North Carolina State University - Industry Cooperative Tree Improvement Program

44TH ANNUAL REPORT

Department of Forestry
College of Forest Resources
NC State University

May 2000

Front Cover

After 30 years of dedicated service to the Cooperative, Bob Weir (Director), Alice Hatcher (Manager, Information Systems), and Jerry Sprague (Tree Improvement Specialist) have retired. Their leadership, diverse experience, and unique mix of skills have contributed in many ways to the accomplishments of the program. Those of us who have worked with Bob, Alice, and Jerry feel many different emotions. First, we are happy for them as they enter the next phase of their "careers". We are envious that they have reached a point in their lives that they will have time to enjoy all the benefits of retirement at such young ages. We will miss their years of experience in the Cooperative especially as the rest of us begin the next cycle of breeding, testing, and selection.

EXECUTIVE SUMMARY

BREEDING, TESTING, AND SELECTION

The Third Cycle Loblolly Breeding Plan has been finalized and the breeding was started this spring.

During the past year, the Cooperative staff and cooperators selected in another 130 diallel progeny tests, bringing the total number of tests screened to 642 which is about 50% of the total tests planted.

During the spring seasons of 1999 and 2000, Cooperators have been busy collecting pollen to form the pollen mixes (PMXs) for the three breeding zones.

In the spring of 2000, there was enough PMX pollen to start breeding in the Coastal and Piedmont zones. About 800 bags were pollinated with the main emphasis on creating checklot seed for use in the testing program.

PROGRESS REPORTS FOR RESEARCH

An analysis of an additional 19 EDMS test series from the Coastal and Piedmont regions confirms results from last year's analysis of the northern (Virginia) EDMS trails: selections for age-8 volume is more efficient using height or volume at earlier ages in terms of gain per unit time. Differences were noted in time trend of h^2 and genetic correlations between Coastal and Piedmont regions.

Results from the Scotland County trails (SETRES-2 Study) suggests that in fertile soil, internal (genetic) factors of the tree roots can substantially influence allocation of mass to above ground parts.

Analysis of the PSSSS shows the Atlantic Coastal sources from SC, GA and FL as the best growers and the northern sources from VA and northern NC as the worst.

SEED PRODUCTION

The 1999 Cooperative seed collection provided 35.9 tons of loblolly pine seed, the largest collections since 1996 and the third largest in the past 10 years.

About 56% of the seed were from second generation orchards; the Coastal source represented 65% of the collection.

ASSOCIATED ACTIVITIES

The Cooperative currently has 7 graduate students working on projects of interest to the Cooperative.

After 30+ years of service, Bob Weir, Director, Alice Hatcher, and Jerry Sprague retired as of May and June, 2000.

Effective June 1, Dr. Tim Mullin will assume responsibilities as Director of the Cooperative Tree Improvement Program.

MEMBERSHIP OF THE TREE IMPROVEMENT COOPERATIVE

Alabama Forestry Commission

Bowater, Inc.

Champion International Corp.

Fort James Corp.

Georgia Forestry Commission

Gulf States Paper Corp.

International Paper Company

Mead Coated Board

N.C. Division of Forest Resources

Molpus Timberland Management, LLC

Rayonier, Inc.

S.C. Commission of Forestry

Smurfit-Stone Container Corp.

Temple Inland Forest, Inc.

Tennessee Department of Agriculture - Forestry Division

The Timber Company

U. S. Alliance Coosa Pines Corp.

Virginia Department of Forestry

Westvâco Corp.

Weyerhaeuser Company

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REFLECTIONS

Robert J. Weir

I came to North Carolina State University in 1968 as a green yet enthusiastic forestry graduate from the University of Maine. I found in North Carolina and across the southeast a group of practical scientists and forestry practitioners that were enthusiastic and energetic about the business of establishing and managing pine plantations. Tree Improvement or the application of the theories and principles of forest genetics was a newly developing component of this plantation forestry, and it was soon to be accepted as an essential element contributing substantially to plantation productivity. It seems rather amazing that during my 30 years of working in southern tree improvement, it has progressed from a new developing technology with promise to a traditional practice that may soon be eclipsed by the wonders of biotechnology applied to forest trees. It is a challenge for someone that grew up as the son of a conservative county forester in the rural northern part of Vermont to understand and accept the speed at which change is occurring in the reforestation practices of the southern region of the United States.

I am also reminded at this time that the real genius of Bruce Zobel, my teacher and mentor, was developing the methods and nurturing the system for translating science and abstract research results into practice. As a result of what Bruce started and the continuing program that I helped to sustain, today we have over 24 million acres of genetically improved pine plantations growing on lands of current and past members of the N.C. State University - Industry Cooperative Tree Improvement Program. The marginal net present value of the genetic improvement estimated from the value of the "extra wood" growing in plantations may currently exceed 50 billion dollars. Now the "new genetics" has the potential to contribute even greater value, IF.........IF......IF.......... in the rush to develop the science and technology someone or some organization will recognize the need and focus on the means to translate the potential into practice. Should this not be done well or in a timely fashion then the great potential regresses to the useless cliché of an "academic exercise". I worry that we are failing to translate the science into effective practice.

I am allowed to reflect on the past 44 years of accomplishment since I have been associated with Cooperative either as student, staff or director for 33 of the 44 years. Upon reflection, I am led to conclude that capable, dedicated team-oriented people were key to the Cooperative's success. Of course, this is not a particularly new idea, but here once again it is shown to be an essential key to success. Strong and innovative leadership could not have produced results without the "workers in the field".

We had strong leadership in the 1950's from the woodlands managers and chief foresters that elected to start a tree improvement cooperative to produce quality planting stock with improved genetic potential at a time when debate raged about the economic value of site preparation and tree planting. Why plant trees when mother nature will give you 10,000 seedlings per acre? Yet once the decision to do tree improvement was made, it was the field manager that made it work !!!! People like Ray Brown (Champion), Roy Hutto (I.P. Company), Frank Vande Linde (Brunswick Pulp), George Oxner (also with Champion), Marvin Zoerb (Union Camp), Walt Chapman (Kimberly Clark), Bill Guinness (Bowater) and there are so many more; I apologize for the many omissions. These people were subsequently replaced by the more current field managers that are so critical to current success: Maxie Maynor and Richard Bryant (International Paper), Gary Gaines (MacMillan Bloedel now Weyerhaeuser), Bobby Cattrett (Fort James), Jake Clark (Bowater), Dave Gerwig (Westvaco), Chris Mead and Ken Colburn (Alabama Forestry Commission), John Hendrickson (Scott Paper, then Kimberly Clark and now Temple), James Hodges (Champion), Wayne Bowman (Virginia Dept. of Forestry), Jerry Boyd and George Brantley (also of Champion) and again there are so many more capable people that I have failed to mention - my regrets but thanks to each of you. A General without field troops wins no battles.

Truly the back bone of the Cooperative's success are these key people. You have been friends and you have taught us and your colleagues a great deal as we worked together to develop this very successful program. We have done a pretty decent job and some of you will continue to contribute to this enterprise for years to come. I know for me, Alice and Jerry, we think it is time to move on to the next phase because we recently realized that every single person working in the Tree Improvement Cooperative when we started has left through retirement or promotion.

Finally I wish to convey the following notions as The Cooperative completes year 44. Changes are evident everywhere! Mergers, buyouts and the sale of timberlands by industrial members have diminished program participation and financial support. These activities have triggered salvage efforts to rescue data and genetic material from genetic tests of members that have departed. At the same time several members are intensifying investments in genetic based research and development in hopes of bringing into practice technologies such as mass production of full-siblings, clonal forestry, production of "seedlings" from somatic embryogenic cultures, and eventually genetic transformation or production of genetically engineered trees. The exploitation of genetic gain though open market seed, and seedlings sales and the marketing of reforestation services by member organizations is changing the "business climate" of the Cooperative to one of competition among members, sometimes at the expense of cooperation and collaboration. Collectively these changes are very significant, and the Cooperative and indeed all cooperative programs in the region are being forced to consider options for future organization and focus. A key question is what elements of research and development can be effectively conducted in a consortium sponsored cooperative and what elements may be best conducted in a proprietary environment that seeks to protect discoveries and intellectual property? As answers to these tough questions are being worked out, the Cooperative Program leadership and staffing are in a state of transition following the recent retirement of key, long-term employees.

While all of this is a unfolding, members of The Tree Improvement Cooperative are realizing unprecedented benefits from past investments in the Cooperative's research and development activities. In the past two decades, members have produced enough genetically improved seed to plant over 24 million acres of genetically improved loblolly pine. In the last four to five years well over half of the acres reforested by Cooperative members were planted with second-generation seed orchard material that is estimated to provide from 14% to 23% more volume at harvest than first-generation seed orchard material. Third-cycle seed orchard acres are being established at a rapid pace. Since the collective annual reforestation program of all Cooperative members is approximately 40% of the tree seedlings planted in the nation, the impact of these activities is enormous.

