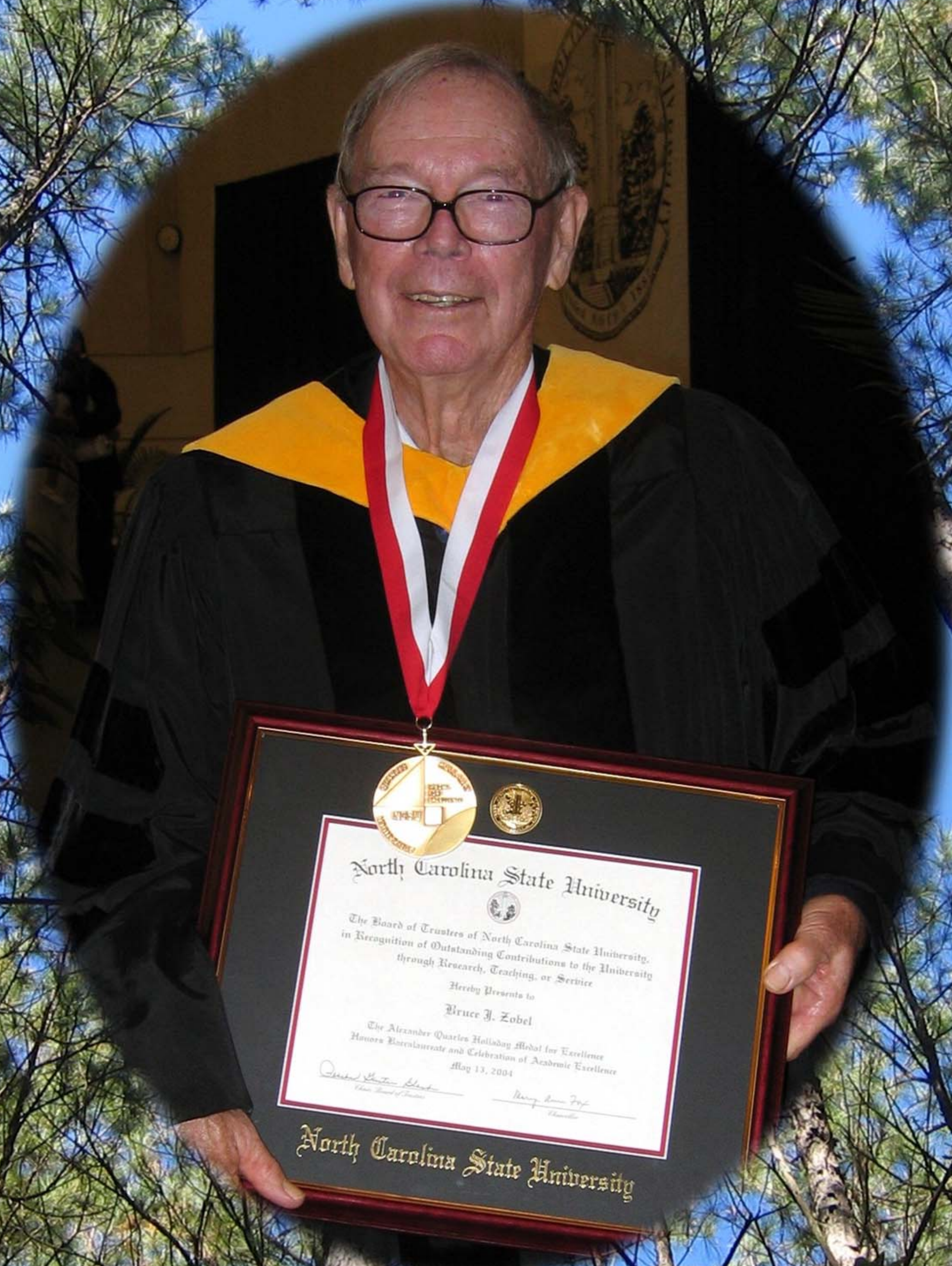
North Carolina State University Cooperative Tree Improvement Program 55th Annual Report



Dedicated to Dr. Bruce Zobel 1920 - 2011

Department of Forestry and Environmental Resources
College of Natural Resources, May 2011

NC STATE UNIVERSITY

55th Annual Report

May 2011

Department of Forestry and Environmental Resources

College of Natural Resources

North Carolina State University

Raleigh, NC

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Executive Summary

Tree improvement and forestry lost one of its great leaders when Dr. Bruce Zobel passed away this year. Bruce was the first director of the Cooperative Tree Improvement Program and a leader in the field for many years.

SELECTION, BREEDING, AND TESTING

77% of the total PMX (pollen mix) breeding is complete. The Coastal PMX breeding is the farthest along, with 82% of breeding completed. However, Piedmont and Northern breeding is moving along nicely with 71% and 76% of breeding finished, respectively.

For the Sawtimber Elite Breeding (SEPop), the first cones were collected in 2010. In March 2011, over 3000 flowers were bred in over 350 pollination bags.

Since 2005, Cooperative members have installed 78 PMX tests across all three breeding regions.

The NCSU Cooperative Tree Improvement PRS™ has been updated and is being used to relate information to internal units within organizations as well as with customers.

The final two ACE trials were established by Cooperative members for a total of 8 clonal the Southeast, from North Carolina to Alabama.

The second clonal testing effort has begun with the Piedmont Elite Diallel Population. Seedlings from 40 crosses have been inoculated at the Resistance Screening Center, and survivors will be hedged to produce rooted cuttings for clonal testing.

Longleaf pine trials were established from Virginia to Louisiana in 2010-11. In all, seedlots from 154 families are being tested, coming primarily from parent trees in seed orchards, with the exception of 18 seedlots that were collected from natural stands.

The first 3rd-cycle polymix tests were measured and analyzed this year. As expected, there are outstanding selections arising from the Cooperative's third cycle program. Among the top 50 parents ranked for volume, there were eight third cycle selections. Seven of those selections were clustered within the top 20.

SEED PRODUCTION

Compared to last year, overall seed yields were down 15%, but there was a significant increase in the amount of seed collected from the Northern and Piedmont orchards.

With the Cooperative poised to roll out a cycle of outstanding new selections, Cooperators have begun plans to establish 4th-cycle seed orchards

RESEARCH

At the SETRES2 site in Scotland County, NC, provenance- or family-specific asymptotic parameters were most significant in accounting for differences in growth over time. The Lost Pines Texas provenance had a higher carrying capacity than the Atlantic Coastal Provenance.

The CTGN project has been supported by USDA for the past four years to move molecular genetic marker genotyping and trait analysis into application in the university-based cooperative tree improvement programs. Promising results for genomic selection have been found.

A five-year, $20 million project entitled "Integrating research, education and extension for enhancing southern pine climate change mitigation and adaptation" was funded by the USDA NIFA beginning March 1, 2011. The project is headed by Dr. Tim Martin at UFL.

A grant from the Biofuels Center of NC will fund our new Loblolly Pine Biomass Genetics/Cropping Study.

ASSOCIATED ACTIVITIES, GRADUATE STUDENTS, COOPERATIVE STAFF, MEMBERSHIP

Outreach and teaching efforts increased this year. This past year was a banner year for graduating Tree Improvement students with 4 PhD and 1 MS students graduating and entering the work force.

There are 11 Full Members and 15 Contributing Members in the Cooperative

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Bruce John Zobel, 1920-2011

Dr. Bruce Zobel circa 1956

Dr. Bruce Zobel passed away February 5, 2011. Bruce was Professor Emeritus in the Department of Forestry and Environmental Resources at NC State University. Bruce, his wife Barbara, and his family moved to "State College" in 1956 when Bruce was hired to head the newly formed Cooperative Tree Improvement Program. Bruce directed the Cooperative until his "retirement" in 1979. After retiring, Dr. Zobel founded Zobel Forestry Associates, an international forestry consulting firm and continued his "missionary" work in production forestry and tree improvement around the world.

Bruce's legacy with the Cooperative and other programs continues today. Bruce had many scientific accomplishments in his career, but he was best known as an authority in his special discipline, the genetic improvement and variation of wood properties. He received worldwide acclaim for his fundamental research contribution in this field when in 1975 he was the first forester to be awarded the TAPPI Gold Medal for "outstanding contributions to the technical progress of the pulp and paper industry." In 1972, he received the O. Max Gardner Award, the University of North Carolina's highest faculty honor. He was also recognized by the Society of American Foresters and the American Forestry Association. As recently as 2004, the North Carolina State University Board of Trustees awarded the Alexander Quarles Holladay Medal for Excellence to Bruce in recognition of his outstanding career at NC State. The Holladay Medal is the highest honor bestowed on a faculty member by the trustees and the university. The list of awards Bruce has received goes on and on.

Bruce was a teacher and mentor without equal. Well over 100 graduate students feel fortunate to have studied in association with him. Many of these students hold positions of substantial responsibility in universities, governments, and industries throughout the world. The true mark of excellence in teaching is the ability to teach thinking and independent reasoning; Bruce was unsurpassed in this capacity.

Bruce's accomplishments with the Cooperative Tree Improvement Program in the southern US were truly revolutionary. Because of his influence, forestry and the productivity of forest plantations have been forever enhanced. For example, foresters in the southern United States are responsible for more than 75 percent of the nation's tree planting, and more than 95 percent of the seedlings are genetically improved pines. Bruce was directly responsible for most of the southern pine tree improvement activities at one time or another. As Director of the NCSU Cooperative, he guided the research and operational forest genetics activities of company and state organizations throughout the South. These tree improvement programs now plant almost 1 billion southern pine seedlings each year.

