involvement in tree improvement is further evidence of their philosophy that excellence in forest management is good business.

The South is undoubtedly the "wood basket" of the United States, so there is no doubt that genetics will continue to have a major impact on forest productivity in this region. Nevertheless, the business landscape for forestry has become more diverse and more complicated. Whether Cooperative Tree Improvement will continue to lead research and application of genetics to improve forest productivity will depend largely on our ability to accommodate the diverse visions of the many forestland owners in our Region.

Tim Mullin, Director

SELECTION, BREEDING, AND TESTING

THIRD-CYCLE SELECTION PROGRESS

YIPEE!! Finally, field selection for the 3rd-cycle breeding population was officially completed this year! In total, 283 test series (1,132 tests) were established by cooperators during the second breeding cycle. All of these progeny tests have now been analyzed and their breeding values have been calculated. A total of 3,470 parents have been evaluated and their breeding values summarized and compiled into the Cooperative Database.

Individual breeding values were calculated for all progeny in these tests. A list of selection candidates was first "pre-screened" by cooperators in the field, with the final selection grading usually supervised by a member of the Coop program staff. Steve McKeand graded the very first third-cycle selection right after Hurricane Hugo in February of 1990. Almost exactly 13 years later, Steve also claimed the honor of grading our final, third-cycle selection – kind of hard to deny that privilege to the current staff member with the longest service!

During this past year, Cooperative members made new selections from the final **106** progeny tests, yielding **73** new selections. This brings the total to **968**. Of these, 402 selections are for the Coastal breeding program, 394 are for the Piedmont program, and 172 are for the Northern program.

With selection complete, additional breeding sublines were created and most third-cycle selections have now been assigned. These assignments will facilitate breeding activities of the mainline breeding population. The progress of subline formation within the breeding programs is summarized in **Table 1**.

All third-cycle selections are being grafted into breeding orchards and a few of the "truly elite" selections are being incorporated into new third-cycle seed orchards.

*The **first** third-cycle selection was made in a Westvāco progeny test by Davis Gerwig, soon after it was badly damaged damaged by Hurricane Hugo*

*With Steve Wright looking on, Maxie Maynor extracts a wood core from the **final** third-cycle selection, made this year by the North Carolina Forest Service*

Table 1. Summary of third-cycle breeding sublines for the Coastal, Piedmont, and Northern breeding programs

Program - region	Number of sublines	Number of cooperators	Number of selections	Total % gain in height	Total % gain in volume
Coastal- Atlantic Coastal	15	6	171	11	28
Coastal- Florida	2	2	27	18	60
Coastal- Lower Gulf	15	7	152	11	29
Piedmont- GA and SC	21	7	243	12	38
Piedmont- Upper Gulf	10	5	119	11	34
Northern zone	13	4	164	8	26
TOTALS	76		876		

THIRD-CYCLE BREEDING UPDATE

Third-cycle breeding is being conducted within sublines, formed for each of three pollen-mix zones. There are currently 32 sublines with 350 selections in the Coastal zone, 31 sublines with 362 selections in the Piedmont zone, and 13 sublines with 164 selections in the Northern zone.

Pollen from 20 clones in each zone has been collected to form the pollen mix for polycross breeding, and there is sufficient pollen mix for this year's breeding in Northern, Coastal, and Piedmont zones. This is the first year that we are not limited in how much pollen we can send out to cooperators. We received requests and were able to send, approximately 3500 ml for the Coastal zone, 1800 ml for the Piedmont zone, and 850 ml for the Northern zone.

The Cooperative's breeding work is progressing well with all major tasks:

1) More pollen for the polycross (PMX) mix from each of the three breeding zones was collected, processed and stored for breeding. The designated pollen parents have been assigned to all organizations in each zone for grafting into breeding orchards or top-grafting on large trees, assuring sufficient pollen production for the cooperative breeding in the next few years.

2) Polycross mating is more active this year, with more members participating than in 2002. The high priority is still to create the checklot seed needed for a new round of field testing. Some seeds have been collected this year, but more will be needed to reach our goal. Ten clones were designated in each of the testing zones as female parents for checklot seed. These clones are crossed with the PMX for that zone to create checklot seed. The expected checklot seed needs for the three zones are as follows: Northern 600 seed per parent; Coastal 1500 seed per parent; and Piedmont 800 seed per parent.

3) More polycross mating is being done this year for sublines in all three regions. Collectively, well over 5,500 bags were pollinated this spring by our members.

4) A limited number of controlled full-sib crosses were made this year within several sublines by a few cooperators. These controlled crosses will generate seeds for within family-selection for the next breeding cycle.

RESEARCH

FINANCIAL ANALYSIS OF SEED ORCHARD ESTABLISHMENT ALTERNATIVES

The North Carolina State University-Industry Cooperative Tree Improvement Program has completed two cycles of breeding and is now implementing the 3rd cycle of breeding for improving loblolly pine. Members of the Cooperative are producing most of their current seed needs from rogued, 2nd-generation seed orchards. Work to establish new seed orchards for the future is underway or being planned. Several alternatives for new orchard development are of interest. Members may choose:

1. A 3rd-cycle mixed orchard composed of both tested 2nd-generation selections and 3rd-generation offspring selections, or

2. A 3rd-cycle offspring orchard composed entirely of new 3rd-generation offspring selections.

3. A 2.5-generation seed orchard with all tested parents. Because the seed orchard composition was simulated, gain estimates for fully rogued 2nd-generation orchards and 2.5-generation orchards were identical. Therefore, the standard or base case used in these analyses was a fully rogued 2nd-generation orchard.

Time of establishment is also of interest. Because genetic tests were not all established at once, breeding value information and new selections become available over a period of several years. It was possible to start new 3rd-cycle orchards in the late 1990's with only a portion of the total selection pool available. Alternatively, establishment could be delayed until spring 2004, the first "grafting season" when all the progeny test data and new selections are expected to be available. Genetic gain estimates are substantially different for Coastal and Piedmont regions so analyses were done for each region. Because cost data and discount rates are different for Industry and State Agency members, distinct analyses were also done for these two member types.

Based on the cost survey data of Cooperators, the aims of this study were to: (1) provide a comparative analysis of genetic gains, costs, and financial returns associated with each of seed orchard options; (2) determine the sensitivity of each option's net present value when the discount rate, timber prices, seed yield, and the accuracy of the genetic gain predictions are varied; and (3) develop recommendations for genetic program managers applicable to their operational tree improvement programs.

Materials and Methods

Fixed and variable cost information was solicited from members of the NCSU-ICTIP by surveying selected members (**Figure 1**). The data were collected confidentially and anonymously, especially for the private industries, and were differentiated based on only whether they originated from a state agency or a private industry from the Piedmont or Coastal Plain. The data in each group were averaged before being used for analysis.

The genetic gains for parent selections were based on 2nd-generation breeding values estimated from the Cooperative's loblolly pine breeding program. Genetic gain for 2nd-generation families was based on the open-pollinated progeny tests by the Cooperative. Breeding values of families were calculated using the best linear unbiased predictions (BLUP) method and genetic gains were estimated based on the breeding value estimates. The average for all families was an estimate of the average gain of the 2nd-generation orchards at establishment, while the average for the best 30% of families was representative of the gain that is possible after these orchards are heavily rogued. The genetic gain for 3rd-generation offspring selections was predicted using variance components, heritability and selection intensity values derived from the Cooperative's database or appropriate for the Cooperative breeding population.

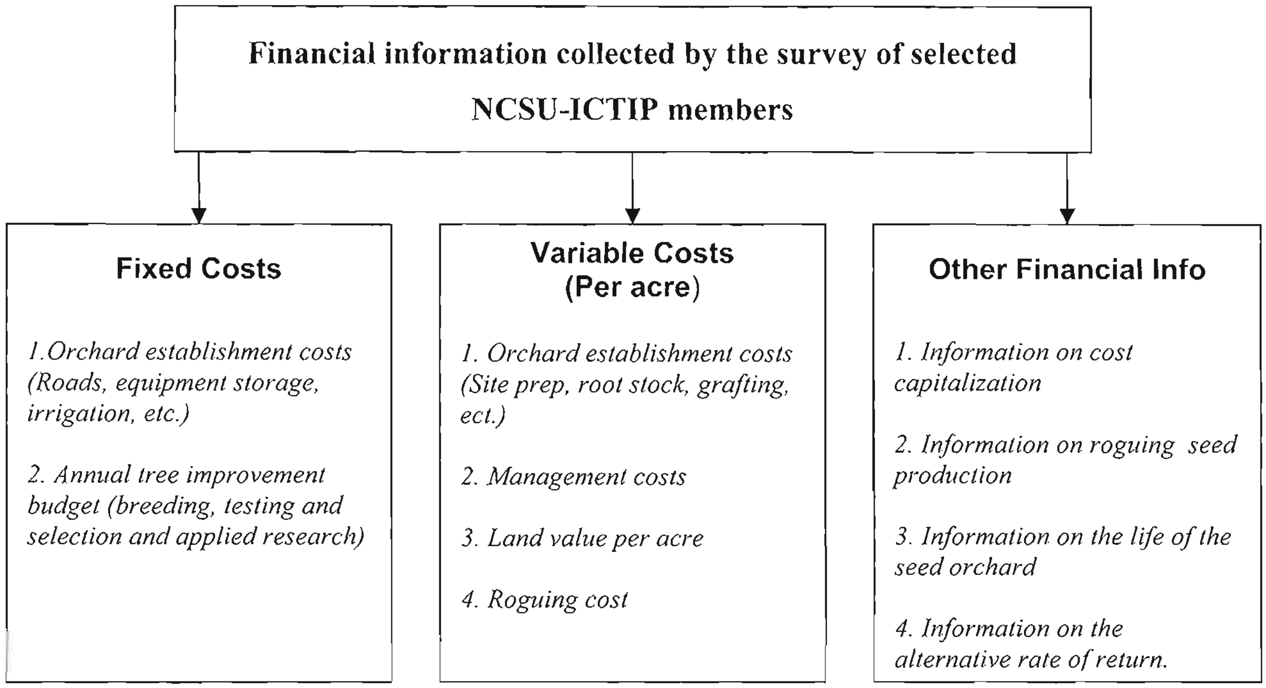


Figure 1. Fixed- and variable-cost information collected from members of the NCSU-ICTIP.

Using estimated and predicted genetic gains for loblolly pine as well as orchard development and management costs, Net Present Value (NPV) analyses were done for each of the seed orchard establishment options, two establishment times, for the Piedmont and Coastal Plain regions, and for Industry and State Agency members. State Agency and Industry members of the Cooperative provided cost and program management data in the form of a confidential survey. The data were averaged for both member types.

