Forest Research Review

March 2010

Twenty-year-old white oak saplings. The one on the left received no treatment while the other received a crop tree release plus fertilizer application five years ago. Both saplings were 2.1 inches in dbh in early 2005. The one on the left is now 2.2 inches while the one on the right is 3.6 inches.

In this issue...

VDOF Research Program

Welcome to the latest edition of the Virginia Department of Forestry's Research Review. This issue contains updates from our research cooperatives and several ongoing tests: longleaf and eastern white pine establishment; white oak crop tree release and fertilization, and tipmoth control treatments. There is also a review of past research associated with the effects of hardwood competition on loblolly pine growth intended as a reminder of why and when it is important to release pine stands from competing vegetation.

The spring and summer of 2009 were busy for the tree improvement program.

- In April, we completed VDOF's first effort at mass-controlled pollination (MCP) for loblolly pine seed production (described in the last issue). We could have as many as one million MCP seedlings for our nursery crop in 2011.
- In late August, 20 bushels of shortleaf cones were collected from the orchard at New Kent Forestry Center through a collaborative project with Virginia State University. Seed from this effort will be used to install a test to compare seedlings from our orchard to those from other geographic locations.
- In September, native Virginia longleaf cones were collected from trees on International Paper's South Quay property south of Franklin, VA. Sixty-one bushels of cones were collected and will provide seedlings over the next several years for reforestation projects in the original native range of longleaf in Virginia.
- Also in September, more than 440 bushels of loblolly pine cones were gathered from 350 trees at the New Kent Forestry Center's third-cycle loblolly orchard. Seed from these cones will yield some of the fastest-growing and best-formed loblolly seedlings VDOF has ever produced, and will be a significant part of the nursery's crop in 2011.

We've recently co-authored two publications that have gone to press: "Nine-year growth responses to planting density manipulation and repeated early fertilization in a loblolly pine stand in the Virginia Piedmont" in the Southern Journal of Applied Forestry (33(3): pp. 109-114, by C. A. Carlson, T. R. Fox, J. Creighton, P. M. Dougherty and J. R. Johnson) and "Evaluation of Riparian Forests Established by the Cooperative Restoration Enhancement Program (CREP) in Virginia" in the Journal of Soil and Water Conservation (by B. N. Bradburn, W. M. Aust, C. A. Dolloff, D. Cumbia, J. Creighton).

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.

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Research Cooperatives

Forest Modeling Research Cooperative

(formerly the Loblolly Pine Growth and Yield Coop) (www.fw.vt.edu/g&y_coop/) Effects of initial spacing on height development of loblolly pine. Co-op Report 156 by Clara Antón-Fernández, Harold E. Burkhart, Mike R. Strub and Ralph L. Amateis.

Site index is not a constant; dominant and codominant tree heights will be different depending on stand density (planting spacing) so you will need to consider this when using growth and yield forecasting models. Planting more trees per acre results in not only smaller tree diameters but also shorter trees across a wide range of densities.

In planning forestry operations, reliable estimates of future growth and yield are critical. One of the main factors affecting stand dynamics and, hence, defining the response of the stand to different silvicultural treatments and the outcomes of such interventions, is site productivity. The most widely used method for assessing site quality, site index (SI), is based on the relationship between dominant height and age. In applying the site index concept, one typically assumes that height development is not affected by stand density or thinning treatment. This assumption has been challenged by recent studies on loblolly pine. A detailed dataset with initial densities ranging from 303 trees per acre to 2,722 trees per acre and covering ages one through 25 after plantation establishment was used to study and model the effect of initial spacing on height development of loblolly pine (one location of this study is on VDOF's Appomattox-Buckingham State Forest).

Results from this study show that density has a negative effect on dominant height growth across a broad range of planting spacings. More dense stands (closer spacing) show a smaller site index (dominant height at age 25) than less dense stands (wider spacing). The height development trajectories for the different spacings begin to diverge at about the age of crown closure and do not converge over the time span of typical rotations.

Forest Nutrition Cooperative

(www.forestnutrition.org) Sinuosity in Loblolly Pine: Impacts on Wood and Log Quality. FNC Research Note No. 36. October 2009

Sinuous (s-shaped) stems in young trees correct themselves and contain the sinuous growth within the juvenile core, but trees that were once sinuous produce significantly weaker wood than those that never were.

A survey of the severity and occurrence of stem sinuosity (speed wobble, oscillating stem curvature) was conducted on six sites in North Carolina and South Carolina (USA) in stands two years after establishment. Approximately 230 trees on each site were measured for height, diameter and degree of sinuosity in the stem at the beginning of the growing season and again after the completion of the growing season. Fifty-two percent of the trees increased in sinuosity over the growing season. Using stand records and observations by local foresters, two mature stands of loblolly pine were located in the Atlantic Coastal Plain where excessive stem sinuosity was reported to be present at ages one to three. Seven trees were felled from each site.

