NORTH CAROLINA STATE UNIVERSITY
INDUSTRY COOPERATIVE TREE IMPROVEMENT PROGRAM

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

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MAY 1993

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

EXECUTIVE SUMMARY

Progress reports for research:

- Foliar application of urea effectively delivered a sufficient amount of nitrogen but did not stimulate flower production.
- Genetic variation in foliar nutrient content showed provenance by location interactions of significance.
- Stem sinuosity is more evident on southern seed sources.
- DNA samples were collected and preserved and a very large field planting (13,000 seedlings) was established for a project designed to map quantitative trait loci (QTL's) controlling juvenile shoot growth in loblolly pine.

Four new research studies were initiated by the Cooperative:

- Phenological variation in shoot elongation and diameter growth and their relationships to wood formation and density.
- Effects of Uniconazol, a growth retardant, on loblolly pine grafts.
- Timing of application of nitrogenous fertilizers in a second generation seed orchard.
- An evaluation of cold hardiness from a southerly located northern source seed orchard.

Substantial activity occurred in the breeding, testing and selection component of the program.

- Wrap up plans for the diallel breeding and testing of second generation and plantation selections were completed; test establishment will be completed in three years.
- Field evaluation of a multi-trait selection index began and third generation selections were made using the index in five different diallel testing programs.
- A new breeding strategy for 3rd cycle breeding was approved.
- Planning was completed and initiated on the breeding and testing of a Piedmont Elite Population (PEP).

While the seed harvest in 1992 was modest in size, selective harvesting from the best parents resulted in a seed crop with outstanding genetic value. Nearly 50% of the 1992 harvest came from second generation seed orchards.

The Cooperative has eight graduate students working on degrees, three on M.S. degrees and five on their Ph.D. The students come from seven different countries.

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INTRODUCTION

The North Carolina State University - Industry Cooperative Tree Improvement Program has completed 37 years of continuous operation. It has been a productive yet demanding and challenging year for all organizations associated with the Cooperative.

Members have worked hard to complete the 2nd cycle of breeding. Testing work has intensified. The wrap up of the 2nd cycle breeding and progeny test establishment is moving forward aggressively. Progress has been outstanding. Then came the "storm of the century" in mid-March and many organizations were burdened with substantial damage and clean up work in their orchards and genetic tests. Recovery is already evident, however, in the damaged orchards and tests.

During the last year, the Cooperative finalized and approved a 3rd Cycle Breeding Strategy which will guide our genetic resource development well into the next century. The key element of this plan is the management of a hierarchy of breeding populations with major resource allocation to the trees with highest genetic value. Elite populations will be developed to maximize short term gain, a Mainline population will allow continued improvement for many cycles, while Genetic Diversity Archives will provide the mechanism to respond constructively to the uncertainties of a very long term future. The strategy adopted will in the future provide greater gain per cycle at a cost that is half or less than half the current level of expenditure.

During the year, field evaluation of a multi-trait selection index was initiated. The goal of the index is to maximize value return at rotation through selection at age 6 , utilizing appropriate weights on tree height, straightness, and rust resistance. The index has been used to choose 3rd generation selections in the testing programs of five different Cooperative members. The index has performed well.

Research activity continues to be strong and provides a good foundation for future technology development and implementation. Several new studies were initiated and results and progress on others are reported herein or will be reviewed during the annual advisory meeting.

It has been a productive and successful year, despite the difficulties and challenges. The future is promising. While the effort required will be substantial, the enthusiasm to move forward, focused on achieving maximum genetic improvement of loblolly pine, is high.

RESEARCH

AN EVALUATION OF FOLIAR APPLICATION OF UREA TO STIMULATE FLOWERING IN LOBLOLLY PINE

Nitrogen is the only nutrient that has consistently enhanced flowering in conifers. Research with several of the southern pines has resulted in the operational use of nitrogenous fertilizers to promote flowering in seed orchards. An alternative to ground applied fertilizers is the foliar application of nutrients. The efficacy of the foliar application of nutrients in correcting nutrient deficiencies and in improving both yield and quality has been demonstrated in numerous tree species.

In keeping with current environmental awareness, this application technique offers the possibility of greater efficiency by reducing the amount of nitrogen applied per acre, since the nitrogen is applied directly to the trees. The direct application of the nitrogen means the nitrogen is neither subject to heavy uptake by the grasses nor rapid leaching from the soil profile.

Beginning in 1989, the foliar application of urea to stimulate flowering in loblolly pine has been evaluated in Bowater's second generation Piedmont orchard at Oak Park, Georgia. In 1989 the study included the eight treatments listed in Table 1. The same treatments

TABLE 1 Eight treatments included in the urea flowering study at Bowater's (SDW) orchard

Treatment	Treatment Description	Treatment	Treatment Description
A	Single foliar application of urea applied the week of July 17	E	Two applications of foliar urea — the weeks of July 31 and August 14
B	Single foliar application of urea applied the week of July 31	F	Three applications of foliar urea — the weeks of July 17, July 31, and August 14
C	Single foliar application of urea applied the week of August 14	G	Ammonium nitrate — 300 lbs./acre applied the week of July 31
D	Two applications of foliar urea—the weeks of July 17 and July 31	H	No supplemental nitrogen fertilization

TABLE 2 Mean[1] number of flowers per tree in the urea flowering study

Treatment	1990	1991	1992
G	46a	31a	76a
H	39ab	24ab	47b
C	39ab	18bc	16c
E	32bc	8c	13c
A	18c	17bc	20c
D	18c	15bc	22c
B	17c	14bc	20c
F	15c	11c	11c

TABLE 3 Mean[1] level of foliar nitogen per tree in the urea flowering study.

Treatment	1989	1990	1991
E	1.32a	1.42bc	1.18bc
F	1.27ab	1.55a	1.29a
G	1.26ab	1.52ab	1.32a
B	1.22ab	1.33cd	1.13cd
D	1.19ab	1.36bcd	1.16bcd
A	1.19ab	1.32bcd	1.16bcd
C	1.18ab	1.37ab	1.25ab
H	1.16ab	1.25d	1.07d

[1] *Means followed by the same letter are not significantly different at $P<0.05$.*

were applied in 1990 and 1991 but the application dates were delayed two weeks, beginning the first week in August and ending the first week in September while maintaining the same pattern as noted for 1989. The urea spray solution was prepared by mixing 10 pounds of urea per 100 gallons of water with 12.8 ounces of a spreader sticker (Ag98) and 9.5 ounces of Ag44 buffering agent to adjust the pH of the solution to approximately 5.5. The spray solution was applied to each treatment tree to the point of runoff from the foliage. The ammonium nitrate treatment consisted of an operational rate of 300 lbs./acre equivalent. The ammonium nitrate was applied on an individual tree basis within a circular area with the radius corresponding to the individual tree's total height. The area within this circle was calculated and the appropriate amount of ammonium nitrate applied.

The mean number of flowers per tree was greatest for the operational ammonium nitrate treatment (Table 2). The foliar urea applications produced fewer flowers per tree than the control. In fact, the multiple application urea treatments ranked lowest in flower production of all the treatments. A reasonable explanation for these results is that the urea, even at the low rates employed in the study, was actually detrimental to the plants. A slight amount of foliage burn following spraying indicated the phytotoxic impact of the urea. While the foliage injury appeared to be minor, the plants appear to react negatively in flowering response to the urea applications.

Analyses at the end of the 1989, 1990, and 1991 treatment seasons indicated that levels of foliar nitrogen varied significantly by treatment (Table 3). The foliar applications, particularly the triple application treatment (F), were basically as effective as the ammonium nitrate treatment (G) in increasing the level of foliar nitrogen.

The results of this study indicate that the use of foliar applied nitrogen in the form of urea, while effective in increasing levels of foliar nitrogen comparable to the standard application of ammonium nitrate, failed to stimulate flowering. Because of the failure to promote flowering, the foliar application of urea does not appear to offer a means of reducing the use of heavy rates of ammonium nitrate and the subsequent potential of nitrate leaching to the ground water or off site movement.

GENETIC VARIATION IN FOLIAR NUTRIENT CONTENT AMONG PROVENANCES OF LOBLOLLY PINE

In the 36th annual report, plans were outlined for the project being conducted by graduate student, Jorge Vasquez, working jointly with the N.C. State University Forest Nutrition Cooperative and the Tree Improvement Cooperative. The study was designed to investigate the variation in foliar nutrient concentration among families and provenances of loblolly pine.

The productivity of hundreds of thousands of acres of forest plantations has been improved substantially through nutrition amendments. While fertilization has been used extensively in the southeast, the benefit received from this silvicultural investment remains a function of diagnostic ability. How should tracts and stands be chosen for fertilization to provide a predictable economic response? Many factors may influence the effective diagnosis of nutrition needs, including the genetics of the trees being planted. To date, virtually all fertilizer prescriptions have been based upon average genotypic responses. If provenances and families respond differently to fertilization, an understanding of the genotypic variation is required to diagnose the optimum levels of nutrients required by specific or small groups of genotypes. This understanding is especially important for the optimal management of family block plantations that are established with one or a few open-pollinated families. Family block planting systems are currently being used by more than 70% of the Cooperative membership.

Study objectives are:

(1) Determine the genetic variation in foliar macro- and micronutrient concentrations and nutrient ratios in 10-year-old loblolly pines.

(2) Determine the relative contribution of provenance and family within provenance effects on nutrition as well as the genotype by nutrient interaction among sites.