Bruce Zobel and Bob McElwee started the NC State Tree Improvement program in 1956. This picture is from the Cooperative's 1st Annual Report

Personal reflection

I came to NC State in August 1978 to pursue my PhD with Dr. Zobel. My wife, Lou, and two daughters loaded up all our worldly possessions and moved to Raleigh. Dr. Zobel's reputation in forestry and genetics was world renowned, and I wanted to learn from *the* authority. I knew that this was an important decision in my young career, but little did I know what impact Dr. Zobel's mentoring, scholarship, leadership, personality, and friendship would have on me. These past few weeks since Bruce's passing, I have reflected many times on some life's "what ifs". What would my life have been without the 32-year relationship with Bruce? Coming to Raleigh was the first step. Watching my family grow in number and in age, 2 sons, 2 sons-in-law, a daughter-in-law, and 4 grandchildren, all happened because we came to NC State. My career at NC State would not have happened, and life would be very different, if not for Bruce.

After completing my PhD with Bruce, I was hired as an Assistant Professor in Forestry and had the office next to his for over 25 years. I was amazed at the number of world leaders in forestry and tree improvement that sought his guidance. It was not uncommon to overhear Bruce talking to company executives in Brazil, Sweden, Indonesia, or New York or to scientists or government leaders about forestry issues. His advice was coveted throughout the world. Still, Bruce would always find time to talk with graduate students about their research projects, beginning freshmen wanting to know about career opportunities in forestry, and colleagues and former students who would stop in to visit. It would be easy for Bruce to be arrogant and not have time for these seemingly insignificant visits, but everyone was welcome and all were important to him.

Even with his incredible travel schedule around the world, Dr. Zobel always made sure that he was in Raleigh for his spring classes… after he retired. He was truly a gifted teacher. Students would flock to his graduate Forest Genetics class to learn from the master. When I taught this course with Bruce, I always joked with him that he told the best "war stories" of any teacher I knew. He always felt that students would learn best from real-world examples that brought together both theory and practice. I suppose the combination of theory and practice best describes Bruce's professional career.

Barbara and Bruce Zobel , 2008

As tree breeders, we have unique responsibilities. Our legacy to forestry lives in perpetuity. The trees we breed today are the foundation for future forests. Stewardship of our genetic resources is a responsibility that that we cherish and respect. No tree breeder has had a greater influence on forests and forestry than Bruce Zobel.

We will miss him, and we thank him.

Steve McKeand
May 2011

Bruce's last day in the Tree Improvement office, in Biltmore Hall, January 22, 2009

SELECTION, BREEDING, AND TESTING

Third-cycle Mainline Breeding Progress

Mainline breeding has progressed well since last year, with 77% of the total PMX (pollen mix) breeding complete. Following the reduction in population sizes as described in the Fall 2007 update of the Third Cycle Implementation Plan, the cooperative is poised to rapidly complete PMX testing. The Coastal PMX breeding is the farthest along, with 82% of breeding completed. However, Piedmont and Northern breeding is moving along nicely with 71% and 76% of breeding finished, respectively.

We are using a complementary design, with polycross mating for among family selection and full-sib mating for within-family selection. The numbers of completed PMX crosses are summarized in Table 1. The Coastal Plain region has made the most progress with 82% of PMX breeding complete by Fall 2010.

Full-Sib breeding has continued, but slowed some, due to the recent changes that placed priority on completing PMX crosses. The decision was made to put emphasis on PMX breeding to ensure proper ranking of parents within each subline, which is determined by measuring the progeny of the selections at age 3 years. These full-sib crosses will generate seeds for within-family selections for the next breeding cycle. Three third-cycle check seedlots were created for each of the three regions by using the same 20-parent pollen mix applied to 10 females of the 20 selections. Checklot breeding has been completed in all three regions (Table 1). Thanks to full members for their breeding efforts.

In addition to the third-cycle checklots, several well-characterized families (common family checks) from the first two cycles of breeding have been crossed with the 20-parent pollen mix. These families are included in all tests to contribute to estimates of variance components and provide better family comparisons. Nearly all breeding is complete on the common family checks.

Figure 1. Number of selections completed versus total number of selections, by Region

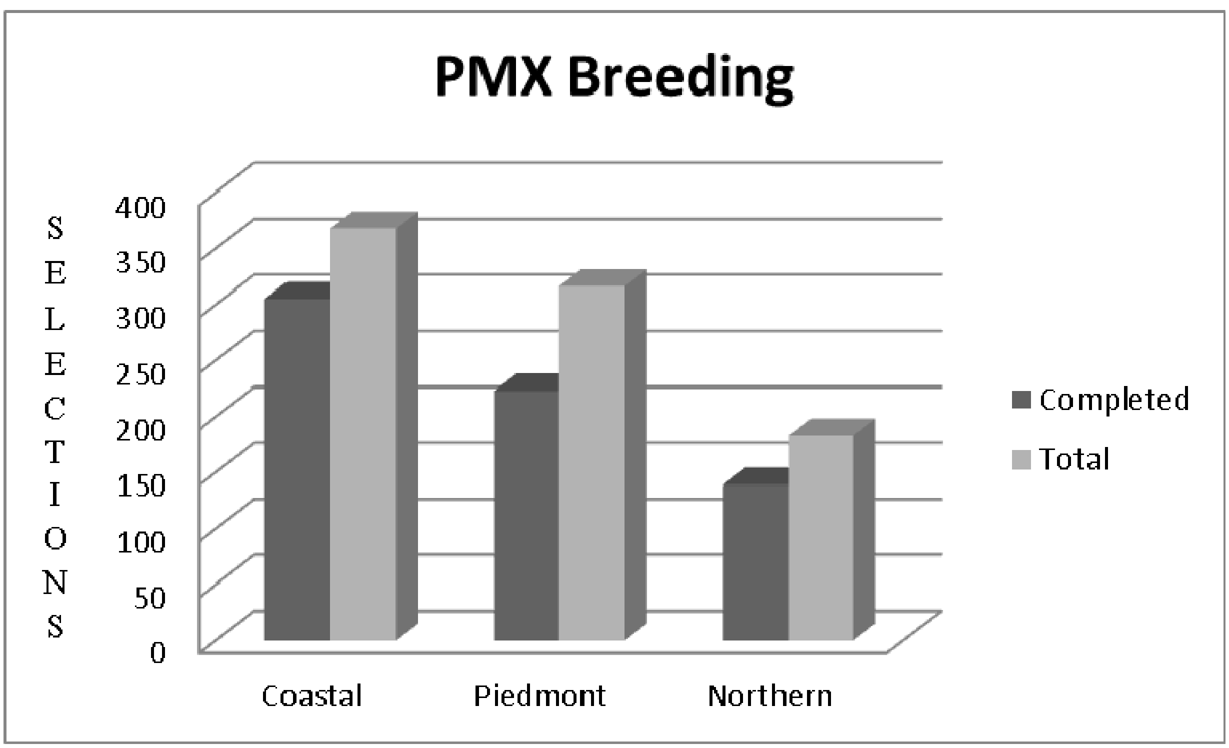


Table 1. Summary of 3rd Cycle PMX breeding progress through Spring 2011

Type of crosses	Breeding Region	# of Sub-lines	Total Parents	# Crosses producing Seed	#Crosses of Sufficient Seed	% Done
Polycross	Coastal	32	368*	329	305	82%
	Piedmont	31	316	223	167	71%
	Northern	13	183	164	139	77%
3ŧÊ˝ßŧ11#	**Total**	**76**	**860**	**700**	**601**	**70%**
PMX checks	Coastal	--	10	10	10	100%
	Piedmont	--	10	10	10	100%
	Northern	--	12**	12	12	100%
PMX CFs	Coastal	--	7	7	7	100%
	Piedmont	--	7	7	6	86%
	Northern	--	7	7	7	100%

#Crosses of Sufficient Seed: A parental cross is counted here if enough seeds have been produced for that cross to establish a full test series.

PMX checks: Polycrossed checklot mixes

PMX CFs: Polycrossed Common Family checks

* Number includes Livingston Parish and late 2nd selections

**There are two alternative PMX checks, but only 10 are to be used in checklot mix

Third-cycle Elite Breeding Progress

The expected gains from our elite breeding populations make it clear that completing this breeding is very important, and cooperators have made great strides in accomplishing this task. In 2010, breeding of the Elite Piedmont diallels was completed, allowing the Cooperative to move forward with rust screening, which is now taking place at the RSC in Asheville, NC and subsequent clonal testing (see Clonal Testing of the Piedmont Elite Diallel Population, p8). In the coming years, the importance of this material will prove to be immense for the Cooperative and many of the landowners of the southeast United States.

Sawtimber Elite Population

The Sawtimber Elite Population (SEPop) is an accumulation of the very best selections across all three breeding regions based upon new and improved breeding values (BLUP). As the title implies, this population is comprised of straight, rust resistant, high-volume selections that are great for sawtimber. The SEPop, like our mainline population, is divided into a Coastal, Northern, and Piedmont regions. The Coastal region has been assigned 76 crosses, while the Piedmont and Northern have 37 and 52 assigned crosses. Crosses were assigned based upon the breeding values for volume gain, stem straightness, forking and rust incidence.

This past fall, cone collections were made in the SEPop for the first time. Crosses that were bred in spring 2009 were collected and the results were very good. We were able to collect enough seed to fulfill the seed needs of 22 crosses.

Mr. Chuck Little was a tremendous help during this year's breeding season at the Cooperative's Arrowhead Breeding Center.

In the spring of 2011, a tremendous amount of work was completed on the Sawtimber Elite Population. Based on conelet counts from the spring 2010 breeding, 47 crosses should be complete and no further breeding was done. Soon after conelet counts were made, breeding commenced on the remaining selections and results have been very good. In all, over 350 bags were applied and a total of 3,385 flowers were pollinated, representing 114 crosses. Furthermore, several cooperators made crosses this spring, adding to the total breeding completed!

This year's SEPop breeding was greatly accelerated by the pollen collection efforts of cooperators, allowing crosses to be made without waiting for pollen production at Arrowhead. Thanks to cooperators for their efforts in providing scion and pollen for this elite population.

Third-Cycle Progeny Testing

Polycross tests

Since the winter of 2004-2005, Cooperative members have installed 78 PMX tests across all three breeding regions. In the fall/winter of 2010-2011, a total of 2 tests were established in the Piedmont region (see Table 1). Over the last five plus years, Cooperators have continued to establish more and more of these progeny trials (Figure 1).