Results

The Net Present Values for each option are presented in **Table 2**. Different options have different seed orchard establishment and life expectancy time lines. For example, rogued 2nd-generation seed orchards will be completely phased out in 15 years, while the 3rd-cycle orchards are estimated to have a 30- and 35-year life span, respectively, including establishment, development and production phases. NPV's were estimated for plantations grown for pulpwood only and when fully merchandized for sawtimber, chip-n-saw and pulpwood. The most important finding of this study was the high profitability of a tree improvement program investment. The extra money spent for research, development (breeding, testing and selection) and seed orchard establishment and management is more than compensated by the added value (both in quantity and quality) of the timber grown from genetically improved pine plantations. The Net Present Values ranged from $2 million for a rogued 2nd-generation orchard (pulp, Piedmont, industry) to $107 million for a 3rd-cycle mixed orchard (merchandised, Coastal Plain, state agency). State-agency NPV's are higher than industry values but that does not mean state agencies have better tree improvement programs, rather it reflects the lower discount rates and management costs used for analyses of state programs. The values in **Table 2** are marginal values directly associated with the investment costs and benefits from the activity or option listed.

Table 2. Net Present Value (x1000) of each seed orchard establishment option for Industry or State Agency member in the Coastal Plain or Piedmont.

		3rd-cycle mixed		3rd-cycle offspring	
	Rogued 2nd-cycle	1999	2004	1999	2004
Private Industry					
Coastal Plain					
Merchandized					
For 15 years	$17,195	$21,074	$19,881	$18,817	$18,950
For 30 years		$34,176	$35,799	$29,000	$30,485
For 35 years			$38,304		$32,297
Pulpwood					
For 15 years	$4,188	$4,474	$4,330	$3,847	$4,052
For 30 years		$7,750	$8,254	$6,296	$6,913
For 35 years			$8,894		$7,375
Piedmont					
Merchandized					
For 15 years	$10,459	$11,188	$11,324	$10,487	$11,095
For 30 years		$16,537	$17,798	$15,957	$17,887
For 35 years			$18,834		$18,970
Pulpwood					
For 15 years	$2,176	$1,456	$1,751	$1,376	$1,739
For 30 years		$2,381	$2,934	$2,367	$2,984
For 35 years			$3,124		$3,182
State Agencies					
Coastal Plain					
Merchandized					
For 15 years	$36,783	$46,092	$42,671	$41,182	$40,846
For 30 years		$89,512	$95,569	$74,930	$79,233
For 35 years			$106,954		$87,474
Pulpwood					
For 15 years	$10,541	$12,583	$11,761	$11,060	$11,146
For 30 years		$25,277	$26,929	$20,645	$22,326
For 35 years			$30,293		$24,782
Piedmont					
Merchandized					
For 15 years	$24,911	$27,994	$27,624	$26,302	$27,142
For 30 years		$47,717	$51,578	$46,496	$52,297
For 35 years			$56,817		$57,766
Pulpwood					
For 15 years	$5,581	$5,137	$5,532	$4,959	$5,507
For 30 years		$8,905	$10,257	$8,983	$10,458
For 35 years			$11,285		$11,525

Net Present Values were very sensitive to estimates of timber price changes over time (**Figure 2**). The values are affected if the stumpage price changes faster or slower than the general rate of inflation. The NPV of various alternatives are also affected by the level of seed production in the orchard which is in turn a function of factors such as orchard site selection, and management efficacy (**Figure 3**).

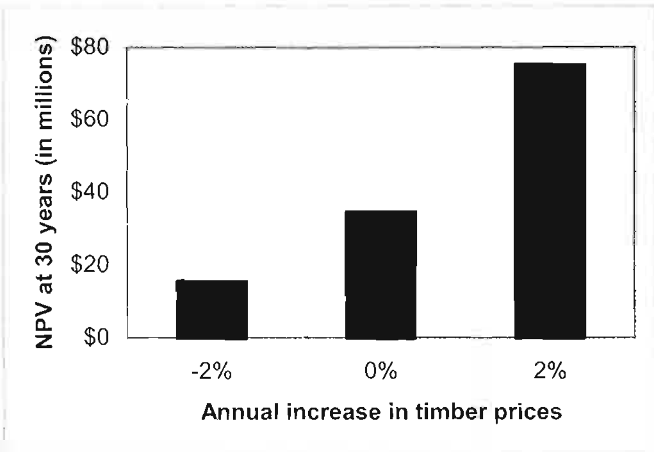


Figure 2. Net Present Value at 30 years of a third cycle mixed orchard established in 1999 on the Coastal Plain and fully merchandized based on the change in annual timber

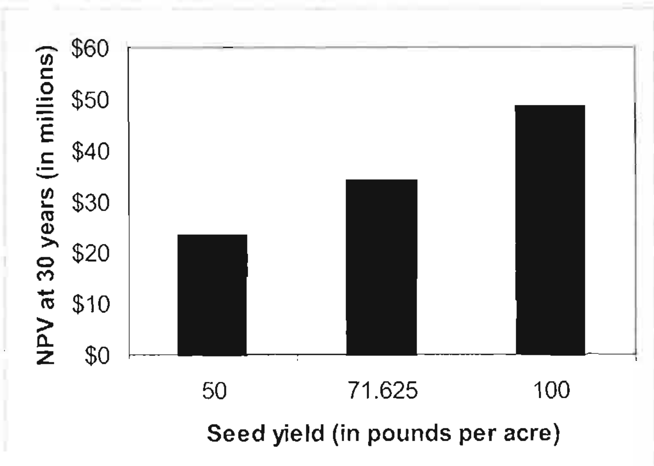


Figure 3. NPV at 30 years of a third cycle mixed orchard established in 1999 on the Coastal Plain and fully merchandized based on

In summary, the economic benefits from loblolly pine genetic improvement are very large. The returns more than offset the marginal costs of breeding, selection and testing along with orchard establishment and roguing. Among the main conclusions from the study are:

1. Genetic improvement of loblolly pine is **VERY** profitable. The benefits are overwhelming in certain cases, for example exceeding $100 million for merchandized timber (a state agency in the Coastal plain).

2. In all cases, the NPV's of the two 3rd-cycle options are higher than unrogued 2nd-generation orchards.

3. It is slightly more profitable to delay establishment of a new orchard to 2004 to take advantage of the fact that all the selections and breeding value information will be available.

4. Positive Net Present Values are quite robust. They are positive in all cases except when all timber is used for pulp and double-digit discount rates are used.

5. Merchandized timber options were in every case more attractive than pulpwood, due to the premium market price for saw timber versus the low market price for the additional pulpwood volume. This is of course true for virtually any investment in higher forest productivity.

6. The 3rd-cycle mixed orchard is recommended because The NPV's are similar to the offspring orchard and known, tested clones provide for operational efficiency and reliable gain.

Additional results are presented in Paul Shannon's M.S. thesis and can be accessed online from N. C. State University at:

http://www.lib.ncsu.edu/theses/available/etd-01112003-101219/

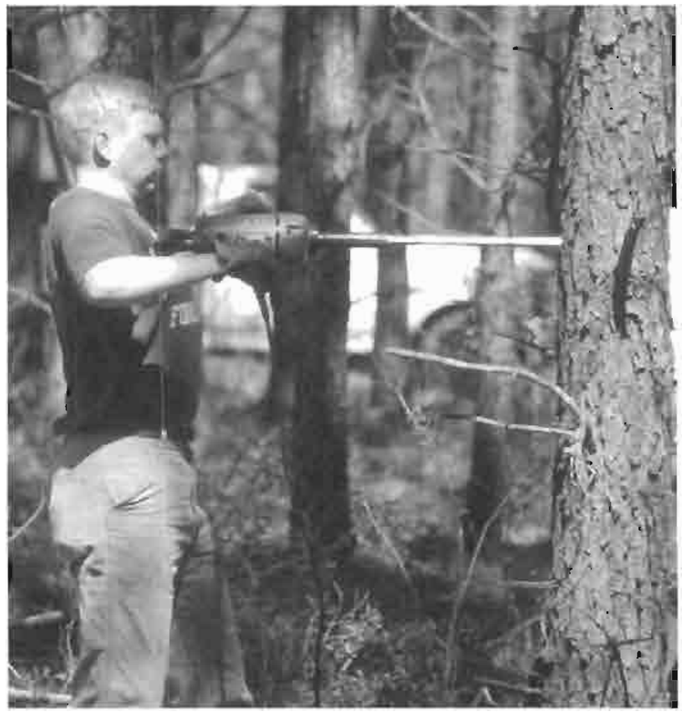
GENETIC VARIATION OF WOOD PROPERTIES IN A DIALLEL PROGENY TEST

Intensive silvicultural practices and genetic improvement of trees have increased forest productivity significantly in the southeast U.S. for loblolly pine. Improved growth of intensively managed loblolly pine plantations has allowed rotation ages to be reduced, compared to that of natural stands. As a result, the percent of juvenile wood from plantations has increased. Compared to mature wood, juvenile wood has low wood density, shorter tracheid length and higher lignin content. As a result, the pulp and paper industry has experienced reduced yields and higher pulping costs due to the increased use of juvenile wood.

Genetic variation in juvenile wood properties is important for improving the quality and uniformity of solid and chemical wood products. Specific gravity, cellulose content, lignin content, average fiber length, and coarseness are several key wood properties that affect the quality and quantity of wood produced either in plantations or in natural stands. Favorable juvenile wood properties may be obtained through a breeding program, if there is significant genetic variation among families and populations. Based on the intensive measurement of key wood and chemical traits from one diallel progeny test, the purpose of this study was to understand genetic variation of important wood quality traits of juvenile loblolly pine.

Materials and Methods

Fourteen full-sib families generated by a 6-parent half-diallel mating design of Piedmont loblolly pine were tested on four sites in the Piedmont of South Carolina. Two of the tests were located in Florence Co., SC. and two in Darlington Co., SC. A randomized complete block design with six replications was used in the field. Each full-sib family was laid out in six-tree row plots in each replication. Wood core samples were collected at breast height from 11-year-old trees using a 12-mm increment borer driven by a generator-powered industrial drill.



Robert Sykes uses an industrial drill to extract wood core samples from a field test in South Carolina

Thin wafers from ring three earlywood, ring three latewood, ring eight earlywood, and ring eight latewood were taken using a microtome. Wood wafers of ring three and ring eight were used to study chemical properties of juvenile (ring 3) and transition (ring 8) wood. Chemical analysis of these samples were done using micro-analytical techniques developed at N. C. State University, which allow the rapid characterization of fiber components and morphology of loblolly pine in a large number of samples. Briefly, the techniques involved are extractive removal, holocellulose preparation, alpha-cellulose and lignin content determination, average fiber length and coarseness analyses. Extractives were removed from all cores using the successive acetone method. The increment cores were then soaked in water overnight before ring samples were taken.