(3) Assess the impact of genetic variation on the critical levels of foliar nutrient concentrations used as diagnostic variables for fertilizer prescriptions in forest plantations.

Material sampled for the study was from four of the 1982 and 1983 Florida Loblolly Pine Provenance/Progeny Trials established by members of the Florida and N.C. State Tree Improvement Cooperatives. The location and height mean for each trial are displayed in Table 4. A total of 52 open-pollinated families were evaluated, an average of 13 from each of the following sources: Marion County, Fl; Levi County, Fl; Southern Atlantic Coastal Plain; and Lower Gulf Coastal Plain.

Foliar nutrient levels were averaged over all provenances and replications at each location to determine if site means were above, below or equivalent to critical nutrient levels (not limiting) as deter-

TABLE 4 Location and height means of test plantings sampled.

COOPERATOR	AGE	COUNTY	STATE	HEIGHT (FEET)
Container Corp.	10	Butler	Alabama	53.7
Rayonier	10	Nassau	Florida	34.1
Scott Paper	9	Greene	Mississippi	39.6
Union Camp	10	Tattnall	Georgia	33.0

mined from results of the N.C. State Forest Nutrition Cooperative's Regionwide 13 trial series. The nitrogen level at the CCA site was well above the critical level; all other sites were equivalent to the critical level. The CCA site was low in magnesium while the other three sites were higher. Phosphorous was not limiting or near the critical level at any of the four sites. Potassium levels were lower than the critical level at all sites except the extremely fast growing CCA site where it was at a luxury consumption level. Calcium levels were low for the CCA and SCO sites and high at the RAY and UCC sites.

Provenance analyses were done for 9 nutrients as well as for height, diameter, needle fascicle dry weight, and specific leaf area. Results for height, nitrogen, and potassium at the provenance level are reported here.

Location effects for height, nitrogen concentration, and potassium concentration were highly significant and substantially correlated (Figures 1-3). At the provenance level important differences were found for height, with the Levi County, Marion County and South Atlantic sources performing the best and the Lower Gulf source being significantly slower growing.

Provenance by location interactions were significant for height, nitrogen concentration, and potassium concentration. However the nature of the interactions were quite different depending on the trait of interest. The provenance by location interaction effects shown for height growth were to a large extent simply a scale effect as the provenances ranked nearly the same at all four locations. Clearly the Lower Gulf source was always the slowest growing provenance.

The potassium concentration by location interaction effects were substantially attributable to scale effects as well. The rankings for potassium percent (K %) did not change substantially across locations. However, the slow growing lower gulf source consistently displayed the highest potassium concentration. Although the differences in K % among provenances are small the association between K % and growth seems to be in sharp contrast to the association of potassium and growth at the location level. Fast growing locations have high K %, while the slowest growing provenance has the highest K %. This is a curious relationship that requires further exploration. Factoring in the influence of a possible dilution effect, faster growing tissues may have lower concentrations because the absolute amount of nutrient is distributed throughout a greater tissue mass, thus explaining some of the apparent contradiction.

Provenance by location interaction effects for nitrogen concentration is highly significant with substantial rank changes occurring across locations. A relationship of nitrogen percent to height growth is not apparent at the provenance level.

The remaining analyses including a discussion of differences at the family level will be available at the completion of Jorge's thesis. This study is revealing some complex genetic/nutrient relationships that need to be elucidated to assist in future nutrient need diagnosis.

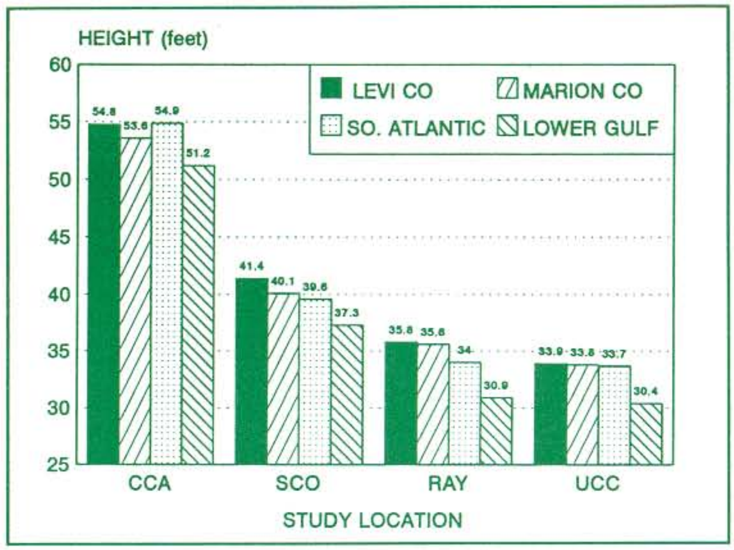


Figure 1. Mean heights by provenance for the four study locations.

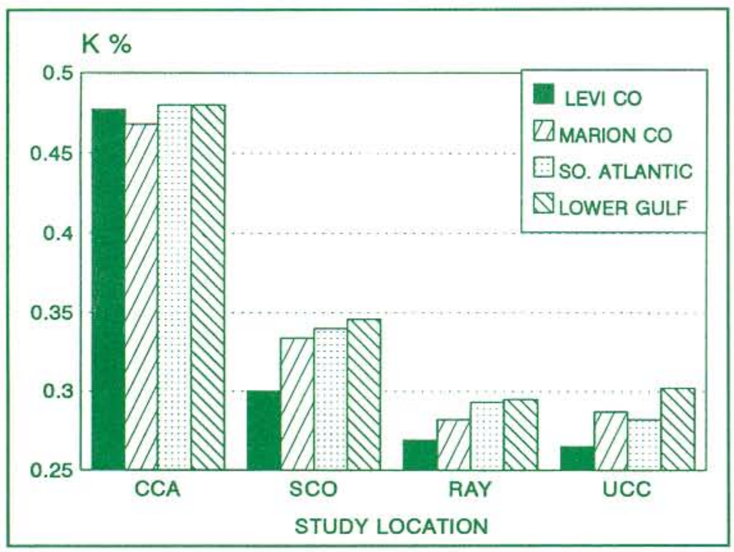


Figure 2. Foliar potassium concentration by provenance and location.

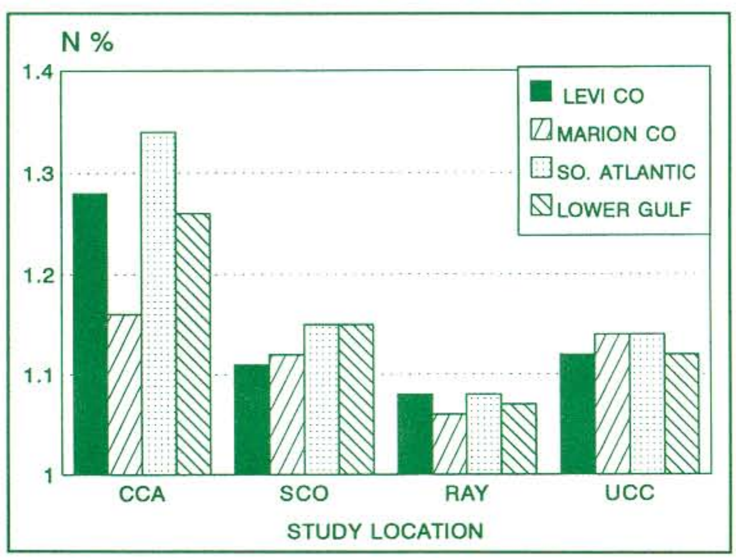


Figure 3. Foliar nitrogen concentration by provenance and test location.

GROWTH AND STEM SINUOSITY OF DIVERSE PROVENANCES OF THREE-YEAR-OLD LOBLOLLY PINE

The Cooperative's Early Selection Verification Study was established in southwest Georgia with 13 to 16 open-pollinated families from each of five provenances to evaluate the use of stem elongation traits for early selection among families within each provenance. In 1992 and 1993 the study was thinned and will be used for the Wood Phenology Study. In 1992 at age 3 years, stem height and sinuosity of the stem and of the branches were measured for 13-16 families from 4 of the provenances (South Atlantic Coastal Plain; Gulf Hammock, FL; Lower Gulf Coastal Plain; Middle\Upper Gulf Coastal Plain). Sinuosity was scored for each tree using a three point rating system. A score of 1 indicated straight stem and branches while a score of 3 was assigned to sinuous stems and branches. Stem and branch sinuosity differed significantly by provenance with the fastest growing provenances having the most sinuous stems (Figure 4). The genetic correlation between branch and stem sinuosity was essentially perfect (r_g=.93 or greater) for all four provenances. As can be seen in Table 5, both bole and branch sinuosity at the provenance level are under moderate genetic control. The average heritability for bole sinuosity was .28 while that of branch sinuosity was .33.

The unfavorable correlation between growth and sinuosity at the provenance level was not evident within provenances where genetic correlations were weak or even favorable. Apparently, the mechanisms causing the faster-growing provenances to be more sinuous were not the same at the family level within provenances. We hypothesize that the large differences in the length of the growing season for trees from the different provenances are partly responsible for the differences in sinuosity. Trees from southern regions grew longer than trees from the northern regions and possibly were not lignified to the same extent, increasing the likelihood of sinuosity.

