Quantifying And Predicting Wood Quality Of Loblolly And Slash Pine Under Intensive Forest Management

Final Technical Report

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Contact:

Richard F. Daniels	(706) 542-7298	ddaniels@uga.edu
Alexander Clark III	(706) 559-4323	aclark@fs.fed.us

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Executive Summary:

The forest industry will increasingly rely on fast-growing intensively managed southern pine plantations to furnish wood and fiber. Intensive silvicultural practices, including competition control, stand density control, fertilization, and genetic improvement are yielding tremendous gains in the quantity of wood production from commercial forest land. How these technologies affect wood properties was heretofore unknown, although there is concern about the suitability of fast-grown wood for traditional forest products. A four year study was undertaken to examine the effects of these intensive practices on the properties of loblolly and slash pine wood by applying a common sampling method over 10 existing field experiments. Early weed control gets young pines off to a rapid start, often with dramatically increased growth rates. This response is all in juvenile wood however, which is low in density and strength. Similar results are found with early Nitrogen fertilization at the time of planting. These treatments increase the proportion of juvenile wood in the tree. Later, mid-rotation fertilization with Nitrogen and Phosphorus can have long term (4-8 year) growth gains. Slight reductions in wood density are short-lived (1-2 years) and occur while the tree is producing dense, stiff mature wood. Impacts of mid-rotation fertilization on wood properties for manufacturing are estimated to be minimal. Genetic differences are evident in wood density and other properties. Single family plantings showed somewhat more uniform properties than bulk improved or unimproved seedlots. Selection of genetic sources with optimal wood properties may counter some of the negative impacts of intensive weed control and fertilization. This work will allow forest managers to better predict the effects of their practices on the quality of their final product.

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Project Objective:
1) Quantify effects of intensive forest management on basic wood properties, including specific gravity, tracheid length, coarseness, microfibril angle, juvenile wood formation, and interactions with soils and geographic location; 2) correlate basic properties with strength, stiffness and yield properties and energy requirements for pulp, paper, and solid products; and 3) develop models that, given tree size and stand history, predict wood quality within the tree, from stump to tip and pith to bark.

Background:
The forest industry will increasingly rely on fast-growing intensively managed southern pine plantations to furnish wood and fiber. Intensive competition control and fertilization promise tremendous gains in wood production. How these technologies affect wood properties, product mix, energy efficiency, and profitability is unknown. For example, intensively managed trees grow rapidly during the early years of the rotation, reach merchantability at a younger age and may produce significantly higher proportions of juvenile wood, raising concern for the use of the new wood supply in traditional products. Juvenile wood is characterized as having lower specific gravity, shorter tracheids with thinner walls, larger microfibril angles and less alpha cellulose than mature wood. The number of annual rings of juvenile wood a tree produces varies geographically and increases from 5-6 years in the lower Coastal Plain to 10-12 years in the Piedmont. The stiffness and strength of structural lumber containing juvenile wood is significantly lower than that of lumber from mature wood and may not meet design specifications. Juvenile wood has significantly higher moisture content than mature wood and is more prone to warp during drying. Pulp chips containing large volumes of juvenile wood have significantly lower packed bulk density resulting in fewer chips per digester cook and yield less pulp per ton of green chips, thus requiring more energy to produce the same volume of pulp as traditional chips. Paper from juvenile wood pulp has good tensile, burst, fold and sheet smoothness but significantly lower tear strength and opacity. The forest industry needs to understand the impact of intensive management on wood properties to facilitate production of quality products and minimize energy requirements.

There is a lack of information on the effects of silvicultural and genetic treatments on cell anatomical structure, specific gravity, wood strength and stiffness and length of juvenility and their interactions with soils and geographic location. Well-designed, long-term field studies are required to quantify and model the effects of intensive management on these wood properties. Fortunately, a wealth of such experiments exists through ongoing research cooperatives. Overlaying wood quality sampling on this existing experimental base is the most efficient way to meet industry's wood properties research and modeling needs. The approach of this project was to partner with the institutions responsible for these experiments to facilitate field sampling of their locations and support graduate student research. Standardized data collection and lab protocols were implemented by a common team. Sample plots from each study were measured by the UGA/Forest Service/Collaborator field crews. The studies sampled are described in the sections below.

General Data Collection Protocol:
As a target, 20-30 trees were sampled per treatment at each location. Trees were cored with a 12mm increment borer at dbh and except where noted, 3 trees per treatment were felled for stem analysis and wood sample collection from stump to tip. Two 12mm increment cores were collected from each tree at the same vertical plane 3 inches apart to provide four radii. Radius 1 was used to determine specific gravity (SG), and radial growth of earlywood and latewood (UGA and Forest Service x-ray densitometers). Radius 2 for selected trees was used to determine microfibril angle (MFA), ring-by-ring using Silviscan (subcontract) and was used for further Near Infrared analysis. Radius 3 was used to determine whole core specific gravity by displacement (USDA Forest Service lab). The fourth radius he was held for future analyses and verification studies.

From each felled tree two 1-inch cross-sectional disks were cut at stump, dbh and 5 feet intervals to a 2-inch top. Two-foot bolts were cut from each tree at 8, 24 and 40 feet. One disk was used to determine weight per cubic foot; the second cut into radial strips for x-ray densitometer analysis. The 2 foot bolts were sawn into small clears and used to determine modulus of elasticity (MOE), modulus of rupture (MOR), toughness, and dimensional stability of juvenile and mature wood using ASTM D143 for small clears (UGA, USDA Forest Service labs). Data were analyzed to determine the effect of intensive management, soils and geographic location on the properties measured. Not all properties were measured or analyzed for all studies. The key variables of interest in each of the intensive management studies are presented in the sections below.