Additionally, members are wrapping up the work associated with the second-cycle breeding, testing and selection program of the Cooperative. This work comprises an enormous investment made over the past 20 years that has an estimated cost to the membership of 35 million dollars. The Cooperative members have bred 3,834 select trees in 639 disconnected 6-parent half-diallels. Over 1,300,000 progeny test seedlings have been grown from some 9,500 controlled-pollinations and these seedlings have been planted in 1,278 progeny tests. To date, data have been collected and breeding value estimates have been made for just over one-half of the parents planted in approximately 600 of the genetic tests. This investment forms the basis for development of the above mentioned 3rd-cycle seed orchards and 3rd-cycle breeding and testing work, or provides the opportunity for the next round (4th-cycle) of genetic gains in productivity. It is anticipated that the work will be completed for the current cycle of improvement by year 2004.

To summarize: We have significant change, possibly even tumultuous times, or at the very least turmoil around us. We have great benefit being realized and the potential for even greater benefit ahead. If members are to continue the success of this endeavor in the years ahead, it would be useful to reflect on several of the keys that have made The Tree Improvement Cooperative at North Carolina State University successful. The keys described below are in part paraphrased and derived from comments first made in 1981 by Dr. Bruce Zobel, the pioneering first Director of The N.C. State Cooperative. Most of these ideas still have considerable merit nearly 20 years later.

To be successful tree improvement requires a large expenditure of effort and money over a long period of time. Because of this it is usually not economical to undertake tree improvement on a small scale. It is an activity that can best be accomplished in a cooperative format. In that way small and large organizations can afford to work very intensively and aggressively with large tree populations. Each member contributes a small part to the large effort of the program.

- All members must make a full commitment. Nothing will ruin a cooperative quicker than having a member or members who fail to fully support their share. Members must contribute financial support and technical support as well as action in field operations. A minimum contribution of time and effort is expected and required from each member.

- Information and ideas must be fully exchanged among members and a proprietary attitude must not prevail. In forest biology research and development that is often far removed from the market place, it is not the available information or genetic material that will give an organization economic advantage, but ***it is the use of available knowledge*** that enables one organization to forge ahead of another. Cooperatives will continue to be useful as long as this is true.

- For efficient operation of a tree improvement cooperative, the membership must identify common objectives that have value to all members. Additionally there may be specific objectives that have merit for individual or small groups of members, but they cannot be the core of the cooperative's purpose.

- There must be pride and value in what the cooperative achieves, both for the overall membership and for each member. Without such value, a cooperative will not be effective nor will it continue to be supported.

- Each member should have equal authority and responsibility and receive equal benefit. Cooperatives in which the larger organizations pay more and thus also have more influence in program direction frequently encounter organizational struggles that diminish effectiveness. This will be a critical consideration as future deliberations related to the N.C. State Tree Improvement Cooperative's financial support are undertaken.

- Strong leadership is needed to pull together the members and to keep them all working together toward a common objective. This need cannot be overemphasized! There should be responsibility of the Director to an advisory committee composed of the member representatives, but the Director is the one who has the authority over the operation of the cooperative and directs actions to achieve its objectives. Management by committee is rarely successful.

- The University that administers the cooperative must provide strong support. The University must receive tangible benefit from the endeavor in terms of enhancement of research and education programs. In turn, the University has the opportunity to provide an administrative set up that provides substantial productivity and resource leverage to the membership.

- Both short and long term objectives are essential. No matter what the attitude at the beginning of a phase, there always will come a time within a cycle of improvement when the question will be asked, "What are we getting for our effort and investment?" Continuous feed back of results from shorter-term projects and efforts are essential to fill the perceived voids in benefits that occur between cycles of improvement.

- Good communication is essential. This is achieved by using the "language" of the program managers. Highly stilted, academic, or complex scientific reporting of results and progress will be self-defeating. The program should not seek to teach the program managers a new language but to put the results of tree improvement progress in the language that the managers best understand. Usually this entails impacts on forest productivity and economic value.

Finally, one needs to only view the work in tree improvement around the world to appreciate that programs that have functioned with multiple organizations working cooperatively have been more successful and have contributed to greater forest productivity achievements at a more rapid pace than those that have struggled "on their own". Tree improvement is a long-term and costly endeavor. The Cooperative approach makes sense!! The N.C. State University - Industry Cooperative Tree Improvement Program has enjoyed 44 years of accomplishment and effective enhancement of forest productivity in the region. It has been my personal good fortune to have been provided the opportunity to work for The Cooperative for 30 years and to direct the program for the past 23 years. Any success that has been realized during this period has resulted from the capable contribution of dedicated and talented staff members that found great satisfaction in working with the action oriented membership. For their efforts and friendship I will be forever grateful.

The foundation is set for even greater success in years ahead. It will require care and effective management by the new director, technical staff, member organizations and university administration working in partnership for this success to be sustained and the potential to be realized. Jerry, Alice and I wish all of you great success and prosperity in the years ahead. Thank you for making the most recent 30 years of our professional lives a pretty good experience (most of the time). We improved trees and are satisfied that the results of our work have been and will continue to be useful.

BREEDING TESTING & SELECTION

THIRD-CYCLE LOBLOLLY PINE BREEDING PROGRAM

While the general framework for the third cycle breeding strategy was outlined by breeding and testing task force (Task Force Report 1992 and McKeand and Bridgwater 1998), much of the genetic parameter information needed to develop the details for the plan was unavailable at the time. Only recently has the information become available from the region-wide diallel progeny tests (Li et al. 1996, 1997, 1999). Genetic parameter estimates from these tests were used in computer simulations to evaluate optimal population sizes and alternative population management procedures. Information from the field tests can now be used to determine optimal test designs and optimal age for assessment, as well as the optimal age for selection. Additionally, recent advances in mass controlled pollination, top-grafting and rooted cutting techniques have necessitated that we make some modifications of the original framework in order to utilize full-sib technology.

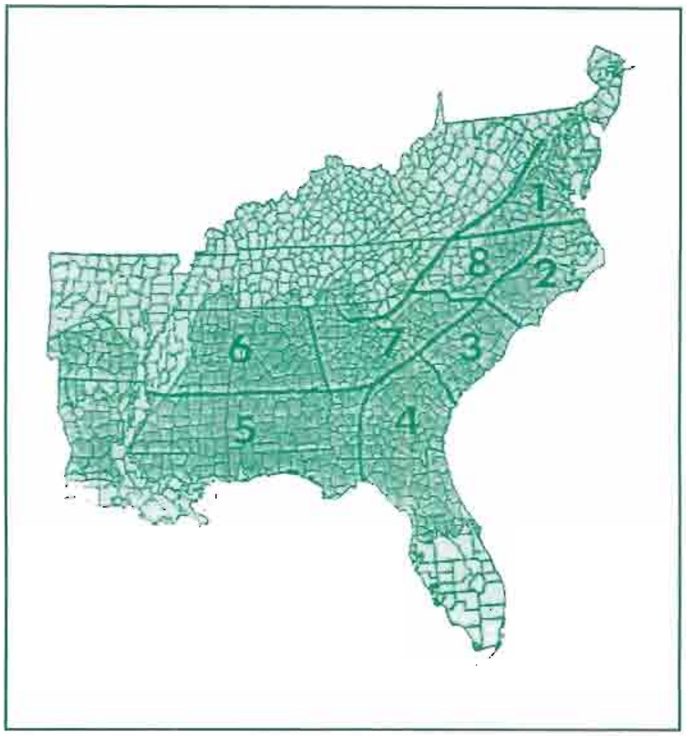

Figure 1. Breeding and Testing Areas for Second-Cycle Progeny Tests:
1. Virginia Coastal Plain and Piedmont
2. North Carolina Coastal Plain
3. South Carolina Coastal Plain
4. Georgia-Florida Coastal Plain
5. Lower Gulf
6. Upper Gulf
7. Georgia and South Carolina Piedmont North Carolina Piedmont

General Pollen Mix Zones for Breeding and Testing

Genetic resources available to the Cooperative for 3rd cycle breeding and long-term, multi-generation improvement will include selections from second-generation diallel tests and from plantation selection diallel tests. The second cycle of breeding and testing activities were grouped in eight general Test Areas and often referred to as regions across the natural ranges of loblolly pine (Figure 1). These regions were used primarily to facilitate new plantation selection, breeding and field-testing. They were not intended to be true "breeding regions."

Loblolly pine provenance tests throughout the geographic range have demonstrated that Piedmont or more northern sources of loblolly are more cold hardy than Coastal sources. The Atlantic Coastal source is noted for its relatively fast growth, whereas the Piedmont source is known to be cold hardy with better stem form. When moved further north or inland, Coastal sources generally outgrow Piedmont sources until environmental stresses become damaging to the Coastal source. Extensive progeny tests and operational deployment from 1st and 2nd cycle breeding show that loblolly pine families are generally well adapted across a wide geographic area. Loblolly pine selections show little genotype by environment interaction and have high family stability in performance across a wide geographic area (Li and McKeand 1989, McKeand et al. 1990). The Atlantic Coastal loblolly pine families have been the favored planting stock for the Lower Gulf region because they usually outperform the Lower Gulf families.

The usefulness of Lower Gulf families for planting in the Atlantic region is not well known at this time. However, a separate breeding area for Lower Gulf is unwarranted because most of the families used for deployment in this area will be from the Atlantic Coastal area. To avoid duplication in effort, a general pollen mix will be used for breeding and testing in both the Atlantic and Lower Gulf Coastal areas. The difference between the Upper Gulf and the Piedmont of Georgia and South Carolina is also small, and genetic materials can be interchanged between these areas. A general pollen mix will also be used for combining the Piedmont and Upper Gulf regions for breeding and testing.