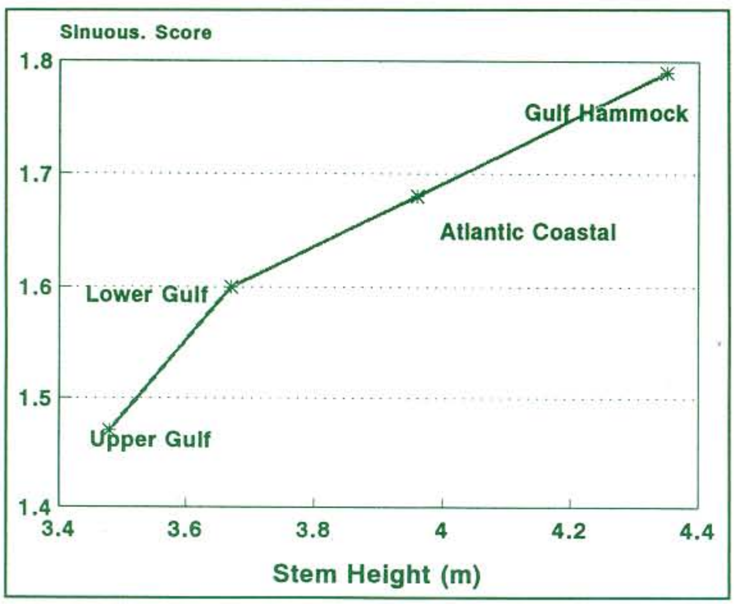


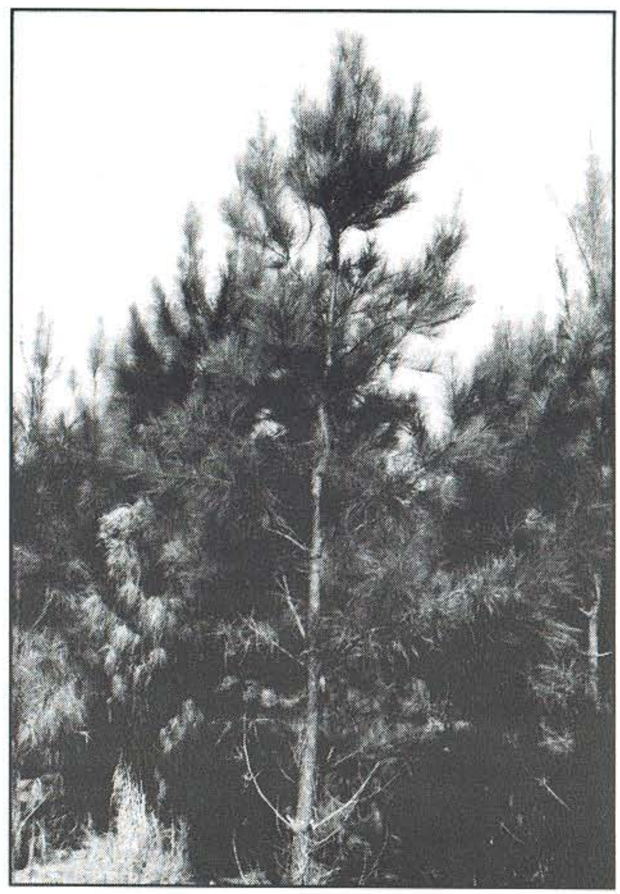
Figure 4. Relationship between stem height and bole sinuousness-provenance means at age three.

TABLE 5 **Mean branch and bole sinuosity score[1] and heritabilities for four provenances[2] of loblolly pine.**

	Provenances			
TRAIT	**ACP**	**GH**	**LG**	**UG**
Bole Sinuosity				
Mean Score	1.68ab	1.79a	1.60b	1.47c
h_2	.24	.20	.33	.35
Branch Sinuosity				
Mean Score	1.83ab	2.01a	1.67b	1.56b
h_2	.21	.32	.27	.54

[1] *Sinuosity score ranged from 1 (straight) to 3 (sinuous). Mean scores followed by the same letter are not significantly different (P ≤.05).*

[2] *ACP=South Atlantic Coastal Plain; GH=Gulf Hammock, FL; LG=Lower Gulf Coastal Plain; UG=Middle/Upper Gulf Coastal Plain*



An example of extreme stem sinuosity which occurs more frequently in fast growing southern seed sources.

MAPPING QUANTITATIVE TRAIT LOCI (QTLS) CONTROLLING JUVENILE SHOOT GROWTH OF LOBLOLLY PINE

The Forest Biotechnology and Tree Improvement Programs at NCSU have received a grant from the USDA Plant Genome Program to determine if major quantitative trait loci (QTLs) exist for economically important traits in loblolly pine. Most quantitative genetics theory is based upon quantitative traits being controlled by numerous genes or alleles at many different loci. Such models of polygenic inheritance imply that each gene has a relatively minor effect, and thus the influence of any one gene would be very difficult to detect. Recent results from crop breeding experiments suggest that the traditional concept of polygenic inheritance for quantitative traits may not always be appropriate. If the phenotypic expression of important traits is influenced by relatively few genes (e.g. oligogenic inheritance), these genes can potentially be identified and mapped using molecular marker techniques recently made available to breeders.

Little is known about the genetic architecture of quantitative traits in genetically heterogeneous organisms such as forest trees. NCSU forest geneticists have developed a new, half-sib approach to QTL analysis in pine which could have broad applicability in tree breeding programs. The half-sib approach will allow us to identify major QTLs and establish their location on a genetic map of loblolly pine. Multi-generation pedigrees and extensive breeding are unnecessary because half-sib families are easily available for many individuals with little breeding. Tree breeding could be accelerated if economically important traits were under oligogenic control and quantitative trait loci (QTLs) could be tracked in cycles of recombination and selection using molecular markers.

This study investigates whether shoot elongation in first- and second-year seedlings is an oligogenic trait in loblolly pine. Shoot elongation has displayed high heritabilities in greenhouse and field experiments and can be used for early selection because of its relatively high juvenile-mature correlation. It is an excellent trait to use experimentally because of the ease of measurement at a young age and the strong genetic control. In November, 1992, 1000 seedlings from each of 13 open-pollinated or pollen-mix families were planted at Federal Paper Board's nursery site at Lumberton, NC. These seedlings will be assessed over the next two years to determine the distribution of shoot elongation phenotypes within each family.

To develop the linkage map, Random Amplified Polymorphic DNA (RAPD) molecular markers assayed from megagametophyte tissue will be used to map 200-300 loci and to determine the exact marker contribution of the seed parent's gamete to each seedling. Bulk segregant analysis of megagametophytes from the extreme phenotypes will be used to identify RAPD polymorphisms likely to be linked with quantitative trait loci (QTLs). RAPD markers identified by bulking will be correlated with cyclic growth to confirm their association with the trait. QTL analysis will be carried out using molecular markers by means of MAPMAKER/QTL to identify regions of the genome which explain significant amounts of variation in early cyclic growth.

As the Cooperative moves into more advanced generations of breeding with loblolly pine, the need to understand the underlying genetic control of quantitative traits becomes more important. How

One of 13,000 seedlings field planted on lands of Federal Paper Board, near Lumberton, NC, as part of the Mapping Quantitative Loci Research Project. A Competitive Grant provides financial support for this important project.

complex are these traits? Are there numerous genes (polygenic inheritance) controlling them, or are there relatively few genes with large effects (oligogenic inheritance) controlling them? The number of genes has tremendous implications for how easily these traits can be manipulated. If few genes are involved, breeding would progress more rapidly than if numerous genes are involved. If QTLs are successfully identified for juvenile shoot elongation, Marker Assisted Selection (MAS) would be incorporated into the experimental breeding population discussed in the 3rd Generation Breeding Plan. The potential benefit to the operational breeding program of the Cooperative can be best evaluated in an experimental population that will be rapidly cycled.

RESEARCH INITIATIVES

During the past year, the following research studies were initiated by the Cooperative:

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

Recent results from the N.C. State Tree Improvement Cooperative and the Western Gulf Cooperative indicate that the fast-growing southern and coastal sources of loblolly pine have low wood specific gravity when compared to northern and inland sources in plantations. This may be partially explained by the relationship between the onset of latewood (the denser portion of the annual ring laid down after the earlywood) and the duration of height growth during the summer. There is evidence that latewood is not formed until shoot elongation ceases. This would imply that short trees have denser wood, but the duration of latewood production (i.e. diameter growth after height growth stops) and tracheid characteristics (e.g. lumen diameter and cell wall thickness) are also key components of wood density. While there appears to be a negative association between growth and specific gravity among provenances, this has not been demonstrated within provenances where little or no correlation between growth and specific gravity traits exists. There may be different associations between shoot elongation, diameter growth, and wood density between geographic sources as compared to within geographic sources.

The Cooperative has obtained support from Georgia Pacific to intensively sample 5-year-old trees from 8 families from each of four different provenances in the Early Selection Verification Trial in southeastern Georgia to determine how wood properties are affected by the timing of the initiation and cessation of height and diameter growth of the trees. The results will indicate if provenances and families can be selected that exhibit both rapid growth and favorable characteristics for wood products.

Effects of Uniconazol on Loblolly Pine Grafts

Growing grafts in large pots held either in a large greenhouse or out-of-doors has been effective in promoting early flower production in loblolly pine. Both techniques have been used to effectively shorten the time to flower production and concomitantly shorten the breeding cycle. The use of greenhouses has been particularly effective in promoting precocious flowering. Despite the success of the containerized grafts, two problems continue to plague the system: 1) Because of rapid growth and the large pots, the greenhouses required for breeding work need to be large with high ceilings, and 2) the large grafts are difficult to move and are very prone to tipping over, particularly out-of-doors. It would be a tremendous advantage if methods were available to constrain the growth of grafts without compromising either precocity or seed quality.