Modeling Approach:
Predictive models were developed to describe the changes in wood properties within a tree. The goal ultimate goal of this work is to define how these wood properties change with intensive management treatments, geography, site quality, age, and environmental conditions. In this study a database is being built to encompass the effects on and within trees of many silvicultural treatments on wood properties. Mathematical models of tree volume and weight are used routinely to estimate timber stand volumes in forest inventories and in yield projection systems. Wood properties were modeled in a similar fashion to wood content along the stem, using models analogous to taper functions. By incorporating these models for predicting wood quality into such applications, forest managers and planners will be able to incorporate wood quality considerations into forest management decisions.

Results and Discussion
Ten designed field experiments, each with multiple treatments and locations, were sampled across the range of loblolly and slash pine. Over 50 plots were measured and thousands of core samples were collected. The specific field and lab methods, the results, and their significance are discussed by intensive management practice, according to the headings Vegetation Control, Stand Density Control, Forest Nutrition, and Genetics – Planting Stock.

Vegetation Control

Auburn University – COMP STUDY (Vegetation control with no fertilization).
A 15-year-old competition control study established at 13 locations from Virginia to Louisiana provided a unique opportunity to examine the effects of intensive vegetation control on wood properties across the South. This study, called the Competition Omission Monitoring Project (COMP), was a cooperative study established by industrial members of the Auburn University Silvicultural Herbicide Cooperative, the USDA Forest Service Southern Research Station, and Virginia Tech and Louisiana Tech Universities. In 1984-1985 genetically improved loblolly pines were planted in experimental plots in seven states. Treatments were: 1) no competition control after chopping and burning; 2) complete woody control for the first 3-5 years; 3) complete herbaceous control for the first 4 years; and 4) complete competition control for 3-5 years. Soil types have been described. The no competition control and complete control treatments were sampled at all 13 locations; all four treatments were measured on a subset of seven locations across the South. Sampling has been completed for all 13 Auburn/USDA Forest Service COMP study locations. To ensure continued integrity of this important study, trees were not felled and only increment cores were collected. Increment cores collected from this study were prepared in the laboratory for in-house x-ray densitometry and contracted MFA analysis.

Results: Early weed control has become a common practice in loblolly pine plantation establishment, providing seedlings with greater allocation of growth resources due to reduced competition from non-crop vegetation. The effects of weed control were evident in increasing early growth in these plots. Trees with weed control attained larger diameters (and heights) than untreated plots in the same time period (Figure 1). This effect led to a larger core of juvenile wood (with low specific gravity) at a given age for weed control treated trees. However, the weed control treatment did not affect the length of time in the juvenile stage of growth, which varied by physiographic location. That is, at any given location, the stands made the transition from juvenile wood to mature wood at about the same age regardless of weed control treatment. While juvenile rings were larger for weed control treatments there appear to be no effects on specific gravity by ring (Figure 2). Overall disk specific gravity is reduced slightly by weed control treatment due to the early increase in size of the juvenile core.

Figure 1. Average Ring Basal Area Over Rings From Pith By Competition Control Treatment

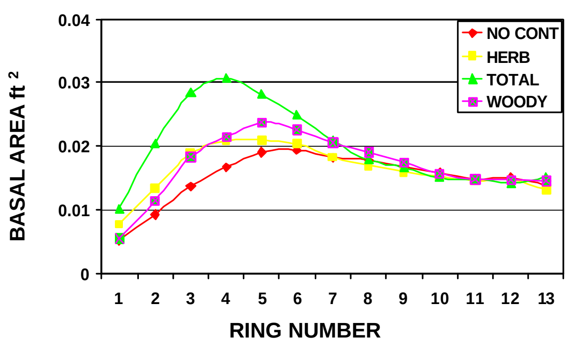
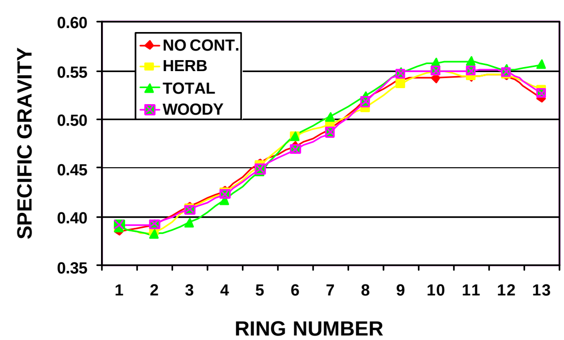


Figure 2. Average Ring Specific Gravity Over Rings From Pith By Competition Control Treatment



Stand Density Control – Planting and Thinning

Virginia Tech Loblolly Pine Growth and Yield Research Cooperative
Southwide intensive culture studies.
The Virginia Tech Loblolly Pine Growth and Yield Research Cooperative established a series of 150 sets of plots, with improved stock, under intensive stand establishment regimes, from Virginia to East Texas. These stands represent the modern crop of fast growing plantations. Treatment plots were scheduled for thinning (at 45 feet tall, 6.5 inches dbh) over the study period, providing opportunity to capture wood quality information. A limited number of these stands have been sampled. Logistics of sample collection and transport combined with the young age of these trees has limited the utility of these samples. Efforts were redirected to the older thinning study.

Southwide thinning study.
The older region-wide loblolly pine thinning study provides a unique one time opportunity to destructively sample 30 to 40 year old loblolly plantations with known history to determine the effect of thinning, climate (physiographic region) and rotation age on wood strength and stiffness. The thinning study was established in 1980-1982 in 186 plantations throughout the native rage of loblolly pine, and consisted of two thinning treatment and a control. Thinning treatments were a light thin (approximately 30% of BA removed) and a heavy thin (50 % of BA removed). This study has been terminated for its original purpose and remaining plots are available for an extremely limited time for destructive sampling.