Following the general distribution of the Cooperative membership, land holdings, test locations, and parental origins of the genetic material, three general zones have been defined for using common pollen mixes for breeding and testing purposes (Figure 2.: 1) PMZ-N: Virginia and northern NC, 2) PMZ-C: Atlantic Coastal plain and Lower Gulf, and 3) PMZ-P: Piedmont regions of SC and GA and Upper Gulf. Twenty parents from the plantation selection population with average breeding values for growth have been selected to generate a pollen mix for each of the three pollen mix zones. The pollen mix will be used within each general zone for polycross breeding and evaluating 3rd cycle selections across sites within the pollen mix zone.

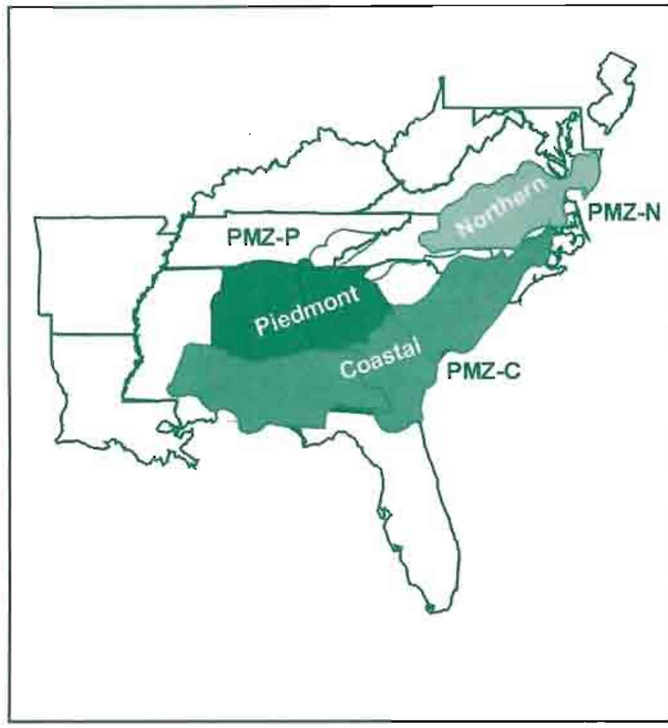

Figure 2. Three Common Pollen Mix zones for the Third Cycle Loblolly Pine Improvement.
1. PMZ-N: Virginia and northern NC,
2. PMZ-C: Atlantic coastal plains and Lower Gulf,
3. PMZ-P: Piedmont regions of SC and GA and Upper Gulf.

Population Size and Structure

Computer simulations with POPSIM (Mullin and Park, 1995) were used to examine the effect of population size and structure on genetic gain in the both short and long term. For the mainline breeding population, genetic gain generally increases with population size from 80 to 640, but the increase above 160 seems to be small for both long term gain and short term gain in seed orchards. The choice of an optimum population size really becomes an economic decision. When taking into account practical considerations (original population size, work load, logistics of coordinated breeding task), an effective population size of 160 seems to be adequate for the mainline breeding program for a given breeding region. However, the 160 selections should be the effective population size, not the census number. The effective population size will be measured using status number, which is calculated from group co-ancestry and indicates, theoretically, the expected number of unrelated, non-inbred individuals in the population.

The expected genetic gain from breeding is generally reduced by subdividing the breeding population into sublines, and the gain reduction is inversely related to the number of sublines. The subline structure would conserve genetic variation in the breeding population for long term genetic gain at the expense of short-term gain. A sublining system is effective for managing inbreeding in breeding and production populations and also provides a flexible way to manage breeding and testing within a geographic area by one or a few closely located cooperators. To provide adequate genetic gain in both the long and short-term, to minimize the potential relatedness within production populations and to provide the options for seed orchard establishment, a minimum of 20 sublines are recommended for managing the mainline breeding population of 160. The mainline populations will be managed as subdivided breeding populations with at least 20 sublines including at least 8 trees (effective numbers) in each subline.

Mating and Testing

The mating design for the mainline breeding will be a complementary design that combines polycross mating to estimate GCA's and control-pollinated matings for within-family selection. A pollen mix of 20 average parents from the plantation selection population from each of the three general breeding and testing areas will be used. The polycross will be used to estimate breeding values and rank selections among and within sublines in the breeding population. The number of controlled crosses will be determined based on the breeding values. The polycross information will also be used to select the best parents for elite breeding populations, for determining the composition of new seed orchards, and to determine the full-sib families from which selections will be made for the next round of breeding.

Sufficient polycross seeds will be produced to establish 6-12 tests on different sites within a given pollen mix zone. For example, to evaluate selections across the wide geographic range of the Coastal zone, the 9-12 tests will be established across the Atlantic coastal and Lower Gulf regions. In the northern zone, a much smaller geographic area, 4-6 tests will be established. The Piedmont zone will probably require 5-8 tests. Polycross tests will be established with a single-tree plot design with 20-25 replications. The single-tree plot design is efficient for estimating family breeding values while providing an opportunity to test more selections together in a test series. Given a census population size of 300, only 6-8 test series are needed for a pollen mix zone. Seedlings will be assessed at age 3 for height and fusiform rust. Age three has been shown to be effective for among family selection and will be used to rank parents for breeding. Later measurements will be made to confirm early assessments and for more reliable gain estimates.

A half-diallel mating design is ideal for generating full-sib combinations for selection. However, with the information from the polycrosses, the number of controlled pollinations can be reduced because only the most desirable crosses are necessary for forward selection. A modified partial-diallel mating system will be used to generate crosses among subline members with the highest expected mid-parent breeding values for within family selection. Selections will be ranked by their polycross breeding values within each 8-parent subline and eight crosses will be made, at least one cross with every selection (Figure 3). The top ranked four selections are involved in the most crosses. The low ranked selections are crossed only with the top ranked selections, not among themselves.

Parents	1	2	3	4	5	6	7	8
1		X	X					X
2			X				X	
3				X		X		
4					X			
5								
6								
7								
8								

Figure 3. The modified partial-diallel mating for each subline in the mainline breeding population, assuming that there are 8 parents per subline and parents are ranked by their breeding values from high to low (1-8).

As a result of the mating, more progenies from the top ranked selections will be available for selection.

Seedlings from the controlled crosses will be planted in full-sib family blocks for within family selection. The family block plots can be established as soon as seeds are available. A block of 36 trees will provide adequate selection intensity for within family. While no replication is needed for within family selection, a second 36-tree block will be planted on a different site by a different cooperator for insurance purposes. Selection of individual trees within full-sib families is expected to be more effective at a later age (i.e., age 5-6) than family selection based on polycross. The best phenotypes will be selected from the family block plots.

Elite Breeding and Testing

An elite breeding population will be developed from an intensively selected subset of the mainline population for short-term genetic gain for each given region. Elite populations are much smaller than the mainline so they can be bred and tested much faster than the mainline population. Elite populations will be bred as a single breeding population to achieve maximum gain and will be managed mainly for short-term gain and to provide genetic material for full-sib deployment strategies such as mass controlled pollination, rooted cuttings, and vegetative propagation for clonal forestry. The best selections can also be used in seed orchards although this will dilute some of the additional gain from the elite breeding. The elite breeding population will not be closed, and the best new genotypes will be infused from the mainline population.

The objective of the mating design for an elite population is to generate the most desirable family combinations for selection and for deployment. The highest ranked selections will be subdivided into small groups for mating purposes. All crosses will be made in a half-diallel mating design to generate all possible favorable combinations.

Field tests for elite breeding need to be replicated across many sites for among family selection and to identify the best full-sib families for deployment. The best trees from the best family combinations will be selected for the next cycle of elite breeding. Extensive field-testing will be done across a wide geographic region and on different soil site types to determine the stability and any genotype by environment interaction. About 12-16 tests will be recommended for a given pollen mix zone, such as the PMZ-N, PMZ-C, and PMZ-P. For a given test, a single-tree plot design with 25-36 replications will be used.

Seed Production and Deployment Strategies

Seed orchard options will always be open for the cooperators who want to establish open-pollinated seed orchards in future generations. Parents with the highest breeding values from replicated polycross tests will be used for seed orchard establishment. The best selections from the elite population can also be included in a seed orchard with the best parents from polycross tests, as long as the relatedness is manageable. The low efficiency of wind-pollinated seed orchards, however, will be a significant barrier to realizing the genetic gain possible from the elite and advanced generation breeding program. The loss of potential gain increases with each cycle of improvement, i.e. pollen contamination will be more detrimental to realized gain from third-cycle seed orchards than it was from first-cycle orchards. Mass controlled pollination using the best parents, can improve genetic gains by increasing the selection intensity within the production population and eliminating pollen contamination.

