FOREST RESEARCH REVIEW

April 2009

VDOFs first mass controlled-pollination effort in the third-cycle loblolly pine seed orchard at the New Kent Forestry Center.

IN THIS ISSUE...

VDOF Research Program

Welcome to the latest edition of the Virginia Department of Forestry's Research Review. Since last fall's publication, the research staff has been busy installing new studies on topics of interest and collecting year-end measurements on our existing plots. In January, we installed a mid-winter test of the basal spray technique we have found successful at other times of the year for controlling tree-of-heaven. In March, we completed the fertilizer applications on our massive test of thinning intensity and stand nutrition at the Appomattox-Buckingham State Forest; thinning was completed in February. We have also installed a follow-up test of the successful tipmoth control insecticides we reported on in the last issue – this time in a 3-year-old stand.

As we go to press, we are in the midst of VDOF's first year of mass-controlled pollination (MCP) for loblolly pine seed production. MCP is a tree breeding technique that increases genetic gains compared to traditional wind-pollination. Female flowers are isolated in pollinating bags (cover photo) to prevent contamination from wind-blown pollen and then fresh pollen from the best male parents are introduced into the bags with a specialized delivery mechanism. The resulting seedlings will be more uniform in growth and vigor because variation caused by uncontrolled pollen sources has been removed. We hope to offer Virginia forest landowners additional gains of 10 to 20 percent or more in volume and sawtimber quality over second- and third-generation, open-pollinated (OP) seedlings from our nurseries.

This issue will provide updates on a number of our ongoing tests. First, we'll summarize some recent publications from the Tree Improvement and Forest Nutrition cooperatives, in which VDOF participates. We'll report on the status of our American Chestnut breeding program and the third year of results from our longleaf pine provenance study. In addition, we'll summarize the response of southern red oak to crop-tree release and fertilization; the most recent data from our studies of biosolids applications and interplanting in loblolly pine, and first-year growth data from our tipmoth control tests.

As always, we hope you'll find the information useful. Please let us know if you have any questions or comments, and visit http://www.dof.virginia.gov/research/index.shtml to browse all of the publications, fact sheets and analytical tools delivered by the VDOF Research Program. And remember that we continue to post occasional updates and other observations/commentaries on the Virginia Forests Blog at http://virginiaforests.blogspot.com/ - check it out between issues of the review!

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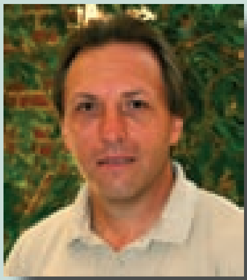

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Genetically Improved Loblolly Pine – Have We Reached our Limit?

Steve McKeand - Director, NC State University Cooperative Tree Improvement Program, Professor of Forestry and Environmental Resources, NC State University

The simple and emphatic answer to this question is NO. We have not come close to reaching the potential genetic gains in productivity, disease resistance and quality traits with breeding programs for loblolly pine in Virginia and throughout the South. Through the application of traditional breeding methods used in agronomic and horticulture crops for decades, tree breeders have developed families or varieties of loblolly pine that produce 30 to 50 percent more wood per acre than what was available 40 years ago. These families are more resistant to fusiform rust disease, have better wood quality due to enhancement of straightness and disease resistance, and are widely adapted to a range of site types and forest management regimes. Virginia landowners plant more than 70,000 acres with loblolly pine seedlings each year, and every seedling comes from the breeding programs of the members of the NC State University Cooperative Tree Improvement Program.[1]

When the best genetic material is planted and given the necessary resources, growth rates of 300 cubic feet per acre per year (approximately eight tons per acre per year) can be readily achieved on many sites. Today's plantations are growing more than twice as fast as plantations of the previous rotation.

Depending on the site quality, forest management inputs and the market prices for harvested products, compared to average families that most landowners plant, we estimate that **the best families are worth between $50 to $300 per acre in present value** (*see McKeand et al. 2006, Journal of Forestry 104:352-358 for details*). Planting the best families can result in substantial increases in site productivity (as much as a 10-foot increase in site index, base age 25 years) and increase the percentage of very straight trees that will increase the number of sawlogs harvested per acre to as much as 80 percent.

[1] Members of the NC State Tree Improvement Cooperative have breeding programs for loblolly pine from Virginia south to Florida and west to Mississippi and Tennessee.

One absolute is that not all loblolly pine families are created equal. There is tremendous genetic variation among families of loblolly pine for almost all traits. If there are 30 families available to plant, there will be a best family, second-best, third-best and so on for each trait (e.g. growth, rust resistance and stem form). All the families from a seed orchard will be good and should be adapted to your region, but some will be better than others.

