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

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THIRTY-FOURTH ANNUAL REPORT

NORTH CAROLINA STATE UNIVERSITY - INDUSTRY COOPERATIVE TREE IMPROVEMENT PROGRAM

EXECUTIVE SUMMARY

Progress reports for six research studies reveal that:

- Under an intensive culture regime heritability for height at each age is lower than for a standard culture regime. The trend for heritability under intensive culture is to increase with age. Under standard culture, the heritability did not change over time.
- There is potential for early genetic selection based on the shoot elongation patterns and nitrogen use efficiency traits under nitrogen limiting conditions.
- Modeling work showed that reselection in a larger main-line breeding population (N = 498) to establish an elite breeding population (N = 48) gave an immediate increase in genetic gains that was not offset by inbreeding depression through 10 generations of breeding and selection.
- In a Sandhills dry site study, sand pine demonstrated superior dry matter production over loblolly, Virginia, slash, and longleaf pines.
- A single application of Oust in April reduced the number of mowings needed for bahia grass ground cover in James River's seed orchard.
- In a Fraser fir genetics study, strong positive correlations between height and quality traits such as crown diameter, crown density, branch diameter, and branch bud number suggest that genetic improvement for fast growth can be combined with improved Christmas tree quality.

Progress continued this past year in the breeding and testing of the Cooperative's 3300 plantation and 720 second generation selections. Currently 74% of the crossing is complete and 22% of the testing.

The 1989 cone and seed harvest was the lowest since 1980.

- Cooperative members harvested 16.1 tons of improved loblolly pine seed in comparison to 42.7 tons in 1988.
- Second generation loblolly orchards produced 2.3 tons of seed which represents 14.5% of the total collection in 1989.
- Only champion's (NC) Coastal loblolly orchard exceeded the 2.0 lbs/bushel mark this year. Collections from one clone (8-73) in this orchard produced an amazing 3.3 lbs/bushel.

During the past year, 11 graduate student programs have been conducted in association with the Tree Improvement Cooperative. Of special note was the completion of degree programs by two doctoral students in 1989-1990: Mary Frances Mahalovich and Bailian Li.

The Cooperative staff and associates continue to produce a large number of publications which influences the progress of forest genetics and will have far reaching impacts on forest productivity.

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HURRICANE HUGO

Millions of acres of forest land in South Carolina were damaged by Hurricane Hugo. Shown is some of the devastation on the Francis Marion National Forest.

Hurricanes are frequent visitors to the Atlantic and Gulf Coastal regions of the Southeastern United States. Often when they hit the coast they deliver a glancing blow, and the full force is not felt. Hugo's unwelcome visit was very different. Shortly after midnight on September 22, 1989, the storm, with sustained winds in excess of 135 mph, made a direct hit on Charleston, South Carolina. It moved rapidly inland in a northwesterly direction through the Coastal and Piedmont regions of South Carolina and the western Piedmont region of North Carolina before it lost intensity. Hugo caused a forestry disaster unparalleled in recent history. Pictures (above and back cover) do not reflect the whole story of Hugo's devastation.

- More than 4 million acres of trees, about 36 percent of South Carolina's forest area, suffered severe damage, (meaning that 50% or more of the tree stems per acre are either broken or blown down).
- 3.3 million board feet, about 19% of South Carolina's total pine sawtimber, was damaged. This represents 3 years of harvesting and a value of over $581 million dollars.
- 3.4 million board feet (23%) of South Carolina's total hardwood resource was damaged, representing 15 years of harvesting and a value of more than $231 million dollars.
- The damage to young timber stands has been assessed at $227 million dollars.
- Total value of damaged timber: $1.04 billion dollars.
- The timber volume lost from Hugo exceeds the combined timber losses from Hurricanes Camille and Frederick, the Mt. St. Helens eruption, and the 1988 Yellowstone fires.

Because several of the counties hardest hit by Hugo traditionally have high wildfire occurrence, Hugo's destruction could be the forerunner of a second disaster, wildfire. Millions of tons of flammable forest debris blankets the ground in twenty-four counties. Huge unbroken fuel beds have been created, where natural fire barriers once existed.

Damage to tree improvement programs in Hugo's path was extensive. Westvaco Corp., International Paper Co., Evergreen Corp., Bowater Inc., South Carolina State Commission of Forestry, and the U.S. Forest Service all sustained extensive damage to tree improvement facilities. Westvaco lost a slash pine orchard and their older blocks of first generation loblolly orchards received heavy damage. In their young second generation orchards, approximately 10% of the trees were broken by the wind. The International Paper Co. Eight Oaks seed orchard near Georgetown was severely damaged with approximately 40% of the trees either broken or blown over. Further inland, Evergreen sustained heavy damage to their Coastal second generation orchard and moderate breakage or windthrow in their second generation Piedmont orchard. Their large breeding greenhouse facility was totally destroyed. The South Carolina State Commission of Forestry complex at Wedgefield suffered severe loss as the Coastal and slash orchards were devastated. Although the Piedmont orchard was badly damaged, enough remains to provide a viable orchard. Hugo continued inland, inflicting damage at Bowater near Rock Hill, S.C., but it was moderate compared to their neighbors down east.

Most organizations maintain a solid inventory of improved seed, thus the impact on regeneration programs will be modest. The most significant long term effect for tree improvement may well be in the breeding and testing program.

The U.S.F.S. orchards on the Francis Marion National Forest near Moncks Corner, S.C. were completely destroyed. The longleaf pine orchard was 99% windthrown, with poor tap root development on a relatively wet site contributing to the loss. Ollie Buckles, the orchard manager, reported that Cooperative Program members were very generous with their offers of assistance and grafting stock. Ollie tried some emergency grafting in an attempt to save some of the select trees that were not preserved elsewhere.

Recovery work for all affected has been expensive, exhausting, and exasperating. Most organizations maintain a solid inventory of improved seed, thus the impact on regeneration programs will be modest. The most significant long term effect for tree improvement may well be in the breeding and testing program. Tree and crown breakage caused the loss of cones and seed in breeding orchards. In Evergreen's case, the breeding greenhouse and the trees in it were destroyed. Numerous diallel tests of several members were damaged or destroyed. Hugo's impact will be felt for years to come.

RESEARCH

Results were obtained during the past year from several Cooperative research projects. Fourth year results from the Intensive Culture of Progeny Tests Project are reported. The Ph.D. thesis research by Dr. Bailian Li examined seedling growth, root and shoot morphology, and nitrogen use efficiency relationships affecting early selection of loblolly pine. The Ph.D. thesis research of Dr. Mary Frances Mahalovich modeled elite populations and positive assortative mating in recurrent selection programs for general combining ability. Other studies producing results at this time include:
Bowater's Dry Site Species Comparison Study; James River's Seed Orchard Turf Management Study; and Heritability Values and Genetic Correlations for Selected Traits in Fraser fir. Results from these studies are reported as follows:

Fourth Year Results of the Intensive Culture Study

The consequence of accelerated growth resulting from intensive culture in genetic tests remains controversial among tree breeders. Some believe that intensive culture improves the quality of genetic information and, therefore, genetic and economic gains are increased. Others argue that intensive cultural practices may result in selections that are poorly adapted to less intensively managed operational forest lands.

Interactions between cultural practices and loblolly pine families have been reported, but usually are large only when differences between the practices are extreme. It is hypothesized that under intensive culture, trees can be measured earlier and will have higher heritability estimates because reduced environmental variation will result in a more accurate assessment of family performance at a younger age. If accelerated growth resulting from intensive culture on productive sites can improve the quality of early information, then the marginal cost of such practices might be offset by greater genetic gain per unit time.

In early 1985, a study was initiated to determine the effect of intensive cultural practices in loblolly pine progeny testing. The objectives of the study were to:

1. Assess performance of progeny grown under intensive culture and "standard" culture regimes, including:
   a. Correlation and interaction analyses of families grown in two quite different cultural regimes.
   b. Influence of cultural regimes on selection reliability.
2. Determine the juvenile-mature correlation for families in these tests (both for standard and intensive culture) with the performance of the same families in the Cooperative's good general combiner tests at ages 12 and/or 16.