Bobby Catrett shows off the first cone from a third-cycle selection in his newly established 3rd cycle clone bank near Butler, AL

To realize the full potential from the elite-breeding program, full-sib technologies through mass controlled pollination, rooted cutting and clonal propagation should be used to produce and deploy the best families. Genetic gains will be maximized by increasing the selection intensity for the production population, capturing the non-additive genetic variance, eliminating pollen contamination and selecting crosses or clones that have the most desirable trait combinations. For example, the second-cycle seed orchard is expected to produce an average of 28% more wood per acre than would be expected from plantations grown from wild seed. If the best three full-sib crosses can be deployed, gain could be as high as 40%. If rooted cuttings or other vegetative propagation methods could be used for the mass production of the best individual tree in the best cross, it would yield as much as 60% more wood per acre at harvest (Li et al. 1997).

THIRD GENERATION SELECTION PROGRESS REPORT

During this past year, the Cooperative staff and cooperators selected in another 130 tests, bringing the total number of tests screened to date to 642. So, about 50% of the 1278 progeny tests planted have now been measured, screened and selected. The past year's effort yielded another 71 new selections, bringing the total to 632. During the upcoming year, the staff and cooperators will be selecting in another 193 tests.

Breeding Update

With the selection work nearing the halfway mark, some of the subline groups were formed this past year so breeding could begin. During the springs of 1999 and 2000, Cooperators have been busy collecting pollen to send to be used for pollen mixes for the Northern, Coastal, and Piedmont breeding zones. Pollen from 20 clones in each zone is to be mixed and used for PMX breeding in the next cycle. In 1999, we received a sufficient amount of pollen to make a mix of 900 ccs for the Coastal zone and 2400 ccs for the Piedmont zone. Unfortunately, not enough pollen was collected from the Northern zone to make any PMX.

The Cooperative's emphasis this spring has been two-fold:

1) Collect more pollen from all three breeding zones to store for breeding in 2001. The des-

ignated pollen parents have also been assigned to backup organizations for grafting over the next couple years, assuring that we will not lose the pollen parent, and thus the PMX, if an organization is sold.

2) Third cycle breeding began this spring in a modest way. Our first priority was to create the checklot seed needed for the next round of testing. Ten clones were designated in each of the breeding zones as female parents for checklot seed. These clones will be crossed with the PMX for that zone to create sufficient checklot seed. Our calculations show that total checklot seed needs for the three zones are as follows: Northern, 14,000 seed; Coastal, 32,000; and Piedmont, 21,000. For the organizations who were ready to cross this spring, we suggested they pollinate about one-third of the total needed for the checklots. Any pollen left after pollinating for the checklots was to be used in crossing the sublines. All in all, some 800 bags were pollinated this spring. It was a modest number but a good start. Third-cycle breeding efforts will be dramatically increasing over the next couple years.

RESEARCH

TIME TREND OF GENETIC PARAMETERS AND SELECTION EFFICIENCY FOR COASTAL AND PIEDMONT LOBLOLLY PINE

Preliminary results from the Early Diallel Measurement Study (EDMS) of the northern population in Virginia indicate that selection for age-8 volume is more efficient using height or volume at earlier age in terms of gain per unit of time (43rd Annual Report, 1999). An additional 19 EDMS test series from Coastal and Piedmont regions were analyzed to determine if there are regional differences in genetic parameter estimates and selection efficiencies. Annual measurements from a total of 275 parents (690 full-sib families) were used to estimate genetic variance components, heritability and age-age genetic correlation for growth traits and the time trend through age 8. Each test series included 4 tests (over 2 years in 2 locations). In each test, 30 crosses of two disconnected 6-parent half-diallels were planted with four check seedlots. The experimental design was randomized complete block with 6 replications and 6-tree row plots. All four tests in a test series were measured annually for height starting at age one and DBH starting at age four.

For each test series, a mixed linear model was used to estimate variance components. The variance components were averaged across several test series within each region and then used to calculate the genetic variance and other parameters for the region. Heritabilities for half-sib, full-sib and within full-sib family were calculated. Genetic correlations among ages and traits were calculated with the variance components estimated within each region. To evaluate selection efficiency, tree volume at age 8 was used as the response trait, i.e., the selection goal, since this is the latest measurement for most EDMS tests. Different selection methods at different ages were evaluated by comparing indirect selection at earlier ages for each trait with direct selection on volume at age 8. Selection efficiency is defined as gain per year.

Time trend of genetic parameters

Similar to the earlier analysis of test series in Virginia, in which dominance variance was found to be less than additive variance, the dominance variance ranged from 20%-40% of total genetic variance for all traits in Coastal and Piedmont regions. This result, together with earlier analyses on the similar diallel tests (Li, 1996), indicates that selected loblolly pine populations in advanced generations may have a different genetic structure and time trend from unselected populations (Balocchi 1992).

Heritability estimates for height were generally higher for the Coastal region than those from Virginia and Piedmont regions (Figure 4). For tree height, heritabilities were all found to increase over time. Although large variations of heritability existed among test series, when averaged over an entire region, tree height heritabilities in all regions increased from ages 1 to 4 and then stabilized over time. The Piedmont population had lower heritabilities at early ages but slightly higher than Virginia after age five. For volume (Figure 4), the time trend was similar but was more than that of tree height in the period from ages 4 to 8. The Coastal population had a higher heritability at early ages and stayed relatively the same over time, while the Piedmont population increased over time. The magnitude of heritabilities for DBH and volume was found to be comparable with the corresponding heritabilities for height.

Genetic correlation with age 8 volume

Time trends for the genetic correlation with 8-year volume were similar to the earlier results for the Virginia region (Figure 5). Tree height had the lowest correlation and largest standard error among three growth traits. For the Coastal population, the correlation increased gradually to 0.8 at age 4 and slightly decreased through age 8 (Figure 5). For tree height in the Piedmont, the genetic correlation with 8-year volume stayed around 0.8 at age 3 with only slight change (Figure 5). The genetic correlation of DBH and volume with 8-year volume uniformly increased with time. It was generally very high and stable among test series.

DBH and volume generally had higher correlations with 8-year volume than did height for all three regions. Unlike in the Virginia region, the differences in average genetic correlation with 8-year volume between height and DBH or volume were small. Particularly at age 4 in the Piedmont population (Figure 5c), the correlation for height was even higher than DBH. However, it must be noted that genetic correlation of tree height with 8-year volume has more variation among test series.

Comparisons were made between indirect selection based on 4-8 year measurements and direct selection on 8-year volume for various selection methods. Gain per year was used to calculate selection efficiency. Selection efficiency larger than 1.0 indicates that indirect selections are more efficient than direct selection.

In most cases, selecting on early volume resulted in the largest response in 8-year volume, but its advantage over selection based on height was not as large as reported earlier. Particularly for the Piedmont population, selection on height seemed to yield equal or more genetic gain than selection on volume. However unpredictable, height correlations (large difference among test series) with 8-year volume called for caution if height should be chosen as the only trait for selection.

If selection was based on height, year 3 is the most efficient age for individual selection methods. For family selection and combined family plus within family selection, year 4 is more efficient. For selection on DBH and volume, the first measurement at age 4 is usually the best choice for selection. The optimal age may shift earlier if measurements earlier than year 4 are available.

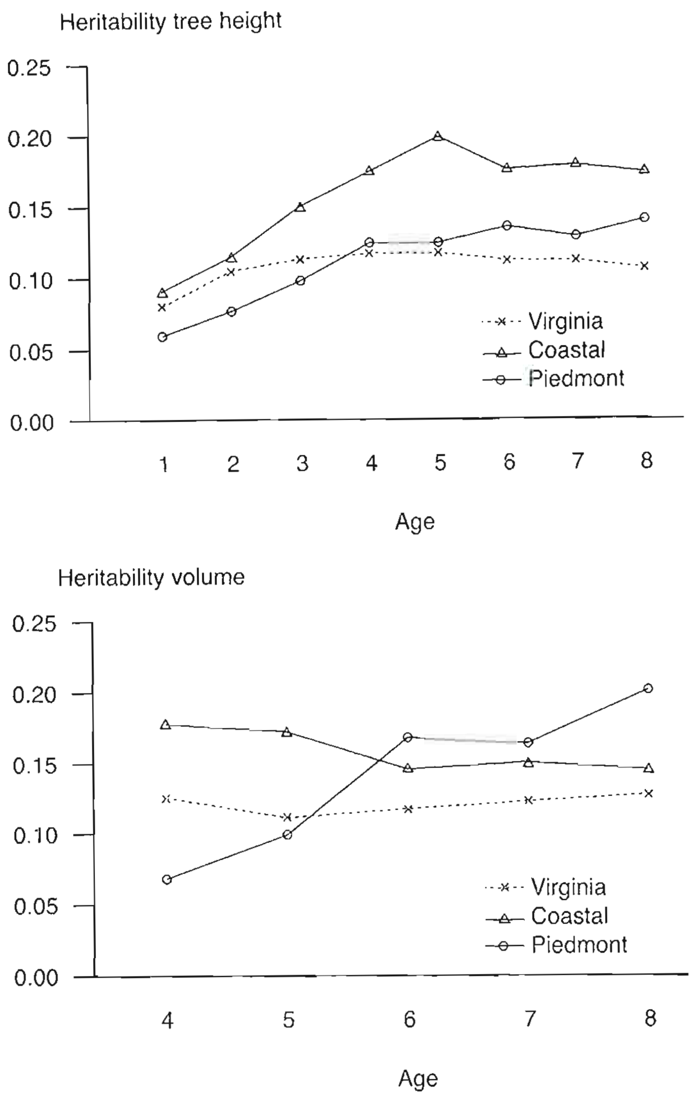

Figure 4. Individual heritability change over time for tree height and volume for Loblolly pine from the Virginia, Coastal and Piedmont regions.