So where are we with our loblolly pine tree improvement programs? Compared to breeders in agronomic crops, such as corn, soybeans, cotton and wheat, we have just begun our genetic improvement programs in forest trees (see Figure 1). The Cooperative Tree Improvement Program at NC State started the breeding effort for loblolly pine in 1956. As we begin the 4th generation of breeding, there is still much more gain to be made to increase the value of loblolly pine to landowners.

So, what are the limitations and constraints to continued genetic gain in loblolly pine? The primary threat to the continuation of gain and increased

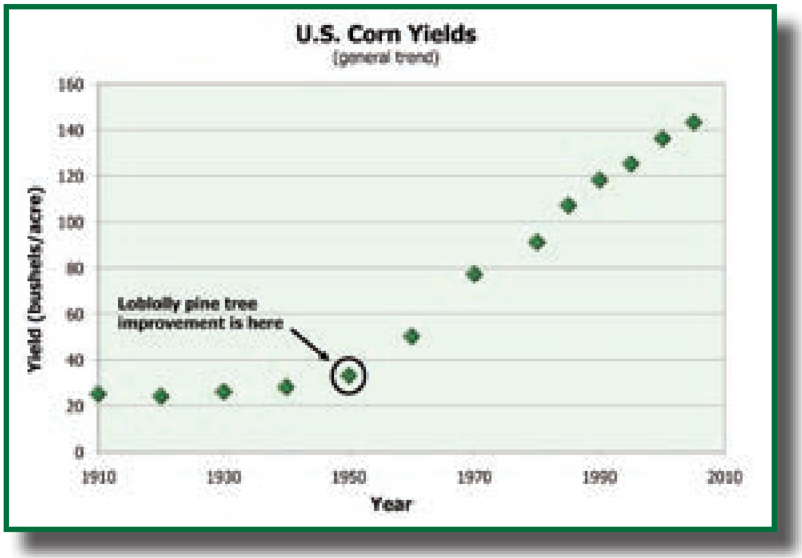

Figure 1. Trends in US corn yields by generation of genetic improvement from 1910 to 2005. Fourth generation highlighted for comparison with progress of loblolly pine tree improvement (currently in the 4th generation).

profit to landowners is the likely reduction in effort by tree improvement programs in the region. As the forest industry has transformed with mergers and consolidations, the number of tree improvement, seed orchard and nursery programs has decreased dramatically. Compared to only 20 years ago, the number of companies and state agencies actively involved in the NC State Cooperative's breeding program has gone from 29 to 12. In Virginia, there is only one organization (VDOF) that is actively breeding trees for our landowners. In the 1990s, there were five.

With the current, aggressive breeding programs in the Cooperative, we estimate that the value of plantations established increases about one percent each year (i.e. the trees planted this year are one percent more valuable than the trees planted last year). This is due to better genetic material being generated from the breeding programs every year. For instance, seedlings available in the 2008-09 planting season came from the cone crop harvested in 2007 when 2nd-generation seed orchards contributed about 77 percent of the total seed, and the higher-valued 3rd-generation orchards produced about 12 percent of the seed crop. Third-generation seeds will make up a higher percentage of the crop in the coming years, and will produce faster-growing, higher-quality, more valuable plantations.

The economic consequence of reducing the effort in tree breeding is staggering. If the genetic gain per year is reduced to any extent, the regional financial impacts are worth millions of dollars. For example, the present value of a series of continuously improved plantations[2] was estimated to be $12,255 per planted acre (i.e. a non-ending series of genetically better plantations of one acre being planted each year). If these same plantations were established with the same genetic quality of seedlings each year (i.e. genetic improvement stopped so that the genetic gain is reduced from one percent per year to zero percent per year), the present value would be $10,262 per acre planted or $1,993 per acre less since all future seedlings would be the same as those planted today.

While it is not likely that tree improvement will stop, there is no question that tree improvement progress could slow down considerably. If efforts were scaled back only slightly, so that genetic gain is reduced from one percent per year to 0.9 percent per year, the present value loss to a landowner would be $232 per acre planted per year. For Virginia, where 70,000+ acres of loblolly pine are planted each year, the lost opportunity would be more than $16,240,000 of present value. For the entire South, where about 1.2 million acres of loblolly pine are planted each year, the loss in value to all landowners from this slight reduction in genetic improvement would be $288,963,723.

We are fortunate in Virginia that the VDOF is a long-term and aggressive supporter of tree improvement. In the Cooperative, we diligently work to maintain the intensive efforts in breeding and production of improved genetic stock so that forest landowners will not suffer lost financial benefits in future plantations, and all citizens of Virginia will benefit from more productive and profitable forests.