Early and latewood means of physio-chemical wood traits within each ring were compared using

T-tests. Analysis of variance was conducted to compare full-sib families using the SAS GLM procedure. A general linear mixed model was used to estimate variance components. Individual, family-mean and within-full-sib family heritabilities were estimated for wood density and amplitude using causal variance components.

Back at the lab, Robert Sykes uses a UV-visible spectrophotometer to measure the absorbance of a solution of dissolved wood and acid, in order to determine lignin content.

Preliminary Results

Earlywood and latewood of ring three were significantly different for alpha-cellulose content (ACY), weighted average fiber length (FLW) and coarseness (COA) ($p < 0.0001$) but not for lignin content (LIG) ($p < 0.3134$). Latewood from ring three had greater ACY, FLW and COA. The difference between latewood and earlywood for ACY, FLW, and COA was more pronounced in ring eight (transition wood) compared to ring three (juvenile wood). Latewood of ring eight had greater ACY, longer average fiber length and greater coarseness than earlywood. FLW for latewood of ring eight was 13.4% longer than earlywood of the same ring. Early and latewood of ring eight were not different for LIG.

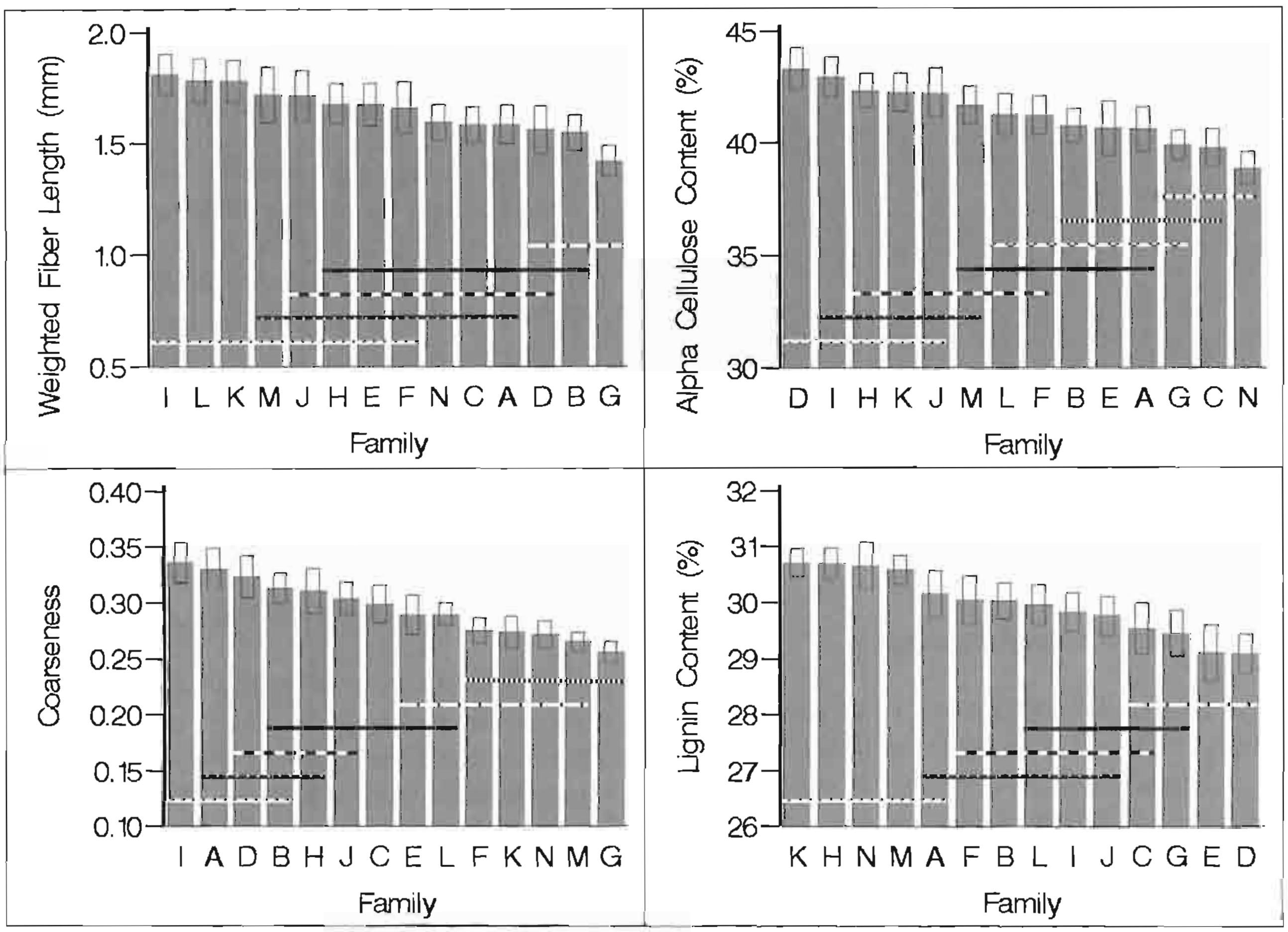
Families differed significantly for all the chemical and morphological wood properties at the $p < 0.001$ level (**Figure 4**). Family-wood type interactions within a ring were not significant. Family means for FLW ranged from 1.42 (family I) to 1.81 mm (family G) (**Figure 4**). There was considerable variation among families for COA. Family I had the greatest COA, whereas family G had the lowest values. Families I and G were consistent in ranking for FLW and COA. Family means for alpha cellulose content ranged from 38.8 to 43.3 %, with family D having the highest value and family N the lowest. Little variation was observed among families for lignin. Family E had the lowest lignin content (29.1 %), while family K had the highest lignin content (30.7 %).

The chemical and morphological wood properties had higher heritabilities at the transition wood (ring 8) than in juvenile wood (ring 3) (**Table 3**). For example, full-sib family heritability for ACY was 0.38 at the juvenile wood, whereas it was 0.55 at the transition wood. Heritabilities for ACY and COA were close and higher than those of FLW, both at ring three and at ring eight. For lignin, all heritabilities were essentially zero at ring three, whereas heritabilities were considerably high at ring eight. When data from both rings were combined, lower heritabilities were observed for all traits compared to the individual-ring data.

Moderately high full-sib family heritabilities were estimated for ACY, FLW and COA (**Table 3**). Weak individual and within full-sib family heritabilities were observed for earlywood of ring three. Heritabilities could not be estimated for lignin at earlywood and latewood of ring three due to lack of genetic variation. Family heritabilities were higher then individual heritabilities. Latewood heritabilities for ring three were higher than earlywood heritabilities. In contrast to ring three, heritabilities for earlywood and latewood of ring eight were similar and higher for all traits, except lignin. Among all the traits studied, COA and ACY had the highest heritabilities, whereas lignin was more controlled by non-genetic effects.

Cellulose content had high genetic correlation with wood density, suggesting that improving for one trait would positively affect other trait (**Table 4**). Similarly, coarseness and fiber length had positive genetic relationships with density. Since wood density is observed more effectively and has already been incorporated into tree improvement programs, improving wood density of the population would be enough to improve other traits. Latewood fibers are thicker and longer than earlywood fibers and result in higher alpha cellulose content and coarseness values. In this study, a high and positive genetic correlation (0.99) was observed between fiber length and coarseness, indicating that long fiber is associated with thicker fiber wall.

Based on our preliminary results, considerable genetic variation was detected for all chemical and morphological traits for loblolly pine. Heritabilities were moderate to high for all traits. High positive genetic correlations between cellulose content, fiber length and wood density suggested simultaneous improvement of chemical wood properties and wood density is feasible. Results from this study showed that genetic improvement for these important traits for pulp and paper production could be possible by selection based on the transition wood assessments.



Note: Families within the same line were not significantly different at 5% significance level.

Figure 4. Rankings of 14 full-sib family means (A - N) and 95% confidence intervals for average fiber length, alpha cellulose content, coarseness, and lignin content

Table 3. Heritabilities (± standard error) for fiber length (FLW), alpha cellulose yield (ACY), coarseness (COA) and lignin content (LIG) for earlywood and latewood of ring 3 and ring 8 (3E, 3L, 8E and 8L), mean of each ring and whole core.

		Ring 3			Ring 8			
Heritability[1]	**Trait**	**3E**	**3L**	**Whole ring**	**8E**	**8L**	**Whole ring**	**Whole core**
h^2_i	FLW	0.05 ± 0.08	0.09 ± 0.10	0.09 ± 0.10	0.23 ± 0.22	0.25 ± 0.20	0.28 ± 0.23	0.08 ± 0.06
	ACY	0.07 ± 0.14	0.14 ± 0.17	0.13 ± 0.18	0.32 ± 0.23	0.36 ± 0.31	0.43 ± 0.32	0.12 ± 0.10
	COA	0.08 ± 0.11	0.31 ± 0.22	0.32 ± 0.25	0.23 ± 0.19	0.22 ± 0.18	0.37 ± 0.29	0.16 ± 0.12
	LIG	-[2]	-	-	0.04 ± 0.11	0.16 ± 0.21	0.13 ± 0.19	0.00 ± 0.08
h^2_{HS}	FLW	0.04 ± 0.31	0.52 ± 0.27	0.54 ± 0.21	0.61 ± 0.20	0.67 ± 0.13	0.65 ± 0.15	0.52 ± 0.18
	ACY	0.37 ± 0.44	0.53 ± 0.29	0.48 ± 0.33	0.72 ± 0.09	0.66 ± 0.15	0.70 ± 0.11	0.58 ± 0.16
	COA	0.44 ± 0.34	0.71 ± 0.10	0.69 ± 0.12	0.66 ± 0.14	0.66 ± 0.14	0.68 ± 0.13	0.61 ± 0.15
	LIG	-	-	-	0.26 ± 0.56	0.54 ± 0.31	0.48 ± 0.35	0.01 ± 0.78
h^2_{FS}	FLW	0.26 ± 0.29	0.35 ± 0.31	0.38 ± 0.26	0.47 ± 0.30	0.58 ± 0.24	0.55 ± 0.26	0.35 ± 0.21
	ACY	0.21 ± 0.36	0.37 ± 0.34	0.32 ± 0.35	0.68 ± 0.20	0.57 ± 0.27	0.64 ± 0.23	0.43 ± 0.22
	COA	0.27 ± 0.32	0.66 ± 0.21	0.61 ± 0.23	0.55 ± 0.25	0.55 ± 0.26	0.60 ± 0.25	0.48 ± 0.22
	LIG	-	-	-	0.13 ± 0.36	0.38 ± 0.38	0.31 ± 0.37	0.00 ± 0.32
h^2_{WFS}	FLW	0.03 ± 0.04	0.05 ± 0.06	0.05 ± 0.06	0.14 ± 0.14	0.15 ± 0.13	0.17 ± 0.15	0.04 ± 0.04
	ACY	0.04 ± 0.08	0.08 ± 0.10	0.08 ± 0.11	0.19 ± 0.14	0.23 ± 0.21	0.28 ± 0.23	0.07 ± 0.06
	COA	0.05 ± 0.07	0.18 ± 0.14	0.20 ± 0.16	0.13 ± 0.12	0.13 ± 0.11	0.24 ± 0.20	0.09± 0.07
	LIG	-	-	-	0.02 ± 0.06	0.10 ± 0.13	0.08 ± 0.12	0.00 ± 0.04