In April 2011, seed was sent out to cooperators for the establishment of Coastal region PMX tests in 2011-2012. A total of 6 tests comprised of 59 families were distributed to Cooperative members. This seed will be sown and seedlings will be established into the field. Thanks to all the Cooperative members for their efforts to get these tests in the ground!

Beyond establishing new PMX tests, in 2010 the first PMX series (C-PMX1) tests were measured and analyzed for Breeding Values at Age 6.

Table 1. Third-cycle Polycross (PMX) progeny tests established through year 2010.

Region	Test Series	2004-2005	2005-2006	2006-2007	2007-2009	2009-2011	Total
Coastal	CPMX1	15					*15*
Coastal	CPMX2		5	5			*10*
Coastal	CPMX3			5	5		*10*
Coastal	CPMX4				8		*8*
Piedmont	PPMX1		3	5			*8*
Piedmont	PPMX2				8		*8*
Piedmont	PPMX3					6	*6*
Northern	NPMX1				4		*4*
Northern	NPMX2					4	*4*
Total	Total	15	8	15	25	10	

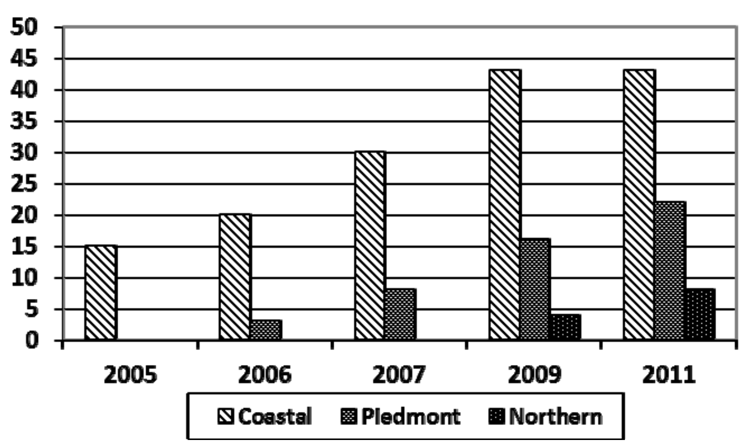
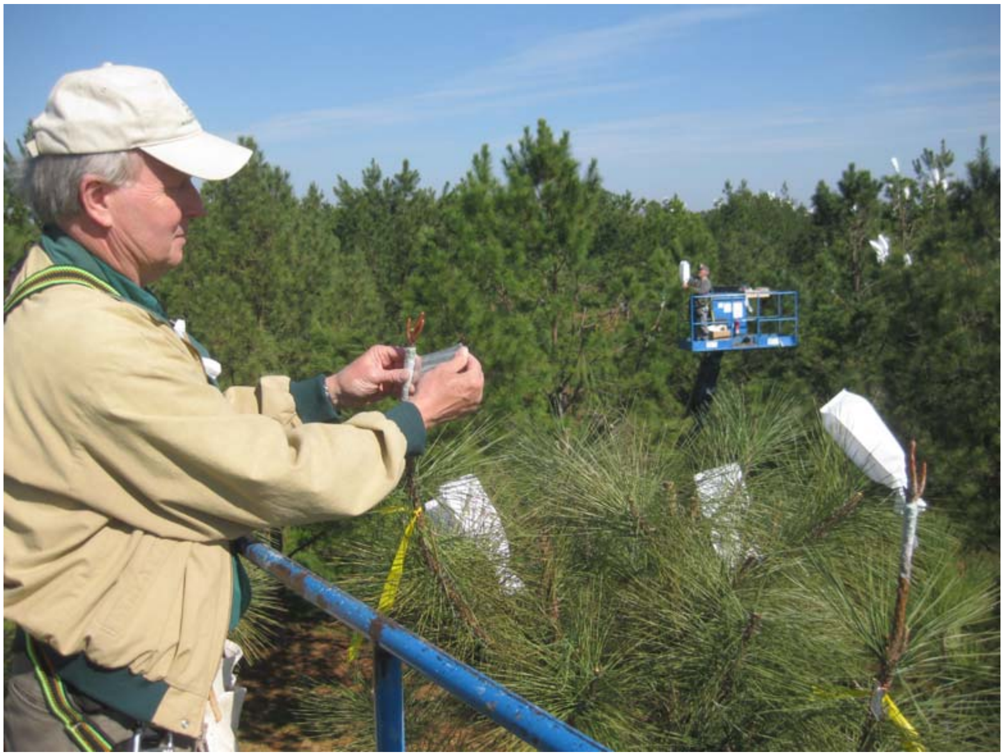


Figure 1. Cumulative number of Third-cycle PMX tests established, 2005 to 2011.



J.B. Jett topgrafting elite scions for SEPop (foreground) while Chuck Little handles bagging flowers (background)

Loblolly Pine Performance Rating System (PRS™) Updates

Many landowners are often not knowledgeable about the genetic quality of the seedlings they purchase. If landowners were better informed of the benefits of using specific families for forest regeneration, then they can determine when it is appropriate to invest in the higher priced and higher genetic quality seedlings to recognize the increase in the net present value of their plantation investment. The NCSU Cooperative Tree Improvement PRS™ was developed to help present genetic information in an easily interpreted, standardized format. Members are using the PRS™ to relate information to internal units within organizations as well as with customers.

We are continuously improving the quality of information, and this past year we updated the Coastal region PRS™ databases distributed to Cooperative members. These versions fully incorporated the "Big BLUP" analysis results (see 52nd and 53rd Annual Reports for descriptions of "Big BLUP" project). These tools have been well received and are widely used. The flexible BLUP protocol can seamlessly integrate new phenotypic data; for instance the new Third-cycle PMX data was recently added in February 2011 (see Results from the First Polymix Test Series, page 11).

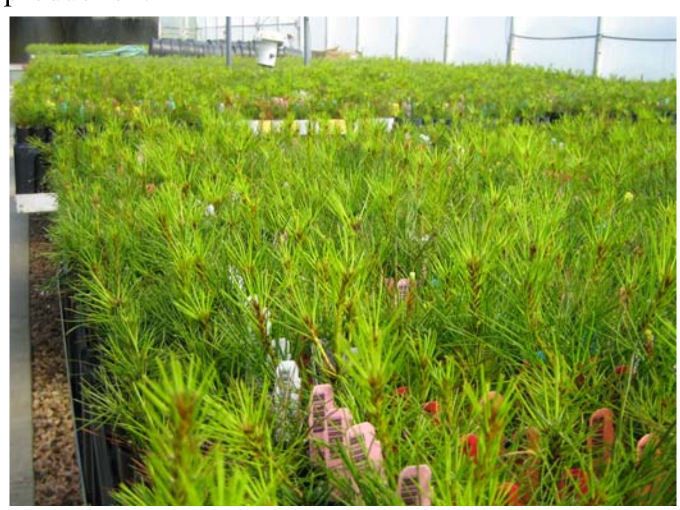
As we reach out to more landowners and forestry consultants through workshops, PRS™ is always high on our list of things to promote. Interested parties can now visit the website at, www.treeimprovement.org/prs, and educate themselves on how to interpret PRS™ for their regeneration decisions. We are exploring ways to make the PRS™ reference webpage more interactive to make this tool more helpful to landowners.

The Atlantic Coastal Elite Population: Progress and Plans

Over the past several years, tremendous Cooperative time, effort and resources have been put towards our Atlantic Coastal Elite (ACE) Population. Consisting of 55 full-sib crosses, the breeding effort that went into these elite selections required a substantial amount of effort from members. After several years of breeding, enough seed was produced by the fall of 2007 to begin the process of testing the progeny of these elite crosses.

The first step in testing the ACE selections was inoculating progeny seedlings with a very high spore load of *Cronartiium quercuum* f. sp. *fusiforme,* the causal agent of fusiform rust. After inoculation, only the seedlings that were free of rust galls were kept for further testing. This step increases the probability of the progeny from these selections being resistant to rust. By deploying rust resistant trees, the economic and ecological value of the material is further increased.

Furthermore, to maximize the genetic gains of the population, clonal testing of the progeny has been incorporated to increase the within-family heritabilities and also to allow for among family selections. The increased within-family selection power gives greater likelihood that the forward selections themselves can be confidently grafted directly into orchards for seed production.



Cuttings ready for the field.

Progress

In January and February of this year, the final two ACE trials were established by Cooperative members. In all, 8 clonal tests were established throughout the Southeast, from North Carolina to Alabama. By planting across such a broad geographic region, we minimize the risk of mortality due to climatic events, verify adaptability, and increase the exposure to various strains of fusiform rust.

Locations of Atlantic Coastal Elite Clonal Trials

Plans

With all Atlantic Coastal Elite tests now established, the coming years will be just as important as the past few years, and there will be much work to do by the Cooperative. This work begins now and involves the careful management of each test. The goal in each test is to keep competition and insect effects to a minimum, resulting in healthy and vigorous experimental trees. Also, survival assessments will be conducted on the two ACE tests established this past winter.

We plan to measure each of the ACE tests after the 3rd growing season and the 6th growing season. Each tree will be assessed for height, diameter at breast height (DBH), fusiform rust, and straightness. We will likely assess more traits than what has been listed, but the final details have not yet been determined. With the first tests established in 2010, age 3 assessments will begin in the winter of 2012-13.

Clonal Testing of the Piedmont Elite Diallel Population

The elite breeding populations in the NC State Tree Improvement Program are intensively managed subsets of the mainline population selected for short-term genetic gain for each of the three geographic regions in the Cooperative. Elite populations are much smaller, so they can be bred and tested much faster than the mainline population. Elite populations in each region are managed primarily for short-term gain to provide selections for seed orchards and to enhance vegetative propagation for clonal forestry systems.