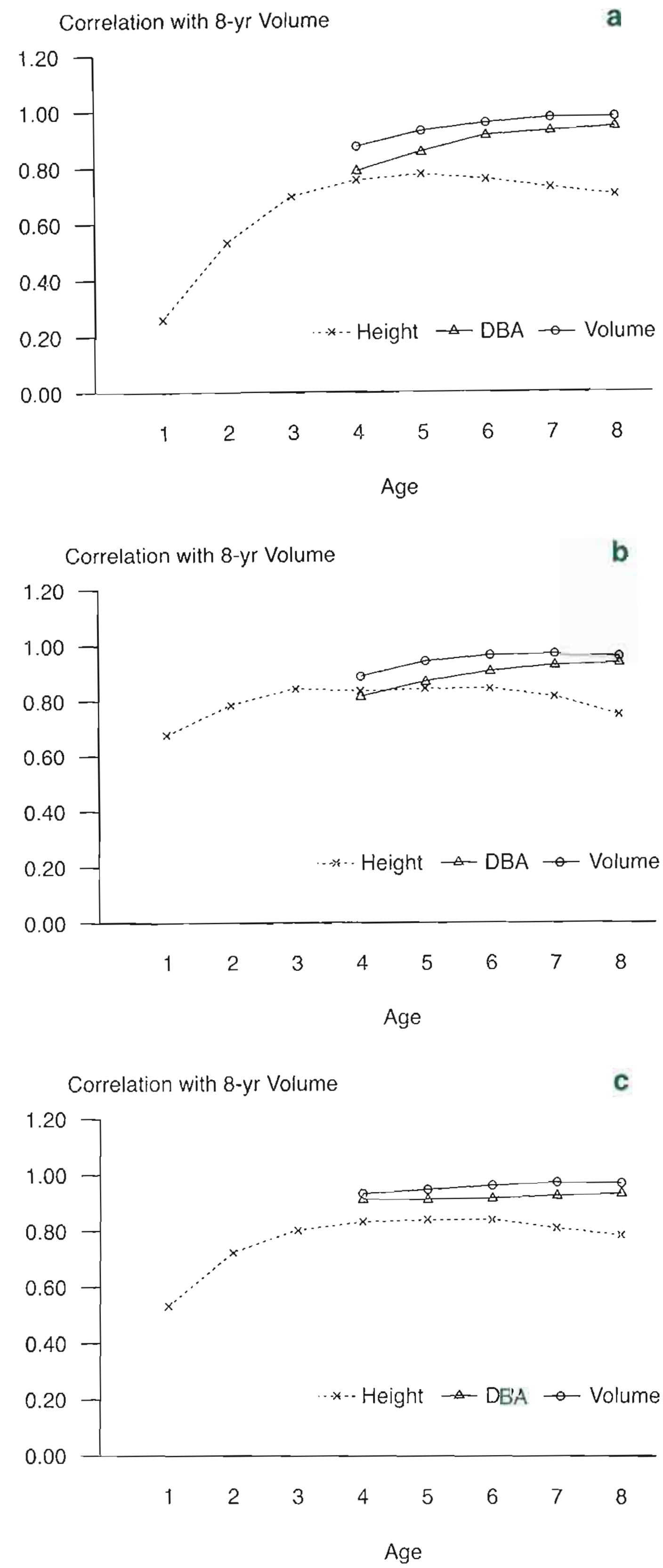

Figure 5 (right). Genetic correlations of tree height, DBH and volume with 8-year volume for loblolly pine from the Virginia (a), Coastal (b) and Piedmont (c) regions

THE GENOTYPE & NUTRITION EFFECTS ON VOLUME PRODUCTION & STRAND-LEVEL LEAF AREA IN LOBLOLLY PINE

The SETRES-2 (SouthEast Tree Research and Education Site –2) Study in Scotland County, NC was established in 1994 by scientists in the Tree Improvement, Forest Biotechnology, and Forest Nutrition Cooperatives at N.C. State University. The primary objectives are to better understand the genetic and physiological controls of productivity variation in loblolly pine. In just the first 6 years, the study has been an extremely valuable resource for silviculturists, tree breeders, molecular geneticists, and physiologists. We have started to better understand how loblolly pine families respond to nutrition amendments both above and below ground. Drs. Mary Topa, Bill Retzlaff, and David Weinstein at the Boyce Thompson Institute for Plant Research have collaborated on an Agenda 2020 project on below-ground responses to nutrition of four of the families. While results are just coming in, it appears that fine root turnover and water use can explain much of the family variation in growth. Stay tuned for more results in the coming months.

Our work with the cad-n1 mutation in family 7-1037 has started to show some fascinating results. The effects of the cad-n1 gene on lignin characteristics and volume growth have been reported in the past few years (e.g. Wu et al. 1999 in the publication list). We have just completed the first look at the effect of the cad-n1 in the 6-year-old trees at SETRES-2. The effect on growth seen in younger trees appears to occur at age 6 in the fertilized trees (we have not completed analyses of the control trees). The cad-n1 heterozygotes in 7-1037 are growing faster. There are also some very preliminary results suggesting the more efficient pulping characteristics of these trees. An interesting story is unraveling – again, stay tuned for further results.

Graduate student, Josh Handest, is near the end of his MS program funded by companies directly supporting the SETRES-2 project. He has been evaluating productivity / stemwood production relationships through age 5 years. The results of the provenance level portion of his work are summarized below.

The SETRES-2 study site is located in the Sandhills of North Carolina in Scotland Co. in a split-split-plot design with two fertilizer treatments as the first split plot (Control = no nutrients; Fertilized = optimal levels of N, P, K, Ca, Mg, S applied annually or as needed), and provenances as the second split. Five open-pollinated families each from the Atlantic Coastal Plain (ACP) and the Lost Pines Texas (LPT) provenances were planted as containerized seedlings in the fall/winter of 1993/94. Each family plot consists of 100 trees planted at 5' x 7' spacing. The full blocks are replicated ten times.

Heights and diameters have been measured annually, and per acre volume at age five years was estimated. Leaf area index (LAI) was estimated using the Li-Cor LAI2000 plant canopy analyzer. Each plot was measured after the fifth growing season in January and March of 1999 then averaged to estimate LAI from the 1998 cohort of foliage. Analyses of variance were done on height, volume, LAI, and growth efficiency (volume per unit leaf area) in order to identify significant differences and interactions among treatments, provenances and families within provenances.

The fertilizer treatment effects are dramatic due to the optimal annual nutrient additions and the natural infertility of the Sandhills site. Height growth has been consistently higher in the fertilized plots throughout the life of the study (10.7' in control plots and 15.5' fertilized plots at age 5). Cumulative volume and LAI have both shown a three-fold increase due to nutrient addition (Figures 6 and 7).

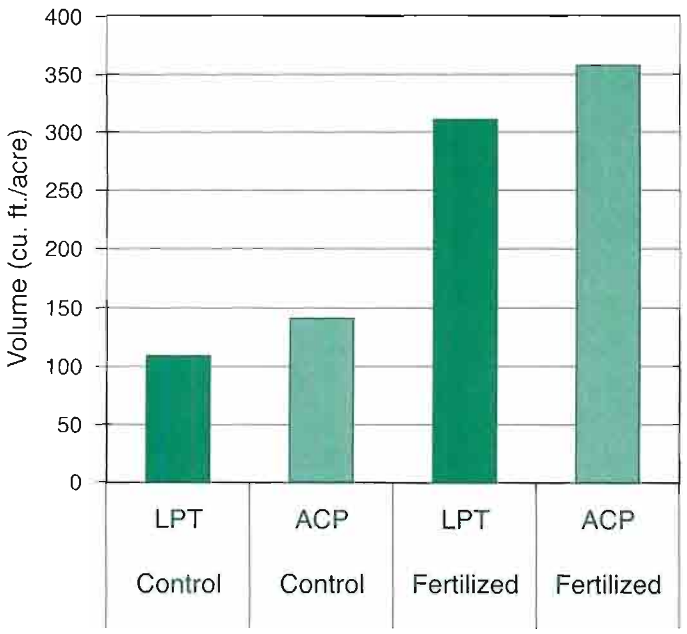

Figure 6. Volume per acre estimates at age 5 years for the Lost Pines Texas (LPT) and Atlantic Coastal Plain (ACP) provenances in the Control and Fertilized plots at SETRES-2