[1] h^2_i individual, h^2_{HS} half-sib , h^2_{FS} full-sib and h^2_{WFS} within full-sib heritability
[2] Heritabilities could not be estimated due to zero GCA variance

Table 4. Genetic correlations (above diagonal) and phenotypic correlations (below diagonal) among fiber length (FLW), alpha cellulose yield (ACY), coarseness (COA), lignin content (LIG) and wood density for transition wood (ring 8)

	FLW	**ACY**	**COA**	**LIG**	**Density**
FLW		0.37 ± 0.48	0.99 ± 0.01	-0.39 ± 0.66	0.95 ± 0.25
ACY	0.52 ***		0.40 ± 0.45	-0.99 ± 0.01	0.56 ± 0.51
COA	0.13 *	0.33 ***		0.57 ± 0.51	0.32 ± 0.55
LIG	-0.03	-0.10	-0.11		-[1]
Density	0.10	0.13 *	0.12	-0.04	

*, ***: Coefficients are significant at 0.05 and 0.001 level respectively. Number of observations used ranged from 183 to 242

[1] Genetic correlation was not estimable due to zero GCA variance for lignin

PRELIMINARY RESULTS FROM THE PIEDMONT ELITE POPULATION STUDY OF LOBLOLLY PINE

Hybridization among provenances of forest tree species with different adaptive and growth traits is a strategy to capture hybrid vigor with desirable traits. A special Piedmont elite breeding population for loblolly pine was created within the N.C. State University-Industry Cooperative Tree Improvement Program by crossing selected individuals from the Atlantic Coastal and Piedmont sources. The purpose was to create hybrids that may combine the fast growth of Coastal sources with the cold hardiness of Piedmont sources, which can then be planted in Piedmont regions where environmental conditions are adverse for pure Coastal source of loblolly pine.

A greenhouse study has shown the inter-provenance hybrids to be superior for growth and also maintain sufficient cold-hardiness based the freezing tests (Kegley 1999). The same hybrids and the pure parental crosses have been planted in 15 tests across five Piedmont regions since 1997. Data were collected from four-year tests and analysed. The objectives were: (1) to evaluate Atlantic Coastal and Piedmont loblolly pine sources and their inter-provenance hybrids for height, volume and survival across Piedmont regions; and (2) to assess the level of genetic variation within populations and the stability of family performance across environments.

Materials and Methods

Twenty superior clones of Atlantic Coastal (C) and Piedmont (P) sources were selected for this study. Four different populations of intra-provenance crosses (CxC, PxP) and inter-provenance hybrids (CxP, PxC) were generated, by crossing these twenty clones with pollen mixes from 20-30 average clones from each of the two regions. Fifteen experimental trials were established during 1997 across five Piedmont regions: Fall Line (Lower Piedmont), Middle Piedmont West, Middle Piedmont East, Upper North Piedmont and Upper Gulf Piedmont (**Figure 5**).

Measurements at age four were made for tree height, DBH and survival. Volume was calculated for individual trees in each test. The combined analysis of tests across regions and analysis within each region were carried out for tree height and volume with the Proc GLM and Proc Mixed procedures in SAS. Variance components of random effects were estimated by restricted maximum likelihood (REML) and individual tree heritability values were estimated across and within Piedmont regions. Stability of family performance across sites was evaluated by regression. Type-B genetic correlations for pairs of regions were estimated.

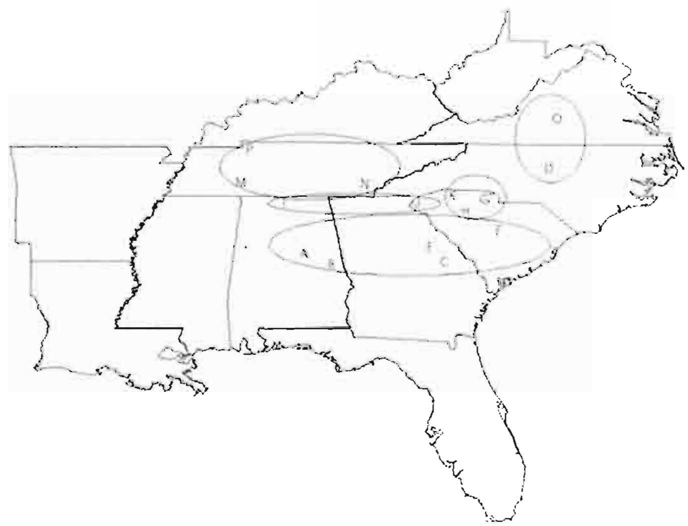


Figure 5. Relative location of experimental sites and geographic regions.

Preliminary Results

Inter-provenance hybrids exhibited intermediate height growth between the two parental populations. The hybrids of CxC and CxP were the best growing populations, followed by PxC and PxP, except in Middle Piedmont West where CxP had the best height growth. Inter-provenance hybrids performed better than Piedmont pure population almost in all regions. A general decline of growth was noticed for all populations as regions became more north or inland (**Figure 6**).

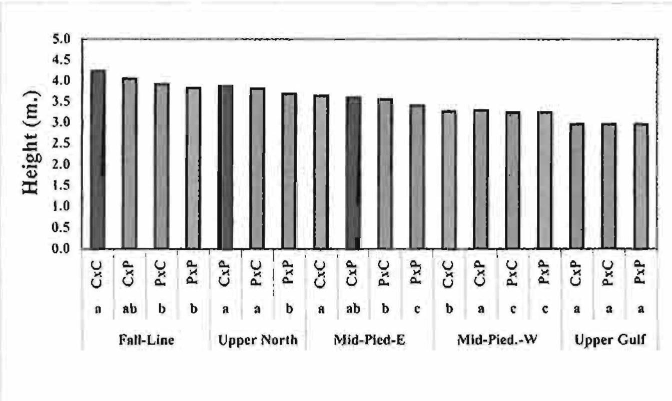


Figure 6. Mean height of inter-provenance Coastal x Piedmont (CxP), Piedmont x Coastal (PxC) and intra-provenance Coastal x Coastal (CxC) and Piedmont x Piedmont (PxP) populations of loblolly pine at different regions. (Different letters denote significance at p=.05 level).

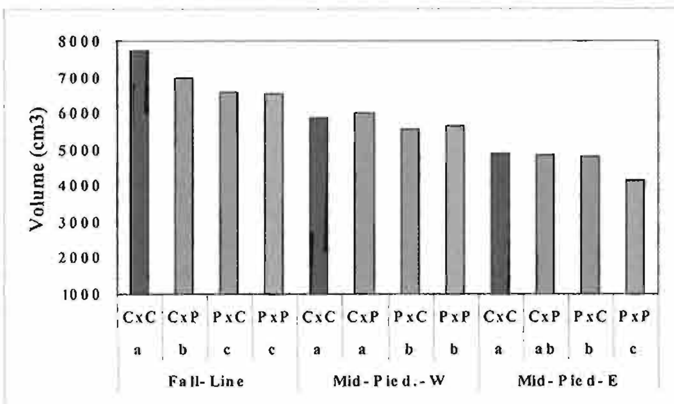


Figure 7. Mean volume of inter-provenance Coastal x Piedmont (CxP), Piedmont x Coastal (PxC) and intra-provenance Coastal x Coastal (CxC) and Piedmont x Piedmont (PxP) populations of loblolly pine at different regions. (Different letters denote significance at $p<0.05$ level).

Table 5. Mean population height and volume (cm^3) across regions. (CxP : Coastal X Piedmont, PxC: Piedmont x Coastal, CxC: Coastal x Coastal, PxP: Piedmont x Piedmont). (Different letters denote significance at $p<0.05$ level).

Population	Mean Height (m)	Mean Volume (cm^3)
CxC		6214.94 a
CxP	3.5765 a	5944.26 ab
PxC	3.4867 ab	5605.49 ab
PxP	3.4161 b	5364.89 b

The CxP inter-provenance hybrids produced significantly more volume than Piedmont intra-provenance population in all regions, while PxC only in Middle-Piedmont West. Reduction of volume was also noticed as regions became more inland (**Figure 7**).

The combined analysis across regions revealed that both hybrid populations performed better than pure Piedmont, with CxP having significantly better performance (**Table 5**).

Comparing with pure Piedmont crosses, positive mean responses of inter-provenance hybrids were observed in height performance in all regions, especially in Fall-Line, Middle-Piedmont East and Upper North Piedmont. The CxP exhibited higher superiority, ranging from 0.16% to 5.81% in different regions. Similar results were obtained for volume growth, but the superiority of CxP was greater and ranged among 6% to 16%. Survival differences among populations were not significant, except in sites at Upper Gulf Piedmont, where PxP exhibited significantly better survival.

Heritability estimates derived from the combined analysis of variance revealed weak additive genetic control of both growth traits. From the values estimated on a population level across regions, higher additive genetic control of CxP inter-provenance population over both growth traits was recorded (**Table 6**).

Table 6. Individual heritability estimates (standard error in parentheses) for both traits derived from combined analysis for regions and populations and from combined analysis for regions per population. (CxP: Coastal x Piedmont, PxC: Piedmont x Coastal, CxC : Coastal x Coastal, PxP: Piedmont x Piedmont)

Population	Individual heritability (h^2_i) Height	Individual heritability (h^2_i) Volume
All populations	0.098 (0.020)	0.093 (0.021)
CxC	0.104 (0.020)	0.107 (0.023)
CxP	0.142 (0.026)	0.147 (0.029)
PxC	0.087 (0.018)	0.033 (0.012)
PxP	0.088 (0.018)	0.081 (0.019)

Families within populations varied greatly in their mean performance and stability across environments, which indicated a great potential for selection within populations. A decline of percentage of responsive to environmental conditions families (b>1) was recorded, from CxC population (60% of families with b>1 for height and 75% for volume), to CxP (60% for height and 55% for volume), to PxC (35% for height to 30% for volume) and PxP population (15% for height and 35% for volume). The above observations indicated that families of inter- and intra-provenance crosses sharing the same female parent respond similarly to different environments.

Strong Type-B genetic correlation coefficient was recorded among Fall-Line and Middle-Piedmont East, while moderate coefficients were scored among Fall-Line and Upper North Piedmont, as well as among Middle-Piedmont East and Upper North. Moderate correlation was noticed among Middle-Piedmont West and Upper Gulf (**Table 7**).