Open-pollinated seeds from 15 families were used in the study. These same families, originally selected in the upper Coastal region of Alabama and Mississippi, are widely planted in the Cooperative's Good General Combiner tests. In June 1985, intensive culture tests were established at three locations in Alabama and Georgia on lands of Weyerhaeuser, Union Camp, and Proctor and Gamble Cellulose. The cultural treatments used are shown in Table 1.

TABLE 1 Cultural treatments for intensive culture study.

Yr.	Standard Culture	Intensive Culture
1	1 application of Furadan No additional herbicide after site preparation No fertilizer	2 applications of Furadan Additional herbicide Fertilizer (10-10-10)
2	No application of Furadan Reduce growth of hardwood sprouts only No fertilizer	2 applications of Furadan No competing vegetation throughout growing season Application of fertilizer
3	No Furadan No herbicide No fertilizer	2 applications of Furadan No herbicide Application of fertilizer
4	No Furadan No herbicide No fertilizer	No Furadan No herbicide Application of fertilizer
5	No Furadan No herbicide Fertilizer prescription	2 applications of Furadan No herbicide Application of fertilizer

Analyses combined over the 3 test sites for height at ages 2, 3, & 4 years and rust and survival at year 4, revealed highly significant family and treatment effects for height but slightly less significant effects for rust. Survival was generally high, thus for this trait family and treatment differences were small. Treatment by family differences (g x e interaction) were not significant; i.e., families performed essentially the same in both the standard and intensive treatment.

Figures 1 and 2 show the effect of the cultural regimes on individual and family mean heritability. With intensive culture lower estimates of heritability occurred at each age. Similar results have been observed in other studies. It can be hypothesized that intensive culture may remove some of the environmental stresses that families respond to differentially, and hence families behave more alike when stress is reduced at young ages.

Apparently, within family plot environmental variance is increased with intensive culture since the family mean heritabilities are not nearly as different in the two cultural regimes as the individual tree heritabilities. The trend for heritability under intensive culture is to increase with age. Under standard culture, the heritability has not changed over time.

The impact of cultural regime on h^2 is important since juvenile h^2 is part of the selection equation. If intensive management of tests results in lower heritability then gains will be reduced, especially from within family selection. The trials will be followed for several more years to evaluate the long term trends in the genetic and environmental variance estimates.

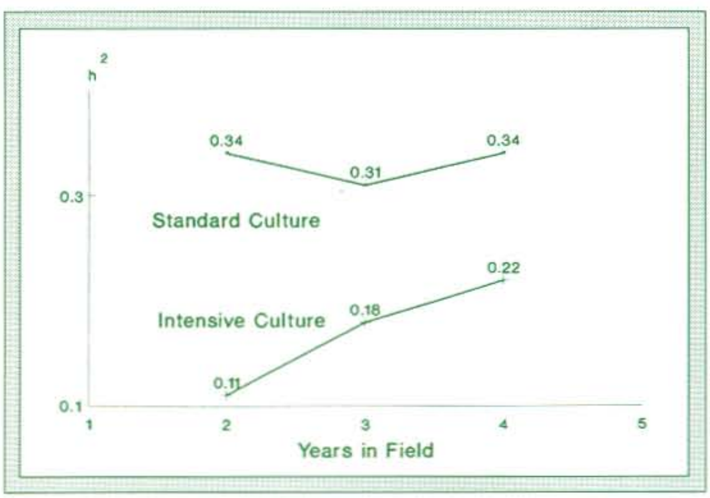

Figure 1

Loblolly Pine Intensive Culture Study: Effect of Cultural Regime on Individual Heritability for Height-Ages 2,3,4.

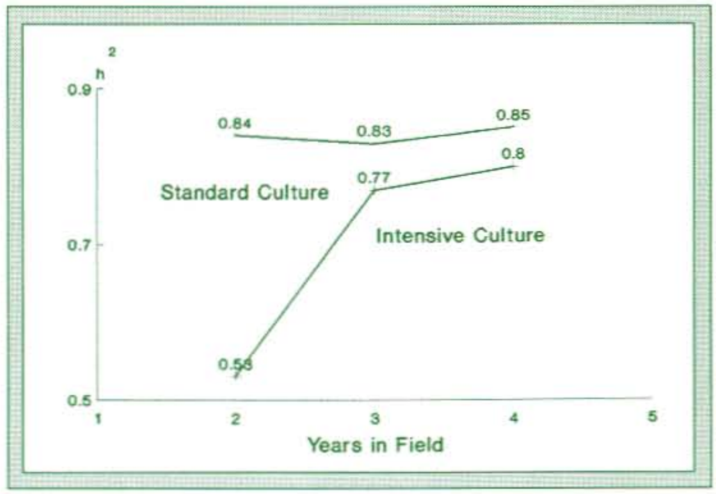

Figure 2

Loblolly Pine Intensive Culture Study: Effect of Cultural Regime on Family Mean Heritability for Height-Ages 2,3,4.

Correlations of family means under intensive and standard culture with family means in the Cooperative's Good General Combiner Tests were low (around .2) for all ages and treatments. Even when annual increment (which usually displays a higher correlation) was used, there was no improvement.

The 5-year data for the Intensive Culture Tests is presently being taken, so further analysis will soon be available. These tests promise to yield some very interesting results in the next few years.

Early Selection of Loblolly Pine Based on Seedling Growth, Root and Shoot Morphology and Nitrogen Use Efficiency.

(Summary of Dr. Bailian Li's Ph.D Research).

Seedlings of 23 open-pollinated loblolly pine families from the Coastal Plain of northern North Carolina and southern Virginia were planted in a greenhouse under two nitrogen (N) conditions (5 and 50 ppm) for twenty weeks. Significant genetic variation was detected among families in root length and the number of first order lateral roots. Heritability estimates were generally high for these root traits. There were positive genetic correlations between root characteristics and seedling growth, especially under the low N condition. Seedlings under low N produced greater root length per root dry weight. Genotypic variation in dry weight allocations to stem, needles, and roots was examined by allometric analysis. Differences in dry weight partitioning among genotypes was found to be related to stem growth.

Genetic differences among loblolly pine families in root growth were reflected in their N absorption. N use efficiency, defined as stem dry weight per unit of N applied in the medium, was partitioned into two components: uptake and utilization efficiency. Genetic differences were detected for these N use efficiency traits. The contribution ("C" value) of the two components to the variation in N use efficiency among families was different at two N levels (Figure 3). The efficiency of N uptake (C = .53) and utilization (C = .47) contributed equally to the variation in N use at the low N condition, but mainly utilization efficiency (C = .72) contributed to it under the high N condition. N use efficiency was positively associated with root size and seedling growth. High heritabilities and correlations of N use efficiency traits with seedling growth indicated the possibility of increasing tree growth by selecting for N use efficiency.

TABLE 2 Family mean correlations of seedling shoot characters with 12-year height performance levels for two N treatments.

Traits	Low N	High N	Combined
Total Height	0.47*	0.21	0.43*
Cycle Numbers	0.51*	0.43*	0.44*
Summer Growth	0.58**	0.48*	0.52*
# Stem Units	0.54**	0.35	0.47*
Mean Stem Unit Length	0.02	0.18	0.13

*, **: Significantly different at $p \leq 0.05$ and $p \leq 0.01$, respectively.

Differences among genotypes were also detected for the number of growth cycles, cycle lengths, summer shoot elongation, number of stem units, and total seedling height. Nitrogen treatment had a significant effect on these differences. The number of stem units accounted for most of the differences in shoot elongation. Heritability estimates for cycle numbers, summer shoot length and the number of stem units were higher than those for seedling height. Positive correlations were found between family mean seedling height and 12-year height performance levels in the field, and correlations increased substantially after seedlings had set the first terminal bud (Table 2). Summer shoot growth, cycle numbers, and the number of stem units showed stronger correlations with field performance than the seedling height. The correlations were consistently higher under low N than under the high N condition. From this research, a potential appears to exist for early genetic selection based on shoot elongation patterns and N use efficiency traits under the N limiting conditions.