To increase the gain possible from the Piedmont Elite Diallel Population clonal testing in the progeny trials will increase the within-family heritabilities and allow among family selections to be made. The increased within-family selection power gives higher likelihood that the forward selections themselves can be confidently grafted directly to production orchards.

At the NCSU Horticulture Field Laboratory (HFL), the Cooperative has the capacity to handle hedge management and cutting production at a reasonable cost. This is the second population to undergo this process, Clonal Trial 1: Atlantic Coastal Elite population (ACE) being the first. The formal name for this population is Clonal Trial 2: Piedmont Elite Diallel Population (PEDP).

Since fusiform rust resistance is important in the Piedmont region, all seedlings will be screened at the USDA Forest Service Resistance Screening Center (RSC) in Asheville, NC. We will use a broad-base field inoculum that covers the eventual deployment range for these genotypes. The inoculum density is high, 50,000 spores/ml, to ensure that the seedlings are fully exposed to the various sources of inocula. At five months post inoculation, the galled seedlings will be culled. The assumption is that a seedling with "no gall" response at the RSC would be more likely to be resistant in the field than seedlings with galls. Through this culling, we eliminate genotypes potentially susceptible to rust in the field, and we are able to focus on selection for growth and quality traits in the remaining seedlings. As with ACE, we expect to cull some crosses and parents out of the population entirely.

The entirety of the PEDP had been truncated (see Annual Report 54, p. 4), and sufficient number of seeds for this clonal testing approach from existing crosses comprised 70% of the population (40 crosses total). Based on experiences with the ACE population, 40 crosses combined with checklots will yield an ideal number of plants to manage as hedges.

Seeds were put in stratification January 2011 and shipped to the RSC in early March; seedlings were inoculated in May. We plan to recover non-diseased seedlings 4 months post inoculation, which should allow enough time for diseased seedlings to form a visible gall. We will take a final phenotype score for rust at 6 months post inoculation and let that be the basis for heritability analysis, but the early assessment will help us cull out trees and reduce transport costs. The seedlings will be repotted and overwintered (2011-12) at the HFL, and cuttings will be rooted in February 2013. The target is to have rooted cuttings randomized and ready for field planting in fall 2013, so we will be asking members to prepare test sites in the summer 2013. Overall field designs will be developed once preliminary screening results from the RSC are known.

By the time the PEDP clonal tests are near completion at the HFL and ready to be planted in the field, we expect to have enough seed in hand from one of the other elite breeding lines, such as SEPop, so that the next round of clonal testing can be started. This timeline helps create a continuous source of new elite trials to be planted approximately every 3-4 years, fitting into our goal of creating shorter cycles of data and germplasm availability to the Cooperative.

Longleaf Genetic Trials

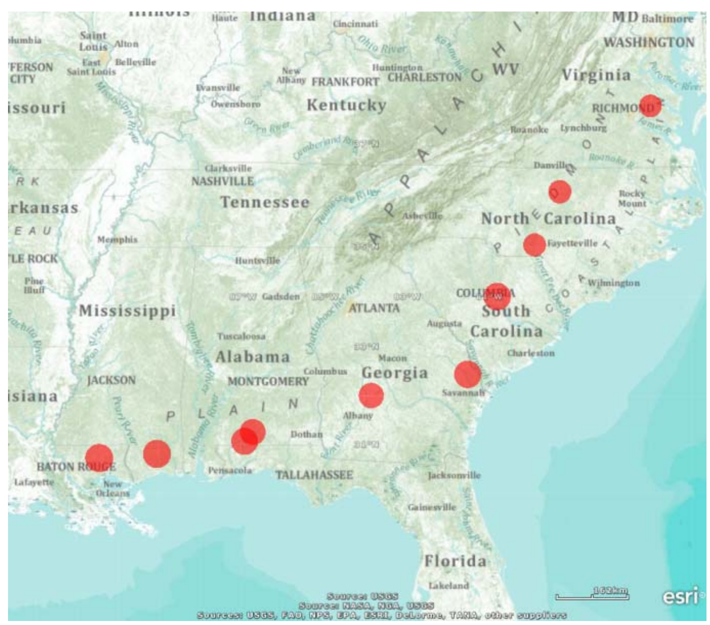
Background

Longleaf pine was once a dominant and economically important pine species in the southeastern US. However, after hundreds of years of fire suppression and intensive logging, longleaf acreage has dramatically declined. More recently, the replacement of remaining longleaf acreage with faster growing southern pine species has caused longleaf pine ecosystems to become even rarer across a vast range.

Unlike other major southern pines, relatively little is known about genetic variation in longleaf pine including its basic geographic genetic variation. In addition, recent outbreaks have demonstrated the importance of selecting and planting trees with resistance to fusiform rust; brown spot and pitch canker resistance may be desirable also. Such genetic information is critical for effective deployment for the purposes of conventional forest operations for timber and straw, ecosystem restoration, and/or carbon sequestration.

The longleaf pine cone crop in 2009 was good throughout much of the South and was excellent in some areas such as the Carolina Sandhills. Unfortunately, relatively little is known about the genetic quality of much of the seed collected from seed orchards and seed production areas in many regions. Orchards in the Carolinas, Georgia, Alabama, and Mississippi have never been as well tested as seed orchards in Florida, the Lower Gulf Coastal, and the Western Gulf Coastal regions. For example, in the NC State Cooperative Tree Improvement Program, most of the 8+/- seed orchards established 30+ years ago were either never tested or were very poorly tested. The same is true for some orchards established by the USDA Forest Service. With the current effort to establish 300,000 acres of new longleaf plantations annually, there is an urgent need to use the best genetic sources of longleaf pine available for the multitude of objectives that landowners and/or government agencies might have.

The select trees established in these orchards were chosen for superior growth and stem form from natural stands. Although the gains in the performance of the progeny from these orchard trees compared to progeny from trees in natural stands are likely to be modest, there will be some selections that have superior attributes for various traits. Some landowners might be interested in timber production or pine straw production, and there will likely be significant genetic variation for traits affecting these and other management objectives. Disease resistance (fusiform rust, pitch canker, and brown spot) will likely be under moderate to strong genetic control as well. One thing is certain, not all longleaf pines were created equal. Some will be better than others for almost any trait that a forester or landowner or government agency can conceive. Through progeny/provenance testing, we can assess the genetic variation for many desirable traits, and landowners can decide which seedlots with what desirable attributes should be deployed.



Locations of Longleaf trials established in Fall/ Winter of 2011-2011

Progress

In spring 2010, our Cooperative received funding from the USDA Forest Service and began collaboration with Forest Service scientists and others on an effort that will be an invaluable contribution to the restoration and reforestation of longleaf pine. As a result of this collaboration, this past winter 10 long-term field trials were established across the native range of the species. These trials will serve as a platform to study the effects of climate change and adaptability while also allowing data to be collected on various growth traits and disease incidence, which will help us better understand the genetic variation in the species. In all, seedlots from 154 families are being tested, coming primarily from parent trees in seed orchards, with the exception of 18 seedlots that were collected from natural stands.

We appreciate the efforts of Cooperative members, private landowners, Duke University, Auburn University, and the USDA Forest Service that have helped make this testing effort possible.

Above: Crew from Larson & McGowin, Inc. install a longleaf trial on land owned by the Hodges Famlily near Brewton, AL.

Left: Phillip Mead with Pacolet-Milliken lays out NCSU grown longleaf seedlings near Statesboro, GA.

Third-Cycle Progeny Testing:

Results from the First Polymix (PMX) Test Series of the Coastal Region Breeding Program

Estimating the parental breeding values of third-cycle selections, through polymix progeny testing, is an important facet of the Cooperative's Third Cycle breeding program. In fall 2010, we were able to begin these evaluations with the 6-year measurements of the first series of Coastal PMX tests.

Third-cycle selections were topgrafted and polymix bred for progeny testing. To facilitate progeny testing in the field, the Coastal families were grouped into six series (CPMX1 to CPMX6). Coastal PMX Series 1 progeny tests were measured at age 6 years in fall 2010, and data were analyzed in January 2011. The CPMX Series 1 included 70 families, of which 65 were third-cycle selections. The remaining were checklots, such as Coastal checklot mix (C-CK) and some common check families, such as 7-56. Selections were tested and measured at 13 sites across the Coastal Plain region. However, because of poor survival (66%) at one site, data from 12 sites were analyzed. There were up to three fold differences among sites for volume growth.

Because of scale differences among sites, we fit heterogeneous error and additive genetic variances for each site for height and volume. Heritabilities for volume at each site are given in Table 1. Individual-tree narrow-sense heritabilities for volume were generally higher for the third cycle selections (for series CPMX1) compared to estimates for second cycle full-sib (diallel) tests. Although heritabilities were high, we saw a large range; e.g., from 0.20 to 0.52.

Despite large differences between sites for volume growth, we did not see a clear relationship between volume growth (site mean basis) and the individual-tree narrow-sense heritability (beta=-0.06, Pr=0.289). Sites with higher heritabilities contribute more to the parental BVs compared to sites with lower heritabilities.

Comparative Performance of third cycle selections

We also incorporated the CPMX1 test series into the overall Coastal regional analysis ("Big BLUP") in order to obtain comparable predictions of new selections with the selections in the first and second cycle of breeding and testing. As can be seen in Figure 1, there are outstanding selections arising from the Co-

Table 1. Site means, individual tree heritability for volume, and coefficient of variation for traits measured at age 6

Test Site	Height (ft.)	Volume (Ind. Tree, ft^3)	h^2 Vol.	Strt Score	Rust freq.	Forking freq.	HT_cv	VOL_cv
01	23.7	1.10	0.52	3.57	0.02	0.33	14.4	41.1
02	29.7	2.08	0.41	3.53	0.20	0.49	6.9	22.2
03	27.7	1.38	0.24	3.40	0.35	0.10	12.2	39.9
04	25.6	1.37	0.26	1.90	0.26	0.23	10.7	34.6
05	28.9	2.29	0.20	1.75	0.46	0.21	10.8	32.8
06	21.7	0.77	0.37	1.34	0.33	0.06	16.4	43.5
07	29.0	1.85	0.29	3.46	0.60	0.15	10.4	35.3
08	28.4	1.93	0.32	3.53	0.25	0.28	8.4	27.3
09	25.6	0.97	0.35	3.55	0.39	0.05	11.5	37.4
10	26.2	1.40	0.32	3.55	0.29	0.17	10.8	34.3
11	28.1	1.51	0.41	3.53	0.40	0.07	11.9	41.4
12	21.8	0.84	0.33	2.29	0.00	0.00	11.5	37.7
Overall	**26.3**	**1.45**	**0.33**	**2.97**	**0.29**	**0.18**	**15.1**	**48.1**

operative's third cycle program. Among the top 50 parents ranked for volume, there were eight third cycle selections. Seven of those selections were clustered within the top 20.