Effects of Thinning and Urea and Control Release Fertilizer Applications on the Growth of Mid-rotation Loblolly Pine in the Virginia Piedmont

Colleen Carlson and Tom Fox, Forest Nutrition Cooperative Research Note 31

This report summarizes 3.5 years of growth responses to thinning and mid-rotation fertilization in a loblolly pine stand located on the Piedmont. The treatments included an untreated control; a thinned treatment without fertilization, and a factorial combination of nitrogen (N) fertilizer type (urea or controlled release urea) and timing of application (summer and winter). At study installation, the trees were 22 years old and the stand had a basal area of 189 ft.^{2}/acre.

Thinning had the greatest impact on tree growth. Both mean diameter increment and mean tree volume showed significant positive responses to thinning. There was no statistically verifiable response to fertilization. Mean tree volume was significantly less in the unthinned-unfertilized treatments, and slow diameter growth and mortality

[2] Assumptions are: one percent gain/year in stumpage value due to genetics; a base stumpage value of $2,500 per acre harvested at 25 years; a six percent interest rate, and the forestry plantation program is continuous for 100 years (effectively an infinite series of annual payments of stagnant or increasing stumpage values).

have resulted in the unthinned plots stagnating at just less than 185 $ft.^2$/acre. None of the treatments affected height increment. The mean tree volume increment was greater with summer compared to the winter fertilizer application.

The lack of statistically significant fertilizer response is surprising. Other studies have shown responses to nitrogen applications in established stands on the Piedmont. Possible reasons for the lack of response include adverse weather conditions during and after the fertilization (no records); the chosen stand was not limited by nutrients and consequently was not responsive to fertilization; the experimental design and inherent stand variability were not sufficiently sensitive in detecting the response, or the complete hardwood vegetation control that was conducted prior to trial establishment, which could have resulted in decomposing vegetation adding to the nutrient pool across all treatments thus making the difference between the control plots and the fertilized plots less apparent.

Genetics and Restoration

American Chestnut Breeding Program

Wayne Bowman, research forester, Virginia Department of Forestry

The Department of Forestry's efforts into the chestnut work began in 1969 when Tom Dierauf first began collaborating with the Connecticut Department of Agriculture and planted hybrid chestnuts on the Lesesne State Forest in Nelson County. Since 1969, breeding work has continued uninterrupted at the Lesesne as large surviving American chestnuts from throughout Virginia have been crossed with these original hybrid chestnuts and their off-spring. The goal is to breed the blight resistance from the Chinese chestnut tree while keeping the form of the American chestnut tree. The end tree would be blight resistant with the shape and form of the pure American tree. Today, we have a few 15/16th American chestnut seedlings from this work and we continue to develop more. The 15/16th trees will be crossed with other 15/16th trees. A small percentage of their offspring should be resistant to the chestnut blight and look like the pure American chestnut tree. This cross could be possibly 10 to 20 years away at the current rate the VDOF program is progressing. Those trees would be planted in test blocks to determine exactly how resistant they will be to the blight.

In 2008, we bagged and crossed more than 2,200 (7/8th and 15/16th American) hybrid chestnut flowers at Lesesne. We planted more than 600 15/16th American chestnuts from the American Chestnut Foundation's (TACF) Virginia research farms inside an eight-foot-tall woven wire fence on the Matthews State Forest. Another 7,000 pure and hybrid American chestnut nuts were seeded at our Augusta nursery for TACF and were just lifted this spring to be put on test sites.

Most recently – this March – the Department of Forestry planted more than 800 American chestnut seedlings from the 2008 crop at both the Lesesne orchard in Nelson County and at the New Kent Forestry Center. They consist of 7/8th and 15/16th American chestnut crosses (Figure 2).

In summary, the Department of Forestry continues to actively collect pollen from known large surviving American chestnut trees in Virginia and use this pollen in making crosses on hybrid chestnut trees at our Lesesne State Forest. We continue cooperating with other groups and organizations making space available for research and testing sites. We all have the same goal: a resistant American chestnut tree planted back in Virginia's forest.

An excellent overview of the efforts by the American Chestnut Foundation and the USDA Forest Service can be found in the June, 2008 issue of Compass (http://www.srs.fs.usda.gov/compass/issue11/issue11.pdf).

Figure 2. A 15/16th American chestnut hybrid planted at the Lesesne State Forest breeding orchard.

Longleaf Provenance Study

In the March 2008 issue, we presented early data from our longleaf pine provenance study at Sandy Point State Forest, and the New Kent and Garland Gray forestry centers (Figure 3). The goal of this work is to assess the effect of geographic seed origin from the entire range of longleaf pine on establishment success and growth and yield in Virginia. Eight different geographic sources of longleaf are being compared in 25 tree plots replicated twice at each of the three locations.

After three years of growth, the results continue to show that seed collected in Southampton County from some of the few remaining native Virginia longleaf has outperformed all other seed sources in terms of survival, mean tree height and emergence from the grass stage (Table 1, Figures 4 and 5). Based on these results, we recommend planting native Virginia seedlings if available.