Modeling Elite Populations and Positive Assortative Mating in Recurrent Selection Programs for General Combining Ability

Graduate student, Mary Frances Mahalovich, recently completed her Ph.D. thesis study of elite populations and positive assortative mating in recurrent selection programs for general combining ability. An algorithm for allele modeling demonstrated the utility of adding elite populations to the hierarchy of populations currently employed in tree improvement. Additive and partial dominance gene models were constructed for a trait with 50 loci. A large (n = 498), random mated main-line population was simulated, where selected individuals were used to initiate positive assortative and random mated elite populations of medium (n = 48) and small

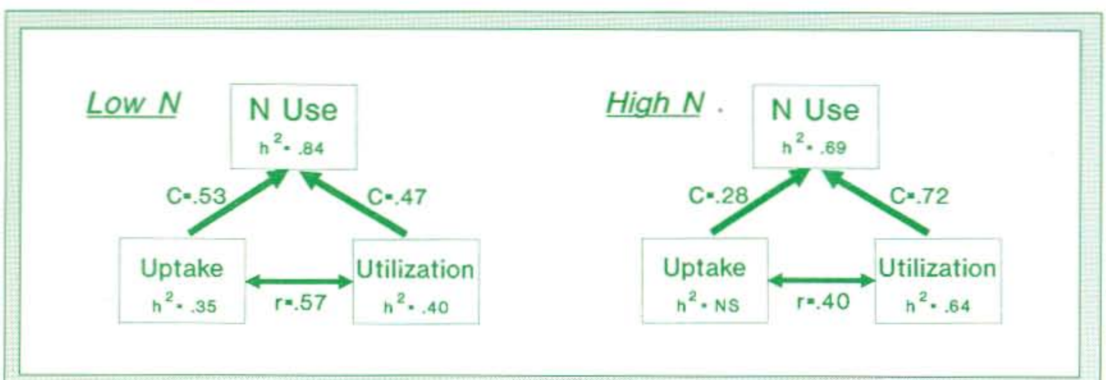

Figure 3
Flow charts for low and high nitrogen treatments depicting heritable variation (h^2 values), contribution coefficients (C values) and family mean correlation (r values) for nitrogen use and uptake and utilization components.

size (n = 12). Single-pair and 6-parent disconnected half diallel mating designs were evaluated in combination with mass and family plus within-family selection for heritabilities of 0.1, 0.2 and 0.3. Long-term effects in closed breeding populations were contrasted to periodic enrichment of the elite populations with main-line selections to offset inbreeding.

Percent increase in gain over the main-line population for the n = 48 elite populations in five breeding cycles varied between 26%-84%, increasing as heritability increased. N = 12 elite populations were 47%-131% greater than the main-line population. Positive assortative mating at $h^2 = 0.2$ and 0.3 yielded 1%-12% more gain than random mating. Inbreeding coefficients over 21 generations ranged between 0-0.4 in the main-line population, 0-0.28 in n = 48 elite populations, and 0-0.74 in n = 12 elite populations.

No consistent differences existed between mating design or mating scheme employed for the additive gene model. For the partial dominance gene model, n = 48 elite populations increased realized gain over the main-line population by 20-81% with mass selection, 37-141% for family plus within-family selection, and 47-128% employing an enrichment scheme. For n = 12 elite populations, gains over the main-line population were 43-108% for mass selection, 46-174% for family plus within-family selection, and 64-155% with enrichment. Positive assortative mating was only consistently greater than random mating for $h^2 = 0.2$ and n = 48. Positive assortative mating was 3-12% greater than random mating for family plus within-family selection with n = 48, depending upon heritability and generation, but no different than random mating for n = 12 with maximal control of coancestry.

Positive assortative mating with selection was not an effective strategy to produce large numbers of positive phenotypic extremes. Enrichment did reduce inbreeding coefficients in the n = 48 and n = 12 populations; however, selection differentials were reduced such that gains were equal to or less than those with no enrichment.

Bowater's Dry Site Species Comparison Study

This study was instigated to compare species performance on the "sandhill" lands in the Carolinas. These sites, located between the Piedmont and Coastal zones, are typically deep sands and very dry, making tree growth marginal. In 1972, Bowater established a drought resistance study in Chesterfield, S.C. Three sources of loblolly pine, two sources of Virginia pine, and one source each of slash pine, sand pine, and longleaf pine were planted in 50 tree (5 x 10) block plots and replicated four times.

Total tree height and dbh were measured on the 24 internal trees of each source block. Increment cores (11 mm diam.) were taken bark-to-bark on eight dominant/co-dominant trees

Early selection procedures are an important research focus for the Cooperative. Height increment is being measured in the Early Selection Verification Trial following the first growing season in the field. Locations of this study are with Great Southern Paper Co. and International Paper Co.

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Table 3. Mean survival, total height, dbh, volume per tree, and dry weight per tree at age sixteen for the Bowater Carolina drought resistance study, Chesterfield Co., SC.

Species	% Survival[1]	Total Ht (ft)	Dbh (IN)	Volume/ Tree(ft^3)	Dry Wt./ Tree(lbs)
Sand Pine (Choctawhatchee)	78 c	39.8a	6.9a	5.3a	147a
Texas Loblolly[3] (BA311-1 X op)	93	37.5	6.1	3.2	102
Virginia Pine (Lyons SPA[2])	99a	27.7 c	5.0 bc	2.0 b	58 b
Virginia Pine (Maryland)	99a	27.0 c	4.6 c	1.8 b	53 b
Loblolly Pine (Davenport SPA)	87 bc	29.4 bc	5.1 bc	1.9 b	58 b
Loblolly Pine (Seed Orchard)	81 bc	30.4 bc	5.3 b	2.0 b	64 b
Slash Pine	49 d	35.1ab	5.4 b	2.3 b	71 b
Longleaf[4]	14 e				

1 Means within each column followed by the same letter are not statistically different ($P \leq .05$).
2 SPA = seed production area.
3 The Texas loblolly is from a single parent and does not represent either a source or a species. Therefore, it was not included in the statistical tests with the other species or sources.
4 The survival of longleaf was so poor that it was not included in any analyses other than survival.

Table 4. Mean volume per acre and dry weight per acre at age sixteen for the Bowater Carolina drought resistance study, Chesterfield Co., SC.

Species	Volume/Acre (Ft^3)[1]	Weighted Specific Gravity	Dry Weight/Acre (lbs)
Sand Pine (Choctawhatchee)	2527a	.44 c	69526a
Texas Loblolly[3] (BA311-1 X op)	1784	.52	57735
Virginia Pine (Lyons SPA[2])	1220 b	.46 bc	34673 b
Virginia Pine (Maryland)	1037 bc	.47 b	30455 b
Loblolly Pine (Davenport SPA)	1010 bc	.48 b	30345 b
Loblolly Pine (Seed Orchard)	978 bc	.50a	30760 b
Slash Pine	691 c	.48 b	20900 b
Longleaf[4]			