The top eight third-cycle selections were not only exceptionally high for volume growth but also were among the best for stem straightness and for fusiform rust resistance (Figure 2). For example, the parent that is circled in the 3D plot was the best for rust resistance and was among the top 10 best for straightness.

Based on this first series of polymix tests, we expect that over the next 9 years, we will identify many more outstanding selections that will be ready to include in production seed orchard as well as into our breeding programs. Six-year data from Coastal PMX tests will be coming in over the next 8 years, with Piedmont data coming in starting in 2013, and Northern data starting in 2015. All 3rd-cycle testing should be complete by 2020.

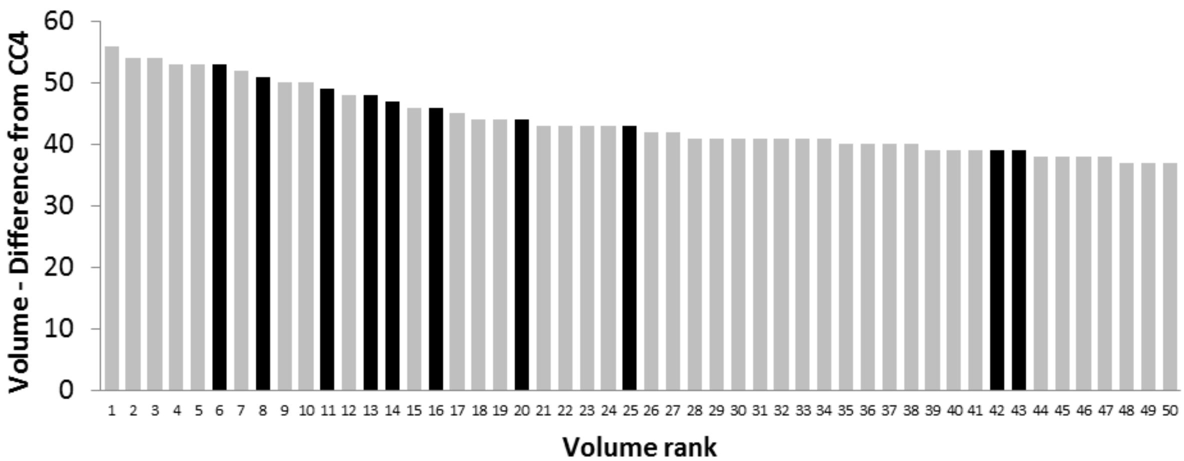


Figure 1. The bars in the figure show positive deviation of parental volume BVs from the CC4 checklot for the top 50 parents in the Coastal Region. The third-cycle selections are shown by black bars. The rest of the selections are shown by gray bars.

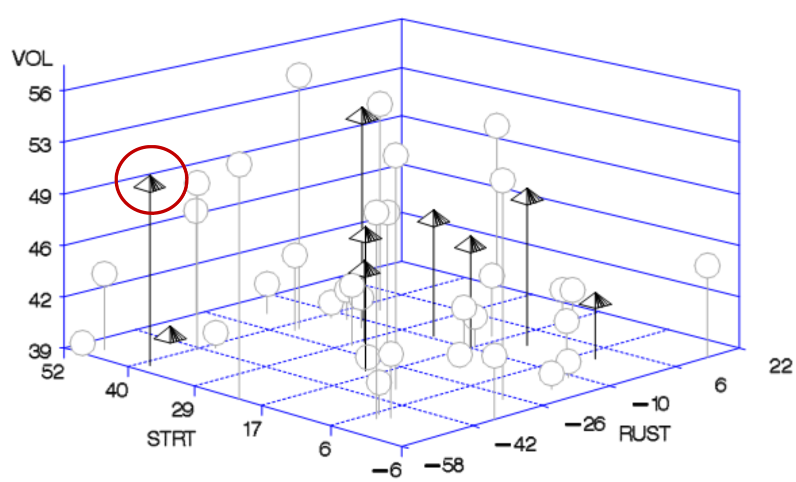


Figure 2. A 3D plot shows the top 50 parents in the Coastal Big BLUP for volume (vertical axis), straightness and rust disease incidence. The pyramid shapes are the new third-cycle selections. Negative rust values indicate less rust compared to the CC4 checklot. Positive volume and straightness values are favorable. The circled selection combines very favorable values for all three traits.

SEED AND CONE YIELDS

Cooperative members collected 13.4 tons of loblolly pine seed in 2010 (Table 1). Compared to last year, overall seed yields were down 15%, but there was a significant increase in the amount of seed collected from the Northern and Piedmont orchards. Also, for the first time, seed was collected from Northern third-cycle orchards. Over 60 million seedlings can be planted this coming growing season from the combined 3rd-Cycle seed production.

Annual seed yields have varied over the years due to regeneration needs, changes in membership within the Cooperative, environmental factors, and growth and technology within the industry (Figure 1). For the last 10 years, cooperators have produced sufficient quantities of improved seed, and therefore have been able to be increasingly selective at cone harvest. From 1968 to 2010, over 2.3 million pounds of improved seed have been produced by Cooperative members. At 12,000 seedlings per pound, this is enough seed to grow over 28 billion improved seedlings. We look forward to greater production from advanced generation seed orchards in the near future!

Table 1. Comparison of 2010 seed and cone yields with previous year.

Provenance	Bushels Of Cones		Pounds Of Seed		Pounds per Bushel	
	2010	2009	2010	2009	2010	2009
Coastal 1.0	0	526	N/A	821	N/A	1.56
Coastal 2.0	8103	12042	11387	17938	1.405282	1.49
Coastal 3.0	3363	5327	3857	6856	1.146893	1.29
Piedmont 1.0	0	1622	N/A	2121	N/A	1.31
Piedmont 2.0	7026	3440	8992	4599	1.279818	1.34
Piedmont 3.0	1202	1913	1283	2301	1.067388	1.20
Northern 2.0	1706	525	1037	494	0.607855	0.94
Northern 3.0	262	0	224	N/A	0.854962	N/A
Totals	21662	25395	26780	35130	1.06	1.30

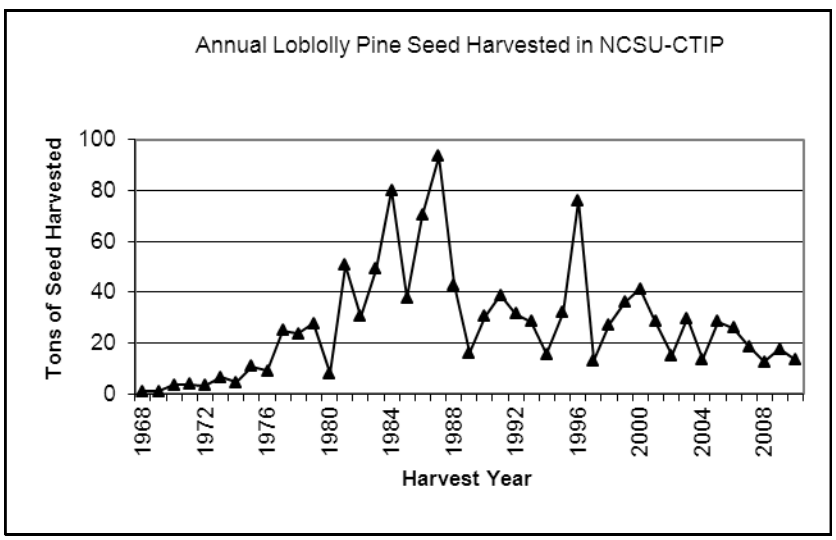


Figure 1. Annual seed yields from 1968 to 2008

New Orchards are Getting Started

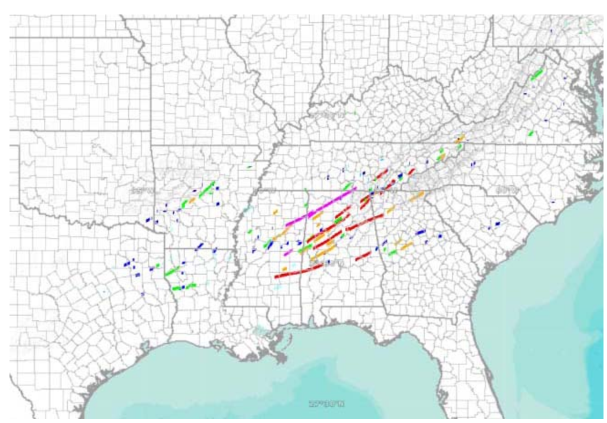
With the Cooperative poised to roll out a cycle of outstanding new selections, Cooperators have begun plans to establish 4th-cycle seed orchards. Working with the Coop staff, The Westervelt Company has identified an entirely new seed orchard complex to be located near the town of Pickensville, Alabama. Formerly in a young planation, the approximately 50 acres have been cleared, roads improved, electrical service run, a new well drilled, and an irrigation system started. The grafts pictured below represents the best selections currently available, and the orchard is being set up to facilitate mass production of full-sib seedlings. Ample room exists at this new location to accommodate additional selections and will provide Westervelt a new area for their seed orchard operations.

2007 imagery of the Westervelt seed orchard site.

Recently transplanted grafts for the first round of orchard development.