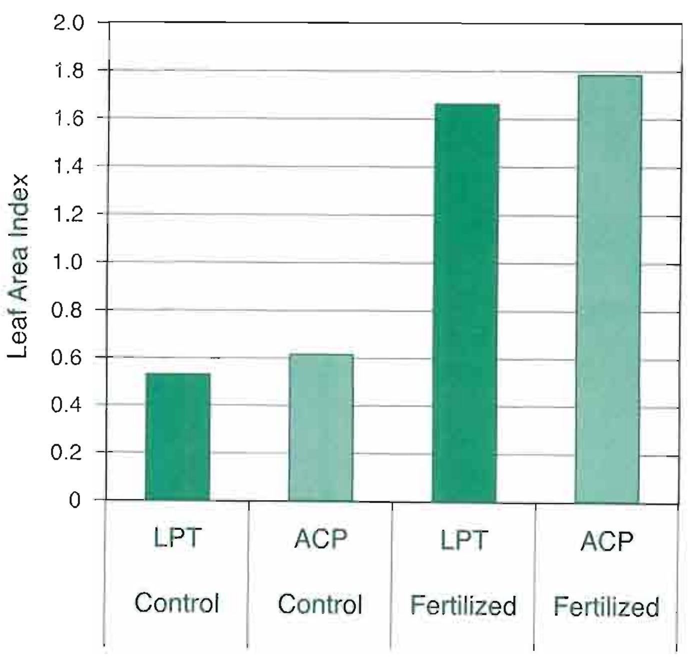

Figure 7. Leaf Area Index (LAI) estimates at age 5 years for the Lost Pines Texas (LPT) and Atlantic Coastal Plain (ACP) provenances in the Control and Fertilized plots at SETRES-2

The ACP provenance has significantly greater production in per acre volume than the LPT provenance (25% greater on control sites and 12% greater on fertilized). Early research suggested that the LPT families were "drought-hardy" and may do well on these sandy, well-drained sites. However, even on the control plots, LPT families do not do as well as the ACP families. This trend also holds true for height and LAI.

There is a positive relationship between LAI and volume production at the provenance level. The ACP provenance tends to have higher leaf area and greater volume increment growth. This study only deals with two provenances so it would hardly be possible to conclude that a provenance with a higher leaf area will always have superior volume production. However, these findings do correlate well with those of Boltz et al. (1986) who found that leaf area does contribute to the differences in production among provenances.

While significant GxE was found for volume, no rank changes were detected at the provenance level. The ACP provenance had a greater response to fertilizer, and hence, GxE was significant. However, these results are very similar to the type of responses seen in other trials (e.g. the PSSSS in this Annual Report). Faster growing seedlots tend to be the most responsive to environmental amendments. This is further support for the practice of putting the best genetic stock on the best sites.

It will be important to see how the increasing intra-stand competition for site resources will affect the growth of each provenance and family in the coming years. As resources become more limited on this dry, infertile site, it is possible that provenances may perform very differently and the GxE may become more important.

TARGETING EARLY SELECTION OF SUPERIOR GENOTYPES FOR INTENSIVE CULTURE

Intensive cultural practices, now common in industrial forest plantations, enhance the site conditions in which new selections are deployed. Hence new selection criteria based on physiological or morphological characteristics may be beneficial. We sought to evaluate seedling characteristics that confer an early growth advantage following fertilization at time of planting. But how do fast-growing genotypes exploit soil resources for growth advantage? Of course, roots function to acquire and utilize soil resources (water and nutrients), but just how important is root function to tree growth, and are these root properties strongly associated with more easily measured traits in other parts of the tree, such as leaves?

Jim Grissom, PhD student working with the Cooperative in conjunction with the SETRES-2 Study in Scotland County, NC has investigated various aspects of the physiological basis of shoot and root control on growth and biomass allocation in young seedlings of loblolly pine. He used a novel grafting technique and grew genotypes of different growth patterns to assess the effects of roots (rootstocks) versus shoots (scions) on numerous biomass and physiological parameters. A synopsis of his findings is presented.

Figure 8. Scions and rootstocks of 12-week old loblolly pine seedlings from both the ACP and LPT families were grafted on to each other in all possible combinations.

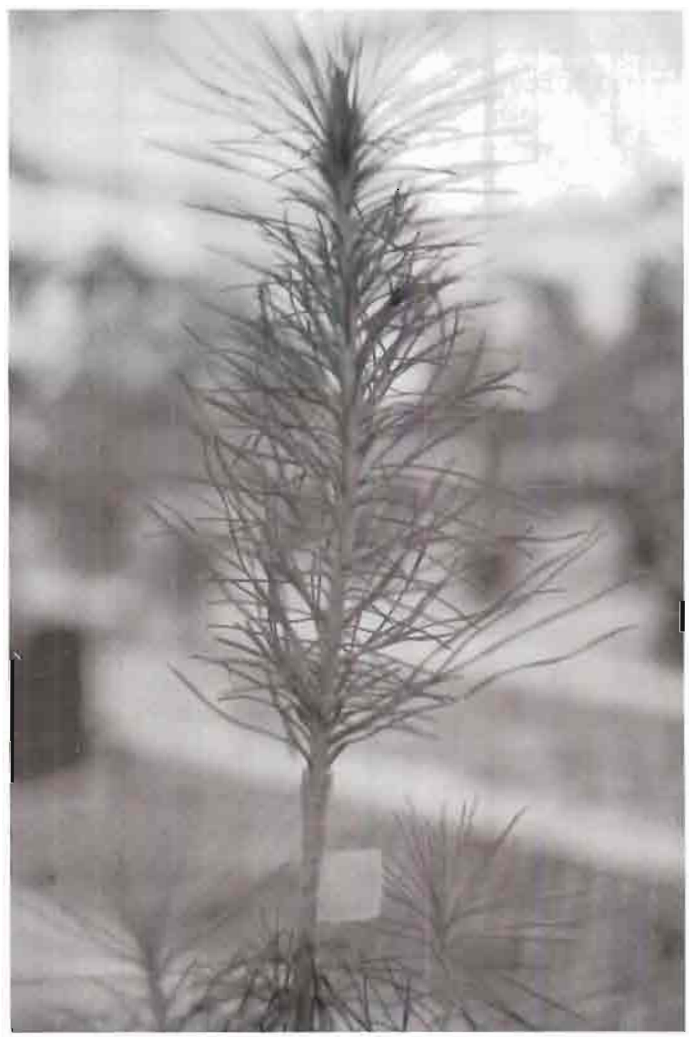

Figure 9. Approximately 6 weeks after grafting, success exceeded 95% using these very juvenile trees. Note the graft union is still wrapped in Parafilm.

Figure 10. Both above- and below-ground biomass was estimated from the 600 trees that were harvested in Jim Grissom's PhD study in 1999.

Ten open-pollinated families of loblolly pine from two diverse provenances were used, five from a mesic ecotype (Atlantic Coastal Plain – ACP) and five from a xeric ecotype (Lost Pines Texas – LPT). Twelve-week-old seedlings were grafted reciprocally to facilitate distinction of scion-rootstock effects (Figure 8 and 9). Normal (un-grafted) seedlings, as well as self-grafted ones, were included as controls. In January 1998, the container-grown seedlings were planted on a sandy, infertile site in Scotland County, NC, in a split-plot layout. Half of the plots were fertilized with a granular mixture of N, P, K plus micronutrients, applied twice during each growing season in March and June. Both in fall of 1998 and 1999, 600 trees (shoots and roots) were harvested from two blocks (Figure 10). Harvested trees were dried and weighed as separate components of leaves, stems, and roots.

Biomass accumulation differed between the two provenances mainly in the fertilized plots. When not fertilized, the provenances differed only in their allocation to roots. Since genotypic effects were evident mainly in the fertilized treatment, all of the following results pertain to the fertilized trees. Seedlings of the mesic (ACP) provenance exhibited greater biomass in above-ground components. This finding concurs with a separate lath-house experiment using the same provenances. Allocation to branches of mesic-source trees increased markedly with seedling size, suggesting that mass allocation to this component may be important at an early age.

The grafting operation was highly successful, but as expected, some early hindrance of overall growth was evident. For total height, scion effects corresponded to those of ungrafted genotypes, and rootstock effects were minimal. Grafting was associated with slightly reduced total biomass, but not with any changes in biomass allocation to plant organs.

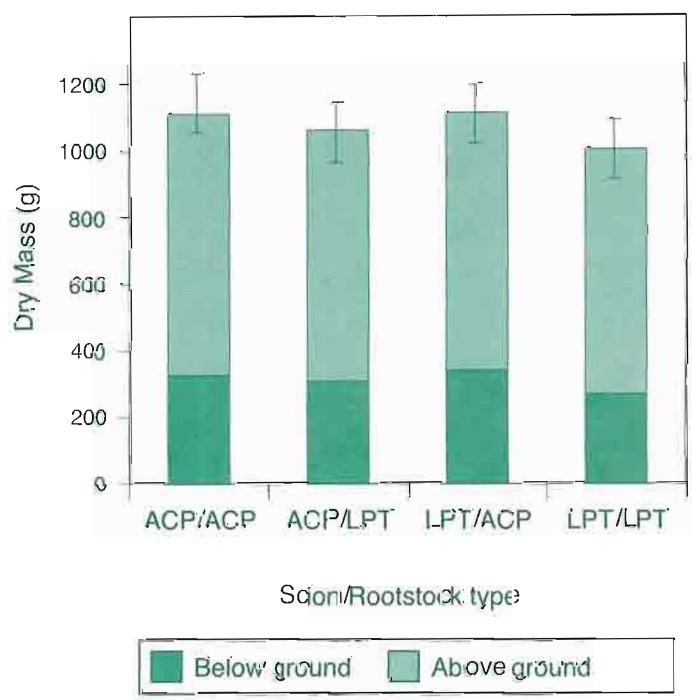

Figure 11. Total dry matter (g) in aboveground and belowground components of grafted loblolly pine seedlings, after two years of growth in fertilized field plots. Standard error bars pertain to total biomass means.