1 Means followed by the same letter are not statistically different ($P \leq .05$).
2 SPA = seed production area.
3 The Texas loblolly is from a single parent and does not represent either a source or a species. Therefore, it was not included in the statistical tests with the other species or sources.
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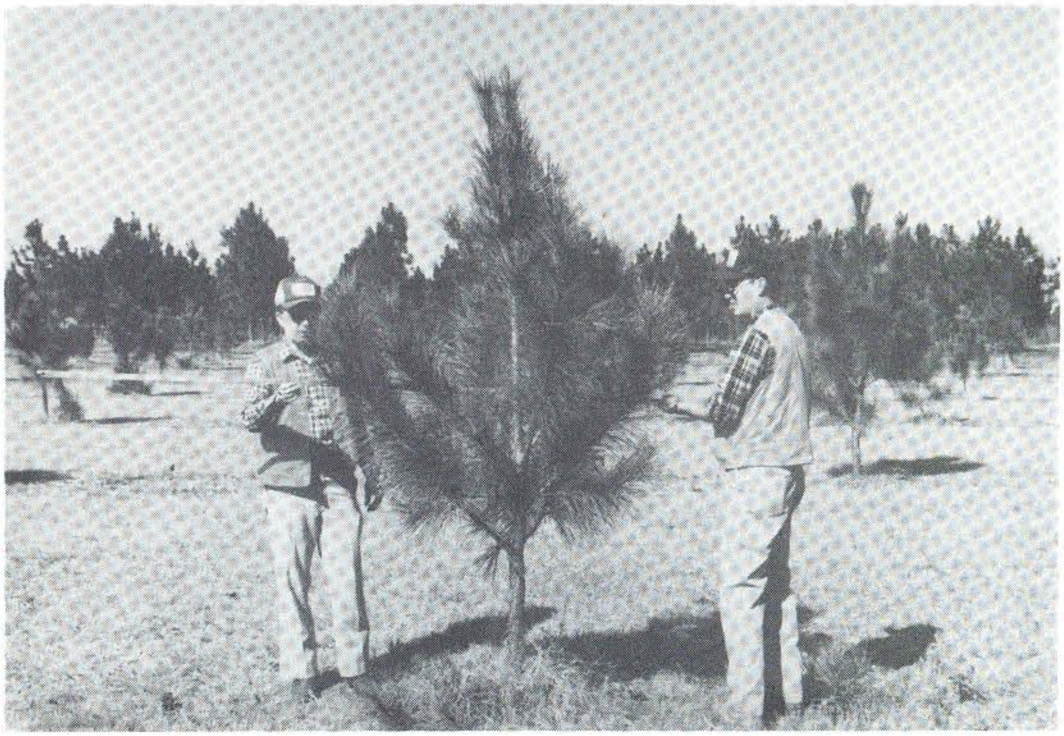

The Cooperative's Rootstock Study is designed to answer some basic questions regarding the potential dwarfing effects of selected families and to provide a better understanding of rootstock/scion interaction.

per species/source plot in each replication for a total of 32 sample trees per species/source. Because of poor survival, longleaf was not sampled. Total cubic foot volumes were calculated for each species using equations from the Forest Survey program of the U. S. Forest Service.

Mean survival, total height, dbh, volume and dry weight per tree at age 16 are shown in Table 3. Overall survival in this planting was acceptable with the exception of longleaf and slash pine. While sand pine did not rank first in survival, the growth of sand pine on this site was outstanding.

The combination of good height and diameter growth coupled with reasonable survival translates into substantial volume production for sand pine. As shown in Table 4, sand pine had a mean volume per acre of 2527 cubic feet. The single Texas loblolly family had the next highest production at 1784 cubic feet. On a per acre basis, sand pine produced 2.5 times as

TABLE 3 Mean survival, total height, dbh, volume per tree, and dry weight per tree at age sixteen for the Bowater Carolina drought resistance study, Chesterfield Co., SC.

Species	% Survival[1]	Total Ht (ft)	Dbh (IN)	Volume/ Tree(ft^3)	Dry Wt./ Tree(lbs)
Sand Pine (Choctawhatchee)	78[c]	39.8[a]	6.9[a]	5.3[a]	182[a]
Texas Loblolly[3] (BA311-1 X op)	93	37.5	6.1	3.2	142
Virginia Pine (Maryland)	99[a]	27.7[c]	4.6[c]	1.8[b]	60[b]
Loblolly Pine (Davenport SPA[2])	8[bc]	29.4[bc]	5.1[bc]	1.9[b]	89[b]
Loblolly Pine (Seed Orchard)	8[bc]	35.1[ab]	5.4[b]	2.3[b]	82[b]
Slash Pine	49[d]	35.1[ab]	5.4[b]	2.3[b]	82[b]
Longleaf[4]	14[c]				

[1] Means within each column followed by the same letter are not statistically different (P = .05).
[2] SPA = seed production area.
[3] The Texas loblolly is from a single parent and does not represent either a source or a species. Therefore, it was not included in the statistical tests with the other species or sources.
[4] The survival of longleaf was so poor that it was not included in any analyses other than survival.

TABLE 4 Mean volume per acre and dry weight per acre at age sixteen for the Bowater Carolina drought resistance study, Chesterfield Co., SC.

Species	Volume/Acre $(Ft^3)^1$	Weighted Specific Gravity	Dry Weight/ Acre (lbs)
Sand Pine (Choctawhatchee)	2527[a]	.44[c]	34692[a]
Texas Loblolly[3] (BA311-1 X op)	1784	.52	28701
Virginia Pine (Lyons SPA[2])	1220[b]	.46[bc]	14352[b]
Virginia Pine (Maryland)	1037[bc]	.47[b]	11852[b]
Loblolly Pine (Davenport SPA)	1010[bc]	.48[b]	17851[b]
Loblolly Pine (Seed Orchard)	978[bc]	.50[a]	18196[b]
Slash Pine	691[c]	.48[b]	14862[b]
Longleaf[4]			

[1] Means followed by the same letter are not statistically different (P < = .05).
[2] SPA = seed production area.
[3] The Texas loblolly is from a single parent and does not represent either a source or a species. Therefore, it was not included in the statistical tests with the other species or sources.
[4] The survival of longleaf was so poor that it was not included in any analyses other than survival.

much cubic volume and the Texas family produced 70% more than either of the other loblolly sources. These results are not surprising since sand pine and the Texas loblolly are both adapted to dry conditions.

Converting the volume per acre into dry weight of wood per acre also shows sand pine to be tremendously productive (Table 4). However, the superiority of sand pine is less on a dry weight basis because of its rather low specific gravity. Of the loblolly material tested, the Texas family was the best. It had better survival, decent growth, and a higher specific gravity than sand pine. Yet despite these attributes, the Texas family was no match for the better height and diameter growth of the sand pine.

As other studies have shown, material from the Texas loblolly source displayed excellent fusiform rust resistance (3.6% infection vs 50+% for local loblolly). The slash pine showed lower percent infection (25%) than the two indigenous loblolly sources and this could be because many of the infected slash had died due to rust.

In summary, sand pine demonstrated superior performance on these sites and should be seriously considered in the regeneration of droughty deep sand sites.

Herbicide Suppression of Turf Grass Growth In a Loblolly Pine Seed Orchard

During the 1989 growing season, James River Corporation continued their studies on the use of sub-lethal doses of herbicides to reduce the need to mow in their loblolly pine seed orchards. Based on the results obtained in 1988, only four treatments were evaluated during the 1989 season:

1. Control, no herbicides.
2. 11.78 g Oust/25 gallons of water/acre applied in April.
3. 11.78 g Oust + 179 ml Roundup/25 gallons of water/acre applied in April.
4. 11.78 g Oust + 179 ml Roundup/25 gallons of water/acre applied in April and repeated in late June.

These four treatments were installed in an orchard with ground cover consisting primarily of bahia grass. Treatment plots 30 x 15 feet in size, were replicated four times. The effectiveness of the treatments in reducing turf growth was evaluated by mowing two 15-foot strips each month in each treatment using a walk behind mower with a grass catching attachment. The fresh weight of the clippings was determined for each sample strip beginning one month after the initiation of the study and continuing through August.

Changes in species composition were monitored by evaluating three 1 sq. ft. sample plots in each of the two strips selected for mowing each month. Species composition was noted just before mowing.

Treatment differences were highly significant ($P \leq .05$) during June and July and were marginally significant at $P \leq .10$ in August. All of the herbicide treatments were essentially equal in reducing growth of the ground cover (Figure 4). While the combination of Oust and Roundup, applied either once (April) or twice (April and June), may have a slight advantage over Oust alone, differences do not appear to warrant the costs of the added chemical or repeat applications. Clipping weights in August for the herbicide treatments were approximately 36 percent less than the control plot.