The VA Tech thinning study was sampled as follows: Four trees were destructively sampled in each of three treatment plots (control, light thin, and heavy thin) at four thinning study installations in each of the Atlantic Coastal Plain, Piedmont and Hilly Gulf Coastal Plain physiographic provinces. Cross-sectional disks were cut at 5-foot intervals up the stem for annual ring growth and specific gravity analysis and weight per volume determination. Bolts 2-feet long were cut at 8-, 24-, and 40- feet for strength, stiffness and toughness determination following ASTM D-143. Before cutting the sample bolts, acoustic stiffness of the logs was measured in the field with a newly acquired tool, the Director HM-200 (Fiber – Gen). Emphasis on this study was to determine stiffness patterns for mature trees to develop forest management guidelines for growing plantation loblolly pine with strength and stiffness needed to meet lumber standards. Acoustic stiffness was measured on all cut trees and then for each 16’ log. Predicted stiffness estimates from sonic measurements were compared with modulus of elasticity (MOE) and modulus of rupture (MOR) determined from static bending small clear samples in the laboratory.

Results:
Sonic velocity was a better predictor of MOE in the first log (r^2=0.64) than in either the second (r^2=0.41) or third (r^2=0.49) log (Figure 3). The predictive validity of sonic velocity seems suited for use as a general classification index. Sonics poorly predicted SG and MOR. This was expected because sonic velocity is directly related to elasticity (stiffness) not the failure point of the material.

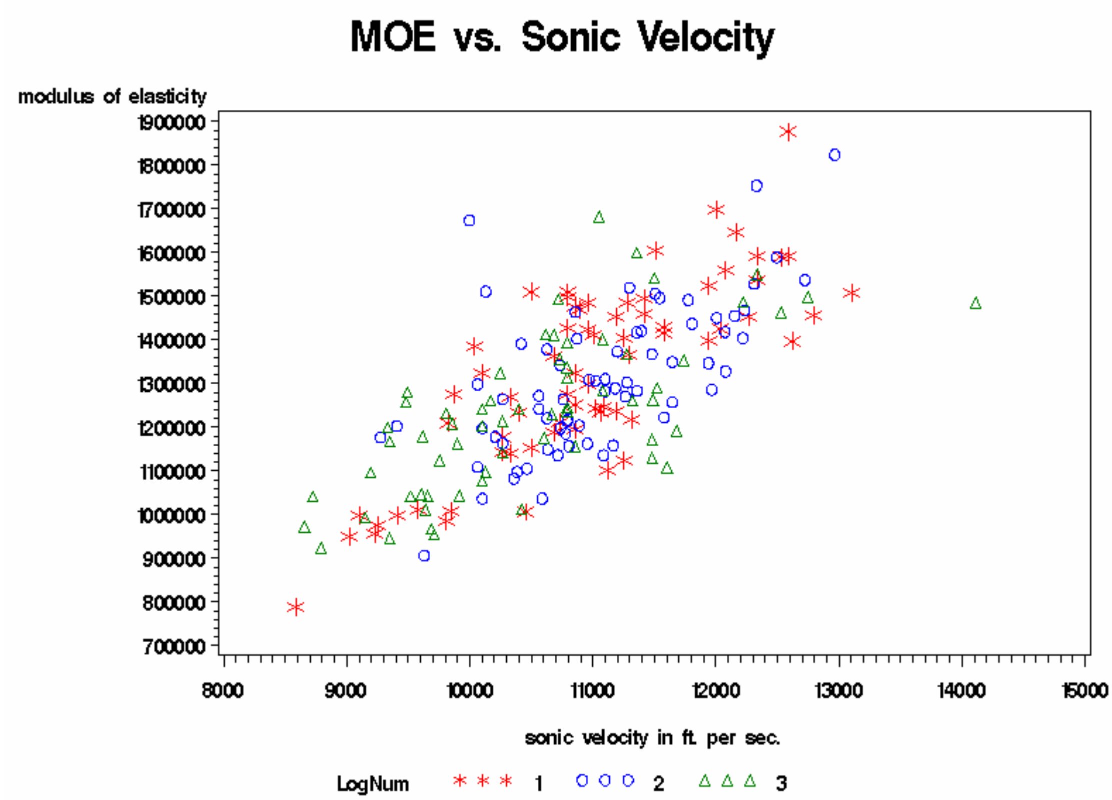


Figure 3. Stiffness (MOE) is correlated with sonic velocity for loblolly pine logs.

Forest Nutrition Effects on Wood Quality

Among intensive treatments, fertilization has the greatest potential to affect wood properties. Designed field experiments were identified early to examine the effects of 1) fertilization and site preparation alternatives at planting, 2) mid-rotation treatments, and 3) multiple fertilization regimes on wood properties.

Fertilization at Planting

North Carolina State University – Regionwide 7 fertilization and site preparation alternatives at planting. The NC State Forest Nutrition Cooperative (NCSFNC) installed the Regionwide 7 studies from 1978 to 1981 to include 4-replications 2x2x2 factorial study of site preparation, weed control, and fertilization at planting. These studies have demonstrated the role of initial nutrition and site preparation on growth and they provide a unique opportunity to examine the effects of these treatments on wood properties near rotation age. Five treatments were sampled on 4 installations that have remained in-tact. A 5th installation had been harvested by the landowner and is no longer available for sampling.

Results: The affects of fertilization at planting on earlywood, latewood, and ring specific gravity are very similar to the results found in the COMP study: increasing early growth due to fertilization increases the size (proportion) of the juvenile core, decreasing overall wood density.

A nonlinear model was used to describe the transition of from juvenile wood to mature wood, using latewood specific gravity criteria (Figure 3). Differences in the transition age can be attributed to treatment and study location.

Effects of early treatments on wood properties appears to be limited to 1) changes in the diameter of the juvenile core and, to a lesser extent, 2) changes in transition ages to mature wood properties. Both effects combine to affect the proportion of juvenile wood at harvest. However, early site preparation, weed control, and fertilization treatments do not seem to have an influence on the wood properties of mature wood *per se*.