When fertilized, rootstocks altered allocation to aboveground biomass (Figure 11), most prominently to branches and stems. In particular, the mesic rootstock was associated with greater mass in aboveground components, regardless of scion genotype. It can be inferred from this finding that the mesic rootstock responds to fertilization by increasing dry matter production throughout the plant, including aboveground parts. The mesic rootstock appears to exert a large effect on growth at the whole-plant level when given sufficient soil resources.

These results suggest that in fertile soil, internal (genetic) factors of tree roots can substantially influence allocation of mass to above-ground parts. Since soil nutrition is an important external factor, the mechanism by which roots exert their influence likely involves uptake or utilization of mineral nutrients. More importantly, the degree of control that a plant organ exerts upon whole-plant growth may depend heavily on the genotypic make-up of that organ. In the fertilized treatment of this experiment, it appears that the mesic genotypes exert heavy influence on growth, whether they function as scion or rootstock. Progress is also being made in identifying physiological traits in leaves that appear to be related to early growth performance in intensive cultural regimes.

PLANTATION SELECTION SEED SOURCE STUDY (PSSSS) - AGE 4 RESULTS FROM COASTAL TRIALS

In the late 1980's the Cooperative embarked on a very large effort to evaluate the patterns of geographic variation and the stability of performance of the intensively selected plantation selections made in the 1970's and 1980's. These 3000+ trees form about 85% of the base population for the Cooperative's current and future improvement program, yet we know very little about the geographic patterns of variation for them. Since these trees were not selected from natural stands, there are questions about the patterns of variation that might be found for this large population. Do trees selected in the Coastal regions perform better than trees in the Piedmont for volume production? Will the superior cold tolerance and stem form that we typically see from more northern and inland sources also be seen in these trees? We questioned whether the patterns of variation would be similar to what has been observed in earlier provenance trials such as the Southwide Pine Seed Source Study, since the original source for many or the plantation selections was unknown. Widespread seed movement in the early days of plantation programs in the South was very common, so the performance of these trees could be very different than expected.

Breeding for PSSSS commenced in the mid 80's, using a pollen mix mating design. Plantation selections were grouped into 7 seed sources that closely corresponded to the Testing Areas the Cooperative has used for the 2nd-generation breeding program (Figure 1). Within each region, 20 clones were randomly selected as females, and 40 clones were used as pollen parents in the pollen mix. Two types of trials were established throughout the working area of the Cooperative. The single-tree-plots were established as randomized complete blocks (replicated 24 times at each site) with the 140 pollen mix families and the local checklot. These trials were to be measured at ages 4 and 8. Long-term block plot trials were also established at each site to be measured through rotation age. To date, we have 4-year measurements from 12 trials established in the early to mid 1990's. In the southern Atlantic and Gulf Coastal Plains, there are data from 8 different trials ranging from southern NC to southern MS. The seed source results from these single-tree-plot trials are summarized below.

The seed source effects for all traits (height, volume, % rust, and straightness) were highly significant (Table 1). No real surprises for any trait was found. The Coastal South Carolina, Georgia & Florida, and North Carolina seed sources ranked in

Table 1. Seed source means at age 4 years for different traits across 8 PSSSS trials in the south Atlantic and Gulf Coastal Plains.

Seed Source	Height (ft)	Volume (cu.ft.)	% Rust Infection	Straightness
3-Coastal SC	15.0 [a]	0.391 [a]	33.7 [c]	3.48 [ab]
4-Coastal GA & FL	14.7 [b]	0.367 [ab]	34.3 [c]	3.50 [a]
2-Coastal NC	14.6 [c]	0.347 [b]	41.2 [ab]	3.44 [abc]
6-Upper Gulf	14.3 [d]	0.338 [b]	43.8 [a]	3.49 [a]
5-Lower Gulf	14.3 [d]	0.334 [b]	38.6 [b]	3.42 [bc]
7-Piedmont GA, SC, NC	14.2 [d]	0.334 [b]	40.2 [b]	3.40 [c]
1-VA and northern NC	13.4 [e]	0.268 [c]	39.6 [b]	3.30 [d]

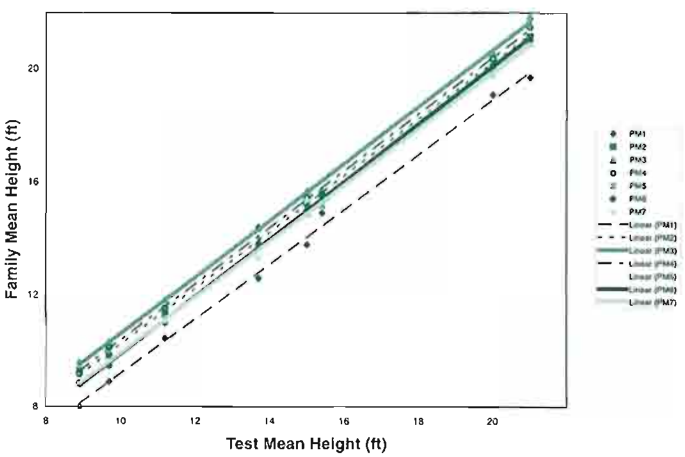

Figure 12. Seed source means for age 4 height at 8 test sites in the south Atlantic and Gulf Coastal Plains.

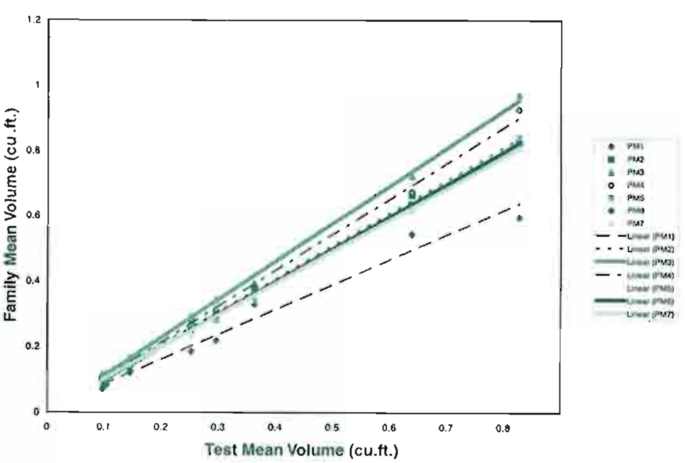

Figure 13. Seed source means for age 4 volume at 8 test sites in the south Atlantic and Gulf Coastal Plains.

that order at the top of the list. The Upper Gulf, Lower Gulf, and Piedmont sources were all about the same for height and volume, and the most northern source from Virginia and the northern Piedmont of North Carolina was significantly worse than all the others for growth traits. At least at this early age, the geographic patterns of variation for height and volume are what we would expect based on previous provenance and progeny trials.

There were not large differences among the seed sources for rust infection or straightness. Coastal SC and Coastal GA&FL had the lowest rust infection, but they were also among the more crooked sources. There is tremendous family variation within each of these sources (results not presented here), so fast-growing, rust-resistant, straight families can be found from these outstanding seed sources.

There were highly significant seed source by test location interaction effects for height and volume. This could suggest that the best seed source for these 8 coastal locations could be different. When the performance of each seed source at each location was plotted (Figures 12 and 13), it is clear that very little rank change occurred. The best growers at virtually every site were the Atlantic Coastal sources from SC, GA, and FL, and the worst source was the most northern source from VA and northern NC. The others were clumped in the middle at most all test sites.

The genotype by environment interaction for these seed sources is very similar to what was found in previous work with Good General Combiner Trials and the SETRES-2 trial in Scotland County. For volume especially, the G x E is primarily due to differences in responsiveness of the different seed sources and not rank change. The faster-growing seed sources respond more to increases in site productivity than do the slower-growing seed sources.

As we have found before, this is a win-win result, at least at this early age. The best growing sources appear to be the best across this wide range of sites in the Coastal Plains. As more tests are measured, these data will be combined with data from other PSSSS trials to look at performance across even wider ranges of sites. We will also look at the long-term performance of these seed sources and families within source in the block-plot trials to validate these preliminary results.

SEED ORCHARD

SEED AND CONE YIELDS

The 1999 seed collection for the Cooperative provided 35.9 tons of loblolly pine seed, a 32% increase over the 98 crop of 27.2 tons and the largest collections since 1996 (75.8 tons). It was the third largest crop collected in the past 10 years. (Table 2).

Seed yields in pounds per bushel were also up (1.43 as compared to 1.22 in 98). About 56% of the total seed came from second generation orchards and about 65% of the collection was from the Coastal source (Table 3).