The butt logs (8 ft.) were removed from each tree along with a bolt (2 ft.) from the remaining felled tree. A single veneer containing the pith from each butt log was used to calculate log volume, juvenile wood volume and the volume of sinuous growth. Seven trees (half of the 14 sampled) at the two sites were found to have had severe sinuosity earlier in their lives. Three took only one year to correct the sinuous growth and return to a normal growth pattern, two took an additional year, one took a third year, and one tree returned to a straight appearance by the end of the fifth year after the initiation of sinuous growth. Therefore, the sinuous portions of all seven trees were entirely contained within the juvenile core of the tree.

The two-foot section was processed further. Clear static bending specimens were machined and tested. There was a difference between the mean modulus of elasticity (MOE) measurements of the mature wood. Trees that were found to be non-sinuous produced mature wood that was significantly stiffer than the sinuous trees.

Longleaf Pine Establishment – Final Report

When establishing containerized longleaf pine on old fields, scalp before planting to turn over the top three to five inches of sod and plant the seedling so the container plug is exposed by half to one inch.

In early 2005, we planted a study designed to test the effects of site preparation methods and planting depth on the establishment and early growth of longleaf pine on an old-field site. Treatments included mechanical site preparation (scalping to turn over the top three to five inches of sod along an approximate 2 to 3 ft. swath); herbicide treatment (Oustar at 8, 12 or 16 oz./acre and Arsenal + Oust at 4 + 2 oz./acre), and varied planting depth (container plug even with ground line or exposed by half to one inch). We completed the final measurement of this test after the 2009 growing season (age five). Previously, we found that a combination of scalping, shallow planting depth (i.e. with half inch or more of the plug exposed), and light to moderate herbicide application (Oustar at 8 to 12 oz./acre) were the most effective treatments to maximize early growth and survival.

Our data after five years (Table 1, Figure 1) confirm these findings. The single most important factor in old field establishment success is scalping. Shallow planting and Oustar at 8 to 12 oz./acre are also helpful (Figure 2). Higher Oustar rates (16 oz./acre) and the Arsenal x Oust tank mix (at 4 and 2 oz./acre respectively) were detrimental to seedling growth and increased mortality substantially. It should be noted that other researchers have found that the Arsenal x Oust treatment works quite well when applied in May or later, but our treatment was applied on April 13. Scalping and shallow planting led to results as good as any in the study (75% to 83% survival with 70% to 86% of seedlings 4.5 ft. or taller in height). Figure 3 shows the combined effect of survival (assuming 450 trees per acre originally planted) and growth differences integrated as a volume index for each treatment; the scalped, shallow-planted plots with or without 8 oz./acre of Oustar (treatments 3, 4 and 8) were superior.

Table 1. Summary of mortality; grass stage emergence, and height growth after three years at the longleaf pine establishment study at New Kent Forestry Center.

Treat-ment #	Planting Depth	Mechanical Treatment	Herbicide Treatment	Geographic Source	HT. (ft.)	DBH (in.)	Survival (%)	% w/ DBH	Volume Index
1	Shallow	No Scalp	None	NC	3.47	1.13	31.67%	31.58%	39
2	Deep	Scalp	None	NC	5.09	1.33	71.67%	48.84%	275
3	Shallow	Scalp	None	NC	6.05	1.36	75.00%	68.89%	376
4	Shallow	Scalp	Oustar 8 oz.	NC	6.66	1.35	76.67%	82.61%	473
5	Shallow	Scalp	Oustar 12 oz.	NC	5.86	1.25	78.33%	72.34%	337
6	Shallow	Scalp	Oustar 16 oz.	NC	5.97	1.22	65.00%	71.79%	275
7	Shallow	Scalp	Arsenal Oust	NC	4.35	0.94	31.67%	42.11%	34
8	Shallow	Scalp	None	GA Mountain	6.51	1.27	83.33%	86.00%	445
9	Shallow	Scalp	None	GA Coast	4.60	1.17	71.67%	48.84%	170

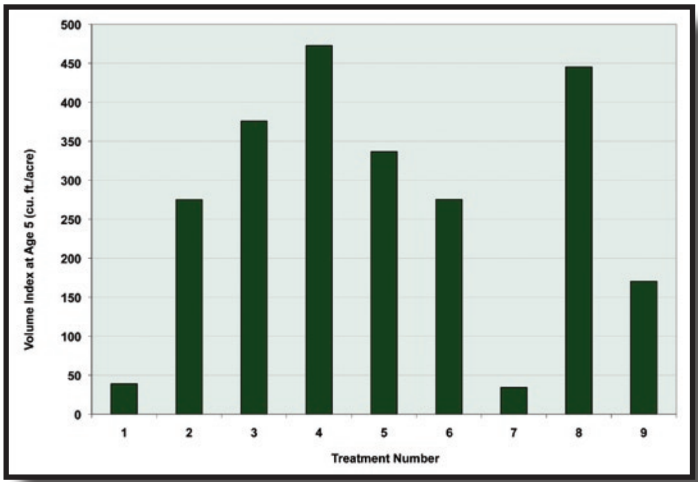


Figure 1. Volume index (calculated as dbh squared times height, assuming a planting density of 450 trees per acre) – a measure of comparative treatment performance on the longleaf pine establishment study plots after five growing seasons.