Severe Storms and Tornadoes Impact the South

Spring 2011 has been full of devastating tornados across the South. On April 16, North Carolina had a record number of tornado outbreaks, one having touched down very close to the NCSU campus. On April 27, the Southeast experienced hundreds of very powerful tornadoes. While damage was widespread, our Cooperators in the hardest hit areas reported relatively minor damage and fared the storms well all things considered.



Paths of tornadoes from the April 27, 2011 storms. Source: noaa.gov

Research

Genetic Effects on Long-term Growth in Loblolly Pine [1]

Virtually all loblolly pine seedlings currently planted in the southeastern US have been genetically improved through selection and breeding. When deployed operationally, the vast majority of these seedlings are planted in single-family blocks. Optimal deployment of improved planting stock requires an understanding of how trees respond at both the individual-tree and stand level. Three tests were utilized to examine the growth of trees in single-family block plantings.

The first study utilized the SETRES-2 test in Scotland County, North Carolina. Ten open-pollinated families from two very different provenances, Atlantic Coastal Plain and Lost Pines Texas, were grown in single-family block plots to test for growth differences between provenances and among families under severely deficient and optimal nutrition regimes on a nutrient-deficient and dry site. The three-parameter Chapman-Richards function was fit to plot means over time by both provenance and family by nutrition treatment. Models with provenance- or family-specific parameters of the Chapman-Richards were tested for significant improvement over the use of global parameters.

Significant nutrition by provenance interactions were found for stand-level traits of basal area per hectare and volume per hectare, as well as significant family differences. Mean individual tree size was significantly higher in the Atlantic Coastal Plain provenance, but higher mortality in the fertilized treatment (Figure 1) resulted in the provenance by nutrition treatment interaction at the stand level.

In general, provenance- or family-specific asymptotic parameters were most significant in accounting for differences in growth over time (Figure 2). Several traits required the use of local asymptotic and rate parameters in the fertilized treatment only. For modeling growth, a growth multiplier would be sufficient for the majority of traits. In some cases, adding a time multiplier could improve model predictions, but would likely be needed one for only a few families.

Linear regressions were fit to selected subsets for various genotypes at the maximum size-density frontier. Significant differences in the intercept parameters were found between the provenances, but no difference existed in the slope parameters for the provenances, indicating a difference in carrying capacity. The Lost Pines Texas provenance had a higher carrying capacity (Figure 3). Tests of the five open-pollinated families of the Atlantic Coastal Plain provenance showed the intercepts differed for the maximum size-density lines of most families, but the slope of only one family differed from the other four families (Figure X4). Results showed that genotypes with superior individual-tree growth may not have the highest stand-level yields, particularly if not managed properly.

The effectiveness of early, indirect selection for breeding programs is dependent upon the association between the selection trait and the traits that are of interest at harvest, and the presence of phenotypic differences among genotypes at harvest. Two tests established by MeadWestvaco in South Carolina with first- and second-generation families were examined to address these concerns.

Significant differences between genotypes planted in single-family blocks were found at all ages tested through 23 and 24 years. Differences in individual-tree characteristics of height, diameter and volume were highly significant at ages 6, 12, 17, 23, and 24. However, in both tests differences in the stand-level traits of volume per hectare and basal area per hectare were significant at age 6, but differences lost signifi-

[1] *This is a summary of Ben Smith's PhD research. Ben completed his degree in fall 2010.*

cance over time. Although the interaction of family by deployment type was significant for many of the traits examined, it was not for individual-tree volume at age 6, indicating that improvement in selection at age 6 would not be realized by changing progeny tests from mixed-family plantings to single-family blocks.

Figure 1. Mean survival of ACP and LPT provenances in control and fertilized nutrition treatments. Mortality increased for ACP in fertilized plots due to fast growth and inter-tree competition.

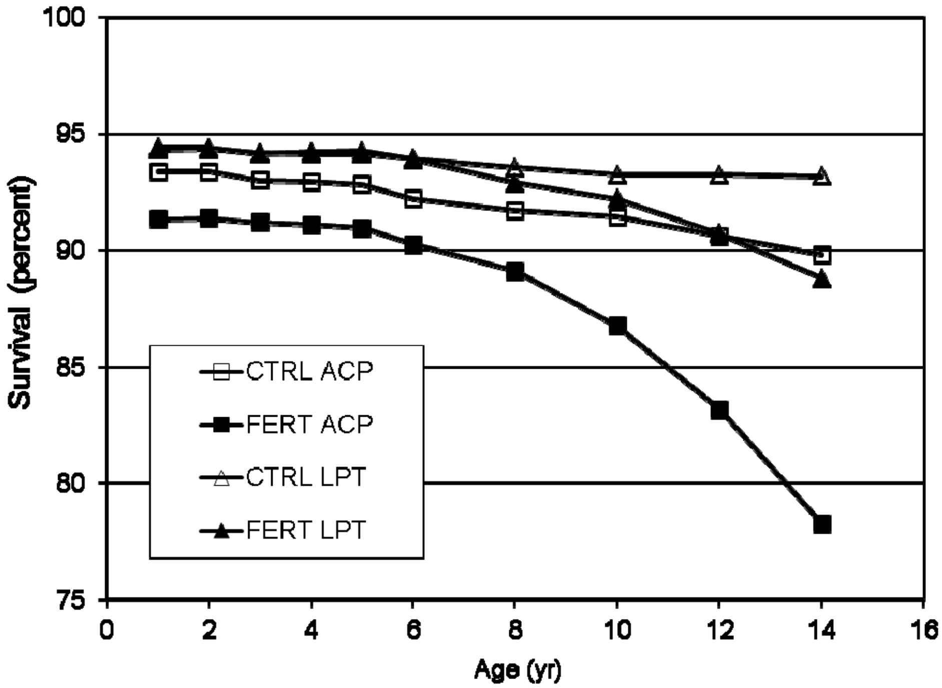


Figure 2. Chapman-Richards function fitted to observed mean volume per hectare for fertilized treatment, over time. Functions were fitted with provenance-specific asymptotic and shape parameters as indicated significantly different by reduction in SSE. The control treatment contained insufficient curvature for fitting the Chapman-Richards function.

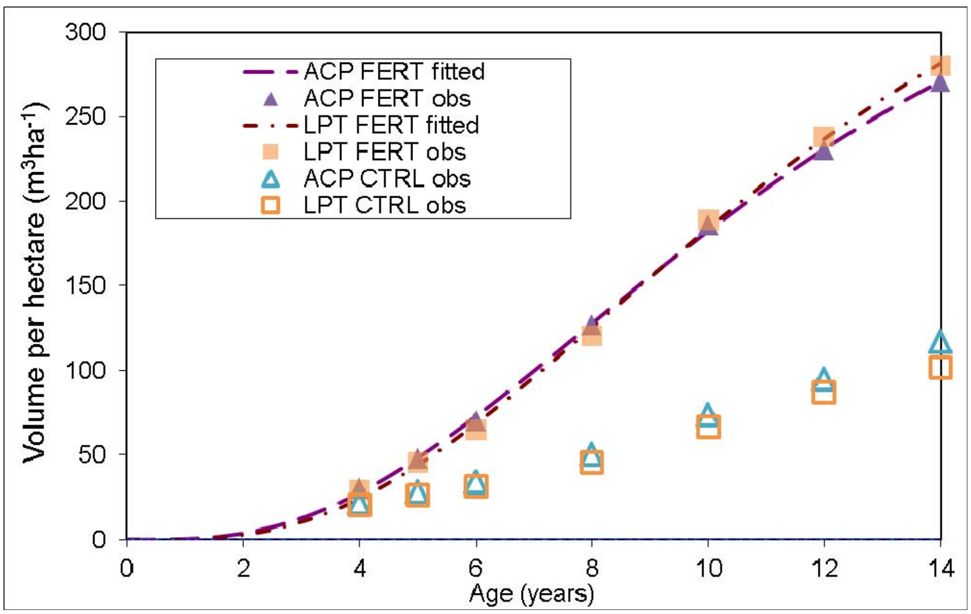


Figure 3. Log of quadratic mean diameter over log of density, by provenance. Black-filled symbols represent the subsets of 20 observations from each provenance utilized for fitting maximum size-density regression lines, with the individually-fit regression lines. The lower range of quadratic mean diameter is not shown.