Many growth retardants have been tried over the years to control conifer growth. Recent work has indicated the effectiveness of Uniconazol in reducing height growth of loblolly pine by 55% in three year old seedlings after one growing season with no phytotoxic effects. The objectives of this study are to evaluate the effects of Uniconazol on: 1) reducing height growth of containerized loblolly pine grafts in a greenhouse environment and 2) on the flower production and seed quality in grafts of loblolly pine.

The study is being conducted in the Bowater, Inc., Carolina Woodlands Division breeding greenhouse at Rock Hill, SC. Grafts of ten second generation clones were made during the spring of 1993. The successful grafts will be transplanted to standard 30 gallon containers filled with the operational soilless potting mix in May, 1993. Three treatments will be applied in November, 1993: 1) Uniconazol applied at a rate of 2 grams per graft as a soil drench using two gallons of water; 2) Uniconazol applied at 4 grams per tree in a 2 gallon soil drench/tree; and 3) control.

Height and ground line stem diameter will be measured at the beginning of the study. Subsequent height and stem diameter measurements will be done at the end of each growing season for four growing seasons. Flowering will be determined each spring following the initiation of the study through 1998. When all clones have begun to flower, a polymix will be applied (around 1998) and seed collected (1999) to evaluate the impact of Uniconazol on seed size and quality and seed per cone.

Timing the Application of Nitrogenous Fertilizers in a Second Generation Seed Orchard

The most widely accepted cultural practice to enhance cone production in southern pine seed orchards is fertilization. Nitrogen is probably the most important mineral element used to promote flowering. Based on previous work it has become a "standard" practice to apply nitrogenous fertilizers in southern pine seed orchards during the late-July to early-August period. This basic timing concept for nitrogenous fertilizers has been applied across the entire southeastern United States from the Gulf Coast to Maryland.

Observations by the orchard manager over the past three years at the Bowater Southern Division Woodlands seed orchard at Oak Park, GA seem to indicate that the "standard" timing of ammonium nitrate fertilization may not be optimal for this particular location. Flowering responses appear to be greater following fertilizer applications made earlier in the growing season. For example, the 1990 cone crop in the Piedmont seed orchard was preceded by a split application of ammonium nitrate during the spring of 1988 and again that summer at an average rate of 166 lbs/acre. The 1990 cone crop averaged approximately 64 cones per tree. In 1989, 1990 and 1991 all nitrogen has been applied in late summer. Subsequent cone crops have been approximately two-thirds the 1990 crop. Additionally, the Dwarfing Rootstock Study and the Plantation Selection clone bank material have been receiving fertilization earlier in the season and experiencing heavy per tree cone crops.

Variation in flowering responses to nitrogenous fertilizers depending on the location of the seed orchard have not been evaluated. The purpose of this study is to address the question of optimal timing of nitrogenous fertilization for a specific location. The second generation Piedmont seed orchard at Oak Park, Georgia will be utilized in the study. Ammonium nitrate will be applied at the operational rate of 400 lbs/acre. Four timing treatments will be included:

Mid-spring .... week of April 27, 1992

Mid-June .... week of June 8, 1992

Late-July .... week of July 27, 1992

Mid-September .... week of September 10, 1992

Treatments were initiated in the spring of 1992 and will be repeated annually for four to five years at approximately the same time periods and intervals.

An Evaluation of Seed Orchard Loblolly Pine Cold Hardiness on the Cumberland Plateau

Screening loblolly pine for cold hardiness has traditionally focused on southern seed sources planted in areas with more severe winters north of the natural range in Tennessee, western Kentucky, and southern Illinois. Recently, seed orchards of northern sources have been planted in southern locations to take advantage of milder climates and more prolific seed production. There is a concern that pollen contamination from cold-intolerant native southern stands could result in reduced cold hardiness of seedlings grown from seed produced in these seed orchards. Pollen contamination in southern pine seed orchards has been estimated from 30 to over 88 percent.

The Bowater, Inc. Woodlands Cold Hardy loblolly pine seed orchard is located at Oak Park, GA and at age 5 has already produced seed crops of 26 lbs/acre. An evaluation of orchard phenology indicates that there is some overlap between female flower receptivity in the orchard and pollen release by wild trees in the vicinity. The operational significance of contamination in this orchard cannot, however, be determined from simple phenology studies. A lowering of cold tolerance potential for seed produced by certain early or late flowering clones is a possibility. Another possibility is that growth of this material may actually be enhanced by out-crossing to the faster growing southern source.

The objective of this project is to evaluate the practical impact of pollen contamination on the cold hardiness (for purposes of this study cold hardiness will include both survival and growth performance) of seedlings grown from seed produced in the Oak Park Cold Hardy Seed Orchard.

Four pollen types will be evaluated in the study:

— Open-pollinated seed year 1 — 1991.

— Open-pollinated seed year 2 — 1992.

— Control pollinations for each of three phenology categories (early flowering, average flowering, late flowering) using a pollen mix of 12 pollens collected from clones in the Mountain seed orchard at Carters, Georgia.

— Control pollination for each of the three phenology categories using a pollen mix of 15 pollens from a Georgia Coastal Plain orchard.

The study will be established in two locations in each of two years. The field plantings will be located as far north on the Cumberland Plateau as is operationally reasonable.

BREEDING, TESTING, AND SELECTION

STATUS OF DIALLEL BREEDING AND TESTING

Plans were developed in the summer of 1992 for the wrap-up of the current cycle of breeding and testing. As in the first generation, clones exist in the plantation and second generation populations which, for biological reasons, have not flowered or produced seed in sufficient quantities for inclusion in standard diallel tests. Each breeding program was carefully analyzed to ascertain its current breeding and testing status. Specific recommendations, coordinated within a breeding region, were made for completion of each individual breeding program. Recommendations included:

1) Plant five-tree diallels
2) Continue crossing for one more year
3) Plant unbred and/or untested clones in open-pollinated tests. Establish block plots with any available control-pollinated seed.

Regional workshops were held in the fall of 1992 to discuss the recommendations for completion of the current breeding and testing cycle with members in each area.

In summary, the breeding has been essentially completed for both the plantation and second generation populations. The small amount of breeding recommended for the spring of 1993 was primarily aimed at supplementing a few weak cells in what were otherwise completed diallels.

All eight breeding regions will complete test establishment in 1996 (Figure 5, page 12). On completion of the 1993 test establishment (June 30, 1993), all breeding regions will have established over 50% of the breeding population in field tests. The workload for the 1994 test establishment year will be extremely heavy with 16.8% of the population being established in field tests in one year.

Figures 6-10 (page 12) show, by breeding area, the percentage of the population for which third generation selections will be available through the year 2003. Based on current plans, 50% of third generation selections will be available for breeding work and orchard establishment in 1999 or 2000.

Progeny test establishment and maintenance is a major activity of all Cooperative members for the remainder of the decade. Billy Arnold proudly shows off Mead diallel tests on the Moore Tract, located in Clay County, Georgia.

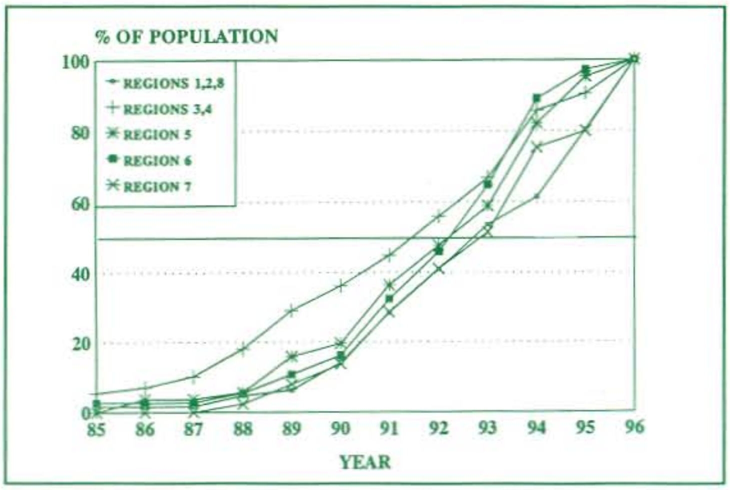


Figure 5. *Percent of population with test establishment completed by region.*

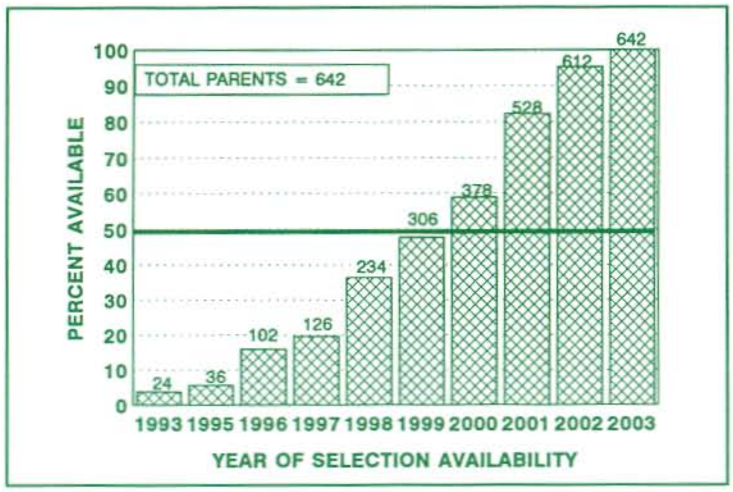


Figure 8. *Percent of population with third generation selections available for region 5.*