Figure 2. Five-year-old longleaf pine established after scalping, shallow planting and Oustar application at 12 oz./acre (left) compared to scalping and shallow planting with no herbicide treatment (right).

American Chestnut Q & A

Wayne Bowman, research forester

As awareness grows of the progress of VDOF and others working to develop blight-resistant American chestnuts, we have begun to receive more questions. Wayne Bowman provides the following answers to two of the most common ones:

How should I store American chestnut nuts and plant them in the spring?

Place your nuts in plastic quart Ziploc storage bags. In the bag place damp (not saturated) peat moss. The bag should have small holes punched in it. Punch several holes in the plastic bag using a paper clip. Store the bag over winter in a refrigerator. Do not freeze the nut. In the spring, the nuts should be growing (the root radicle will be protruding from the nut) and ready to plant. Be careful not to break off the new growth when planting. Place the new root growth down in the soil. Protection from voles, squirrels and deer will be needed. A piece of metal flashing taped in a circular tube placed around the nut when planting will keep voles and squirrels from the nut (an example is pictured in the last issue). Push the metal tube two to three inches down into the soil around the nut. Some type of cage or fencing will likely also be needed to keep deer from browsing these tender seedlings.

Where can I get American chestnut seedlings?

In addition to the VDOF, testing is being done by the American Chestnut Foundation and the USDA Forest Service at several locations to evaluate growth and blight resistance of the latest hybrids. To our knowledge, hybrid American chestnut seedlings that should be resistant to the blight are not available to the general public yet from any source. Pure American chestnut seedlings may be available, but it is likely that they will be susceptible and eventually succumb to the blight.

Effects of Competing Hardwood Vegetation on Loblolly Pine – A Review

Even small amounts of hardwood competition in a young loblolly pine stand will greatly reduce the growth rate and long-term yield of the pines. If your goal is to quickly reforest an area or accelerate and increase cash flows, remove hardwood competition as early as possible in the life of the stand.

Research has shown that: 1) hardwoods are more competitive than pines; 2) even codominant or intermediate woody plants interfere with pine basal area growth, and 3) once hardwoods become established in a pine stand, they are not "outgrown" by the pines.

How much hardwood competition is too much?

Woody plant competition (Figure 3) reduces pine plantation productivity. For example, data from a 27-year-old site preparation study in Alabama (Glover and Zutter, 1993[1]) showed a very strong relationship between pine basal area at age 27 and number of hardwood stems greater than one inch dbh at age three (Figure 4a) and percent basal area in hardwood at age six (Figure 4b). These results show that pine yield can be reduced even by relatively low levels of hardwood stocking. It doesn't take much hardwood to be a problem.

[1] Glover, G. R. and B. R. Zutter. 1993. Loblolly pine and mixed hardwood stand dynamics for 27 years following chemical, mechanical and manual site preparation. Can. J. For. Res. 23:2126-2132.

Figure 3. Dense sweetgum competition in a two-year-old loblolly pine (arrow) plantation near Franklin, VA.