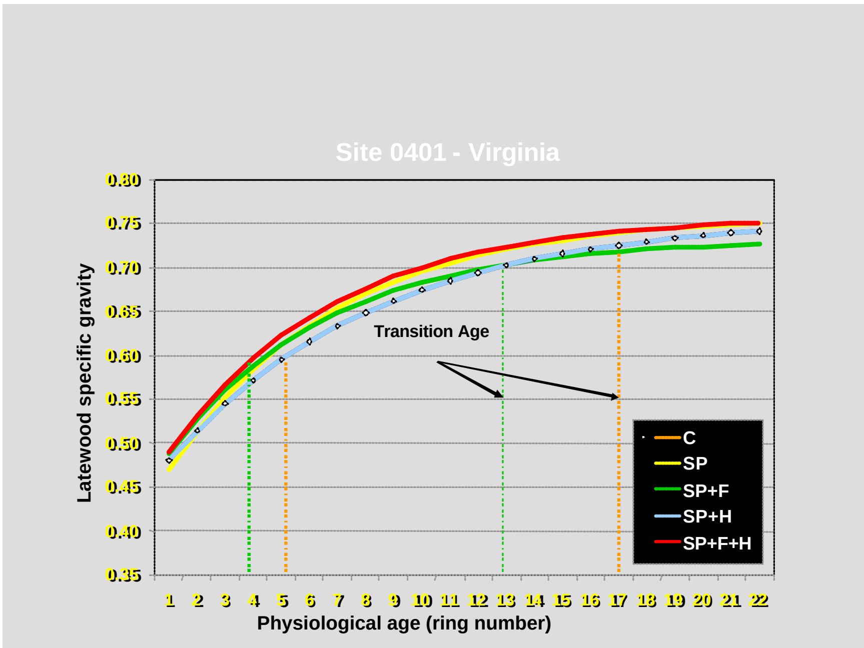


Figure 4. Asymptotic regression models for latewood specific gravity and estimated transition zone and transition age

A decision was made in November 2002 to concentrate sampling effort on midrotation fertilization treatments and studies with multiple fertilization treatments. The following studies were selected for sampling.

<u>Mid-rotation Fertilization</u>

<u>University of Florida – Understory competition control plus fertilization studies (G-series).</u> This competition control plus fertilization study provides the opportunity to examine the effects of understory competition control plus fertilization at stand establishment and mid rotation on wood properties at age 15. Six sites were sampled (3 loblolly and 3 slash) in Georgia and Florida. The 4 treatments sampled all include early weed control and mid-rotation brush control. The nutrition treatments include no fertilization; P at planting plus N+P at mid-rotation; N+ P at planting and N+P at mid-rotation; and N+P +K at planting and

N+P+K at mid-rotation. 36 trees were bored per treatment location (9 per rep) in each of the four treatments at each of the 6 locations. No trees were felled due to young age of the study.

North Carolina State University – Regionwide mid-rotation fertilization studies. The NC State Forest Nutrition Cooperative (NCSFNC) has installed a series of regionwide studies (RW-13, 15) to determine the effects of mid-rotation fertilizations and multiple fertilizations. These studies were treated at age 12-15 and are now over 25 years old. They have been terminated for their original purpose and are available for destructive sampling. Two RW-13 studies (Virginia and NC) were sampled. This study has the greatest range of nitrogen fertilization. Treatments include 4 mid-rotation fertilization treatments: 25 P, 100N+25P, 200N+25P, and 300N+25P. RW-15 studies were planned to be sampled (SC and AL). Changes in land ownership and objectives eliminated many of the plots initially identified for sampling.

MeadWestvaco N + K study. MeadWestvaco established a study of mid-rotation N and K fertilization in loblolly pine. The site was 33 years old and available for destructive sampling. Treatments at age 20 included: 0N0K, 100N+0K, 200N+0K, 200N+100K. All plots had adequate P. The sampling protocol matched that in the NC State RW-13,15.

Results: Analysis of three mid-rotation fertilization studies indicate somewhat consistent reductions in specific gravity (SG) immediately following fertilization with Nitrogen. However, there appear to be no consistent long-term negative impacts of increased nutrition on SG. While the growth response to fertilization may last 4-8 years, the wood formed after fertilization shows slight reductions in SG that last just one or two years. The reductions in SG are slight, less than 10% on average and do not reduce SG to juvenile levels.

The most dramatic demonstration of the response of wood density to fertilization was in the NC State RW-13 installation on Weyerhaeuser land at New Bern, NC. This study site received three levels of nitrogen application (100, 200, and 300 lbs./ac.) at age 11. All plots including the control were fertilized at age 23. After each fertilization a dip in latewood specific gravity is evident. Further, the magnitude of the reduction SG is a function of the nitrogen application rate. (Figure 5). The negative response to SG can be seen to be small and short-lived. Even at the most severe case, the 300 lb./ac. treatment, the latewood SG did not dip below 0.700, which can be considered still well within the mature wood range of wood density.