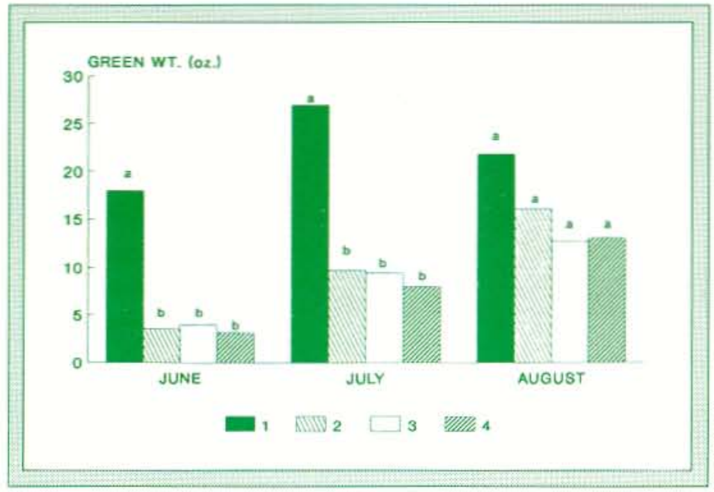

Figure 4

Mean clipping weight/25 sq. ft. for four herbicide treatments in the James River Turf Study.

Analyses of species composition in the sample plots indicated the herbicides reduced the frequency of bahia grass in the treatment plots. The frequency of bahia grass was essentially the same for all of the herbicide treatments (Figure 5). As in the case of turf growth, it does not appear that the combination treatments had any advantage over the single April application of Oust.

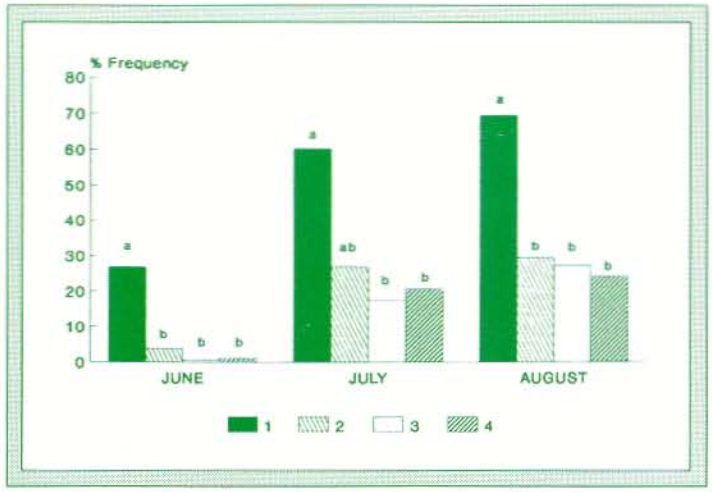

Figure 5

Mean frequency of occurrence of bahia grass for four herbicide treatments in the James River Turf Study.

An on site appraisal by orchard manager Jerry Bolen indicated that the herbicide stunting of the turf was not as effective as that obtained in the previous season's study. An unusually wet June and July may have reduced the effectiveness of the treatments to reduce turf growth. However, Jerry's opinion was that mowing every three weeks instead of every two weeks would have been appropriate on the herbicide stunted grass.

Heritability Values and Genetic Correlations of Selected Traits in Fraser Fir

There is a tremendous potential to genetically improve both the quality and growth of Fraser fir for Christmas tree production. Recently completed work by graduate student Yecai Liu indicates that selection and breeding for an improved Fraser fir Christmas tree should yield outstanding dividends.

The heritabilities and genotypic correlations of height growth and several quality related traits were estimated from the fourth year measurements of the Fraser Fir Provenance Study. The design of the Fraser Fir Provenance Study was covered in detail in the 30th Annual Report of the N.C. State University-Industry Cooperative Tree Improvement Program. Briefly, however, the study consists of open-pollinated Fraser fir progeny grown from seed collected at different elevations from five mountain sources and outplanted at three locations in western North Carolina. The planting sites vary in elevation with the Bald Mountain site at 5100 feet, Purchase Knob at 4400 feet, and Crossnore at approximately 3000 feet elevation.

TABLE 5 Individual tree (h_i^2) and family mean (h_f^2) heritability estimates combined over three planting locations for selected traits in four-year-old Fraser fir of the Fraser Fir Provenance Study.

	Height	Crown Diameter	Branch Diameter	# Branch Buds	# Terminal Buds	Density
h_i^2	0.42	0.32	0.28	0.41	0.13	0.34
h_f^2	0.85	0.83	0.79	0.86	0.57	0.82

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THIRTY-FOURTH ANNUAL REPORT N. C. STATE UNIVERSITY-INDUSTRY COOPERATIVE TREE PROGRAM

Table 6. Genetic correlation between selected traits in four-year-old Fraser fir in the Fraser Fir Provenance Study[1]

	Crown Diameter	Density Diameter	Branch Buds	# Terminal	# Branch Buds
Height	.894	.689	.859	.258	.732
Crown diameter		.586	.714	.407	.570
Density		.633		.583	.961
Branch Diameter				.078NS	.734
# Terminal buds					.323

1 Unless noted as nonsignificant (NS) correlations are highly significant at $P \leq = .01$.

Both individual tree and family mean heritability estimates for total height, crown diameter, branch diameter, branch bud number, and number of buds in the terminal bud cluster were calculated. An estimate of crown density was developed by multiplying the number of terminal buds by the number of branch buds. Results presented in Table 5 indicate that these growth and quality traits are under moderate to strong genetic control. Since gains from selection depend on heritabilities as well as selection differential and total variation, tree improvement efforts with Fraser fir should be very productive.

As an example of the potential improvement possible from selection and breeding, data from the Crossnore planting location were used to calculate expected gain in height growth. Assuming that the top 10% of the population were selected and bred, and given a mean total height of 4.2 feet, the expected gain was estimated to be 38%. This percent improvement equates to a shift in mean height from 4.2 feet to 5.7 feet at age four.

Genetic correlations are presented in Table 6. The strong positive correlations between height and quality traits such as crown diameter, density, branch diameter, and number of branch buds are important since they indicate that genetic improvement for fast growth can be combined with improved Christmas tree quality.

Plans for this study include evaluation at age eight which is the nominal rotation age for this species. The final assessment will include the use of USDA Christmas tree grades and the assignment of a dollar value to each tree. The economic value of various traits will be evaluated and combined with genetic estimates to develop a selection index for future tree selection and breeding efforts with Fraser fir.

BREEDING, TESTING AND SELECTION

Breeding and Testing Progress Report

In spite of two consecutive poor flower years, the Cooperative continues to make progress in the breeding and testing of plantation and second generation selections. Currently, crossing for the plantation material is estimated at 77% complete while the second generation is about 70% complete. Test establishment is approximately 22% complete for both the plantation and the second generation tests (Figure 6).

An additional 114 advanced generation tests were established in 1989, including 103 plantation and 11 second generation tests, for a total of 292 tests (Figure 7). This represents about a 64% increase over last year's number and in 1990 many more are scheduled to be planted. Cooperators are expecting to establish the majority of tests for this breeding cycle in the next three to four years. Projected test establishment is illustrated in Figure 8. It appears that peak establishment will occur in 1992. Cooperators are preparing for this large testing load by selecting test sites well in advance. Many cooperators are swapping tests in order to more evenly distribute their testing workload.

Progress in the second generation breeding was particularly encouraging this past year as a number of diallels were completed and are ready for planting. After the 1989 cone harvest, 10 diallels were ready for planting in Area 1 — Chesapeake, the Virginia Department of Forestry, and Union Camp will establish these tests within the next year. Other areas are starting to show progress also; two diallels were completed for Area 6, four for Area 7 and two in Area 8. With 70% of the second generation crossing completed, many more tests will be ready for establishment in the next two to three years.

Third Generation Selection

The FIRST third generation selection, 11-3001, was identified and graded in a second generation diallel progeny test of Westvaco Corporation during February 1990. This is a significant occurrence in the Cooperative's genetic resource development effort. Third generation selections can be used to establish third cycle seed orchards and will be bred to form the foundation for a fourth cycle of improvement.