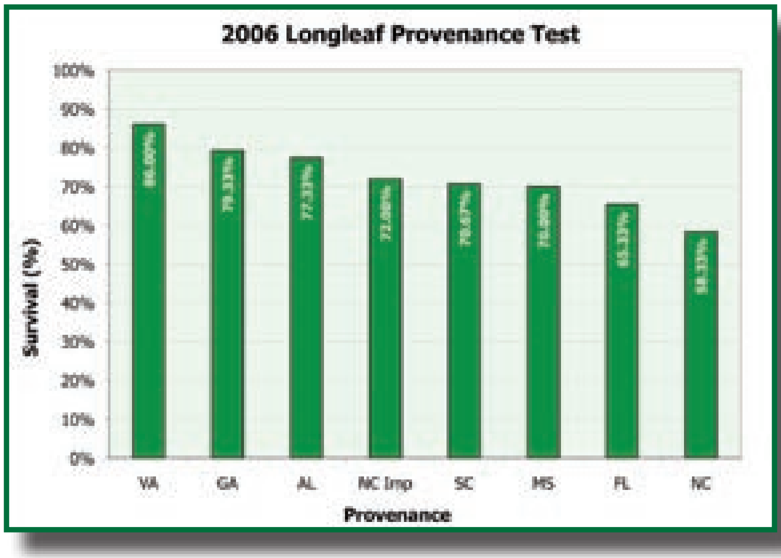

Figure 4. Survival after three growing seasons of longleaf pine from eight geographic sources when planted in Virginia.

Figure 3. The longleaf provenance study New Kent Forestry Center location.

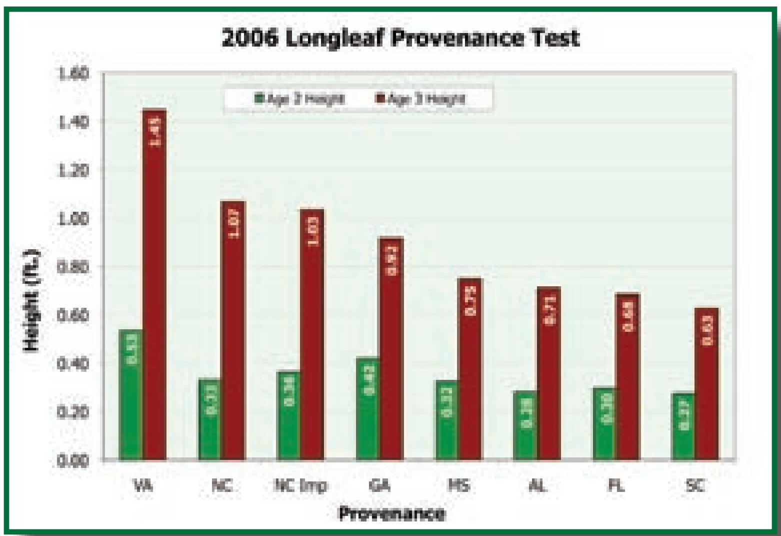

Figure 5. Average tree height after three growing seasons of longleaf pine from eight geographic sources when planted in Virginia.

Table 1. Longleaf pine provenance study New Kent Forestry Center location.

Location	Survival (%)	Height (ft.)	Out of Grass Stage (%)
Southampton Co., VA	86.00	1.45	80.67
Genetically Improved Stock, NC	72.00	0.75	54.67
Richmond Co., NC	58.33	0.92	65.33
Dorchester Co., SC	70.67	0.68	54.67
Forest Co., MS	70.00	1.07	55.56
Talladega Co., AL	77.33	0.63	60.67
Colquitt Co., GA	79.33	1.03	66.00
Santa Rosa Co., FL	65.33	0.71	61.33

Effects of Biosolid Applications on Growth and Foliar Nutrient Concentrations in Thinned Mid-Rotation Loblolly Pine

A year ago we reported early results from a study installed in October 2006 to compare the effects of biosolid applications and traditional inorganic fertilizer (urea + diammonium phosphate (DAP)) on the growth of thinned mid-rotation loblolly pine. The plots (Figure 6) were installed in western Essex County in a recently-thinned (summer 2006) loblolly pine stand. The experimental design is a randomized complete block with four replications of four treatments (all applied in June of 2007): 1) no application; 2) urea + DAP at a rate of 200 lbs./acre of nitrogen; 3) lime-stabilized biosolid material from Arlington, VA, applied at 200 lb./acre of plant available nitrogen (PAN), and 4) biosolids at 400 lbs./acre PAN.