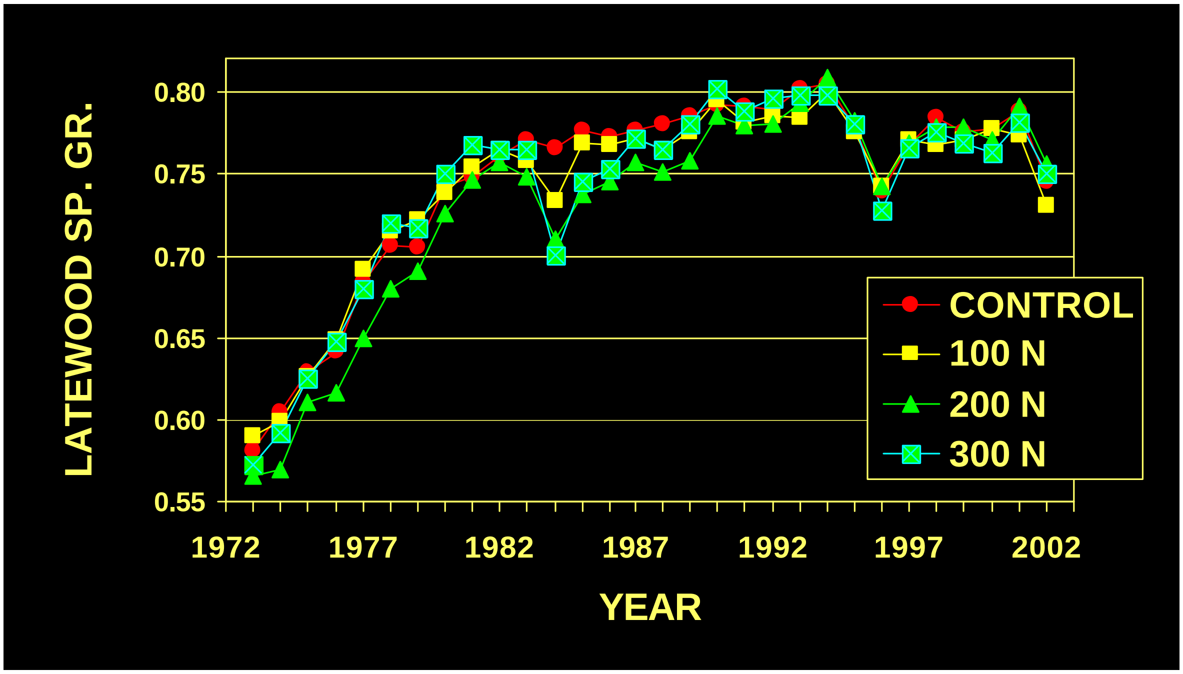


Figure 5. Effect of mid-rotation fertilization on latewood specific gravity (NCSU RW-13 NEW BERN, NC)

Multiple/Annual Fertilization

SETRES – USDA Forest Service and NC State University. A tremendous opportunity opened during the course of this grant to look at wood properties in the continuously fertilized (Nitrogen), irrigated SETRES study. Trees were bored only in this 19 year-old landmark study including treatments: control, irrigation only, fertilization only, and irrigation+fertilization. Treatments have been applied annually since 1992.

Results:

The SETRES study showed tremendous response in basal area and volume growth to annual Nitrogen fertilization. Fertilized plots more than doubled growth of either the control or irrigated-only plots (Figure 6). With annual nitrogen fertilization, there were significant and long-term reductions in SG over that in control and irrigated-only plots (Figure 7). Further analysis revealed that reductions were in the SG of latewood, rather than the proportion of latewood. Earlywood SG remained constant. High nutrient regimes resulting from annual fertilizer applications lead to significantly increased wood production, but the wood formed under those nutrient regimes is low in density. The suppression of wood density lasted the length of the study period. Fertilized plots produced wood that barely could be classified as mature wood (SG > 0.500) (Clark et al. 2006). These results from SETRES corroborate the findings of Clark et al. (2004) for annually fertilized loblolly pine in Georgia.

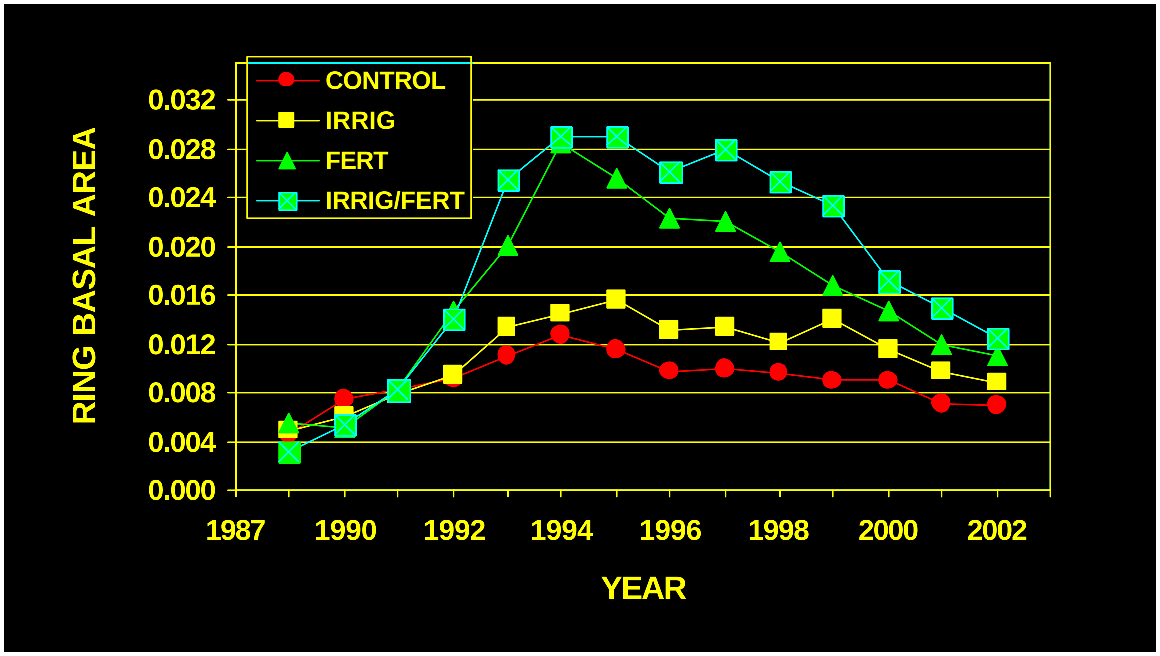


Figure 6. Effect of annual fertilization and irrigation on ring basal area growth of loblolly pine (NCSU-SETRES)