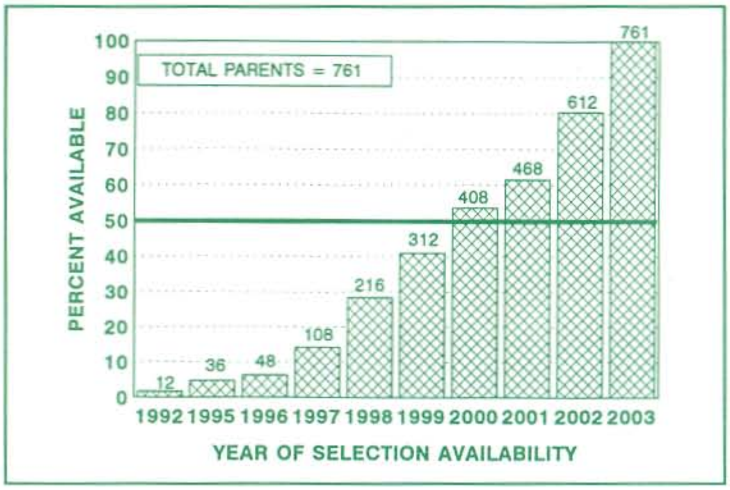


Figure 6. *Percent of population with third generation selections available for regions 1, 2, and 8 combined.*

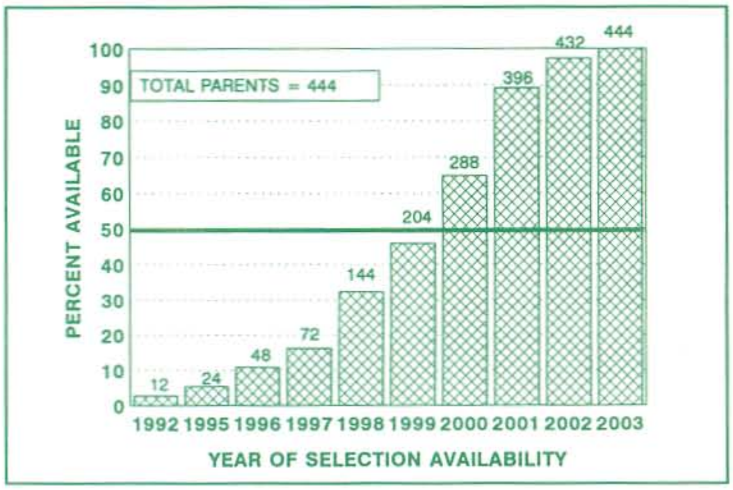


Figure 9. *Percent of population with third generation selections available for region 6.*

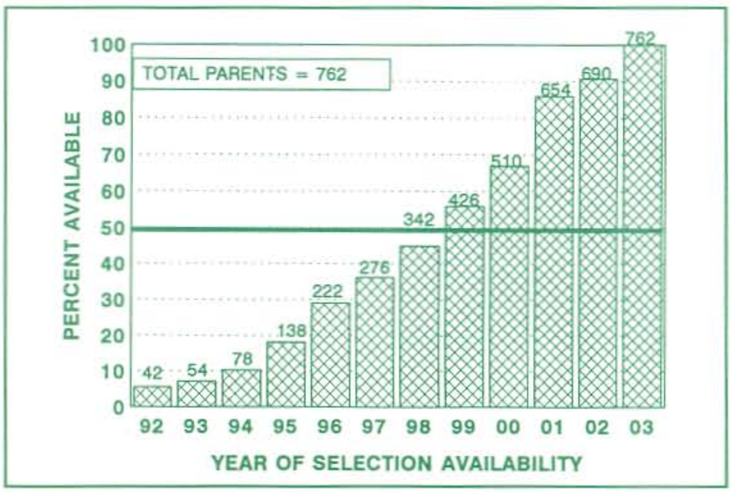


Figure 7. *Percent of population with third generation selections available for regions 3 and 4 combined.*

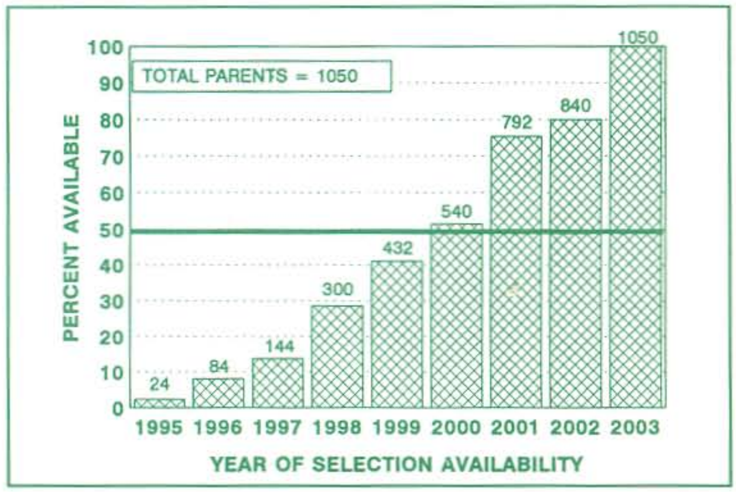


Figure 10. *Percent of population with third generation selections available for region 7.*

A multi-trait selection index is being evaluated for use in identifying outstanding third generation selections. Booth Chilcutt observes a possible future candidate for selection in one of S.C. Commission of Forestry's 4-year-old tests.

SELECTION INDEX

A selection index is a mathematical method for incorporating several selection criteria into a single value in such a way that expected genetic gains are maximized. For example, in the Cooperative's selection program, total tree height, straightness score, and where appropriate, fusiform rust infection, all measured at age 6, will be used to select trees for the next cycle of breeding. The characters used as criteria for selection do not necessarily need to be the same as those in the selection goal. Again using the Cooperative program as an example, increased volume, straightness and rust resistance are the selection goals. The characters in the criterion need not be the same as the characters in the goal since indirect selection can be more effective than direct selection. For example, indirect selection for height generally yields greater expected genetic gains than direct selection for volume since the genetic correlation between height and volume is very high (always in excess of 0.9) and the heritability for height is usually greater than that for volume.

The form of the index criteria and goal which is being tested for use in the cooperative selection program is:

[CRITERIA] = b_1(Ind. Ht age 6) + b_2(Fam. Ht age 6) + b_3(Ind. Strt. Score age 6) + b_4 (Fam. Strt. Score age 6) + b_5(Fam. Rust % age 6) =

[GOAL] = a_1(Ind. Vol at Rotation) + a_2(Ind. Strt. at Rotation) + a_3(Fam. Rust % at age 6)

The b_i values are the weights applied to each trait to arrive at an index score which will be used to rank each tree in each test. These weights are the result of mathematical calculations that maximize expected genetic gains from selection. Determining the appropriate weights for both individual-tree values and family means for each trait increases the accuracy of selection since the family information provides useful genetic information about the individual candidate trees. Unfortunately, there are very few genetic tests with periodic measurements through rotation. Data from the NCSU-International Paper Co. Heritability Study in Bainbridge, GA were used to calculate the genetic variances and covariances needed to calculate the index weights.

The a_i values are economic weights that specify the value of a unit change in each trait in value. These were calculated by conducting various mill studies to determine, for example, what a unit change in straightness score is worth in terms of product value at harvest. Value is assigned only to the individual-tree values for volume and straightness in the criterion vector since selection is done on an individual-tree basis. The goal of selection for rust resistance is to reduce the family rust infection percentage at age 6, rather than rotation. Of course, it is desirable to reduce fusiform rust infection at all ages, but reducing fusiform rust at an early stand age reduces losses both from mortality and from lower product values at harvest.

The selection index illustrated above is the form that will be implemented in stands which have sufficiently high rust infection percentages at age 6 to give a reliable basis for selecting for rust resistance. Rust percentages of at least 20% are required before rust resistance will be given weight in the criterion matrix. Reducing rust infection is a goal of the selection program, however, it is not productive to include it as a criterion when rust infection is very low.

The first tests in which the selection index was applied had very low rust infection percentages. The family percentage of rust infection is still in the goal matrix, and gains can still be expected in that trait even though it was not included in the criterion matrix (i.e. b_5=0). This is possible since there are genetic correlations among the traits included in the index and selection for one results in changes in the others. The family percentage of rust infection at age 6 was simply excluded from the criterion matrix since it was at such low levels.

This spring, two selection indexes have been tested, one which had weights (b_i) estimated to maximize gains in stumpage value of stands managed to produce primarily pulpwood; and a second which had weights estimated to maximize gains in stumpage value of stands managed to produce primarily solid wood products. The first places relatively more weight on growth rate than on stem form (straightness score) than the second. This is reasonable, since straight trees produce more, higher quality lumber than crooked trees; and, while crooked trees do produce less, lower-quality pulp, the impact is not so great as when the product goal is sawtimber.