A total of 15 selections were graded in cooperative test series

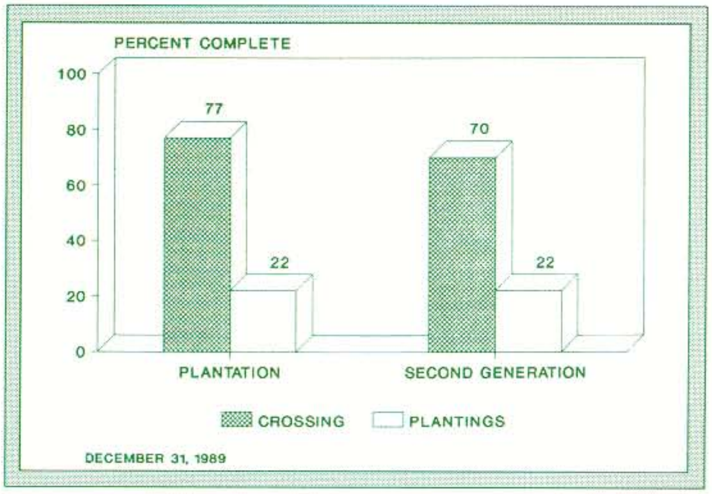


Figure 6

Overall status of the plantation and second generation breeding and testing program.

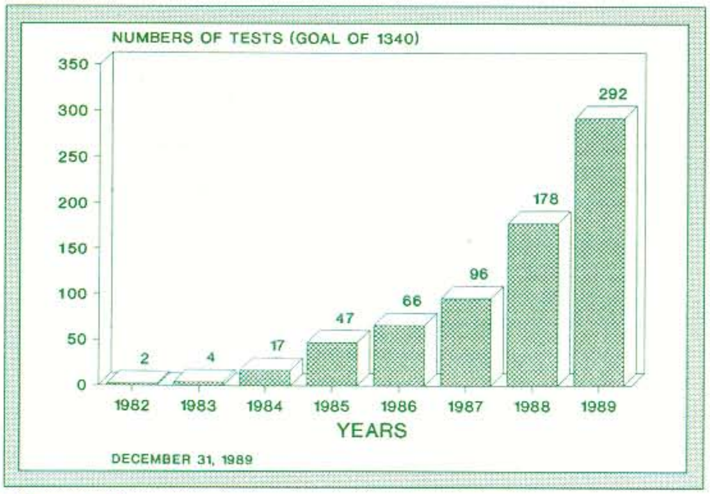


Figure 7

Cumulative number of advanced generation progeny tests established.

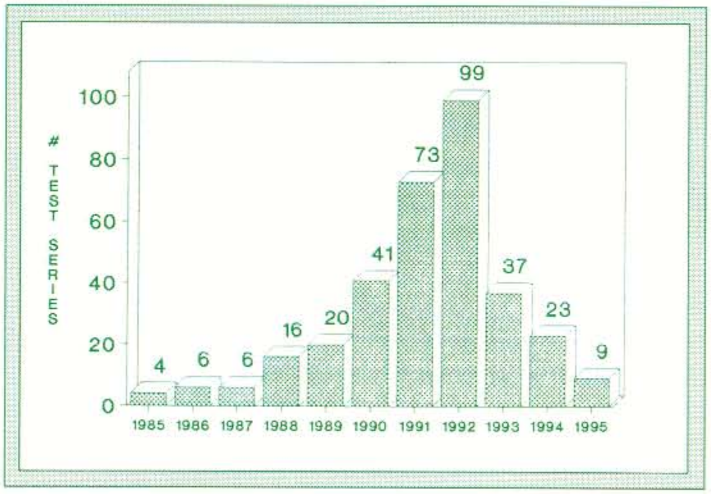
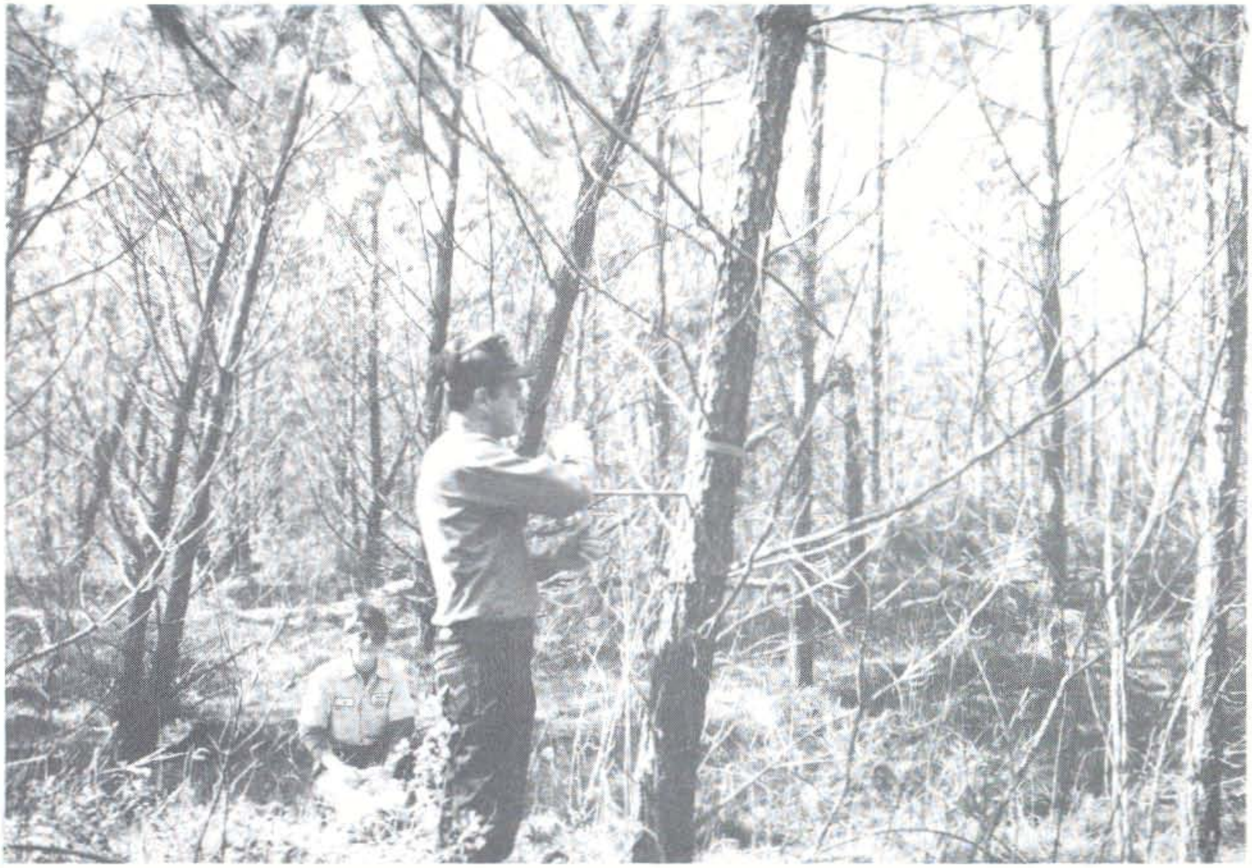


Figure 8

Projected number of test series established by year.



Thanks Hugo! The process of making third generation selections was a real challenge and started a year early because of Hurricane Hugo. Dave Gerwig of Westvaco is taking a wood sample from the first third generation selection made by the Cooperative.

25 which was comprised of second generation diallels 106 and 107. The four tests in this series were planted in the Coastal Plain of South Carolina in April of 1984 and 1985, two tests in each year. The tests established in 1984 had completed six growing seasons in the field and the 1985 tests were five years old. According to program plans, selection in these tests should not have occurred until 1991, when all four tests in the series reached age six in the field. Hurricane Hugo changed our plan; tests in series 25 were severely damaged by the storm. With many trees broken and others bent and/or twisted beyond recovery, the long term survival of these tests was in jeopardy. Thus, we decided to make these selections one year in advance of schedule. It was, in essence, a salvage operation. Nevertheless, some quality selections from some outstanding families were identified.