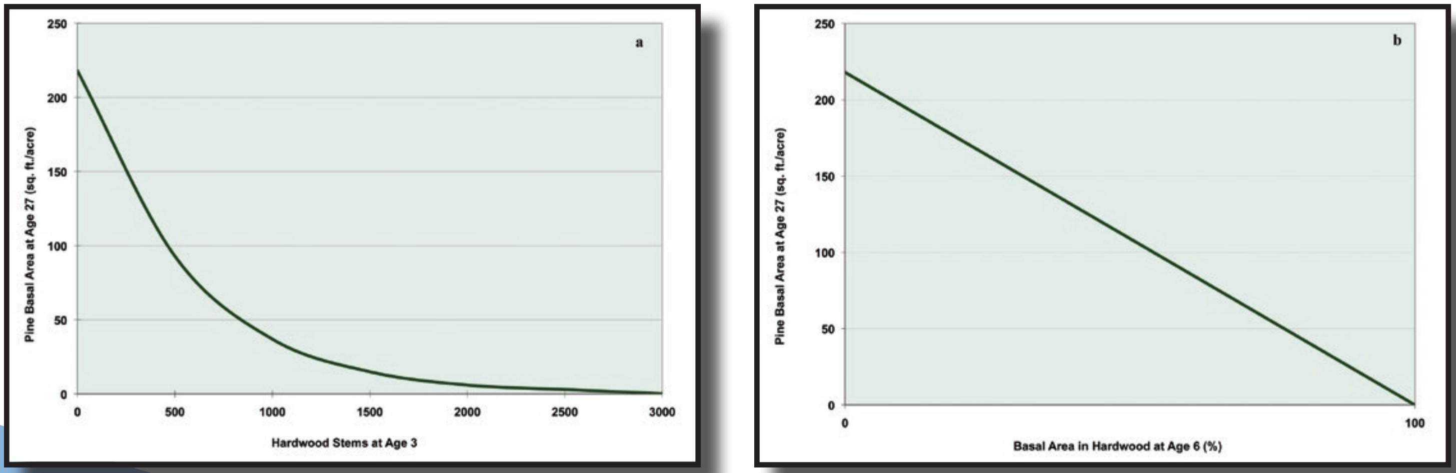


Figure 4. Relationship between pine basal area at age 27 and number of hardwood stems greater than one inch dbh at age three (a) and percentage of total basal area in hardwood at age six (b) (adapted from Glover and Zutter, 1993[1]).

Do all hardwoods affect pine growth equally?

In Arkansas, fall-applied imazapyr reduced the percent hardwood basal area from 10% (10 sq. ft./ac) to 3%; this reduction in competition increased pine mean annual increment by approximately one ton/acre/year for the seven-year period after treatment (Quicke, et al., 1996[2]). On this site, every 1.0 sq. ft. of hardwood basal area replaced 3.1 sq. ft. of pine basal area over relatively low levels of hardwood basal areas (Figure 5). Results from a much larger region-wide study show that each square foot of hardwood basal area reduces pine basal area by 1.4 sq. ft. at age 11 (AUSHC, 1998[3]). The difference in displacement of pine basal area between the two studies may be partially related to the branching patterns of the hardwood species involved; the oaks and hickories seem to be more competitive than sweetgum.

Findings also suggest that hardwoods capable of reaching the main canopy have a greater competitive effect than hardwood shrubs. In fact, the growth response from controlling "arborescent" hardwoods is about twice as large as that obtained from controlling shrubs. This difference likely results from the fact that hardwoods in the main canopy compete with the planted pines for light as well as moisture and nutrients while those below do not compete for light.

Has any research been conducted in Virginia?

It is easy to be skeptical regarding research results from "elsewhere." We in Virginia are fortunate, because perhaps the most important and extensive early data regarding pine release were developed by the Virginia Department of Forestry. Between 1967 and 1975, Tom Dierauf of the VDOF installed 26 release studies in 16 Piedmont and Coastal Plain Virginia counties using 2, 4, 5-T and hand chopping to remove hardwood competition from loblolly pine plantations between one and nine years in age. The growth of unreleased versus released stands (both pine and hardwood components) was monitored for up to 18 years after treatment and results are reported in 26 VDOF Occasional Reports between 1984 and 1991 (http://www.dof.virginia.gov/research/index.shtml).

The data from these sites formed the basis for many of the predictive models and analyses widely accepted by the forestry community today. Hardwood basal area was usually very high in these studies, the stands were older when released than currently recommended, and hardwood control was not comparable to what can be achieved by modern herbicides and treatment methods. So, in effect, the results of those plots provide a conservative estimate of pine response.

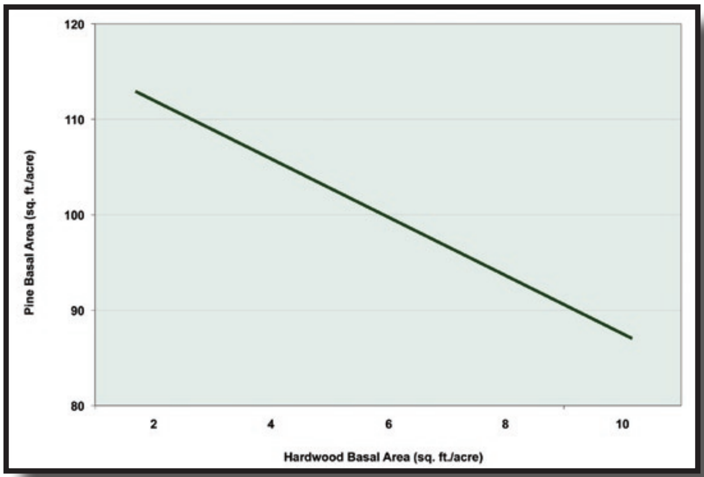


Figure 5. Pine basal area versus hardwood basal area seven growing seasons after treatment (Quicke et al., 1996[3]).