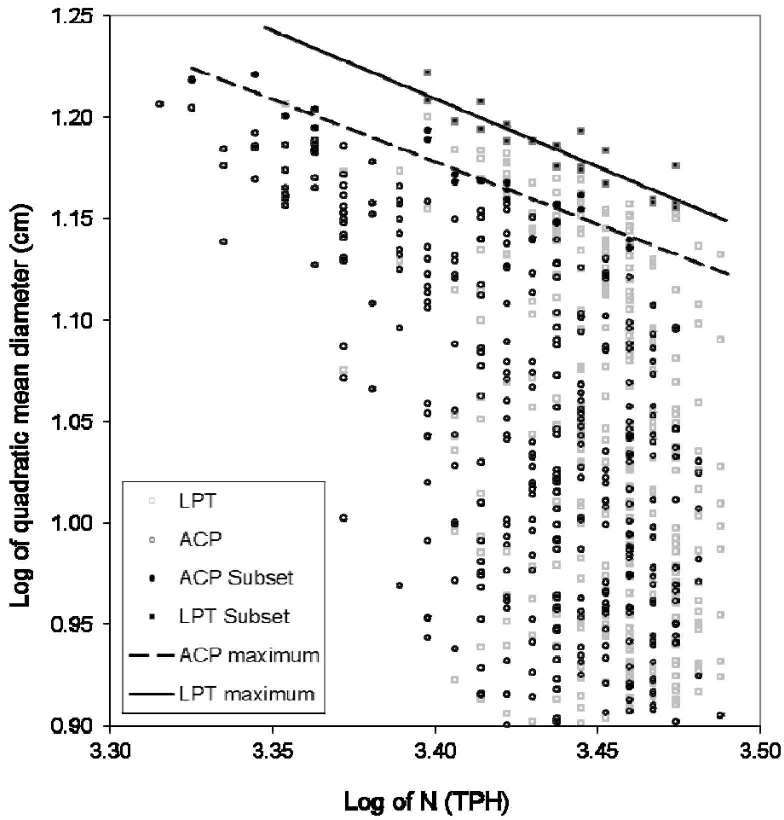
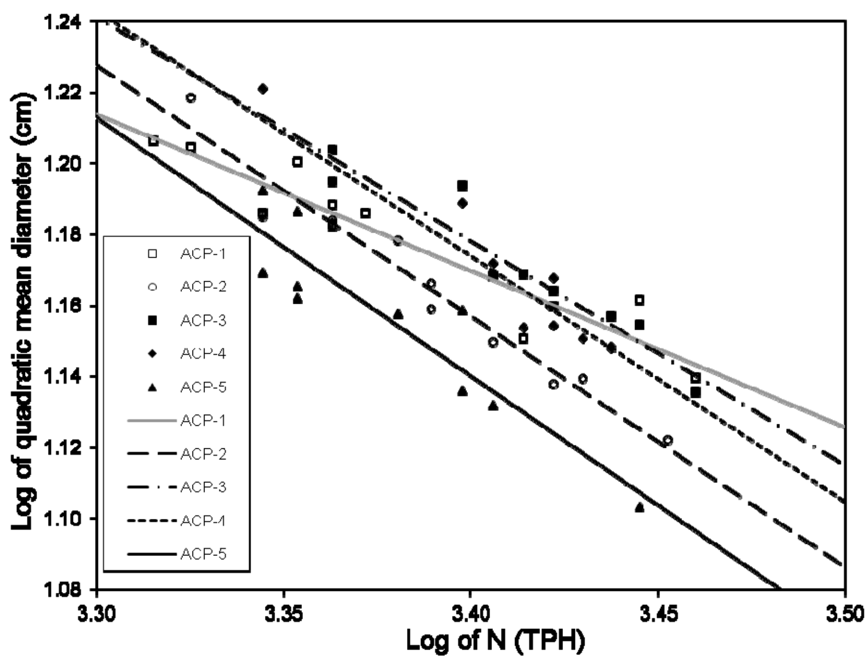


Figure 4. Individually-fitted maximum size density lines of the families in the fertilized treatment of the ACP provenance. Pairwise comparisons indicated that the slope and intercept of ACP-1 differed from all other families, except ACP-3 with which it shared a common slope and intercept. Families ACP-3 and ACP-4 shared a common slope and intercept, while all remaining pairs of families shared only a common slope with differing intercepts.



Conifer Translational Genomics Network (CTGN)

The CTGN project has been supported by USDA for the past four years to move molecular genetic marker genotyping and trait analysis into application in the university-based cooperative tree improvement programs based at NC State, University of Florida, Texas A&M University, and Oregon State University. Two PhD students at NC State, Jaime Zapata-Valenzuela and Funda Öğüt, are working on different aspects of this project.

Jaime's research has focused on analysis of genotype and phenotype data from a set of clonal tests, and has examined the value of marker genotypes at about 3400 loci in understanding relationships within and among families. Traditional quantitative genetics uses estimates of relationships among individuals within families that are accurate on average, but are much less accurate for any individual pair of full-sibling or half-sibling trees. Molecular marker genotypes provide a more accurate estimate of the actual or realized relationships within families, and can therefore improve the power of statistical models to predict genetic value of individuals within families. The density of molecular marker genotypes provided by the CTGN is not high enough to allow identification of individual genes that control the traits being analyzed in these trials (height, volume, lignin content, or cellulose content), but the results are an encouraging indication that the basic strategy is sound.

Funda's research is focused on simulation of breeding populations and comparison of different methods for estimating the true values of missing genotypes. Genotype data may be missing from a dataset due to failure of the assay, or due to an experimental design in which costs are reduced by determining genotypes of a small number of individuals at all marker loci, and a larger number at a subset of the marker loci. Similar methods are used in livestock breeding programs, and have the potential to bring marker genotyping costs down to the point where direct application in tree breeding programs will be cost-effective.

Climate Change CAP

A five-year, $20 million project entitled "Integrating research, education and extension for enhancing southern pine climate change mitigation and adaptation" was funded by the USDA National Institute of Food and Agriculture, beginning March 1, 2011. The project director is Dr. Tim Martin at the University of Florida, with a total of 51 participants at 12 institutions across the South. The overall goals of the project are to create, synthesize, and disseminate the necessary knowledge to enable southern forest landowners

- to harness pine forest productivity to mitigate atmospheric CO2,
- to more efficiently utilize nitrogen and other fertilizer inputs,
- and to adapt their forest management approaches to increase resilience in the face of changing climate.

The USDA objectives for these large, long-term projects on agricultural and forestry production systems are to reduce the use of energy, nitrogen fertilizer, and water by 10% and increase carbon sequestration by 15% during the next 20 years. These long-term goals are to be achieved through three parallel efforts: to reduce greenhouse gas emissions in forestry and maximize carbon sequestration in forest plantation; to maximize resiliency and reduce impact of climate change on productivity of forest systems and reduce carbon, nitrogen and water footprints under changing climate conditions; and to carry out extension, education, and outreach activities to increase the numbers of scientists, educators and professionals with skills to address the risks that climate change may pose to production forestry.

Several faculty at NC State are involved with this project, including those in the Tree Improvement and Forest Productivity cooperatives, as well as others with expertise in physiology, economics, extension, and climatology. One objective is to integrate data from different disciplines into a cohesive whole that describes the performance of different families of loblolly pine across the Southeast. These datasets can then be used to develop a decision support system to help landowners review regional-level predictions of possible climate changes and choose which families to plant based on their own assessment of acceptable risks and possible benefits. A second objective is to extend previous work on genetic analysis of productivity and survival in an effort to find ways of accelerating breeding cycles to produce more productive planting stock that will be resilient to projected changes in climate conditions.

Grants received

This was an unprecedented year for soliciting grant funds for southern pine research, and it kept the TIP staff busy from May to December writing proposals. In all, we either led the effort or contributed to seven new proposals, and the award amounts ranged from $5 million up to $20 million over five years. We were successful on three proposals and are anxiously awaiting final word on the final one for the year. The following grants are a show of our success:

Continuing Grants

Steve McKeand, Fikret Isik, Ross Whetten. Subcontract with the University of California – Davis, USDA Coordinated Agricultural Project (CAP). NCSU portion $548,819. Conifer Translational Genomics Network. 9/07 to 9/11

Sunkyu Park, Ross Whetten, Steve McKeand, Fikret Isik. Economic Analysis of Pine Biomass Feedstocks for Ethanol Production. $ 162,438. Biofuels Center of North Carolina. 10/09 to 9/11.

Fikret Isik is a co-principal investigator with Vincent Chiang and Ron Sederoff on a NSF Plant Genome grant, Regulation and Modeling of Lignin Biosynthesis. 09/09 to 08/13.

New Grants

Steve McKeand and Josh Steiger. Funding from USDA Forest Service for “Progeny Testing of Longleaf Pine Seed Orchards”. $40,000 from 7/10 to 6/11.

Ross Whetten , Steve McKeand, Fikret Isik. Subcontract with the University of Florida, USDA Coordinated Agricultural Project (CAP) “Integrating research, education and extension for enhancing southern pine climate change mitigation and adaptation”. TIP portion $ 867,665. Climate Change, 3/11 to 2/16.

Steve McKeand, Bronson Bullock, Ross Whetten, and Fikret Isik. Biofuels Center of North Carolina. “Loblolly Pine Biomass Genetics/Cropping Study”. $148,419. 7/11 to 9/14.

Associated Activities

Meetings, Workshops and Short Courses

The last week of October 2010 we joined forces with the Forest Productivity Cooperative and had our PRS workshop and the annual Contact meeting in New Bern, NC. The half day PRS workshop was for members that wanted to know more about the Performance Rating System, how to use it, and describing the new temperature ranges associated with selections. A combined field tour at the Hofmann forest had more than 100 folks out in the field looking at *Eucalyptus* screening trials and the GST (Genetics x Spacing x Thinning) Study. In spite of the mosquitos almost carrying everyone away, we had a successful trip and came back to Eastern NC BBQ by the Trent River.

Contact Meeting at the Hofmann Forest

Tori, Josh, and Jadie at the TIP display during the NCSU Earth Day celebration.

On April 12, NC State Tree Improvement helped host a workshop at the Hofmann Forest in conjunction with NC Tree Farm Association titled “Genetics and Silviculture of Loblolly Pine”. Forest landowners learned how forest productivity is impacted by resource availability, what genetic options are available, and how to manage the improved genetics. Through these types of workshops, we continue to spread the word about the benefits of Cooperative Tree Improvement efforts in the Southeast and stressing the importance of being an informed landowner.

For the first time Tree Improvement made an appearance, or shall we say an impression, at the NCSU Earth Day celebration held on April 15, 2011. We took the information from some very recent research that Mike Aspinwall (recent PhD graduate supported by the Cooperative), Steve McKeand, and John King are publishing to the NCSU “Brickyard” to educate the visitors about the increased carbon uptake of genetically improved pine. The big message was ***increased productivity = increased carbon sequestration***; as we continue to improve pine, we will also continue to increase carbon uptake.

NCSU student participating in our Earth Day event

Tree Improvement Staff, left to right: Fikret Isik, Tori Batista-Brooks, Steve McKeand, Jim Grissom, Josh Steiger, J.B. Jett, Saul Garcia, and Ross Whetten.

Staff

We have been running lean this year being one man down after Patrick Cumbie's departure and over three months of Tori Brooks' absence during maternity leave. But the good news was that we had two great people step in to help out with the administrative duties and keep us all in line, Eileen Broderick and Carolina Thomson - they are the best! We are also still looking to fill the Associate Director position as soon as possible, but with state funding in jeopardy, we are entering into this endeavor very carefully.