Total height, crown height and diameter were measured on each tree in the tenth-acre measurement plots in the winter of 2006-2007 and again one and two years later. As Table 2 and Figure 7 show, there has been a statistically significant early effect of added nutrients. The fertilized (either with biosolids or traditional inorganic fertilizers) plots have grown about 36 percent more in diameter than the untreated plots. Although statistically not significant, there are also trends emerging to suggest that fertilized trees are also growing more in height and retaining a larger live crown.

Of even greater interest are the recent results of foliar nutrient analyses conducted on pine needle samples collected from each plot before treatment and again one year after treatment. With the invaluable help of our colleagues with the Forest Nutrition Coop at Virginia Tech, we were able to verify that the pine trees in fertilized plots exhibit significantly increased concentrations of nitrogen and phosphorus (Table 3, Figure 8) compared to the untreated plots. In particular, it appears that nitrogen may have been a growth-limiting factor, as it was below the accepted critical level of 1.10 percent before treatment. Additions of fertilizers have raised this level to nearly 1.4 percent on some plots.

Of even greater interest are the recent results of foliar nutrient analyses conducted on pine

Figure 6. One plot of the 2006 study treated with biosolids at 200 lb./acre of plant-available nitrogen.

Table 2. Loblolly pine growth responses two growing seasons after application of two rates of biosolids and inorganic urea plus DAP fertilizer.

Treatment	DBH Growth (in.)	Height Growth (ft.)	Live Crown Ratio (%)
untreated	0.33	0.9	40.2
200 lb. biosolids	0.46	2.9	40.3
400 lb. biosolids	0.45	2.1	41.3
urea + dap	0.44	3.8	42.3

needle samples collected from each plot before treatment and again one year after treatment. With the invaluable help of our colleagues with the Forest Nutrition Coop at Virginia Tech, we were able to verify that the pine trees in fertilized plots exhibit significantly increased concentrations of nitrogen and phosphorus (Table 3, Figure 7) compared to the untreated plots. It appears that nitrogen may have been a growth-limiting factor, as it was below the accepted critical level of 1.10 percent before treatment. Additions of fertilizers have raised this level to more than 1.6 percent on some plots.

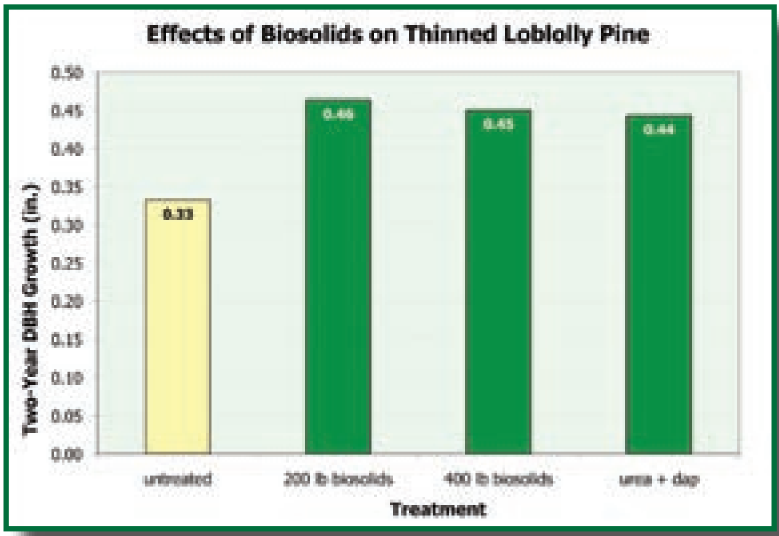

Figure 7. Average loblolly pine diameter growth two years after treatment in the 2006 biosolids plots.

Table 3. Foliar nutrient concentrations in loblolly pine needles before (2006) and one year after (2007) application of biosolids and inorganic fertilizer.

Treatment	Nitrogen			Phosphorus		
	2006	2007	Change	2006	2007	Change
untreated	1.0832	1.1797	0.0965	0.1104	0.1187	0.0083
200 lb. biosolids	1.0389	1.4213	0.3824	0.1159	0.1356	0.0197
400 lb. biosolids	1.0786	1.5565	0.4780	0.1046	0.1296	0.0251
urea + dap	1.0203	1.6106	0.5903	0.1049	0.1367	0.0318