Data on height growth, rust infection, and straightness were summarized for the 12 parents in the test series. All families performed better than the local check for height and straightness. There was very little family variation for rust infection. While growth performance is encouraging, we will not be certain about the genetic quality of the parents in these two diallels until we analyze more diallels. With this in mind, selection was accomplished as follows:

1. Progeny from the two worst performing families were discarded immediately.
2. Selection was designed to maintain the same population size (n = 12) for the two diallels.
3. Crosses were ranked based on mid-parent values and selection candidates from the best mid-parents were listed. For co-ancestry purposes, selection candidates were restricted to three crosses per parent.
4. The top five individuals from each of these "best crosses" were screened in the field.
5. A total of 15 selections from 13 of 30 full sib families in the test series were graded following field inspection. In these tests, damaged by Hugo, field screening and grading was a challenge.

We expect to complete an additional round of third generation selection from second generation diallel tests during the early summer of 1990. Weyerhaeuser Co. established the first test series in the Cooperative in 1982 and 1983. Six year data for all four tests are summarized and screening - selection will be completed according to schedule.

SEED ORCHARD PRODUCTION

Cone and Seed Yields

The 1987 Cooperative cone crop was a record crop, producing 93.3 tons of genetically improved loblolly pine seed. The next year (1988), a rather disappointing 42.7 tons of seed were produced, representing a 54% decline. This year, we must report that the 1989 crop (16.1 tons) was the lowest since 1980 (7.9 tons) (Table 7). In fact, the 1989 crop was the second smallest in the past 13 years. It represents a 63% decline from the 1988 crop and an 83% drop from the record breaking 1987 crop. Table 8 gives a detailed breakdown, by species, comparing the 1989 and 1988 crops. Not only were loblolly yields low, but other species were down as well. Pounds of seed per bushel were also down from 1.47 in 1988 to 1.35 in 1989. The .12 difference does not seem that large, but the most noticeable difference was in the number of orchards producing above the 2.0 pounds of seed per bushel of cones. Only one orchard (Champion's N.C. Coastal) made the Two Pound Honor Roll this past year.

The total production from second generation loblolly orchards was 2.3 tons of seed which represents 14.5% of the total 1989 production. Production from second generation orchards over the past eight years is shown in Figure 9.

It should be noted, though, that these figures are probably worse than reality. With plenty of loblolly seed in storage or available on the market, several organizations opted not to collect their cone crops. Fourteen organizations reported that they collected no cones or collected only selected orchards/clones. With an abundance of seed, several strategies are now being employed. Older 1.0 orchards are being closed down completely, while in others, only the best clones are being collected. So while the 1989 yield was low, harvest strategies contributed, at least in a small way, to the decline in yields.

In spite of two poor cone crops, most organizations have substantial seed inventories and the future seems to be promising, The 1990 cone crop will be much better than the previous two, and the 1990 flower crop was excellent.

Figure 10 shows the cumulative impact the program has had on regeneration since 1980. Enough seed has been produced in this period to regenerate nearly 13 million acres.

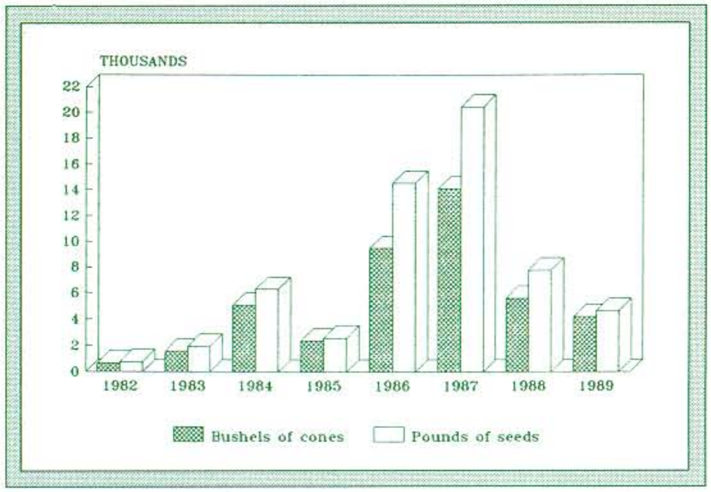


Figure 9
Second generation seed orchard yields for the past eight years.

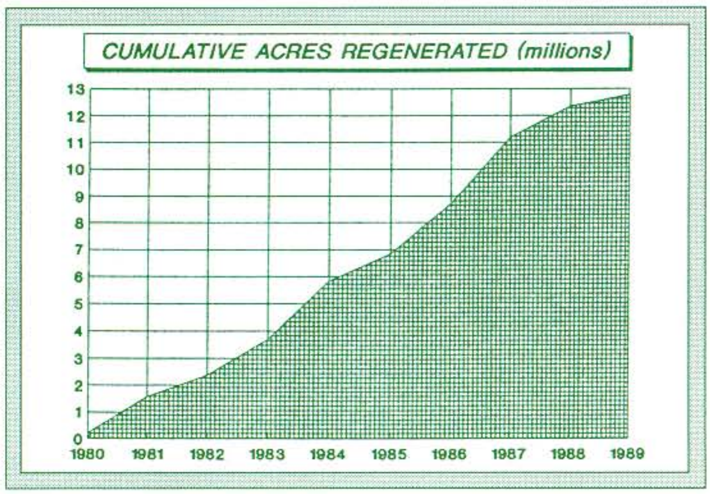


Figure 10
Cumulative regeneration profile for the Cooperative since 1980.

Production Leaders

Total seed production is only part of the story of seed orchard success. Another important element is production efficiency. Pounds of seed per bushel of cones is a good indication of efficiency. Several years ago we started the TWO POUND HONOR ROLL to recognize those orchard managers whose orchards produce over 2.0 pounds per bushel of cones. This year the production efficiency leader and the only member on the HONOR ROLL is the Champion, NC Coastal orchard

TABLE 7 Annual production of cones, seeds, and seedlings from cooperative member's loblolly pine seed orchards since the program's inception. An estimate of acres that could be regenerated with improved seedlings if all seed were used is included.

Harvest Year	Bushels of Seed	Tons Of Seed	Millions of Seedlings	Millions of Acres Regenerated
1969	1,769	1.0	16	0.03
1970	5,146	3.5	56	0.09
1971	6,478	3.7	59	0.10
1972	6,807	3.3	53	0.09
1973	11,853	6.5	103	0.17
1974	8,816	4.4	70	0.12
1975	16,348	10.7	171	0.29
1976	14,656	8.9	142	0.24
1977	32,152	24.8	396	0.66
1978	37,977	23.5	377	0.63
1979	38,693	27.7	443	0.74
1980	15,296	7.9	126	0.21
1981	64,811	50.5	808	1.35
1982	44,761	30.5	488	0.82
1983	68,447	49.0	784	1.31
1984	105,239	80.1	1,282	2.14
1985	52,155	37.8	605	1.01
1986	84,953	70.1	1,122	1.88
1987	112,822	93.3	1,493	2.50
1988	56,822	42.7	683	1.14
1989	23,247	16.1	258	0.43
Total	**809,248**	**595.8**	**9,533**	**15.94**

TABLE 8 Cone and seed yield comparisons for 1989 and 1988.

Species	Bushels of Cones		Pounds of Seed		Pounds of Seed Per Bushel of Cones	
	1989	1988	1989	1988	1989	1988
Coastal 1.0	11,341	31,699	15,246	45,954	1.34	1.45
Piedmont 1.0	7,715	17,928	12,212	29,376	1.58	1.64
Coastal 2.0	2,216	4,584	2,417	6,303	1.09	1.38
Piedmont 2.0	1,975	2,611	2,242	3,702	1.14	1.42
Slash Pine	912	9,191	687	10,412	0.75	1.13
Longleaf	0	750	0	706	- - -	0.94
Virginia	48	97	45	93	0.94	0.96
White Pine	3,342	0	2,268	0	0.68	- - -
Fraser Fir	185	28.5	630	57	3.41	2.00
Total	**27,734**	**66,889**	**35,747**	**96,603**	- - -	- - -

which produced 2.61 lbs/bushel, an all time record. This orchard has appeared on the Honor Roll in 3 of the past 4 years. This accomplishment is especially noteworthy this year when cone and seed yields were poor.