The results show that reducing hardwood competition – even by modest amounts – consistently increased pine yield (by an average of 52%), and pine volume response from release increases as the stand matures. Whether the objective is financial return, carbon sequestration or just faster reforestation, this is why hardwood control is critical to most loblolly pine forest management plans in Virginia.

In addition, the VDOF plots showed that:

1. Relative pine basal area (as a percentage of total stand basal area) is stable after crown closure.
2. Relative hardwood basal area is stable or declines slowly after crown closure.
3. Pine response is related to level of hardwood basal area but varies depending on the growth form of the hardwoods present (i.e. trees vs shrubs, excurrent vs decurrent branching).
4. The relationship between the Free-To-Grow (FTG) index (developed by the VDOF) and percent yield loss was strong at most locations. Regressions estimate a pine yield reduction of approximately one-third for each unit increase in the FTG index.

[2] Quicke, H. E., D. K. Lauer, and G. R. Glover. 1996. Growth responses following herbicide release of loblolly pine from competing hardwoods in the Virginia Piedmont. South. J. Appl. For. 20(4):177-181.
[3] AUSHC. 1998. Degree and timing of release of loblolly pine. Auburn University Silvicultural Herbicide Cooperative 1997 Annual Report. pp. 10-12.

WHITE PINE SURVIVAL AGE THREE RESULTS

To get the best survival and growth in eastern white pine, control weeds before planting and minimize cold storage time. Lammas shoots do not seem to be a factor in early seedling performance.

In the spring of 2006, we planted a study on an old field site near Glade Spring, VA, to test the effects of different storage times; site prep treatments, and seedling condition on the early survival and growth of eastern white pine. We compared seedlings stored for 78, 50, 28 and five days after lifting; scalping, herbicide treatment and no control of competing weeds, and seedlings showing lammas shoots versus no lammas shoots (extra whorls of branches or leader growth extension which develop late in the growing season).

The study is replicated three times in a split plot design with competition control treatments as whole plots and storage treatments as subplots. The subplots are 50-foot rows (10 planted seedlings at five-foot in-row spacing) spaced 10 feet apart.

We have measured the plots three years after planting, and the data are summarized in Table 2. There are significant effects of both site prep method (Figure 6a) and storage time (Figure 6b) on survival and all growth parameters. Scalping to remove weeds led to greatly enhanced growth and survival, but the herbicide treatment failed because the glyphosate treatment plots were all invaded by heavy thistle competition (as a result, that treatment was as bad or worse than doing nothing). There were no differences between seedlings with and without lammas shoots, so those data were combined under the five-day storage treatment averages when comparing cold storage effects. The results show that the less time the seedlings spend in cold storage after lifting, the better their survival and growth will be.

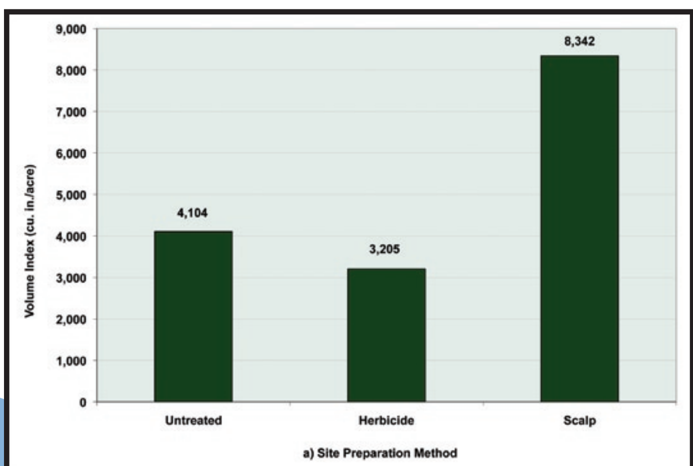
Table 2. Three-year growth and survival summary [averaged by site prep method (a) and storage time (b)] of white pine in the 2006 establishment study. Volume index was calculated as diameter squared times height times survival, assuming an original planting density of 500 trees per acre.

a)

Site Prep Method	Height (ft.)	D6 (in.)	Volume Index (cu. in./acre)	Survival (%)
Untreated	2.25	0.61	4104	68.7%
Herbicide	2.15	0.56	3205	64.0%
Scalp	2.60	0.74	8342	81.3%

b)

Storage Time	Height (ft.)	D6 (in.)	Volume Index (cu. in./acre)	Survival (%)
78	2.10	0.54	2229	46.7%
50	2.17	0.58	3676	66.7%
28	2.46	0.68	6833	86.7%
5 (lammas)	2.29	0.62	7543	83.3%
5 (no lammas)	2.61	0.73	5757	73.3%