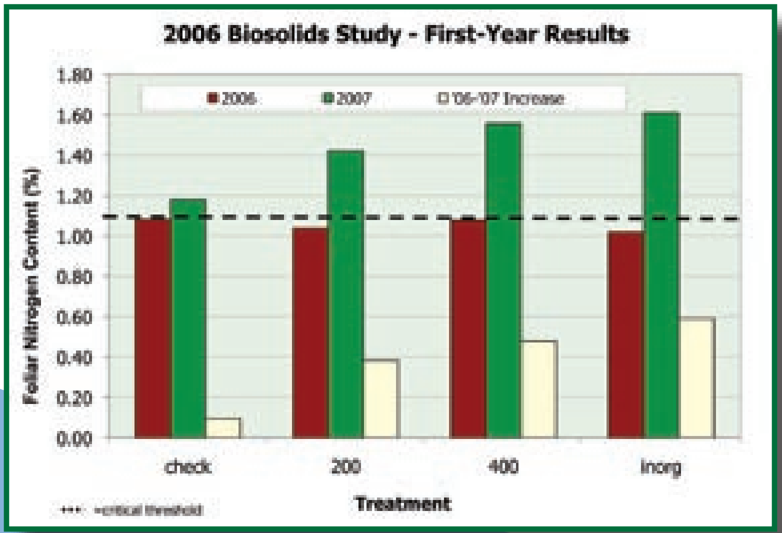

Figure 8. Average nitrogen concentration in loblolly pine needles before and one year after treatment on the biosolids study plots.

Interplanting Loblolly Pine Seedlings in Reduced-Density One-Year-Old Stands

The VDOF research program has published results from two interplanting studies in Occasional Reports 53 (1980) and 106 (1992). In the April 2008 issue of the research review, we reported early results from our follow-up study installed in response to concerns that the results may be different in today's plantations that are established at lower initial densities.

In the recent study, the initial planting had occurred in March 2006 and interplanting was done by the research team in April 2007. The existing stand had a surviving pine density averaging 451 trees per acre. We installed tenth-acre square plots in a randomized complete block design with four replications testing four treatments: 1) no interplanting; 2) reduce density to 300 tpa and interplant in empty spots; 3) reduce density to 200 tpa and interplant in empty spots, and 4) reduce density to 100 tpa and interplant in empty spots. To accomplish the density reductions, we pin flagged all surviving trees and randomly pulled up enough to reach the target density. We then replaced the trees that had been pulled up with an interplant.

Two growing seasons after interplanting (in December 2008, when the original stand was three years old), we again tallied survival and heights of these seedlings. The results are summarized in Table 4 and Figure 9, and show the interplanted seedlings – while still not "catching up" to the original seedlings – have continued to survive and are growing in height. They average around three feet shorter than the original seedlings, but survival seems to have stabilized at more than 90 percent. Under the fairly ideal conditions of this controlled study (i.e. with the research crew interplanting seedlings at exactly the correct spacing to fill in only the empty planting spaces), there may be hope that some of these interplants can contribute to the final stand. We will continue to check the plots annually to determine if and when a clearer answer emerges.

Keep in mind that it would be difficult to get a planting crew to seek and plant only larger openings at exactly the spacing of the original stand. In practice, they would more likely plant a specified number of seedlings per acre to bring the density back to some target (in this study, 450 trees per acre) and as a result would likely achieve a much more patchy stand distribution. Some interplants would be planted close to existing seedlings causing overstocking, which could tend to offset any benefits from seedlings correctly planted where needed. The solution is to plan for and achieve adequate survival the first time around so that interplanting does not have to be considered.

Table 4. Comparison of heights and survival two years after interplanting in the 2007 study.

Trees per Acre	Average Height (ft.)		Survival (%)	
	Originals	Interplants	Originals	Interplants
100	4.95	2.07	100.00	90.07
200	5.58	2.56	100.00	97.03
300	5.73	2.67	96.67	96.00
450 * (check)	5.40		97.25	
* = Original stand, no interplanting				

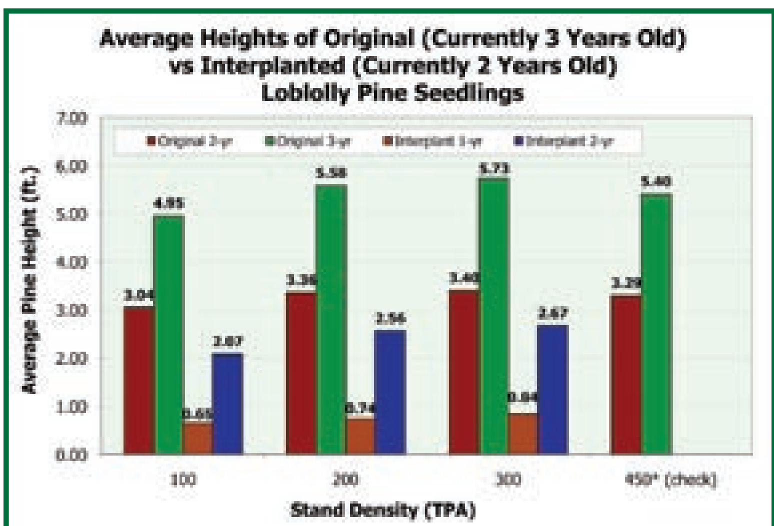

Figure 9. Average total heights of original (red, green) and interplanted (rust, blue) seedlings from the 2007 interplanting study one (2007) and two (2008) growing seasons after the study was installed.