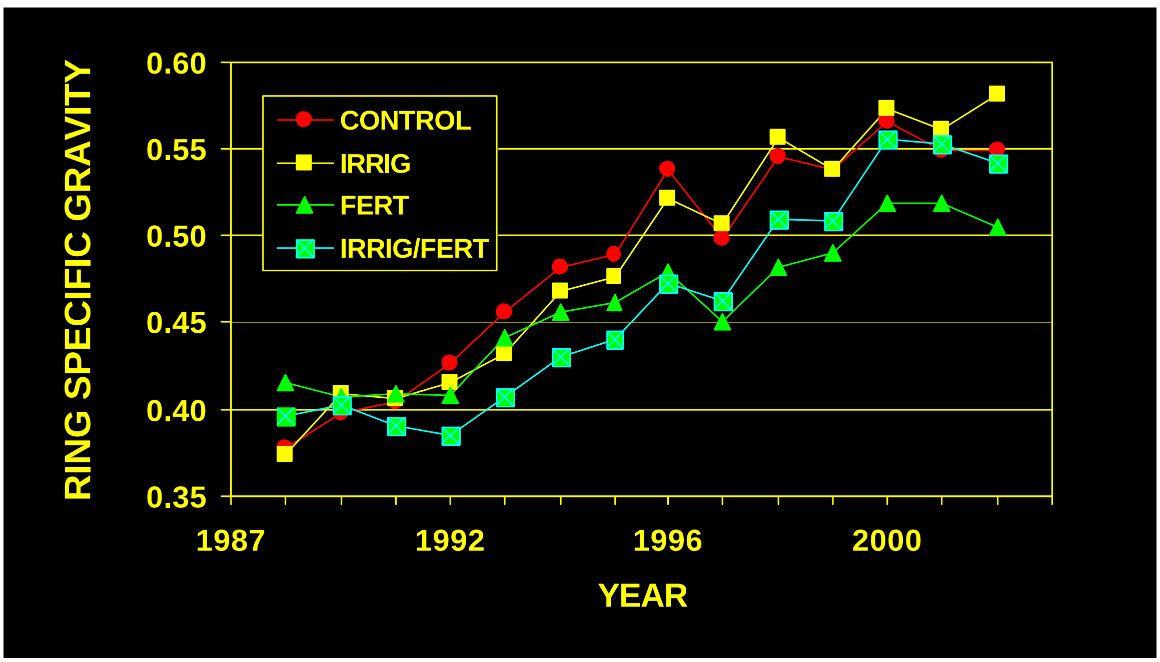


Figure 7. Effect of annual fertilization and irrigation on ring specific gravity of loblolly pine (NCSU-SETRES)

Genetics – Planting Stock

University of Georgia – Planting stock X vegetation control studies.

The UGA Plantation Management Research Cooperative Loblolly Pine Improved Planting Stock X Vegetation Control Study has shed light on the effects and interaction of weed control and genetics on stand development. Thirty-one installations were installed in 1986-7 in the Coastal Plain and Piedmont in AL, FL, GA, and SC. At each installation six common treatments (3x2 factorial) include planting stock (unimproved stock versus bulk lot improved versus single family) crossed with vegetation control (complete control versus no competition control). Sampling these plots for wood properties at age 15 adds an important component to the understanding of these intensive treatment effects.

Four treatments were selected for sampling: unimproved stock with competition control, bulk-lot improved with and without competition control, and family block with competition control. Three loblolly pine families and two slash pine families were selected for the family block plantings. Ten loblolly sites and five slash sites were selected for sampling.

Results:

Differences in growth due to genetic source (unimproved, bulk lot, single family) were small compared to the effect of weed control (Figure 8). Complete vegetation control reduced SG (specific gravity, basal area-weighted cross-section) on average 3% compared to no vegetation control (Figure 9). The SG of a genetically improved bulk lot and single family lots were not on average significantly different than that of the unimproved. On average, the CV (coefficient of variation) for basal area-weighted cross-section SG of the single family was slightly less (0.8-1.4%) then than that of the unimproved or bulk lots, indicating at least some increased uniformity of wood properties within single family plantings.

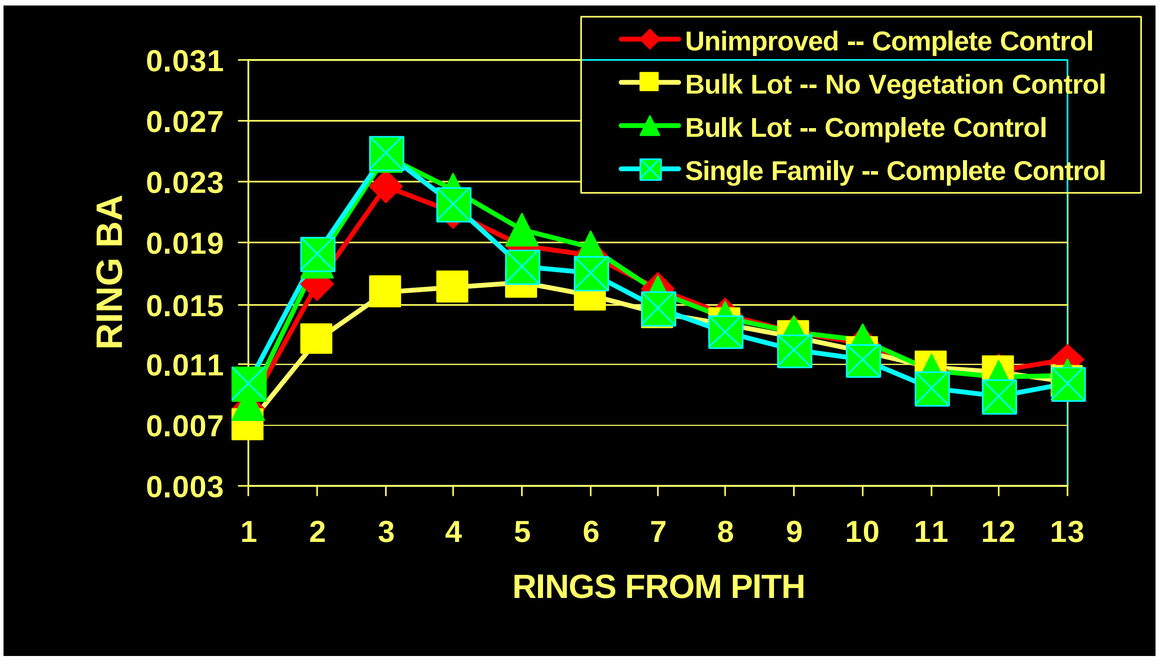


Figure 8. Effect of competition control and genetic improvement on ring basal area growth for loblolly pine