Early results indicated that the inter-specific hybridization among Atlantic Coastal and Piedmont loblolly pine sources could generate trees with growth comparable to the Coastal source and adaptation similar to Piedmont source. Piedmont x Coastal inter-provenance hybrids could be more suitable for planting in some Piedmont environments, while on milder Piedmont sites Coastal x Piedmont might be more appropriate, as indicated by the performance and genetic control over traits. However, longer term monitoring of growth performance, survival and cold adaptation is needed, as trees have chances to be exposed to adverse climatic conditions.

Table 7. Type B genetic correlation coefficients among geographic regions for height.

	Fall Line	Upper-North	Middle-Pied. E	Middle-Pied. W
Fall-Line	*			
Upper-North	**0.5986**	*		
Mid-Pied. E	**0.9513**	**0.5761**	*	
Mid.-Pied. W	0.3646	0.0456	0.2648	*
Upper Gulf	0.3438	0.1429	0.3933	**0.506**

References:

Kegley, A.J. 1999. Evaluation of Atlantic and Piedmont sources of loblolly pine (*Pinus taeda* L.) seedlings and their hybrids for growth and cold hardiness. M.Sc. Thesis. NCSU. College of Natural Resources. Dept. of Forestry. p. 73.

In 2001, a close-spaced field trial was established in Goldsboro, NC by the NC Forest Service to complete the OP testing of their 2nd-generation Coastal Seed Orchard. Based on several Coop studies, selection of families based on greenhouse and one- and two-year-old measurements in closely spaced field trials has been effective for families from the Atlantic Coastal Plain Provenances. Maxie Maynor and Steve McKeand evaluate growth after the second season. Final measurements will be taken this fall at age three for purposes of deployment and roguing orchards.

DEPLOYMENT OF GENETICALLY-IMPROVED LOBLOLLY AND SLASH PINES IN THE SOUTHERN US

In summer 2002, members of the NC State Coop and members of the Cooperative Forest Genetics Research Program at the University of Florida and the Western Gulf Forest Tree Improvement Program at the Texas Forest Service were surveyed concerning deployment practices with genetically improved loblolly and slash pines. The results of the survey turned out to be very interesting, and we published the findings in the Journal of Forestry, April/May 2003 issue. Below is a synopsis of the survey findings and some commentary on the value of the Tree Improvement Cooperatives to enhanced forest productivity in the South.

The 12 southern states accounted for 78% of the nation's tree planting or 2.06 million acres. Available land, favorable political and social attitudes towards production forestry, productive soils, and a moderate climate all favor the growth of plantation forestry in the South. With global demand for timber products increasing at 1.5 to 2% per year at the same time as the area of the world's forests is decreasing, increased productivity of southern plantations has local, regional, national, and global implications. These plantations can help provide timber to meet increasing demands while simultaneously reducing the environmental footprint of industrial forestry by growing more wood on less area. A direct link between increased forest productivity in pine plantations and "saving" natural forests can also be made (see details in the Southern Forest Resource Assessment - http://www.srs.fs.fed.us/sustain/).

Essentially all of the more than 1.2 billion loblolly pine and 150 million slash pine seedlings planted annually are the result of breeding, testing, and selection programs. Estimates of genetic gains from these improvement programs vary depending on the geographic region, cycle of improvement, and degree of roguing in seed orchards, but in general gains in volume production average 10% to 30% over unimproved planting stock.

The tradeoff of gain versus risk has long been recognized as an issue in tree improvement programs. Genetic gain can only be achieved by eliminating undesirable genotypes from the breeding population, but if too few genotypes remain, the risk from narrowing the genetic base becomes too great. This "breeder's dilemma" has been particularly important in tree improvement programs where the results of genetic manipulation are evident for many years or decades in plantations. The theoretical maximum gain would come from deploying the single most productive clone across all the acres a landowner establishes in plantations. For a landowner willing to take risks, especially on relatively few acres, the risk from deploying a single clone may well be offset by the potential gain and financial returns from harvesting more wood at rotation. Landowners that are risk averse may prefer to deploy more genotypes, despite the opportunity for dramatic increases in productivity.

Our objective was to summarize the deployment activities of the forest products industry and small landowners in the South. How are genetically improved genotypes being deployed, what are the levels of genetic diversity in operational plantations, and have foresters seen any problems from the various deployment strategies?

Survey Data

In the summer 2002, we conducted a survey of all company and state forestry agencies that are members of one or more of the three Cooperative Tree Improvement Programs in the southern US. The objective was to determine how genetically-improved seedlings are being deployed in the region. We received a 100% response from all 31 state and industry members of the cooperatives. These companies and states are responsible for planting over 1.3 billion pine seedlings annually in the South, or about 80% of the trees in the entire nation. While there are other nurseries and organizations that plant trees in the region, we estimate that this survey represents at least 90% of the annual regeneration southwide. Results of the first 8 survey questions are included in this report. For this summary, we focus on loblolly pine deployment practices.

The vast majority (84%) of the seedlings being planted in the South are loblolly pine. Of the more than 1.1 billion loblolly seedlings planted each year, about 40% are planted on lands owned or managed by the organizations in the survey. The remaining 60% are for market sales and are planted by other industry landowners and non-industrial private forest (NIPF) landowners. NIPF landowners purchase the large majority of their seedlings from private or state nurseries that participate in one of the three tree improvement cooperatives. Therefore, they realize the benefit of the cooperatives' breeding efforts.

Just over half (54%) the loblolly and slash pine seedlings being deployed come from 2nd-generation seed orchards. No 3rd-generation pines are currently being deployed, but the first seeds from such parents will be harvested in the next 5 years. Although, not quantified, most of the remaining plantations using 1st-generation planting stock have originated from heavily rogued seed orchards or are only the very best families from these orchards.

On average, there are 24 clones in loblolly seed orchards and 42 clones in slash seed orchards, but the number of clones in orchards varies tremendously. The average least number of clones in an orchard was 10, but there were 6 orchards with only 5 to 10 clones. The greatest number of clones in an orchard was 70.

Overall, 59% of the loblolly pine plantations are established as single open-pollinated (OP) family blocks. About 80% of the regeneration on company lands is with OP families compared to 48% of seedlings used for market sales. This has been a major shift in deployment strategy from 30 years ago when virtually all plantations were established with mixed seedlots.

There are 14 companies using family blocks for deployment of loblolly pine, and on average a company will deploy 47 different families on its own land. There are 6 organizations that grow and sell seedlings as specific families, and on average they sell 69 different families. The number of loblolly families deployed as OP family blocks by a single company varies dramatically from as few as 4 families deployed in a single region in any given year to up to 90 families across the south.

The number of loblolly families being planted by a company represents what is deployed across all southern landholdings. A large company may plant a few families in a given region, but numerous families across regions. We did not ask organizations to summarize by region. If the companies with geographically-diverse landholdings are excluded, then the average number of families deployed on company lands within a geographic province is 13.

In recent years, deployment of specific crosses and even some clones of loblolly and slash pines has become feasible. About 4.3 million loblolly (0.4% of annual southwide planting) and 2.5 million slash pine (1.7%) are planted as full-sib families either as mass control- pollinated seedlings or as bulked up full-sib rooted cuttings. On average these are deployed in plantations of 46 acres in size.

To date there are no operational plantations with selected, individual clones being deployed either as rooted cuttings or somatic embryos. Only a few experimental plots and pilot-scale plantations have been established.

The average size of OP family blocks is 80 acres for loblolly and 131 acres for slash pine. For a given company, the block size ranged from 50 to 200 acres for loblolly and from 50 to 300 acres for slash pine. Most landowners limit their clearcut size to meet certification or industry standards (e.g. SFI standards of AF&PA are clearcuts that average 120 acres).

Arguably, the most valuable information from cooperators concerned the risk of deploying pine seedlings as OP family blocks. Are the genetically more homogeneous stands more vulnerable to pests or climatic extremes compared to plantations with very diverse genetic entries? When asked if there have been any unexpected environmental or pest problems such as diseases, insects, cold, or storm damage encountered with family block plantings, no one had experienced any serious problems. The only "problem" mentioned concerned a family being deployed that is not as adapted as thought (e.g., it had been tested for cold or drought tolerance, but not as well tested as it should have been). If there is a severe cold or drought, and a family is affected, the breeder can identify the problem and stop deployment of that family. If deployed in a bulk mix, there is no practical way to identify problem families. Family blocks give the forester more control and can provide additional information to modify deployment decisions. When asked if there have been any outright plantation failures due to the use of family blocks, there was no known example of a plantation failure.

Discussion

Landowners in the South have benefited tremendously from the efforts of members of the tree improvement cooperatives and the intensive tree breeding efforts put forth over the past 50 years. With loblolly and slash pine, we are not aware of any plantations being established with unimproved or wild seedlings. Even with the most modest improvement available, productivity increases due to genetics are about 10%. If the best full-sibs or clones are planted, gains of 35% to 50% are possible.

With relatively little additional cost, many forest landowners are aggressively trying to increase the genetic gain captured from tree improvement programs in the South. The best available OP families from intensively-rogued orchards are being planted, presumably on the best possible sites. Some companies are willing to plant all or the vast majority of their lands with as few as four OP families. While the average number of families being planted by any one company in a region is 13, there were 5 companies that planted between 4 and 9 OP families each year. These families change from year to year, but only the most productive families are being utilized.

As discussed earlier, the conflict arising from the desire to maximize genetic gain from selection while minimizing risk from decreased genetic diversity has long been a critical issue in tree breeding. Loblolly and slash pine breeding programs were initiated with large numbers of selections from wild stands and unimproved plantations. After 2 cycles of selection, breeding populations and seed orchards remain relatively undomesticated, retaining much of the genetic diversity found in natural stands. When OP families from selected seed-orchard clones are deployed, the resulting plantations have relatively high genetic diversity, since: (1) the seed-orchard genotypes are not inbred; (2) there is a very low degree of relatedness among orchard parents contributing pollen; and (3) rates of pollination by non-orchard parents are probably 30%, or perhaps even as high as 50%. Nevertheless, like their agricultural counterparts, tree breeders must be vigilant and monitor plantations to assess the risk of deploying certain genotype mixtures. Given the experiences to date from deploying OP family blocks, there appears to be minimal risk from narrowing the genetic base in these plantations. That said, our experience is limited to the last 30 years and breeders must not become overconfident that risks do not exist.

Tree breeders have emphasized the need to deploy heterogeneous populations, at least at the landscape level. These landscapes may vary from many thousands of acres of plantations that are intensively managed to small plantations that are intermixed with natural pine stands, both upland and bottomland hardwood stands, and agricultural fields. Even though only 15% of commercial forest land is in pine plantations in the South, in some regions, pine plantations can be extensive.