Tipmoth Control Study – Year-End Results

In the last issue of the review, we reported on two successful new treatments for controlling Nantucket pine tipmoth (*Rhyacionia frustrana*). Both products (BASF's PTM, a liquid containing fipronil, and Bayer Environmental Science's SilvaShield, a tablet containing imidacloprid) are systemic and prevented infestations through at least one growing season.

The primary objective of this ongoing research is to determine the effectiveness of these products and (if effective) assess the duration of protection they provide. Associated with this objective is the need to evaluate the growth response to treatment so that interested parties can evaluate the financial thresholds and returns. Treatments included an untreated control plot, PTM (at all sites) and SilvaShield (at five sites). Tipmoth damage (percentage of shoots infested) was evaluated for each of three generations during the growing season and seedling height and groundline diameter (GLD) were assessed after the 2008 growing season. The data were analyzed using analysis of variance (ANOVA).

Table 5 summarizes the data and results of the statistical analyses for the year-end evaluation. Two of the sites (Camp Community College and the Clay Tract in Campbell County) experienced only light tipmoth activity.

Figure 10 shows the average percentage of shoots damaged at the end of the 2008 growing season on the four sites experiencing tip moth damage. At all four, both SilvaShield and PTM reduced (and nearly eliminated) tipmoth damage during the first growing season. Averaged across those sites, unprotected seedlings are suffering considerably more damage (33 percent of shoots) than those treated with either of the insecticides (1.39 and 2.63 percent with SilvaShield and PTM, respectively). The results are highly statistically significant (Pr>F of 0.01 or less) at all four sites.

Research conducted in Georgia and reported in the Southern Journal of Applied Forestry has shown that significant reductions in volume can occur even in trees with relatively low damage levels (10 to 30 percent of shoots infested on average over a three-year period). The results of that analysis suggest that an economic injury level for tipmoth may be reached when damage levels, on average, exceed 30 percent infested shoots (Figure 11 and 12). The first-year damage in the current study averages 33 percent.

Survival has been improved by insecticide treatment at half of the sites; at the Clay location, heavy mortality associated with pales weevil appears to have been prevented by the treatments. Although the trees have only one year in the field, height and GLD have been slightly increased by the tipmoth protection – a result that is statistically significant on three and two sites, respectively.

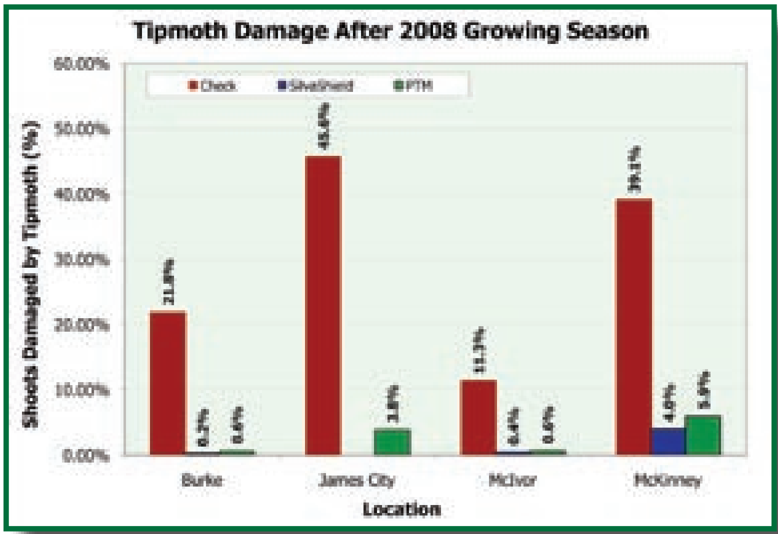

Figure 10. Tipmoth damage (percent of shoots) at four locations after the 2008 growing season.

Table 5. Summary by location of first-year results from the 2008 VDOF tipmoth control study.