Fortunately, the trees selected in the few diallel tests evaluated this spring appear to make perfect sense. The highest value sawlog and pulpwood trees have come from the fastest growing families and are straight. Essentially, the same trees for both indexes have been selected-a good pulpwood tree is a good sawlog tree given our selection criteria and goals. The impact of fusiform rust on selections made using the index has yet to be evaluated. A much better evaluation of the indexes will be available when a broader range of diallel tests reach age 6 years.

THIRD GENERATION BREEDING PLAN

As the North Carolina State University-Industry Cooperative Tree Improvement Program progresses towards the third cycle of breeding, every effort has been made to develop an efficient, cost effective breeding strategy to ensure both short- and long-term benefits for Cooperative members. A primary criterion for the breeding strategy was that it be flexible for current and future breeders. Decisions made in the third-cycle program will influence all future loblolly pine breeding within the Cooperative's working area, and options available to future breeders must not be constrained by the methods employed in the next cycle. In addition, the strategy had to be flexible enough to accommodate the diverse objectives of the membership. While members share in supporting the mission and objectives of the Cooperative, there is a diversity in product goals, aggressiveness of programs, and investment level that has to be considered. Additionally, as new information becomes available, the plan had to be flexible enough to incorporate the information.

The strategy developed for the Cooperative's third-cycle breeding program for loblolly pine provides maximum genetic gain in the short-term and maintains genetic diversity so that long-term genetic gains will also be possible. The strategy will be to manage a hierarchy of three populations, each at a different level of intensity. The **mainline population** will consist of 160 selections that are available to each cooperator (i.e., recruitment population) in a given geographic region. This population will be managed as subdivided breeding populations (40 sublines of 4 trees each) primarily to provide for long-term genetic gain. The most intensively selected and managed hierarchy will be the **elite populations**. A highly selected group of trees (approximately 40 selections) will be managed to provide maximum short-term genetic gain for each member's program. A third hierarchy will be **genetic diversity archives** managed to preserve genotypes with extreme breeding values for individual traits (not necessarily for all traits combined) as an insurance population for environmental or selection criteria changes in future generations. Each generation, decisions will be made as to the value of including these archive selections into the mainline population as well as to the value of breeding this population.

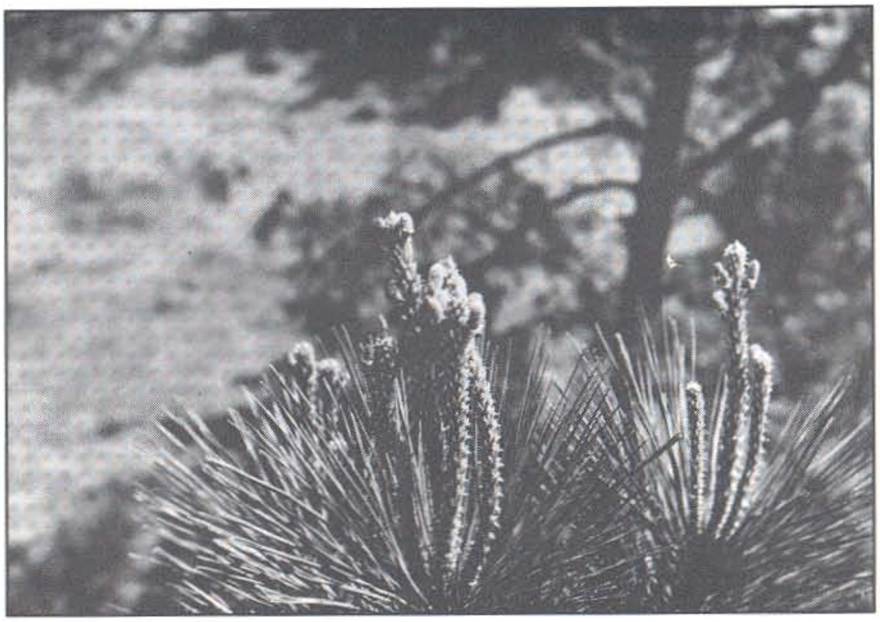
The improved efficiency of this proposed breeding strategy along with the reduction in population sizes compared to the current program, will result in a substantial reduction in effort by individual cooperators. The increase in selection intensity used to reduce the population sizes and the increased rate of breeding made possible with fewer trees will substantially increase gains in the future generations. While the most intensive effort will be devoted to those populations providing immediate genetic and financial gain, the long-term well-being of the genetic resource will be maintained by judicious management of all three hierarchies.

PIEDMONT ELITE POPULATION BREEDING

In June, 1991, a planning process was initiated to establish an elite breeding population for the Piedmont region of NC, SC, and GA. Cooperators participating in development of the Elite Population believe that the potential for increased genetic gain will be worth the extra cost of investing in the breeding, testing, and selection of another population hierarchy.

Most elite breeding populations in the Cooperative will be formed from local mainline populations. For the Piedmont region, it would be premature to select an elite population from the mainline at this time. Third-generation selections will be made starting in 1995 and continuing through 2003. An elite population using the best third-generation clones could not be initiated much before 1999 when approximately 40% of the third-generation selections will be available. There is, however, an opportunity to utilize non-local coastal loblolly pine for the Piedmont regions of the Southeast. Results from numerous provenance trials indicate that Coastal Plain families will generally grow faster than Piedmont families, but are more susceptible to cold and ice breakage and have poorer form. Recent analyses of six of the Cooperative's Good General Combiner tests in the Piedmont of NC, SC, and GA show similar trends. Coastal Plain families, especially those from NC and SC, have displayed outstanding growth in the Piedmont.

Having recognized an opportunity to capitalize on the genetic benefits from utilizing selections from both the Piedmont and Coastal Plain regions, the Cooperative made hybrids between loblolly pine



Breeding for the Piedmont Elite Population began in the spring of 1993. However, some cold damage to flowers may have been sustained during the "Storm of the Century."

clones from many different geographic areas in the 1970's. Twenty-seven second-generation selections from crosses between superior Piedmont and Coastal Plain clones have been identified. Since hybrids are typically intermediate between the two parents, the 27 hybrid selections should display some of the faster growth of the Coastal Plain trees, but have better form and less susceptibility to cold and ice.

Additionally, there is an opportunity to quantify the amount of gain possible from utilizing Piedmont x Coastal Plain hybrids as opposed to local or exotic sources alone. Piedmont families may perform better than hybrids in regions that are challenged by cold (i.e. the northern and inland extremes). In the lower Piedmont, near the fall-line, Coastal Plain selections may be the superior source. Delineating where different populations should be deployed is a high priority for breeders in the Piedmont region.

Two populations will be established for the Piedmont Elite Population breeding program. **Population I** is the 27 hybrid clones already available. **Population II** will result from crosses to be made between 2.5 generation selections starting in the spring of 1993. The strategies that will be utilized to breed, test, and select in Populations I and II are described below:

Piedmont Elite Population I

Most of the 27 clones in Population I were grafted in the spring of 1992 by Bowater Carolina Division Woodlands (greenhouse), Bowater Southern Division Woodlands, Federal Paper Board, and Champion International. The grafts are being intensively managed to enhance flower production so breeding can commence as soon as possible.

The breeding strategy recommended for the Cooperative's Elite Populations will be utilized for Population I. The use of inbreeding is emphasized to rapidly increase homozygosity and the frequency of favorable alleles as well as to increase additive genetic variance. Clones will be outcrossed and small sublines will be developed to ensure long-term gains. Briefly, the clones in Population I will be crossed in 4-parent diallels to produce elite outcrossed progeny. Each clone will be selfed to produce S_1 offspring. The parental clones will be ranked based on breeding values estimated in polymix tests.

For the second and future breeding cycles in the elite population, numerous options are available. Selfing can continue, producing S_2 offspring for the selected S_1's. Progeny from the outcrossed trees (i.e. the six crosses among the 4 parents) can be selfed to create new S_1's. For milder levels of inbreeding, crosses between full-sibs ($\theta = .25$) or crosses among half-sibs ($\theta = .125$) can be made. There are numerous options for crosses among all clones within the elite population (e.g. among S_1's or among any selections within or among sublines would be possible).

If future breeders desire to maintain a sublining system within the elite population, related trees from within each diallel can be maintained within lines. The full-sib and half-sib crosses could be one way of maintaining the genetic integrity of a subline. In fact, the full-sib crosses described above can be considered as 2-tree sublines from within the 4-tree diallels. The selfs are nothing more than one-tree sublines if S_2's are made. Flexibility of future options is a key advantage of this elite population management scheme.

Piedmont Elite Population II

The objectives of Population II are to 1) generate Piedmont and Coastal Plain hybrids to compare to both Piedmont and Coastal families in the Piedmont region, and 2) generate new selections to be used in the elite population breeding program. If only Population I was used, the assumption would be that the hybrids are the best source for the Piedmont. While this is viewed as an acceptable risk for breeders to take (i.e. great gains with some risk), the need to explicitly test the hybrids in the Piedmont and quantify the gains and the risks has been identified as a high priority.

The best genetic quality trees available for breeding at this time are 2.5 generation selections from the Piedmont and Coastal Plain. Second-generation open-pollinated tests (ages 3 to 6) of Bowater (CDW), Bowater (SDW), Champion, Federal, Georgia-Pacific, and Evergreen in the NC, SC, & GA Piedmont and Coastal Plain regions were measured last fall to determine the top clones in each region. The top 20-30 Piedmont and top 20-30 Coastal clones were each crossed with a Piedmont pollen mix (PMX) and a Coastal pollen mix (PMX) generating the following four family types: Piedmont x Piedmont PMX, Piedmont x Coastal PMX, Coastal x Piedmont PMX, and Coastal x Coastal PMX. To compare different family types, tests will be established throughout the Piedmont in three different "regions": 1) lower or fall-line, 2) central, and 3) inland or northern. The different types of families must be challenged with different selection pressures to determine how far they can be pushed. The trials will be measured periodically to evaluate gain and risk potentials.