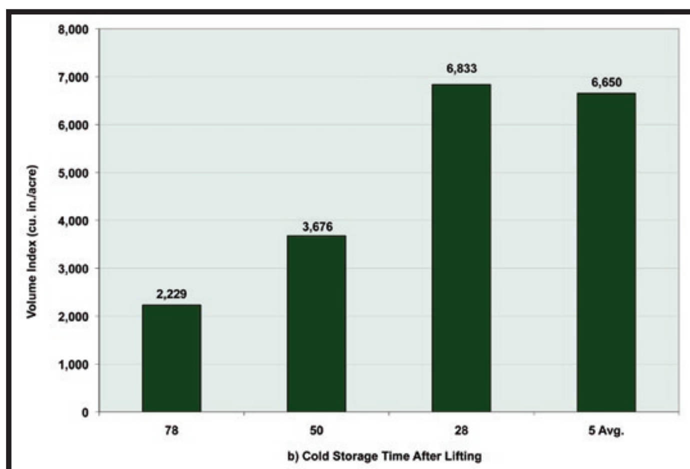


Figure 6. Volume growth of eastern white pine following a) different site preparation methods and b) durations of cold storage after lifting.

Tipmoth Control Study – Second Year Results

SilvaShield (imidacloprid) and PTM (fipronil) both prevented tipmoth damage to loblolly pine through the first two growing seasons after planting, and both improved survival on some sites. Individual tree growth response was not significant on most sites, and was modest where a response occurred, but combined with the improved survival the treatments led to an average volume per acre gain around 70%.

In recent issues, we have reported on our ongoing tests of two new treatments for controlling Nantucket pine tipmoth (Rhyacionia frustrana), which affects growth of loblolly pine throughout its range more than any other insect pest. Both products are systemic; they are absorbed through the tree roots and taken up into the foliage. One (PTM, from BASF) contains fipronil and is a liquid that is mixed with water and injected into the soil near the base of the seedling. The other (SilvaShield, from Bayer Environmental Science) contains the active ingredient imidacloprid and is a tablet that is either placed in the planting hole with the seedling when planted or later inserted into the soil adjacent to the seedling.

In March of 2008, we installed plots in seven newly-planted sites around Virginia. We thank MeadWestvaco for their help and permission to use their property for four locations in Buckingham and Campbell counties. The other locations are on the Appomattox-Buckingham State Forest (ABSF); on private land in James City County, and on the Camp Community College in Southampton County. At every site, we installed four replications of 25-tree row plots in newly-planted loblolly pine stands. Treatments included an untreated check, PTM (at all sites) and SilvaShield (at five sites).

Both products prevented infestations through the first growing season after planting, and now we have completed measurements through the second year. Tipmoth damage (percentage of shoots infested) was evaluated for each of three generations during both growing seasons and seedling height and groundline diameter (GLD) were assessed after each. In addition, a volume index was calculated for each plot as the average volume per tree ($pi * r^2 * h$ with h = tree height and r = ½ tree diameter) times 450 trees per acre (theoretical planting density) times average survival. All data were analyzed using analysis of variance (ANOVA) with an F-value of 0.05 as the threshold of statistical significance.

Three of the sites (Camp Community College, ABSF and the Clay Tract in Campbell County) experienced little or no tipmoth activity the first year, but all seven locations had damage during the second, averaging 25% to 30% of shoots on the untreated plots (Table 3). Both insecticides continued to provide tipmoth protection through the second year, although there is evidence that the protection is waning as damage had increased to 7% to 10% of shoots by the last assessment. ANOVA indicated that the effect of treatments was statistically significant (i.e. real) at all seven sites through August, and at six of the seven through the second year.

There was a tendency for the treatments to also enhance survival – even during periods where no tipmoth damage was present – on some sites (Table 4). The effect was statistically significant on three sites through most of the study period, and marginally significant ($F<0.10$) on several others. Although this study was not designed to look at other pests, our observations indicated that on at least one site the insecticides had prevented mortality due to Pales weevil. Whatever the mechanism, it is fairly clear that both products increased plantation survival, by an overall average of 12% to 13% after two years.

The protection provided by the treatments resulted in a modest growth response, which was statistically significant on only a few of the sites (Table 5). On average, the gains in height, diameter at groundline, and volume index after two years amounted to 9%, 3% and 69%, respectively. The large volume gain was influenced more by the enhanced survival than by increased individual tree size.

Figures 7 and 8 graph the net effect of treatments on tipmoth damage and loblolly pine growth after two years, and Figure 9 compares typical damaged and undamaged trees.

Table 3. Percent of loblolly pine terminals with tipmoth damage in 2008 and 2009.

Date	Treatment			# Signif.[1]
	Untreated	SilvaShield	PTM	
June 2008	1.7%	0.1%	0.9%	1
Aug. 2008	6.7%	0.1%	0.1%	4
Oct. 2008	21.2%	0.9%	2.3%	4
June 2009	24.7%	3.7%	5.3%	7
Aug. 2009	29.3%	2.5%	5.0%	7
Oct. 2009	30.0%	7.3%	9.8%	6

Table 4. Survival of loblolly pine in the during the 2008 and 2009 growing seasons.