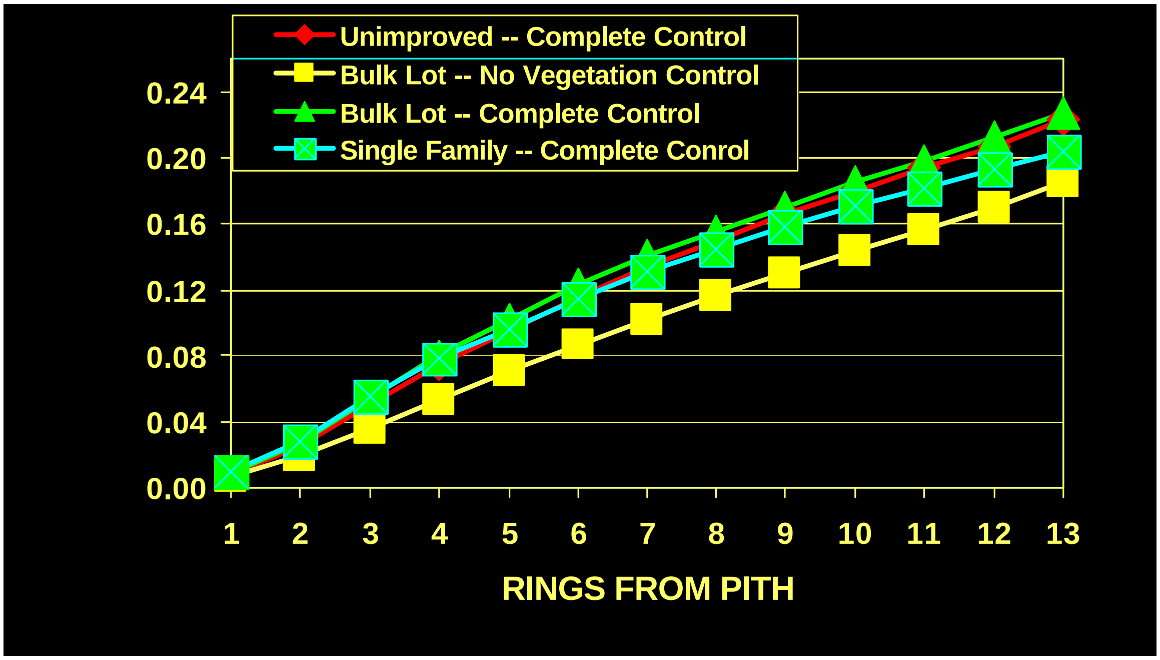


Figure 9. Effect of competition control and genetic improvement on percent latewood for all loblolly pine

Modeling wood properties.

Significant progress was made in developing and fitting mathematical funcitons to describe the 3-dimensional changes in wood properties within the tree. Patterns of wood density were described ring-by-ring from the pith to bark and vertically from stump to tip using mathematical models derived from wood sheath increment. A three parameter Logistic function was used to describe the sigmoid curve of latewood SG from pith to bark (Figure 10). These equations have been refined further to describe mean ring density, latewood density, and latewood proportion. In addition, equations have been developed to describe the baseline changes in wood stiffness (MOE), and strength (MOR) within trees and identifying differences in these properties by Physiographic region across the South (Daniels et al. 2003). Models have also been developed to predict the changes in microfibril angle (MFA) within the tree (Jordan et al. 2005a, 2005b, 2006).

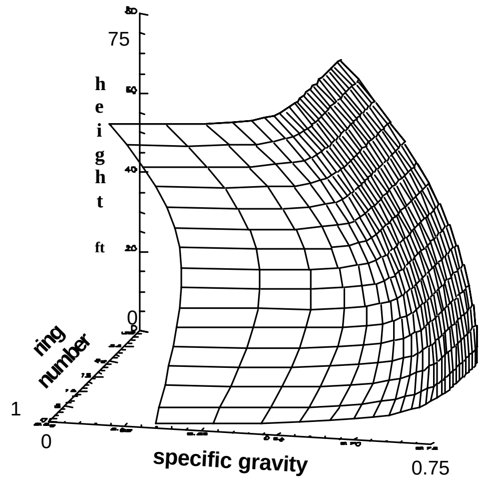


Figure 10. Three-dimensional prediction of latewood specific gravity from Logistic Model

Publications

The following publications and presentations were made possible either in whole or in part by samples and or data collected and analyzed under this research grant.

Refereed Journal Publications:

Clark, A. III, B. E. Borders, R. F. Daniels. 2004. Impact of vegetation control and annual fertilization on wood properties of loblolly pine at age 12. For. Prod.. J. 54(12):90-96

Clark, A III, R. F. Daniels, J. H. Miller. 2006. Effect of controlling herbaceous and woody competing vegetation on wood quality of planted loblolly pine. For. Prod. J. 56(2): 40-46.

Clark, A., III, R. F. Daniels, L. Jordan. 2006. Juvenile / mature wood transition in loblolly pine as defined by annual ring specific gravity, proportion of latewood, and microfibril angle. J. Wood and Fiber Sci. 38(in press) .