With a single orchard on the Honor Roll, this year we chose to recognize several additional production efficiency leaders. After Champion, the next orchards fell between 1.7 and 1.8 pounds per bushel. In second place were Bowater's and

TABLE 9 Production efficiency leaders for the 1989 cone crop.

Cooperator	Orchard Type	Generation	Acres	Age	Lbs/Bu
Champion, NC	Coastal	1.0	21	27	2.61
Champion, SC	Piedmont	1.0	5	29	1.76
Bowater	Piedmont	1.5	30	15	1.76
Weyerhaeuser, NC	N. Coastal	1.0	10	20	1.74
International Paper, SC	S. Coastal	1.0	26	26	1.72
Champion, SC	Piedmont	2.0	20	10	1.71
Weyerhaeuser, NC	Piedmont	1.0	11	27	1.71
Federal	Piedmont	1.0	9	29	1.70
Va. Dept. of For.	Coastal	2.0	20	10	1.70

Congratulations go to James Hodges (Champion, NC), Bob Lee (Champion, SC), Jake Clark (Bowater), Gary Oppenheimer (Weyerhaeuser), Marvin Cribb, (International Paper Co.), Maxie Maynor (Federal Paper Board), and Billy Barber (Virginia Dept. of Forestry) for leading the way in '89

Champion, SC's Piedmont loblolly orchards, tying at 1.76 pounds per bushel. Others in the 1.7 range were the Weyerhaeuser (NC) N. Coastal orchard, the International Paper Company (SC) S. Coastal orchard, the Champion(SC) second generation Piedmont orchard, the Weyerhaeuser (NC) Piedmont orchard, Federal's Piedmont orchard and the Virginia Department of Forestry's second generation Coastal orchards (Table 9). It should be noted that two second generation orchards appear on the list this year.

James Hodges of Champion(NC) reported what may be a new record for clonal production. They collected 30 bushels of cones from clone 8-73 which produced 99 pounds of seed for an astonishing 3.3 pounds per bushel. That is a record that any orchard manager would be pleased to match!!

Seed Orchard Pest Management Subcommittee

A coordinated approach involving industry, government agencies and universities proved highly successful during the 1970's in testing and securing registration of two insecticides for seed orchard use; Guthion was registered in 1976 and Furadan in 1978. No new compounds have been registered for use in seed orchards since Ambush and Pounce were registered in 1982. Today, pesticides we now depend upon are coming under review by the Environmental Protection Agency, and there is no guarantee of their continued availability.

To meet this very serious situation, a new subcommittee concerned with seed orchard pest management was organized during 1989 under the auspices of the Southern Forest Tree Improvement Committee. The Subcommittee membership represents a broad spectrum of persons and organizations. J.B. Jett is representing the Cooperative on this subcommittee.

The Subcommittee has two primary activities: (1) Coordinated efficacy studies for promising pesticides to be conducted in industry and state agency orchards, and (2) Work with chemical manufacturers to extend existing pesticide registrations for seed orchard use.

The subcommittee has already begun efforts in conjunction with FMC Corporation to develop a multi-location efficacy study of Capture. This insecticide has shown promise of cone and seed insect control in screening studies by Dr. Gary DeBarr. This material is expected to be effective at very low rates of active ingredient per acre; apparently does not trigger scale insect epidemics; and, is much safer for applications than a compound such as Guthion. The study will be initiated during the spring of 1991.

Efforts during 1990 are being directed towards obtaining 24C registrations across the southeastern United States and hopefully obtaining some preliminary data regarding the appropriate rates of Capture to be evaluated in 1991. Additional chemicals and biological control systems are being considered for studies in the years ahead. It will take a complete, coordinated approach to insect control if we are to have any hope of maintaining our outstanding seed production levels in the 1990's.

ASSOCIATED ACTIVITIES

Graduate Student Research and Education

The education of graduate students and the research they conduct as part of their degree programs continues to be an important activity of the Cooperative. During the past year, 11 graduate student programs have been undertaken in association with the Tree Improvement Cooperative. Eight were directed toward Masters degrees and three were involved in Ph.D. programs. Of special note is the completion of Ph.D. degree programs by two students in 1989-1990: Mary Frances Mahalovich and Bailian Li.

The graduate students working in association with the Cooperative, the degree to which each aspires and the subject of their research project are listed. 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, and foreign governments.

A substantial number of applicants to our graduate studies program are from foreign nations. This results from two primary factors, 1) the employment opportunities for domestic graduate students are few, and 2) the strong international recognition of our tree breeding research and development success.

STUDENT, DEGREE	*RESEARCH PROJECT*
Claudio Balocchi, Ph. D.	*Modeling clonal propagation systems of Monterey pine in Chile*
Ann Margaret Hughes, Masters	*Seed quality studies in Fraser fir*
Keith Jayawickrama, Masters	*Nutrient and carbohydrate variation among loblolly pine clones grafted on different rootstock families*
Bailian Li, Ph.D.	*Genetic variation of nitrogen use in loblolly pine. (Completed)*
Yecai Li, Masters	*Genetic variation of Fraser fir*
Mary Frances Mahalovich, Ph.D.	*Modeling the genetic consequences of positive assortative mating. (Completed)*
Luis Osorio, Masters	*Vegetative propagation of Pinus maximinoi and P. tecunumanii*
David Porterfield, Masters	*An evaluation of interspecific hybrids of P. clausa x P. virginiana and P. rigida x P. clausa*
Daniel Uribe, Masters	*Leaf area and productivity of loblolly pine families under intensive and standard culture*
Jerry Windham, Masters	*Variation in the number of archegonia per ovule in loblolly pine*
Youhau Zhang, Masters	*Genetic differences in seasonal development patterns associated with fusiform rust resistance in loblolly pine*

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS OF THE COOPERATIVE

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Bramlett, D. L. and F. E. Bridgwater. 1989. Pollen development classification system for loblolly pine. p. 116-121. In: Proc. 20th Southern For. Tree Impr. Conf., Charleston, SC.

Bridgwater, F. E. 1990. Shoot elongation patterns of loblolly pine families selected for contrasting growth potential. For. Sci. (In press).

Frampton, L. J. and J. B. Jett. 1990. Juvenile wood specific gravity of loblolly pine tissue culture plantlets and seedlings. Can. J. For. Res. 19:1347-1350.

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

Mahalovich, M. F. 1990. Modeling positive assortative mating and elite populations in recurrent selection programs for general combining ability. Ph.D. Dissertation. N.C. State University, Raleigh, NC. 128 p.

Mahalovich, M. F. and F. E. Bridgwater. 1989. Modeling elite populations and positive assortative mating in recurrent selection programs for general combining ability. p. 43-49. In: Proc. 20th South For. Tree Impr. Conf., Charleston, SC.

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McKeand, S. E., B. Li, A. V. Hatcher and R. J. Weir. 1990. Stability parameter estimates for stem volume for loblolly pine families growing in different regions in the southeastern United States. For. Sci. 36:10-17.

McKeand, S. E., J. R. Sprague and J. B. Jett. 1988. Management of loblolly pine clone banks for scion production. South. J. Appl. For. 12:231-234.

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Zobel, B. J. and van Buijtenen, J. P. 1989. Wood variation - Its causes and control. Springer-Verlag, Heidelberg, 363 pp.

On September 22, 1989 Hurricane Hugo slammed into Charleston, S.C. and vicinity. Six tree improvement centers associated with the Cooperative suffered substantial damage. Breeding greeenhouses, seed orchards, and progeny tests were devastated.