Of some concern is the desire of some foresters to plant only the best OP family on almost all acres. There are examples of the best family being substantially better than the second best family, and it is difficult to discourage foresters from using this family exclusively. Breeders can quantify the gain for each family relatively easily, but it has been impossible to quantify the risk from using certain genotypes. A challenge for tree improvement research in the coming years will be to quantify acceptable levels of risk in plantations that are established across a range of landscapes. As more homogeneous plantations are established on more acres, both gains and risks must be quantified so landowners can make informed decisions about deployment options.

Members of the NC State University – Industry Cooperative Tree Improvement Program can be proud of the contributions our genetics program has made to increases in forest productivity over the past 47 years. Foresters in the southern United States are responsible for over 75% of the nation's tree planting, and over 95% of these seedlings are genetically improved loblolly and slash pines. Forest productivity increases in southern pine plantations have been dramatic over the past 30 to 50 years. There are few other regions in the world where the combination of silviculture and genetics is having as big an impact on forest productivity. An integral part of the increase in plantation productivity and value has been the improvement in growth rates and wood quality from tree improvement programs in the South.

Members of our Coop, together with those of the Cooperative Forest Genetics Research Program at the University of Florida and the Western Gulf Forest Tree Improvement Program at the Texas Forest Service produce more than 1.1 billion loblolly pine seedlings in nurseries such as this one owned by International Paper.

Survey Questions and Results[1]

1. Annual seedling production (average annual number of seedlings the last 3 years)
   Loblolly: 1,137 million
   Slash: 150 million
   Longleaf: 32 million
   Other: 28 million

2. Number of seedlings deployed on your own lands (average the last 3 years)
   Loblolly: 427 million
   Slash: 73 million
   Longleaf: 6 million
   Other: 3 million

3. Number of seedlings for market sales and/or contracts (average the last 3 years)
   Loblolly: 697 million
   Slash: 86 million
   Longleaf: 28 million
   Other: 25 million

4. Number of seedlings deployed as open-pollinated family blocks (average the last 3 years)
   Loblolly: Company lands: 340 million
   Market sales/contracts: 332 million
   Slash: Company lands: 37 million
   Market sales/contracts: 28 million

5. Percentage of regeneration with 1st-generation seedlings (including 1.5-gen): 46%
   Percentage of regeneration with 2nd-generation seedlings: 54%
   Percentage of regeneration with 3rd-generation seedlings (including 2.5-gen): 0%

6. Number of open-pollinated families deployed as family blocks (average the last 3 years)
   Loblolly: Company lands: 47(average per company)
   Market sales and/or contracts: 66
   Slash: Company lands: 11
   Market sales and/or contracts: 5

7. Average size of family blocks in plantations (on your own lands)
   Loblolly: 77 acres
   Slash: 82 acres

8. How many parent clones are in the seed orchards that supply your seed:
   Loblolly: Rough average: 24 (Max. 36, Min. 14)
   Slash: Rough average: 42 (Max. 55, Min. 25)

[1] Some numbers may not sum up to expected totals because of some slight double counting and estimation of seedlings being planted.

NUCLEUS BREEDING – THE OPTIMUM WAY TO STRUCTURE A BREEDING POPULATION?

The concept of nucleus breeding refers to a hierarchical structuring of the breeding population, which is a common approach in animal breeding programs. The nucleus (elite) tier is on top of the hierarchy, consisting of elite individuals. The nucleus may be either "closed", where there is no gene flow into the nucleus, or "open", where the gene pool in the nucleus is periodically enriched by migration from lower tiers or external populations (Roden 1994).

The concept of nucleus breeding was adopted into breeding plans for radiata pine in Australia and for *Eucalyptus globulus* in Portugal. Cotterill (1989) highlights potential gains made with nucleus breeding as a result of concentrating elite breeding individuals in the nucleus where the majority of investment is concentrated. Maintaining an open-nucleus tier as an integral part of a breeding population has continuously attracted more attention among forest tree breeders.

Although the animal-breeding literature contains numerous examples of breeding under hierarchical structure, rather few theoretical studies have been made considering forest trees. Mahalovich and Bridgewater (1989) showed that a closed nucleus of size 48 maintained higher gain but also resulted in increased average inbreeding compared to larger main-line population. When the elite population was open, inbreeding was kept low, but there was no advantage in gain compared to a closed nucleus. King and Johnson (1993) evaluated an open nucleus with other four mating schemes. Making additional crosses among top elite genotypes in each generation offered more potential for genetic gain, but effective population size was reduced as more selections shared same parents.

In our study, we demonstrate how hierarchical population subdivision affects gain and average relatedness in a seed orchard that serves as the transition point between the breeding population and commercial plantations. We model an open-nucleus breeding system where selection combines both breeding value and genetic diversity.

Methods

We modified a stochastic breeding simulator, POPSIM (Mullin and Park 1995), to include the modeling of an open-nucleus breeding system. A founder population of 48 unrelated and non-inbred breeding individuals was selected randomly (by random sampling from normal distributions of additive, dominance and environmental effects). Variance components were set to approximate growth traits in conifer species (narrow-sense heritability equal to 0.2 and the proportion of dominance to additive genetic variance equal to 0.25). The model also accounted for 1% inbreeding depression per 0.01 unit increase in inbreeding coefficient.

The best breeding individuals out of the initial breeding population were transferred into an elite population and the remainder to the main-line population. Single-pair mating with random assortment of mates was used in both tiers to generate a recruitment population consisting of 24 full-sib families. We assumed a total testing effort of 2400 test genotypes distributed uniformly in recruitment population. Each genotype was clonally replicated by 10 ramets. The breeding value of each progeny genotype was estimated by its clonal mean. Group-merit selection (Lindgren and Mullin 1997), combining both breeding value and average relatedness, was then applied first to select 48 progenies to form the breeding population for the next cycle, and then to reselect elite genotypes from among the breeding population that were then transferred into the elite population. With group-merit selection, it was possible to study a wide range of possible situations varying from no restrictions on relatedness (strong family selection and unbalanced within family selection) to maximum restrictions (absence of family selection and balanced within family selection).

A seed orchard was established in each

generation by selecting the top 6 individuals out of breeding population with no restrictions on relatedness. Selection and breeding was carried in the manner described above for five cycles. Each simulation scenario was replicated by 100 independent runs, providing reliable estimates of various performance measures. The size of the elite population was varied from 1/12 to 1/2 of the total breeding population size (i.e, from 4 to 24). Comparisons were made with a breeding population of 48 trees with no hierarchical structure. Finally, unequal distribution of testing effort was investigated, where progeny testing was concentrated on elite families, keeping the total testing resources constant.

Results and Discussion

Our findings agree in general with those of Mahalovich and Bridgewater (1989) and King and Johnson (1993). The presence of an elite population in an open-nucleus hierarchy has potential to enhance additive genetic variance in the overall breeding population. Since the seed orchard in our model is a selected subset of the breeding population, this generates some potential to realize additional genetic gain. This advantage is, however, affected by the accuracy of breeding value estimates. With low narrow-sense heritability and imperfect breeding value assessment not utilizing all possible information, there is a reduced probability that genotypes being transferred to elite population are really the top available individuals.

When few restrictions on average relatedness are applied during selection, the majority of breeding parents are derived from only a small fraction of families. This is more pronounced in the presence of an elite population where the best genotypes are brought together, resulting in a limited number of superior crosses from which selections are made. Elite populations can therefore lead to higher average relatedness in both the breeding and production populations. As average inbreeding increases, it causes a reduction in within-family genetic variance and lowers the population average genetic value due to inbreeding depression. Applying higher restrictions on relatedness means that selections are more evenly distributed among individual families and fewer selections are derived from top (elite) families. The extreme (but realistic) situation is when all selection is within family, thus the two best genotypes are selected out of each and every family. With a high restriction on relatedness, only a small proportion of breeding individuals comes from elite families, unless the size of elite population is large. As the size of the elite population increases, a smaller number of extreme families is generated. When the penalty on relatedness in selecting the breeding population is high, there is a higher potential for utilizing breeding population additive variance (**Figure 8**) by reselecting the elite population with low restrictions on relatedness. This advantage diminishes, however, since seed orchard selections become more related and average inbreeding in the breeding population increases as well (**Figure 9**).

Figure 10 represents genetic gain in the tested seed orchard after five cycles of breeding, as a function of seed orchard status number. A status number of 6 (equaling the census number) means that seed orchard selections are completely unrelated and non-inbred. The lower the status number, the lower the gene diversity represented by the orchard parents, and the more inbreeding can be expected in seed collected from seed orchard. **Figure 10** shows that the only possibility to obtain some advantage from an elite population is to maintain low status number in seed orchard, something tree breeders usually try to avoid.

Based on the preliminary results of this simulation study, it appears there may be little advantage to investing more testing effort into elite families as it leads to increase in average relatedness in selected production population. Subsequent simulation runs will examine the possibility that positive assortative mating within a single breeding population may be superior to hierarchical stratification of the breeding population using the nucleus breeding concept.

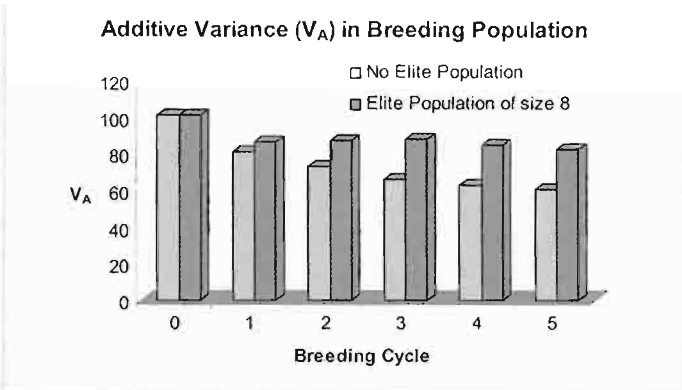


Figure 8. Additive genetic variance in a breeding population after individual breeding cycles. The diagram refers to a situation with balanced within-family selection and no restrictions on relatedness in reselecting an elite population in each cycle.

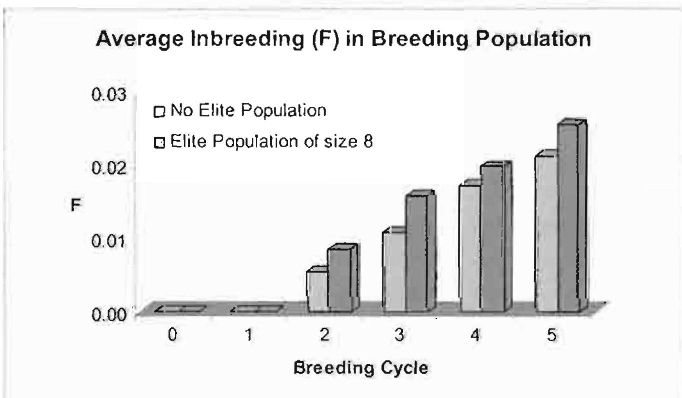


Figure 9. Average inbreeding coefficient in breeding population in individual breeding cycles. The diagram corresponds to situation referred in Figure 8.