The second objective of Population II is to generate full-sib hybrids that can be used in future elite population breeding cycles. A complementary design, essentially the same as that being used in the Cooperative's mainline breeding program, will be used. Data from the polymix tests will be used to determine which parent clones are superior, thus determining from which crosses selections will be made. Control crosses between Piedmont and Coastal clones will be produced in 4x4 factorials to provide a base for recurrent selection. Breeding commenced for the factorials in 1993. Each cooperator participating in development of the elite population will be responsible for breeding one factorial. When a cross is completed, it will be planted in a 36-tree plot so that the best individual can be selected.

SEED ORCHARD PRODUCTION

CONE AND SEED YIELDS

The 1992 loblolly pine seed collection was the third lowest in the past 10 years (Table 6). Members collected 44,547 bushels of cones for a yield of 31.5 tons of seed. Average seed yield per bushel was 1.42 lbs./bushel, essentially the same yield as 1991. Cooperative members continue to be very selective in their harvesting practices. Most are collecting clonally, restricting harvesting to the very best parents, particularly in older first generation orchards. In many instances, first generation orchards have been placed on low maintenance status and only serve as a potential backup seed source in emergency situations. This trend is evidenced by the complete absence of any collection in 27 orchards in 1992. As production in second generation orchards continues to increase, it is anticipated that more of the older orchards will be relegated to low maintenance status or abandoned completely.

The collection of second generation seed in 1992 was a record high 14.4 tons — a 20% increase over the 1991 harvest. Second generation seed collected in 1992 comprised 47% of the total crop (Figure 11). Seed yields for second generation material were still lower than the yield from

TABLE 6 Ten Year Seed Yields from Loblolly Pine Orchards

HARVEST YEAR	BUSHELS OF CONES	TONS OF SEED	LBS./BUSH
1983	68,447	49.0	1.43
1984	105,239	80.1	1.52
1985	52,155	37.8	1.45
1986	84,953	70.1	1.65
1987	112,822	93.3	1.65
1988	56,822	42.7	1.50
1989	23,247	16.1	1.38
1990	50,944	30.4	1.19
1991	55,555	38.8	1.40
1992	44,547	31.5	1.42
Totals/Avg.	**654,731**	**489.7**	**1.50**

first generation orchards. Lower yields in second generation orchards is not unexpected. As pollen availability increases with orchard maturity, yields are expected to increase. Management philosophies in young second generation orchards also contribute to lower yields. Given small cone crops in young orchards, many orchard managers believe that insect control is not justified. As the size of cone crops increases with orchard maturity, management will certainly intensify. Evidence of this is reflected in the yields from some older second generation orchards: Federal's coastal orchard yielded 1.67 lbs./bushel; Union Camp's Georgia orchard, 1.50; Westvaco's coastal orchards, 1.67; Champion, SC piedmont orchard, 1.94; and Bowater (CWD), 1.75.

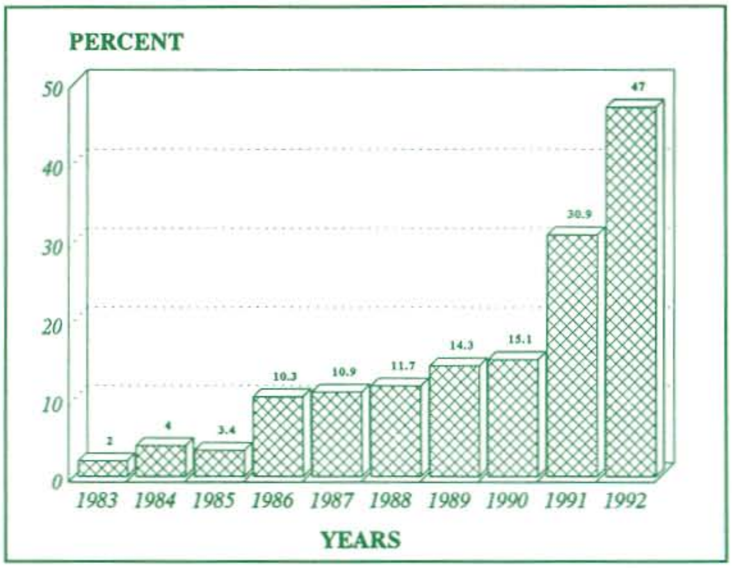


Figure 11. Second generation seed production as percent of total production for past ten years.

PRODUCTION LEADERS

Though the 1992 lbs/bushel yields (1.42) was essentially the same as 1991 (1.40), in contrast to 1991, there were a few orchards that broke the 2.0 lbs./bushel mark. Champion was well represented in the "Leaders of the Pack" as 6 of the top 10 production orchards belonged to Champion (Table 7). Four of the six were above 2.0 lbs./bushel. The Champion (SC) 1.5 piedmont orchard led the list with 2.18 lbs./bushel; this orchard was also the top producing orchard in 1991. Following close behind was Champion's Disease Resistant orchard at 2.16 lbs./bushel, the Champion 1.5 Alabama orchard (in SC) at 2.06 lbs./bushel, and the Champion (FL) 1.5 Eastern loblolly orchard at 2.05 lbs./bushel. Rounding out the leaders were: Westvaco (SC) 1.0 Coastal orchard (1.99); Bowater's (CWD) 1.5 piedmont orchard (1.98); Champion (SC) 2.0 piedmont orchard (1.94); Union Camp's rust resistant orchard (1.81); International Paper's (SC) 1.5 coastal orchard (1.79); Champion (FL) 1.5 Western loblolly orchard (1.77); and Bowater's (CWD) 2.0 piedmont orchard (1.75).

Congratulations to all these orchard managers for their outstanding accomplishments. Special mention goes to George Oxner of Champion, SC. His orchards ranked 1, 2, 3 and 7 in yield per bushel this past year. As a matter of fact, George has been a member of the production leader lists for the past several years. Others to be congratulated are: Homer Gresham, Champion, FL; Dave Gerwig, Westvaco, SC; Jake Clark, Bowater (CWD); Marietta McConnell of International Paper, SC and Marvin Zoerb, Union Camp.

TABLE 7 1992 Seed orchard production leaders.

ORGANIZATION	TYPE	ACRES	AGE	LBS./BUSH.	MANAGER
Champion, SC	1.5 piedmont	20	26	2.18	George Oxner
Champion, SC	Rust Resistant	10	23	2.16	George Oxner
Champion, SC	1.5 Alabama	10	17	2.06	George Oxner
Champion, FL	1.5 E. loblolly	40	15	2.05	Homer Gresham
Westvaco, SC	1.0 Coastal	38	25	1.99	Dave Gerwig
Bowater (CWD)	1.5 piedmont	30	18	1.98	Jake Clark
Champion, SC	2.0 piedmont	15	16	1.94	George Oxner
Union Camp, GA	Rust Resistant	66	20	1.81	Marvin Zoerb
Int'l Paper Co., SC	1.5 coastal	25	17	1.79	M. McConnell
Champion, FL	1.5 W. loblolly	48	15	1.77	Homer Gresham
Bowater (CWD)	2.0 piedmont	38	15	1.75	Jake Clark

A number of orchard managers reported excellent seed yields for specific clones. Clone 12-1066 in James River's second generation seed orchard produced 2.5 lbs./bushel. Mike Williford reported that three clones in the Bowater (SDW) orchard produced well above the orchard average: 1-5 (1.93); 15-26 (1.83); and 1-31 (1.78). Yields on a clonal basis vary greatly. James Hodges of Champion shared an interesting analyses of their SC orchards which were collected clonally (Table 8). In four orchards, 29 clones were collected and yields ranged from a low of .68 lbs./bushel to a high of 3.27 lbs./bushel. Every orchard had one or more clones exceeding 2.0 lbs./bushel. Clone 8-120 in the 1.5 Alabama orchard (SC) produced 3.27 lbs./bushel. Bill Guinness reported that clone 8-120 in the Bowater's orchard produced 3.03 lbs./bushel.

When asked to comment on the outstanding production from the Champion orchards, David Todd responded that numerous factors contributed to their success. If he were to summarize the success , it would be attributed to "attention to details" in all areas from orchard management to seed extraction. Edgar Barr extracts all of Champion's cones at the extractory in Lee, Florida. He monitors the lots very closely and constantly communicates with orchard personnel about problems in extraction. If seed insects are a problem, the orchard manager takes the necessary corrective action, be it an orchard-wide problem or a more clonal problem. If a particular clone is case hardening (in spite of passing the floating test), the orchard managers will adjust the collection date for that clone. With constant communication between Edgar Barrs and the orchard managers, problems are addressed and the result is very efficient seed production. Champion is to be congratulated on their system of management.