Location	Tipmoth (%)				Location	Survival (%)			
	Control	Silva Shield plant	Silva Shield adj	PTM		Control	Silva Shield plant	Silva Shield adj	PTM
Burke [a]	21.8	0.2		0.6	Burke [a]	87.0	99.0		96.0
Clay [ns]	5.5	0.0		2.4	Clay [ns]	33.0	75.0		84.0
James City [a]	45.6			3.8	James City [a]	62.0			79.0
McIvor [a]	26.0	0.0		0.2	McIvor [a]	80.0	90.0		96.0
McKinney [a]	39.1	4.0	4.28	5.9	McKinney [a]	90.6	90.7	88.89	85.3
PDCC [ns]	1.9	0.0		0.0	PDCC [ns]	89.8	74.0		81.0
Location	Height (ft.)				Location	Groundline Diameter (in.)			
	Control	Silva Shield plant	Silva Shield adj	PTM		Control	Silva Shield plant	Silva Shield adj	PTM
Burke [ns]	1.1	1.1		1.1	Burke [a]	0.30	0.28		0.27
Clay [ns]	1.1	1.1		1.2	Clay [ns]	0.30	0.27		0.33
James City [b]	1.2			1.5	James City [a]	0.38			0.43
McIvor [a]	1.3	1.5		1.6	McIvor [a]	0.36	0.38		0.44
McKinney [c]	1.7	2.1	2.0	1.9	McKinney [a]	0.52	0.58	0.55	0.56
PDCC [ns]	1.1	1.0		1.0	PDCC [ns]	0.26	0.23		0.24
ANOVA Pr>F: a=<0.01; b=<0.05; c=<0.10; ns=not-significant									

Figure 11. Loblolly pine shoots severely infested with tipmoth.

Figure 12. Nantucket pine tipmoth (*Rhyacionia frustrana*).

Hardwood Silviculture

Figure 13. A southern red oak responding to crop tree release and fertilization.

The Effects of Crown-Touching Release and Fertilization on Growth of Southern Red Oak

As reported in last spring's issue of the Research Review, we installed a test in early 2007 to determine the responses of southern red oak to a second crop tree release treatment with and without the addition of fertilizer [200 pounds of N (as ammonium nitrate) plus 25 pounds of P (as DAP) per acre – Figure 13].

After two years, the diameter response to the fertilization treatment continues (Figure 14). And as Figure 15 shows, that response is increasing. The 0.52 inches of dbh growth on the fertilized trees in the two years since treatment exceeds that in those released only (0.34 inches) by more than 50 percent. These results in combination with our other crop tree release work (e.g. the March 2007 Research Review), give us growing hope that these tools – perhaps repeated at some yet-to-be-determined frequency – may give us the chance to improve the species composition of our hardwood stands while substantially shortening the rotation length. We plan to expand our work in this subject area.

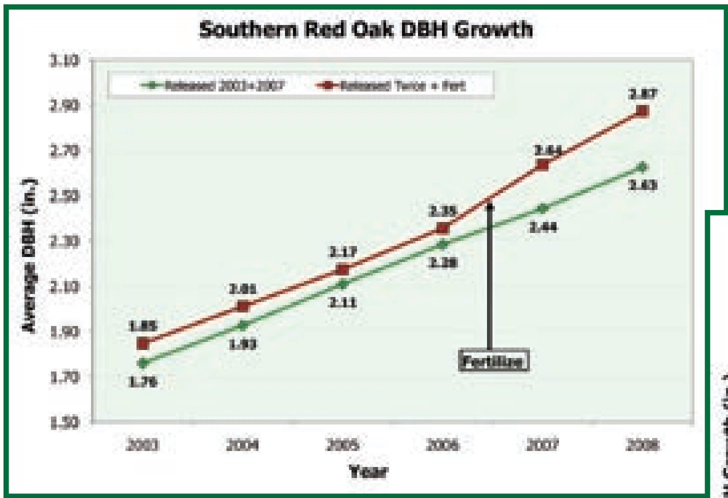

Figure 14. Average dbh of southern red oaks in the crop tree release and fertilization study.

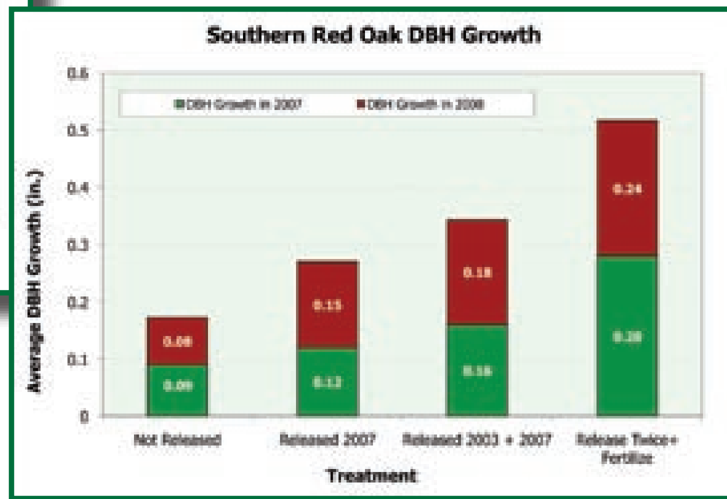

Figure 15. Average dbh growth of southern red oaks in the crop tree release and fertilization study.

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