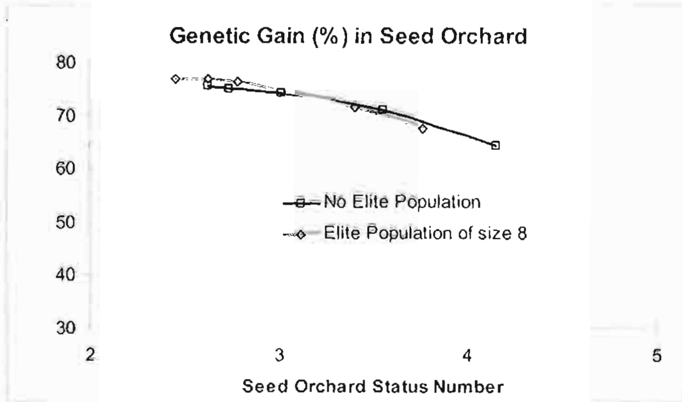


Figure 10. Genetic gain in the 5th tested seed orchard as a function of status number. Figure shows all possible situations from no restrictions on relatedness (very left point) to maximum restrictions on relatedness (very right point). Scales of axes were reduced.

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SCHENCK FOREST GENETICS DEMONSTRATION – ICE DAMAGE ASSESSMENTS

The December 4-5, 2002 ice storm did an incredible amount of damage to trees in central and western North Carolina. Pine stands were particularly hard hit. The ice buildup on foliage and branches often caused stem breakage and even uprooting. At the NC State University Schenck Memorial Forest in Raleigh, some of the most severe damage in the state occurred. Several stands were so severely damaged that the only recourse was to harvest the entire stand. Both a seed tree harvest and clearcut harvest was used to salvage the trees.

The Genetics Demonstration planting at the Schenck Forest was established in 1987 to demonstrate genetic differences in growth and form in loblolly pine. Several full-sib families were planted in 25-tree block plots and 5-tree row plots. A seed orchard mix and an unimproved checklot were also established in large plots in the middle of the planting, for a total of 650 demonstration trees. The study was 16 years old when the ice storm struck. In March 2003 we assessed the planting for damage from the ice.

Aftermath of December 2002 ice storm – Schenck Memorial Forest, Raleigh, NC

Salvage logging operation at the Schenck Memorial Forest, March 2003

Overall, 40% of the trees in the demonstration planting were damaged by the ice (**Figure 11**). We also assessed the severity of damage; 8% of the trees were killed by the ice (e.g. the stem broke below the live crown), and 30% of the trees had severe damage (e.g. a significant portion of the crown was broken).

There were some very interesting family differences for ice damage. Family 11-16 x 7-56 (several plots for a total of 90 trees) was established in this trial to demonstrate dramatic genetic differences in growth and adaptability. Wake County, NC is beyond the northern and inland limit that we would recommend for this Coastal SC family (Schmidtling 2001). As commonly happens for genotypes moved north and inland, through age 15 years, 11-16 x 7-56 survived and grew very well (**Table 8**). As expected, it was significantly larger than the other trees in the trial and the form of the trees was very good.

Figure 11. Ice damage at the Schenck Forest Genetics Demonstration planting.

Table 8. Growth, survival, and form traits at age 15 years for family 11-16x7-56, compared to other trees in the Schenck Forest Genetics Demonstration Trial.

Trait – age 15	11-16x7-56	All others
Survival (%)	90	94
Height (ft.)*	54.7	51.7
Volume/tree (ft^3)*	9.6	7.4
Forking (%)	12	16
Straightness score*	2.5	3.2

* Differences are significant at $p \leq 0.05$

Table 9. Assessment of ice storm damage at age 16 for family 11-16x7-56 compared to other trees in the Schenck Forest Genetics Demonstration Trial.

Trait – age 16	11-16x7-56	All others
Survival (%)*	67	94
Ice damage (%)*	77	34
Severe damage (%)*	72	24
Stem breakage (%)*	54	2

* Differences are significant at $p \leq 0.05$

As we have observed over the years, when significant environmental stresses such as drought, severe cold, or ice occur, families that are moved too far north or inland can be severely damaged. After the ice storm, it became very obvious the 11-16 x 7-56 was not adapted to this northern Piedmont environment (**Figure 12**). This coastal SC family was severely damaged by the ice with 77% of the trees being damaged to some extent (**Table 9**). Over half of the trees had broken stems and are dead or will die soon. Survival was reduced from 90% before the ice storm to 67% following the storm.

Figure 12. Paula Zanker assessing damage in one of the 11-16 x 7-56 plots

Some families survived the ice storm very well. Family 1-523 x 1-516 a fast-growing Piedmont family had only 13% minor damage. Family 1-561 x 1-524 also from the SC Piedmont, but slow growing had 7% minor damage. Neither of these families had major stem breakage.

The severe damage to family 11-16 x 7-56 reinforces the need to be cautious when seed sources are moved north and inland to realize growth advantages. There are limits to how far families can be moved before mal-adaptation becomes a problem. The rule of thumb developed by Schmidtling is to move families no more than 5° - 10° F to a colder minimum winter temperature zone. This relates to moving from one USDA Plant Hardiness Zone to a more northern or inland zone. Trials such as the Coop's Plantation Selection Seed Source Study (PSSSS) and the Piedmont Elite Population (PEP) trials will help fine-tune seed source movement in coming years.

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SEED AND CONE YIELDS

The 2002 seed collection provided approximately 13.5 tons of loblolly pine seed for Cooperative members (last year's crop was 25.5 tons). This yield is much lower than expected, but there was one organization not reporting and many orchards that have been harvested in the past were not harvested in 2002.

Average seed yields in pounds per bushel were higher than 2001 (1.42 vs. 1.21 in 2001). About 83% of the total seed came from second-generation orchards and about 65% of the collection was from Coastal sources (Table 8).

Only one orchard produced above the 2.0 lbs./bushel mark; MeadWestvāco's 2.0 South Carolina Coastal orchard with a yield of 2.07 lbs./bushel. The rest of the top ten producers are shown in Table 2.

Table 8. Comparison of 2002 seed and cone yields with previous year.

Provenance	Bushels of Cones		Pounds of Seed		Pounds per Bushel	
	2002	2001	2002	2001	2002	2001
Coastal 1.0	3,319	9,336	4,259	16,158	1.28	1.44
Coastal 2.0	10,284	26,213	15,156	27,411	1.47	1.05
Coastal 3.0	42	22	50	18	1.19	0.82
Piedmont 1.0	450	457	760	764	1.69	1.67
Piedmont 2.0	7,114	10,015	9,965	12,686	1.40	1.27
Totals	21,209	47,412	28,390	57,037	1.42	1.21

Table 9. Top ten production loblolly orchards in 2002.

Organization	Orchard Type	Age	Lbs./Bushel	Orchard Manager
MeadWestvāco	2.0 Coastal	17	2.07	Dave Gerwig
MeadWestvāco	2.0 Piedmont	16	1.95	Dave Gerwig
International Paper	2.0 Coastal	17	1.89	Larry Foster
MeadWestvāco	1.0 Virginia	32	1.83	Dave Gerwig
Weyerhaeuser Co.	2.0 Coastal		1.79	Franklin Brantley
International Paper	2.0 Coastal	25	1.74	Tim Slichter
Weyerhaeuser Co.	2.0 Piedmont		1.71	Franklin Brantley
Plum Creek Timber Co.	2.0 Coastal	19	1.65	Lorin Clark
Plum Creek Timber Co.	1.0 Piedmont	24	1.65	Lorin Clark
Plum Creek Timber Co.	1.0 Coastal	24	1.61	Lorin Clark

ASSOCIATED ACTIVITIES

TEACHING AND GRADUATE RESEARCH

All Cooperative staff on faculty continue to be active in the delivery of courses in Forest Genetics to students at both the undergraduate and graduate levels. Steve McKeand taught the graduate course in general tree improvement, FOR 725, while Tim Mullin taught Advanced Topics in Quantitative Genetics, FOR 726. Some of our graduate courses are not taught every year, so Bailian Li, who co-teaches FOR 728 Quantitative Forest Genetics Methods with Gary Hodge (CAMCORE) and FOR 727 Tree Improvement Research Methods got a reprieve and a chance to polish their lecture notes for next year.

Unfortunately, the undergraduate course, FOR 411, Forest Tree Genetics and Biology, co-taught by Steve McKeand and Tim Mullin was cancelled this year due to low enrollment. Hopefully, interest among undergraduate students will pick up as FOR 411 becomes a required course for new "tracks" being added to a revised Forest Management curriculum in the Department of Forestry.

Graduate students and the research they conduct as part of their degree programs are extremely important to the Coop. Three of the eight students working in association with the Coop completed their programs this year. The students, the degree to which each aspires, and the subject of their research project are listed below.

Student, Degree, Research Project

Patrick Cumbie, M.S. (In association with Rooted Cutting Program, NCSU). ***Completed.***
Genetic variation in wood properties in clonal and seedling loblolly pine.

Daniel Gräns, Ph.D.
Project not yet determined.

James Grissom, Ph.D.
Growth and physiology of loblolly pine seedlings as affected by genetics of the root system.

Dominic Kain, Ph.D. (With Australia National University). ***Completed***
Inheritance of wood properties in slash by Caribbean pine hybrids.

Hua Li, Ph.D.
Major gene resistance in fusiform rust.

Milan Lstibůrek, Ph.D.
Optimal population structures for forest tree breeding.

Paul Shannon, M.S. ***Completed.***
An evaluation of the financial returns for different seed orchard establishment options.

Rob Sykes, M.S.
Genetic variation in tracheid and wood chemical properties in loblolly pine.

TECHNOLOGY TRANSFER

Besides our involvement in structured academic programs, the Coop is also active in delivering technology transfer activities and participation in collaborative initiatives with other groups. This year was no exception.

IEG-40 Meeting on Silvicultural and Genetic Impacts on Productivity of Southern Forests

Last September 17-19, NC State University hosted the biennial IEG-40 (Information Exchange Group - 40) meeting in Wrightsville Beach, NC. The IEG has a long history of valuable, informative, and enjoyable meetings, and I this year's meeting with the topic, **Silvicultural and Genetic Impacts on Productivity of Southern Forests**, was no exception. Over 100 scientists, foresters, tree breeders, and silviculturists attended the meeting and enjoyed 3 days of interaction on a variety of tree improvement and silviculture topics.