Date	Treatment			# Signif.[1]
	Untreated	SilvaShield	PTM	
June 2008	83.5%	87.6%	91.0%	3
Aug. 2008	77.7%	85.8%	88.7%	3
Oct. 2008	73.8%	85.8%	87.0%	3
June 2009	74.5%	85.4%	87.4%	3
Aug. 2009	74.4%	85.8%	87.1%	2
Oct. 2009	74.2%	86.0%	87.3%	2

Table 5. Height, diameter and volume of loblolly pine after the 2008 and 2009 growing seasons.

Height	Treatment			# Signif.[1]
Date	Untreated	SilvaShield	PTM	
2008	1.3	1.3	1.4	2
2009	3.3	3.9	3.7	1
GLD	Treatment			# Signif.[1]
Date	Untreated	SilvaShield	PTM	
2008	0.35	0.35	0.38	3
2009	0.75	0.87	0.82	1
Volume Index	Treatment			# Signif.[1]
Date	Untreated	SilvaShield	PTM	
2008	5	7	8	3
2009	75	145	110	2

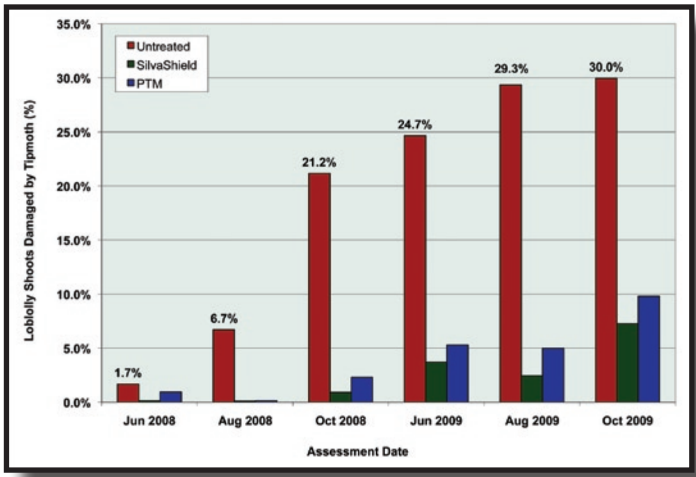


Figure 7. Average percent of loblolly shoots damaged by tipmoth at each assessment.

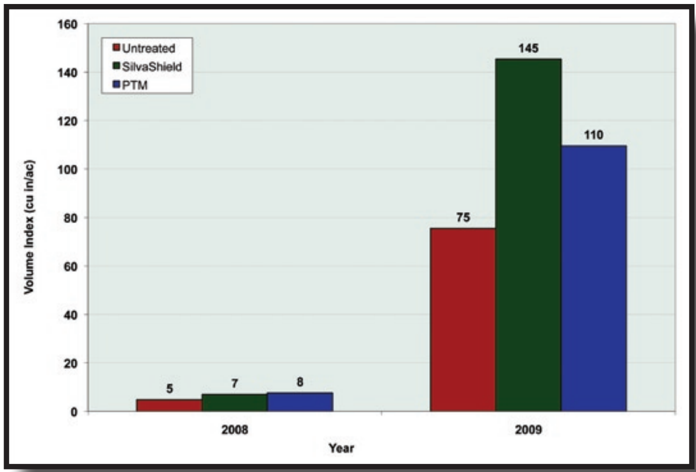


Figure 8. Average volume index (cubic inches per acre) of loblolly pine on plots of the 2008 tipmoth study.

[1] Number of sites where ANOVA showed a significant effect of treatment on percent of damaged shoots at the 0.05 level.