Jones, D., L. Schimleck, G. Peter, R. F. Daniels, and A. Clark. 2005. Nondestructive estimation of *Pinus taeda* L. tracheid morphological characteristics for samples from a wide range of sites in Georgia. *Wood Sci. Technol. 39(7), 529-545.*

Jones, D., L. Schimleck, G. Peter, R. F. Daniels, and A. Clark. 2005. Nondestructive estimation of *Pinus taeda* L. wood properties for samples from a wide range of sites in Georgia. *Can. J. For. Res. 35(1):85-92.*

Jordan, L., K. Berenhaut, R. Souter, and R. F. Daniels. 2005. Completely compatible taper, total and merchantable volume models based on the gamma and inverse gamma probability functions. *For. Sci. 51(6) 578-584.*

Jordan, L., R. F. Daniels, A. Clark, III, and R. He. 2005. Multilevel nonlinear mixed effects models for the modeling of earlywood and latewood microfibril angle. *For. Sci. 51(4) 357-371.*

Jordan, L., R. He, D. B. Hall, A. Clark III, and R. F. Daniels. 2006. Variation in loblolly pine microfibril angle with physiological age, height, and physiographic region. *J. Wood and Fiber Sci. 38 (*in press*).*

Mora, C. , R. F. Daniels, H.. L. Allen, A. Clark III . (Submitted). Modeling corewood-outerwood transition in loblolly pine using specific gravity. Can J. For Res.

Schimleck, L. R., C. Mora, and R.F. Daniels . 2003. Estimation of the physical wood properties of green *Pinus taeda* radial samples by near infrared spectroscopy Can. J. For. Res. 33(12): 2297-2305

Schimleck, L., R. Evans, D. Jones, R. F. Daniels, G. Peter, and A. Clark. 2005. Estimation of microfibril angle and stiffness by near infrared spectroscopy using sample sets having limited wood density variation. *IAWA J. 26(2):175-187.*

Schimleck, L., D. Jones, A. Clark, R. F. Daniels, and G. Peter. 2005 Near infrared spectroscopy for the nondestructive estimation of clear wood properties of *Pinus taeda* L. from the Southern USA. *For. Prod. J. 55(12):21-28.*

Schimleck, L., D. Jones, A. Clark, R. F. Daniels, and G. Peter. 2005. Success in using NIR spectroscopy to estimate wood properties of *Pinus taeda* radial strips not due to autocorrelation. *J. Near Infrared Spectroscopy 13(1):47-52.*

Schimleck, L., R. Evans, D. Jones, R. F. Daniels, G. Peter, and A. Clark III. 2005. Estimation of microfibril angle and stiffness by near infrared spectroscopy using sample sets having limited wood density variation. *IAWA J. 26(2):175-187.*

Schimleck, L., D. Jones, A. Clark, R. F. Daniels, and G. Peter. 2005. Near infrared spectroscopy for the nondestructive estimation of clear wood properties of *Pinus taeda* L. from the Southern USA . *For. Prod. J. 55(12):21-28.*

Schimleck, L., R. Stürzenbecher, C. Mora, D. Jones, R. F. Daniels. 2005. Comparison of *Pinus taeda* L. wood property calibrations based on NIR spectra from the radial-longitudinal and transverse faces of wooden strips. Holzforschung 59 (2), 214-218

<u>Presentations:</u>

Daniels, R. F. and A. Clark. III. 2001. Wood quality under intensive forest management. In: Proceedings: 26th Biennial Southern Forest Tree Improvement Conference. Athens, GA June 26-29, 2001. Univ. GA. Athens, GA.

Clark, A. III and R. F. Daniels. 2001. Estimating moisture content of tree-length roundwood. In: Proceedings TAPPI Pulping/Process & Product Quality Conference; Boston, MA Nov 5-8, 2000. TAPPI Press, Atlanta, GA

Daniels, R. F., R. He, A. Clark III, and R. Souter. 2003. Predicting wood properties of loblolly pine from stump to tip and pith to bark. In: Nepveu, G. (Ed). Proceedings of the Fourth Workshop: Connection Between Forest Resources and Wood Quality: Modelling Approaches and Simulation Software. IUFRO Working Party S5.01-04. Harrison Hot Springs, B.C. CA. Sept 8-14, 2002. INRA-Centre de Recherches de Nancy, France.

Clark III, A. and R. F. Daniels. 2003. Modeling the effects of physiographic region on wood properties of planted loblolly pine in the southeastern United States. In: Nepveu, G. (Ed). Proceedings of the Fourth Workshop: Connection Between Forest Resources and Wood Quality: Modelling Approaches and Simulation Software. IUFRO Working Party S5.01-04. Harrison Hot Springs, B.C. CA. Sept 8-14, 2002. INRA-Centre de Recherches de Nancy, France.

Clark, A. III and R. F. Daniels. 2003. Wood quality of slash pine and its effect on lumber, paper and other products. In: E. D. Dickens, J. P. Barnett, W. G. Hubbard, and E. J. Jokela (Eds). 2002. Slash Pine Symposium General Technical Report-2003. Gen. Tech. Rep. SRS-P. U.S.D.A. Forest Service, Southern Research Station. Asheville, NC.

Clark, A. III,M. R. Strub, L. R. Anderson, H. G. Lloyd, R. F. Daniels, J. H. Scarborough. 2003. Impact of early pruning and thinning on dimension and shop lumber grade yield from loblolly pine sudden saw log study trees. In: Proceedings Twelfth Biennial Southern Silvicultural Conference. Biloxi, MS. Feb 26-28, 2003.

Daniels, R.F. and A. Clark III. 2003 Variation in loblolly pine wood density and moisture content across the U.S. South. In: Proceedings Twelfth Biennial Southern Silvicultural Conference. Biloxi, MS. Feb 26-28, 2003.