Teaching

Teaching both graduate and undergraduate courses is at the center of a University. Faculty associated with the Cooperative teach a wide array of courses. Steve McKeand and Ross Whetten teach FOR 411 (Forest Tree Genetics and Biology), our undergraduate tree improvement course and FOR 725 (Forest Genetics – formerly FOR 611). Ross also taught FOR 350, Professional Development III: Ethical Dilemmas in Natural Resource Management. Fikret Isik taught NR554, Introduction to Data Analysis. J.B. Jett taught FOR727 Tree Improvement Research Techniques.

J.B. teaches his FOR 727 course the skill of grafting.

Faculty and recent PhDs: Ross Whetten, Steve McKeand, Jin Sherry Xiong, Patrick Cumbie, Barry Goldfarb (Head of Forestry Department).

Graduate Students

We continue to support forest research and the training of individuals who will impact the future of forestry. This past year was a banner year for graduating Tree Improvement students: Mike Aspinwall (PhD), Patrick Cumbie (PhD), George Khan (MS), Ben Smith (PhD), and Jin Sherry Xiong (PhD) all received their degrees. Mike is a post-doc at the University of Texas. Patrick is a senior scientist with ArborGen in Summerville, SC. George is a research technician in College of Agriculture and Life Sciences here at NCSU. Ben is a post-doc with the new Alliance for Saving Threatened Forests at NC State. Sherry is a Quantitative Geneticist at Dow AgroSciences in Indianapolis. We are proud of all these folks and their outstanding accomplishments.

Current Students

David Barker, PhD – Genetic differences in loblolly pine for conversion efficiency for cellulosic ethanol.

Aaron Chamblee, MS – Evaluating geographic variation in resistance to fusiform rust disease using the Plantation Selection Seed Source Study.

Graham Ford, MS – Inbreeding effects in loblolly pine

Daniel Gräns, PhD Candidate – Evaluating solid wood properties in loblolly pine and Norway spruce.

Funda Öğüt, PhD – Molecular aided selection and breeding in loblolly pine.

Josh Steiger, MS – Impacts of different levels of genetic homogeneity in loblolly pine in a genetics x spacing x thinning trial in Eastern, NC.

Jaime Zapata, PhD Candidate – Develop breeding strategies that incorporate molecular markers into the selection process.

Membership in the NCSU Cooperative Tree Improvement Program

The full members of the program provide financial support to the University and the in-kind support to make tree improvement happen in the field. Their financial contributions to NC State University support the operations, research, teaching, and outreach components of the program. Support from the Contributing Members is used primarily for the on-the-ground breeding, testing, selection, and archiving efforts by the full members and the Cooperative staff. We could not ask for a more dedicated and supportive group of cooperators.

The newest Contributing Member in FY2011 is Timberland Investment Resources , LLC (TIR).

Full Members

ArborGen

CellFor, Inc.

Georgia Forestry Commission

Hancock Timber Resources Group

North Carolina Division of Forest Resources

Plum Creek Timber Company

Rayonier, Inc.

Tennessee Department of Agriculture

Virginia Department of Forestry

Westervelt Company

Weyerhaeuser Company

Contributing Members

American Forest Management

Biofuels Center of North Carolina

Dougherty & Dougherty Forestry Services, Inc.

International Forest Company

Jordan Lumber & Supply Company

Milliken Forestry Company

Molpus Timberlands Management, LLC

North Carolina Natural Resource Foundation

Pacolet Milliken Enterprises

ProFor

Resource Management Service, LLC

Scotch Land Management, LLC

South Carolina Forestry Commission

Timberland Investment Resources , LLC

Z.V. Pate, Inc.

Publications of Special Interest to Members (2011-2009)

From our inception in 1956, there have been over 800 publications written by Cooperative Scientists, Students, and Associates. Below is a list of publications from the last 3 years. The entire list is available at our web site: http://www.treeimprovement.org/publications

2011

Aspinwall, M.J., J.S. King, J-C. Domec, S.E. McKeand and F. Isik. 2011. Genetic effects on transpiration, canopy conductance, stomatal sensitivity to vapor pressure deficit, and cavitation resistance in loblolly pine. Ecohydrology. Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/eco.197.

Aspinwall, M.J., J.S. King, S.E. McKeand, and B.P. Bullock. 2011. Genetic effects on stand-level uniformity, and above- and belowground biomass production in juvenile loblolly pine. Forest Ecology and Management. (in press).

Aspinwall, M.J., J.S. King, S.E. McKeand, and J-C. Domec. 2011. Leaf-level gas-exchange uniformity and photosynthetic capacity among loblolly pine (Pinus taeda L.) genotypes of contrasting inherent genetic variation. Tree Physiology. 31: 78-91.

Isik, F., C.R. Mora, and L.R. Schimleck. 2011. Genetic variation in *Pinus taeda* wood properties predicted using non-destructive techniques. Online first: DOI 10.1007/s13595-011-0035-9.

Mullin, T.J., Andersson, B., Bastien, J.-C., Beaulieu, J., Burdon, R.D., Dvorak, W.S., King, J.N., Kondo, T., Krakowski, J., Lee, S.D., McKeand, S.E., Pâques, L., Raffin, A., Russell, J., Skrøppa, T., Stoehr, M., and Yanchuk, A.D. 2011. Economic importance, breeding objectives and achievements. Chapter 2 In: Genomics of Conifers. Edited by: C. Plomion and J. Bousquet. Volume in Genomics of Industrial Crops, Series editor: C. Kole. Science Publishers, Inc., New Hampshire; Edenbridge Ltd., UK. (in press).

2010

Aspinwall, M.J., B. Li, S.E. McKeand, F. Isik, and M.L. Gumpertz. 2010. Prediction of whole-stem α-cellulose yield, lignin content, and wood density in juvenile and mature loblolly pine. South. J. Appl. For. 34:84-90.

Cumbie, W.P, A.J. Eckert, J.L. Wegrzyn, R.W. Whetten, D.B. Neale, and B.Goldfarb. 2011. Association genetics of carbon isotope discrimination, height, and foliar nitrogen in a natural population of *Pinus taeda* L. Heredity advance online publication 19 January 2011; doi: 10.1038/hdy.2010.168

Dougherty, D., R. Bryant, H. Burkhart, P. Dougherty, S. Jones, S. McKeand. 2010. Valuing tomorrow's loblolly pine plantations today. Forest Landowner. Jan./Feb. 2010: 19-21.

Eckard, J.T., F. Isik, B. Bullock, B. Li, and M. Gumpertz. 2010. Selection efficiency for solid wood traits in *Pinus taeda* using time-of-flight acoustic and micro-drill resistance methods. For. Sci. 56(3), 233-241.

McKeand, S., P. Cumbie, and B. Abt. 2010. Investment in genetically improved loblolly pine – landowner benefits today and for generations to come. Forest Landowner. Jan./Feb. 2010: 27-29.

Nelson, C.D., T. L. Kubisiak, and H. V. Amerson. 2010. Unravelling and managing fusiform rust disease: a model approach for coevolved forest tree pathosystems. For. Path. 40: 64–72.

Whetten, R.W. and R. Kellison. 2010. Research gap analysis for application of biotechnology to sustaining US forests. J. Forestry 108(4):193-201.

Xiong, S.J., F. Isik, S.E. McKeand and R.W. Whetten. 2010. Genetic variation of stem forking in loblolly pine. For. Sci. 56: 429-436.

2009

Bains, B., F. Isik, W. Strong, B. Jaquish, J.A. McLean, Y.A. El-Kassaby. 2009. Genetic susceptibility of spruce to gall forming adelgids (Hemiptera: Adelgidae). Can. J. Forest Research.39: 2536-2541.

Barker, D.K., S.E. McKeand, F. Isik, and R.W. Whetten. 2009.Analysis of biomass production in young loblolly pine. P. 66-68. In: Proc. 30th South. For. Tree Impr. Conf., Blacksburg, VA.

Cumbie, P.W., R. Whetten, B. Goldfarb, A.J. Eckert, J.L. Wegrzyn, and D.B. Neale. 2009. Association genetics of water relations and growth phenotypes in loblolly pine. P. 33-37. In: Proc. 30th South. For. Tree Impr. Conf., Blacksburg, VA.

Frampton, L.J, F. Isik, M. Benson, and AM Braham. 2009. Variation in resistance to Phytophthora root rot within Turkish and Trojan Fir. The IUFRO 9th International Christmas Tree Research and Extension Conference. 14-18 September 2009, Corvallis, OR. USA.

Gräns, D., B. Hannrup, F. Isik, S-O Lundqvist, and S. McKeand. 2009. Genetic variation and relationships to growth traits for microfibril angle, wood density, and modulus of elasticity in a Norway spruce (*Picea abies*) clonal trial in southern Sweden. Scandinavian J. For. Res. 24(6): 494-503.

Isik, F., H. Amerson, R. Whetten, S. Garcia, S. McKeand. 2009. Fusiform rust Fr genes by bulked inocula interactions in loblolly pine. P. 104-106. In: Proc. 30th South. For. Tree Impr. Conf., Blacksburg, VA.

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Perhaps no picture better illustrates the influence that Bruce Zobel has had on the lives of people from around the world. At the November 2004 IUFRO Joint Conference of Division 2, *Forest Genetics and Tree Breeding in the Age of Genomics: Progress and Future* in Charleston, SC, some of Bruce's former students, postdocs, visitors, friends, and NC State faculty and alumni joined Bruce and Barbara Zobel to thank them for all their contributions. We are all better foresters, tree breeders, scientists, and people because of what we learned from Bruce.

Bruce has inspired us with his work and accomplishments. Clockwise from upper left: early days as a tree breeder in Texas, 1975 TAPPI Gold Medal recipient, 1991 Camcore meeting in Guatemala, 2004 NCSU Holladay Medal recipient, ceremonial tree planting at the 50th Annual Meeting of the NCSU Cooperative Tree Improvement Program, and with his beloved wife Barbara at their mountain retreat.

We'll Miss You Bruce
We Thank You Bruce