TABLE 8 Seed yields on a clonal basis for the 1992 collection from Champion, SC orchards

ORCHARD	# CLONES	AVERAGE lbs./bush	LOW CLONE lbs./bush	HIGH CLONE lbs./bush
1.5 Alabama	9	2.06	0.68	3.27
1.5 piedmont	7	2.18	1.60	2.51
2.0 piedmont	9	1.94	1.67	2.45
Rust resistant	4	2.17	1.96	2.29

ASSOCIATED ACTIVITIES

GRADUATE STUDENT RESEARCH AND EDUCATION

The education of graduate students and the research they conduct as part of their degree programs continues as a high priority activity of the Cooperative. During the past year, 8 graduate students have been working in association with the Tree Improvement Cooperative. The efforts of three were directed toward Masters degrees, and five were involved in Ph. D. programs of study.

Student research projects encompass a range of topics related to tree improvement. Financial support for students comes from a variety of sources: the Tree Improvement Cooperative, the College of Forest Resources - Department of Forestry, the North Carolina State University Agricultural Research Service, the U.S. Forest Service, industry, various fellowship programs, competitive grants, and foreign governments.

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

STUDENT, DEGREE	*RESEARCH PROJECT*
Peter Althoff, M.S.	*Genetic variation in leaf area /productivity stand level measures (Joint project with Forest Nutrition Cooperative)*
Roger Arnold, Ph.D.	*Quantitative genetics of Fraser fir, with emphasis on a multi-trait selection index*
Kevin Harding, Ph.D.	*Age trends of genetic parameters for wood properties for loblolly pine*
Keith Jaywickrama, Ph.D.	*Phenological variation in shoot elongation and diameter growth and their relationships to latewood formation and wood specific gravity in loblolly pine*
Jan Svensson, Ph.D.	*Ecophysiological bases for genetic differences in growth of loblolly pine stands (Joint project with Forest Nutrition Cooperative)*
Jerry Windham, M.S.	*Variation in the number of archegonia per ovule in loblolly pine*
Jorge Vasquez, M.S.	*Nutritional variation among provenances and families of loblolly pine*
Francisco Zamudio, Ph.D.	*Marker assisted breeding in forest trees*

COOPERATIVE TREE IMPROVEMENT PROGRAM ORGANIZATIONAL CHART – MAY, 1993

DR. ROBERT J. WEIR
DIRECTOR

DR. J. B. JETT
ASSOCIATE DIRECTOR

- CHRIS HUNT
  AGRI. RES. TECH. II
- PAULA OTTO
  AGRI.RES.TECH. I

Activities:
- Seed Orchard research and operations
- Lab. and field research and management

DR. STEVEN E. MCKEAND
GENETICIST

- MR. JERRY SPRAGUE
  TREE IMP. SPECIALIST
  (1/2 TIME)

Activities:
- Breeding and testing research and development

MS. ALICE V. HATCHER
MANAGER, INFO. SYSTEMS

- MR. JERRY SPRAGUE
  D.P. SPECIALIST
  (1/2 TIME)
- MS. JEAN PITTMAN
  SECRETARY IV

Activities:
- Data Processing
- Office Management
- Budget Management

MEMBERSHIP OF THE TREE IMPROVEMENT COOPERATIVE

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

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS OF THE COOPERATIVE

Anderson, A.B., L.J. Frampton, S.E. McKeand and J.F. Hodges. 1991. Tissue culture shoot and root system effects on field performance of loblolly pine. Can. J. For. Res. 22:56-61.

Arnold, R., J.B. Jett, and H.L. Allen. 1992. DRIS diagnosis for identifying nutritional influences on cone production in Fraser fir. Soil Sci. Soc. Amer. Jour. 56:586-591.

Balocchi, C. E., F. E. Bridgwater, R. Bryant. 1992. Selection efficiency for a non-selected population of loblolly pine: The North Carolina State University-International Paper Company Heritability Study. For. Sci. (in review).

Balocchi, C. E., F. E. Bridgwater, B. J. Zobel, and S.Jahromi. 1993. Age trends in genetic parameters for tree height in a non-selected population of loblolly pine. For. Sci. vol. 39(2).

Bridgwater, F. E. 1992. Mating Designs. p. 69-95. In: Quantitative Genetics Handbook. L. Fins, S.T. Friedman, and J.V. Brotschol (eds). Kluwer Academic Publishers. London. 403 p.

Bridgwater, F.E., T.D. Blush, and D.L. Bramlett. 1992. Supplemental mass pollination. In: Pollen Management Handbook. USDA Agricultural Handbook. (in press).

Grattapaglia, D., J. Chaparro, P. Wilcox, S. McCord, D. Werner, H. Amerson, S. McKeand, F. Bridgwater, R. Whetten, D. O'Malley, and R. Sederoff. 1992. Mapping in woody plants with RAPD markers: application to breeding in forestry and horticulture. In Proc. Symp. Applications of RAPD Technology to Plant Breeding. Joint Plant Breeding Symp. Series, Crop Sci. Soc. of Am., Am. Soc. for Hort. Sci., and Am. Gen. Assoc., Minneapolis, MN. p. 37-40.

Hodge, G.R. and R.J. Weir. 1993. Freezing stress tolerance of hardy and tender families of loblolly pine. Can. Jour. For. Res. (in press).

Jayawickrama, K.J.S. 1991. Rootstock effects on scion growth, sexual reproduction, nutrient and carbohydrate status and water potential in loblolly pine (Pinus taeda L.). M.S. Thesis. N.C. State Univ., Raleigh, NC. 83p.

Jayawickrama, K.J.S., J.B. Jett and S.E. McKeand. 1991. Rootstock effects in grafted conifers: a review. New Forests 5:157-173.

Jayawickrama, K.J.S., S.E. McKeand, J.B. Jett and E. Young. 1992. Rootstock and scion effects on carbohydrates and mineral nutrients in loblolly pine. Can. J. For. Res. 22:1966-1973.

Jett, J.B., D.L. Bramlett, J.E. Webber, and U. Eriksson. 1992. Pollen collection, storage, and testing. In: Pollen Management Handbook. USDA Agricultural Handbook. (in press).

Jett, J.B. and S.E. McKeand. 1991. The genetic improvement of Fraser fir Christmas trees in North Carolina - an update. Limbs & Needles 18:26.

Jett, J.B., S.E. McKeand, Y. Liu and W.T. Huxster. 1993. Seed source variation for height and crown traits of Fraser fir Christmas trees. South. J. Appl. For. 17:5-9.

Jett, J.B., S.E. McKeand and R.J. Weir. 1991. Stability of juvenile wood specific gravity of loblolly pine in diverse geographic areas. Can. J. For. Res. 21:1080-1085.

Li, B., H.L. Allen and S.E. McKeand. 1991. Nitrogen and family effects on biomass allocation of loblolly pine seedlings. For. Sci. 37:271-283.

Li, B., S.E. McKeand and H.L. Allen. 1991. Genetic variation in nitrogen use efficiency of loblolly pine seedlings. For. Sci. 37:613-626.

Li, B., S.E. McKeand and H.L. Allen. 1991. Seedling shoot growth of loblolly pine families under two nitrogen levels as related to 12-year height. Can. J. For. Res. 21:842-847.

Liu, Y. 1991. Geographic variation of Fraser fir. M.S. Thesis. N.C. State Univ., Raleigh, NC. 53p.

McKeand, S.E. and F.E. Bridgwater. 1992. Third-generation breeding strategy for the North Carolina State University - Industry Cooperative Tree Improvement Program. In: Proc. IUFRO Conf. S2.02-08, Breeding Tropical Trees. Solving tropical forest resource concerns through tree improvement, gene conservation and domestication of new species. Oct. 8-18, 1992. Cartagena and Cali, Colombia.

McKeand, S.E. and F.E. Bridgwater. 1992. Breeding strategy for the third generation in the North Carolina State University Tree Improvement Program. Proc. CIEF Meeting, Jornadas sobre Pinos subtropicales Tomo 1:1-7. Eldorado (Misiones), Argentina. July 5-7, 1992.

Struve, D.K. and S.E. McKeand. 1993. A possible method for accelerating red oak genetic tests. Annales Des Sciences Forestri*res: in press.

Wisniewski, L.A., D.L. Brandan, S.E. McKeand and A.V. Amerson. 1991. The effect of root pruning on the maturation of loblolly pine (Pinus taeda) plantlets, rooted hypocotyls, and seedlings. Can. J. For. Res. 21:1073-1079.

Zobel, B.J. 1992. Silvicultural effects on wood properties. IPEF 2:31-38.

Zobel, B.J. 1992. Vegetative propagation in production forestry . J. For. 90:29-33.

Zobel, B.J. 1993. Clonal forestry in the eucalypts. Chap. 21 in Ahuja, M.R. and W.J. Libby (eds.). Clonal Forestry, pp 140-148.

Zobel, B.J. and C.B. Davey. 1991. The 1989 Wallenberg Prize winner: Torsten Ingestad. Tappi 74(2):60-64.

Zobel, B.J. and J.R. Sprague. 1993. A Forestry Revolution: the history of tree improvement in the Southern United States. Carolina Academic Press.

Zobel, B.J. 1992. El Manejo de los Bosques Dinamicos (Managing the dynamic forest). 1992. Venezuela Forestel 4(12):2-14.

Zobel, B.J. and W.L. Ladrach. 1992. The tropics as an emerging forestry business. IUFRO Conference, Cali, Colombia, 10pp.

The "Storm Of The Century" caused substantial damage to many tree improvement programs in the Region.

The mid-March snow, ice, wind, and cold caused major problems in many seed orchards.

MacMillan Bloedel's 1.5 generation seed orchard suffered extensive limb breakage.

MacMillan's 5-year-old progeny tests were bent but did not break; 1-year-old tests were unscathed.