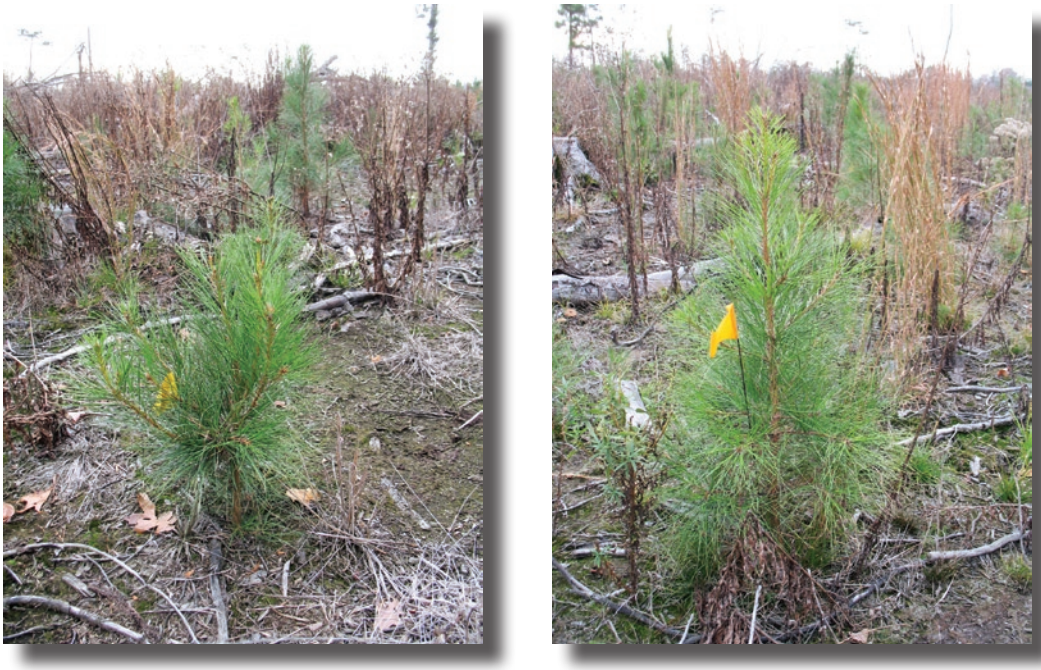


Figure 9. Loblolly pine seedlings with tipmoth damage (left) and undamaged (right) two years after planting.

Hardwood Silviculture

White Oak Crop Tree Release and Fertilization – Five Year Results

Crop tree release of white oak around age 15 has a very positive effect on diameter growth that lasts at least five years. Fertilizer added at the time of release further enhances diameter growth, but that effect lasted only two to three years at this location.

On April 26, 2005, a study was installed in the Burnham Unit of the Appomattox-Buckingham State Forest in a 15-year old mixed hardwood stand. The objective was to evaluate the effects of crop tree release and fertilization on the growth of white oak. Three-tree replications were matched based on diameter breast height (dbh) and total height. Two of the three were selected at random for release (by felling all surrounding trees touching their canopy), and one of those two was then randomly selected to be fertilized at a rate of 200 pounds nitrogen plus 50 pounds phosphorus per acre over tree-centered 10-foot radius circle.

Early results were reported in the February 2007 edition of the research review.

After the end of the 2009 growing seasons, the trees were re-measured for dbh and total height (Table 6).

Table 6. Summary of height (feet) and diameter breast height (dbh – inches) growth of white oak five years following release and fertilization treatments applied at age 15.

Treatment	Height (ft.)		DBH (in.)	
	Age 20	5-Year Growth	Age 20	5-Year Growth
Untreated	36.33	10.36	3.98	0.87
Released	34.89	8.58	4.51	1.39
Released and Fertilized	37.03	10.42	4.61	1.49

Hardwood Silviculture, continued

Without fertilizer treatment, release alone resulted in less height growth than no release. Diameter growth, meanwhile, was improved significantly with release and even more with the addition of fertilizer. But through two years there is a clear response in diameter growth to both release and fertilization. Moreover, the difference between either release or release plus fertilizer and the untreated trees continues to increase (Figure 10). However, the response to the added fertilizer has begun to diminish; beginning in the third year after treatment, fertilized trees have not grown any faster than those that were only released.

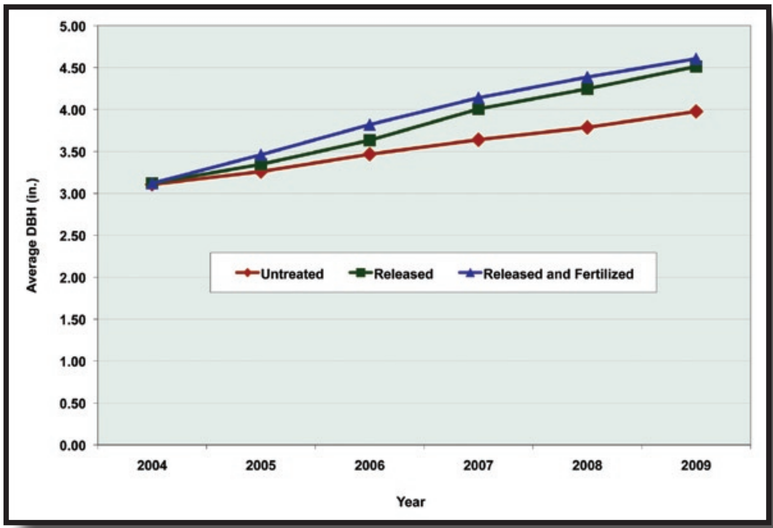


Figure 10. Growth in diameter breast height (dbh – inches) of white oak released and fertilized white oak during five years after treatment.

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