The meeting was a joint effort by the Tree Improvement Coop, Dr. Lee Allen with the Forest Nutrition Coop at NC State, and the Forestry Educational Outreach Program (FEOP) at NC State. We invited the "movers and shakers" in the business of genetics and silviculture in the South. Each speaker presented the current state of the art of knowledge and practice and the vision for the next 10 years concerning forest management and it's impact on productivity and forest products. Publication of papers in a special issue of the Southern Journal of Applied Forestry is in the works and should be an excellent reference for foresters involved with pine plantation management in the South.

Contact Meeting

While an ice storm shut down power and disrupted phone lines back in Raleigh, Coop staff joined our members in Rome, Georgia, for our Annual Contact Meeting, hosted this year by Temple-Inland Forest. The Contact Meeting is an important part of our program, bringing together tree improvement personnel for an update on Coop activity and presentations around a technical theme. This year, the meeting focused on the use of top-grafting as a means to accelerate breeding. Scions from selected trees grafted into the tops of older trees will grow vigorously and produce female strobili in only one or two years, much sooner than normally expected for grafts made on small rootstock. The Coop has now adopted the technique as standard practice, as we try to accelerate the breeding for the 3rd cycle.

As participants at the 2002 Contact Meeting look on, John Hendrickson of Temple-Inland Forest demonstrates his top-grafting techniques in his breeding area at the Brown Farm Tree Improvement Center.

Coop Database Workshops

During 2002, training sessions were offered on the Cooperative Database, a summary of progeny test data and analyses available exclusively to our members. James Grissom, Tree Improvement Analyst with the Coop, served as instructor, and Bailian Li contributed to technical discussions. In April, twelve attendees from five member organizations participated in a two-day workshop held in Tuscaloosa, Alabama. In July, eight attendees participated in another two-day workshop held in Raleigh, NC. Attendees gained valuable hands-on practice with database operations such as querying information from the database and generating custom reports.

Seed Orchard Pest Management Committee: Imidan© and Capture© Efficacy Study for Cone and Seed Insect Control

The Coop has for many years been an active member of the Seed Orchard Pest Management Committee (SOPMC), under the auspices of the Southern Forest Tree Improvement Committee. This year, we collaborated with the SPOMC in an efficacy study of Imidan© and Capture©.

North Carolina Forest Service contributed an orchard and personnel at their Claridge State Nursery in Goldsboro, NC. The study was designed to evaluate the efficacy of Imidan and Capture for coneworm and seed bug control in loblolly and slash pine seed orchards across the South. The current labeled rates were compared to a control with no insecticide application. Imidan (common name: phosmet) is an organophosphate insecticide which has been shown to be effective in single-tree hydraulic spray applications for both coneworms and seed bugs. Imidan is being promoted by the Environmental Protection Agency as a substitute for Guthion©, which has served as the industrial standard for many years. However, Imidan has never been tested for efficacy in conifer seed orchards under operational conditions.

Seeds were extracted in the Coop lab this past fall and winter and were sent to Dr. Don Grossman with the Texas Forest Service. X-ray and cone damage data will be analyzed this year to determine the usefulness of Imidan for seed orchard insect control. This trial is part of the SPOMC's effort to evaluate pest management practices in south-wide trials. Our Coop members have contributed a great deal of time, money, and effort to these trials over the past decades. The work continues, and the support from all the members will be critical in coming years if we are to be successful with seed-orchard insect control measures.

Prior to the Imidan study, Steve Wright (NC Forest Service) tagged branches with first- and second-year cones in the different treatment blocks. These cones were assessed for damage at the end of the growing season.

VISITING SCIENTISTS

Raleigh seems to be a popular choice for Swedes to spend their sabbatical leave. Last year, Dr. Gunnar Jansson came for a 6-month sabbatical from his position with the Forestry Research Institute of Sweden (SkogForsk). This year, Professor Dr. Dag Lindgren from the Swedish University of Agricultural Sciences in Umeå decided to swap the cold, dark months of winter near the Arctic Circle, for the milder climate of North Carolina. (We did our best to make him feel at home, as Raleigh had one its coldest winters on record.) While here, Dag worked on chapters for a new book and gave numerous lectures on such topics as measurement of genetic diversity and the role of biotechnology in forestry. He also gave a "mini-course" on quantitative genetics, introducing his ideas on gene diversity and status effective number to an audience of students, staff and visitors. Dag is currently a co-supervisor for Milan Lstibůrek's Ph.D. program, where he has contributed much insight into the optimal management of breeding populations.

Professor Dr. Dag Lindgren

Dr. Evi Alizoti, a visiting scientist from Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης, Τμήμα Δασολογίας και Φυσικού Περιβάλλοντος (if that's Greek to you, it's otherwise known as the School of Forestry and Natural Environment, Aristotle University of Thessaloniki), is spending a year with us, with funding from her university. Evi was enrolled in academic courses in each semester, and participated as a seminar speaker here in the Department of Forestry and the Department of Horticulture. For her research, Evi worked on data sets she brought with her on performance of Mediterranean pine species (*Pinus halepensis* and *P. brutia*) in Greek provenance trials, as well as data from our own PEP (Piedmont Elite Population) hybrid study. Evi could be counted on for insightful questions at any seminar or conference she attended, and also demonstrated that she makes a pretty mean baklava.

Dr. Evi Alizoti

PROGRAM STAFF

There always seems to be changes to report among our program staff.

Our Administrative Secretary, Mini Jolly, moved across campus to a new position, and a promotion, at the Centre for Student Leadership, Ethics, and Public Service. Congratulations, Mini!

Being without good clerical support is never much fun, so we were ecstatic when Robin Hughes agreed to assume the duties. Robin brings many years of experience with the College and makes a very difficult job look easy!

Paula Zanker, Agricultural Research Technician, who has been working with our group for several years, took a 5-month sabbatical leave to catch her breath, rejoining us in January.

During Paula's absence, Rebecca Weber filled in on technical duties and brought some special talents to bear on the organization of our library and a redesign of our web site.

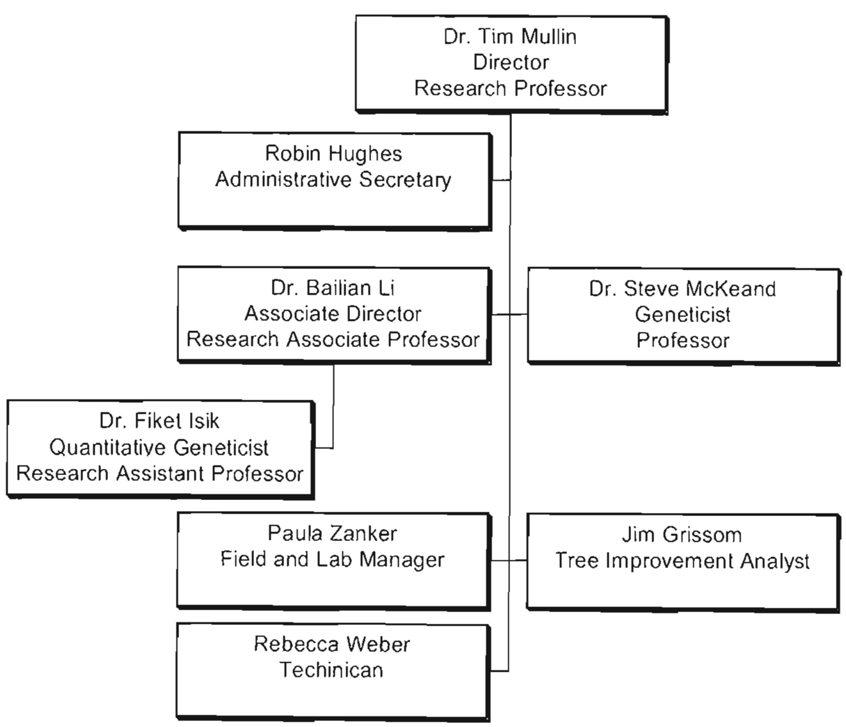
Dr. Fikret Isik, who had worked with us as a post-doc in previous years, received a faculty appointment as Research Assistant Professor. Next year, he'll be teaching a graduate course on data management and will continue his research under our USDA-IFAFS grant.

And finally, Dr. Bailian Li was conferred academic tenure – a significant accomplishment in his career.

POST DOCTORAL FELLOWS

Dr. Bin Xiang warped up his post-doctoral research last year on a DOE grant working on the computer simulation and diallel genetic data analysis for major gene detection. He is now working as a data analyst in California. We appreciate his contribution to the EDMS study and major gene projects.

NCSU-Industry Cooperative Tree Improvement Program
Staffing Chart - March 2003



MEMBERSHIP OF THE TREE IMPROVEMENT COOPERATIVE

The Coop saw fewer changes in its membership this year, but these changes were highly significant. After 47 years' of participation, Bowater Incorporated made the decision to withdraw from the program, as part of its corporate restructuring. Bowater and its employees have made a tremendous contribution to the work of the Coop and they will be sorely missed. On a more positive note, we welcomed Hancock Natural Resources Group as a new member. As of April 2003, membership in the Coop stood at 16, with 6 state agencies and 10 private corporations:

Alabama Forestry Commission
Georgia Forestry Commission
Gulf-States Paper Corp.
Hancock Natural Resources Group
International Paper Company
Joshua Land Management L.L.C.
MeadWestvāco Corp.
N.C. Division of Forest Resources
Rayonier, Inc.
S.C. Commission of Forestry
Smurfit-Stone Container Corp.
Tennessee Forestry Division
Temple-Inland Forest, Inc.
Plum Creek Timber Company
Virginia Department of Forestry
Weyerhaeuser Corp.

Team NCSU Tree Improvement – 2003

From left to right: standing – Bruce Zobel, Robin Hughes, Evi Alizoti, Tim Mullin, Robert Sykes, JB Jett, Jim Grissom, Paula Zanker; kneeling – Bailian Li, Fikret Isik, Steve McKeand; absent – Milan Lstibůrek, Hua Li, Dag Lindgren, Becky Weber

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS

Research and the dissemination of those findings continue to be a critical component of the Cooperative program. Over the past 3 years, program staff members have made a major scholarly contribution in refereed, peer-reviewed journals (21 articles published or in-press), as well as in conference proceedings and other technical publications (19 papers). The support from Cooperative members allows staff to maintain the highest scholarship expected of university faculty, while also directing the research effort towards today's questions and tomorrow's challenges.

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Bowater Incorporated was one of the founding members when the NCSU-Industry Cooperative Tree Improvement Program was started in 1956. Regrettably, this past year, Bowater made the decision to withdraw from forest research and terminated its membership. We owe a lot to the outstanding contributions made by dedicated Bowater employees throughout the company's 47-year tenure with the Coop.