Only three orchards produced above the 2.0 lbs./bushel mark this year; Champion, SC 1.5 Alabama orchard, which traditionally produces very high yields, yielded 2.97 lbs./bushel. Westvaco, Central orchard followed with 2.20 lbs./bushel and in third place was the Westvaco, SC 2.0 Coastal orchard at 2.18 lbs./bushel. The remainder of the top ten producers are shown in Table 4. Several organizations had individual clones producing above the 2.0 lbs./bushel mark. The highest producing clone reported this year was 8-120, which yielded 3.17 lbs./bushel in the Champion 1.5 Alabama orchard.

Table 2. Cooperative cone and seed yields over the past 10 years

Year	Bushels	Pounds	Tons	Lbs./Bushel	Millions of Seedlings	Millions of Acres Regenerated
1990	50,944	60,750	30.4	1.19	547	0.84
1991	55,555	77,555	38.8	1.40	698	1.07
1992	44,547	63,039	31.5	1.42	567	0.87
1993	35,387	46,990	23.5	1.33	423	0.65
1994	25,529	31,104	15.6	1.22	281	0.43
1995	40,250	63,867	31.9	1.57	574	0.88
1996	96,735	151,627	75.8	1.57	1,365	2.10
1997	19,183	25,890	12.9	1.35	232	0.36
1998	44,543	54,469	27.2	1.22	490	0.75
1999	50,211	71,839	35.9	1.45	647	0.99
Totals	462,884	647,130	323.6	1.40	5,824	8.94

Table 3. Comparison of 1999 seed and cone yields with previous year's.

Provenance	Bushels of Cones		Pounds of Seed		Pound per Bushel	
	1999	1998	1999	1998	1999	1998
Coastal 1.0	13,138	13,354	18,286	15,787	1.39	1.18
Coastal 2.0	18,526	16,947	28,508	20,950	1.54	1.24
Piedmont 1.0	9,047	6,636	13,418	8,250	1.48	1.24
Piedmont 2.0	9,500	7,606	11,627	9,482	1.22	1.25
Totals	50,211	44,543	71,839	54,469	1.43	1.22

Table 4. Top ten production loblolly orchards in 1999

Organization	Orchard Type	Age	Lbs./Bushel	Orchard Manager
Champion, SC	1.5 Alabama	23	2.97	Steve Parker
Westvaco, SC	Central	28	2.20	Dave Gerwig
Westvaco, SC	2.0 Coastal	25	2.18	Dave Gerwig
International Paper, FL	2.0 Coastal	22	1.84	Tim Slitcher
Westvaco, SC	2.0 Virginia		1.80	Dave Gerwig
Champion, SC	2.0 Piedmont	23	1.78	Steve Parker
Champion, SC	Rust Resistant	30	1.75	Steve Parker
Bowater, SC	1.5 Piedmont	25	1.71	Jake Clark
International Paper, SC	2.0 Coastal	17	1.69	George Lowerts
Jefferson Smurfit, FL	1.0 Coastal	18	1.65	Dale Rye

ASSOCIATED ACTIVITIES

GRADUATE STUDENT RESEARCH & 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 nine graduate programs have been developing in association with the Tree Improvement Cooperative. Four were directed toward a Masters degree and five were involved in Ph.D. programs. Of special note is the completion of the M.S. degree program by Angelia Kegley and John Mann during the past year. The graduate students working in association with the Cooperative, the degree to which each aspires, and the subject of their research project are listed in the highlighted box in this page.

VISITING SCIENTISTS

Dr. Fikret Isik, a research scientist in forest genetics from the Turkish Forestry Research Institute, has joined us as a visiting scholar since September. His visit was supported by a NATO scholarship for scientific exchange. Dr. Isik worked on several research projects related to provenance variation, genetic variation in shoot morphology and wood quality.

Student, Degree, Research Project

James Grissom, Ph.D.
Regulation of biomass partitioning in loblolly pine seedlings: Influence of root versus shoot processes.

Josh Handest, M.S. (In association with the Nutrition Coop.)
Influence of nutrition and genetics on leaf area / stem wood production.

Dominic Kain, Ph. D.(With Australia National Univ.)
Inheritance of wood properties in slash by caribbean pine hybrids.

Hua, Li, Ph. D.
Major gene is rust resistance

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

Wen Zeng, Ph. D.
Detection of major genes using phenotypic data.

Bin Xiang, Ph. D.
Genetic analysis of diallel tests of loblolly pine.

PROGRAM STAFF

The significant change in the program staff is the retirement of three key players of the Cooperative Tree Improvement Program. Dr. Bob Weir, after 30 years service and 22 years as the director of the Tree Improvement Program, has officially retired on April 30, 2000. Together with him, our manager of information system, Alice Hatcher, and tree improvement specialist, Jerry Sprague, were also retired on April 30 and May 31, respectively. We will miss their years of leadership and diverse experience that have contributed significantly to the success of our Cooperative Tree Improvement Program.

We are pleased to announce that effective June 1, 2000, Dr. Tim Mullin, Genesis Forest Science Canada, Inc. will join us as the Director of the Cooperative Tree Improvement Program. We are looking forward to Tim's contribution and moving forward with our third-cycle breeding, testing and selection program.

OTHER COOPERATIVE RETIREES

During the past year, the Cooperative saw two of its "old-timers" retire from their respective organizations. Bill Guinness retired from Bowater, Inc. on November 1 after almost 40 years of service to that company in the tree improvement field. Bill lead the Bowater tree improvement activities in Rock Hill, SC in a very efficient manner and will always be remembered as a true gentleman with whom everyone enjoyed working. We wish Bill much happiness in his retirement but his presence at Cooperative activities is already sorely missed.

Also retiring in February of this year was George Brantley after 36 years with Champion International. George was involved with the original selections and grafting of Champion's first generation orchards in Tillery, NC and had work with tree improvement until his retirement. In recent years, he had also branched out into other areas of silvicultural research. George's contributions to tree improvement have been very significant for Champion and the Cooperative. George and his contributions will be greatly missed by all.

PUBLICATIONS OF SPECIAL INTEREST TO MEMBERS OF THE COOPERATIVE

Allen, H.L, R.J. Weir, and B. Goldfarb. 1998. Investing in wood production in southern pine plantations. PaperAge April: 20-21.

Anderson, A.B., L.J. Frampton, and R.J. Weir. 1999. Shoot production and rooting ability of cuttings from juvenile greenhouse loblolly pine hedges. Transactions of the IL State Academy of Science. Vol 92, 1&2: 1-14

Belonger, P.J. and S.E. McKeand 1998. Genetic and environmental effects on volume production-and wood density in four southern provenances of loblolly pine. IEG40 Workshop on Wood and Wood Fibers: Properties and Genetic Improvement. Abstract (invited talk).

Frampton, L.J., B. Li, and B. Goldfarb. 2000. Early field growth of loblolly pine rooted cuttings and seedlings. South. J. Appl. For. (24:98-105).

Grissom, J.E. and S.E. McKeand. 1999. Growth and biomass allocation of grafted loblolly pine seedlings from diverse families following fertilization. P.67-69. In: Proc. 25th South. For. Tree Impr. Conf.

Grissom, J.E., R.L. Wu, D.M. O'Malley, and S.E. McKeand. 1999. Response of loblolly pine seedlings from diverse families to controlled nutrient supply. Abstract In: Proc. 25th South. For. Tree Impr. Conf.

Handest, J.A., H.L. Allen, S.E. McKeand. 1999. Genotype and nutrition effects on stand-level leaf area in loblolly pine. P. 70-72. In: Proc. 25th South. For. Tree Impr. Conf.

Harbin, M.C. and S.E. McKeand. 1999. Seed source study of North Carolina and South Carolina Atlantic Coastal Plain loblolly pine in Virginia. P. 73-75. In: Proc. 25th South. For. Tree Impr. Conf.

Jayawickrama, K.J.S., S.E. McKeand, and J.B. Jett. 1998. Phenological variation in height and diameter growth in provenances and families of loblolly pine. New Forests 16:11-25.

Landsberg, J.J., K. H. Johnsen, T.J. Albaugh, H.L. Allen, and S.E. McKeand. 2000. Applying 3-PG, a simple process-based model designed to produce practical results, to data from loblolly pine experiments. For. Sci. (in press).

Li, B., G. Howe, and R. Wu. 1998. Developmental factors responsible for heterosis in aspen hybrid (*Populus tremuloides x P. tremula*). Tree Physiology 18:29-36.

Li, B., S.E. McKeand and R.J. Weir. 1999. Tree improvement and sustainable forestry - impact of two cycles of loblolly pine breeding in the U.S.A. Forest Genetics 6(4):229-234.

Li, B., S.E. McKeand and R.J. Weir. 2000. Impact of forest genetics on sustainable forestry -results from two cycles of loblolly pine breeding in the U.S. Journal of Sustainable Forestry 10:79-85.

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Cooperators like Mead Coated Board are just beginning to reap the benefits from the huge breeding and testing effort from the 2nd generation of tree improvement. Gains from 2nd generation seed orchards (above) have averaged about 20% volume improvement over unimproved material. This 2.5 generation orchard (below) near Sasser, GA is the third cycle of seed orchards for the company. Much of the gain to Cooperative has realized over the past 30 years is due to the hard work and dedicated efforts of Bob, Alice, Jerry and people like Bill Guinness (left) who recently retired after nearly 40 years of service with Bowater. We will all miss them.