THE APPLICATION OF NIRVANA TO SILVICULTURAL STUDIES

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Abstract—Previous results from this laboratory have shown that near infrared (NIR) spectroscopy, coupled with multivariate analysis, can be a powerful tool for the prediction of wood quality. While wood quality measurements are of utility, their determination can be both time and labor intensive, thus limiting their use where large sample sizes are concerned. This paper will demonstrate the applicability of the NIRVANA system to such studies, in particular the automated property assessment of increment cores. This system has been successfully applied to a set of longleaf cores obtained from a variety of sites within the Southeastern United States. Mechanical property models based on longleaf pine were applied to the NIR data, from which modulus of elasticity (MOE) and modulus of rupture (MOR) predictions were obtained for the cores. These initial results, while promising, did indicate the need for the inclusion of some of the new samples (from the various sites) into the calibration set to provide more robust models.

INTRODUCTION

The use of rapid assessment techniques for the characterization of wood has gained considerable interest throughout the forest products industry. Near infrared (NIR) spectroscopy, coupled with multivariate analysis, has been shown to be rapid, nondestructive, and requiring minimal sample preparation, making it ideal for process monitoring and quality control applications (So and others 2004). Multivariate analytical techniques, such as projection to latent structures (PLS) regression, have been used to develop calibration models for a variety of properties, utilizing both NIR and traditionally acquired data. These include: physical properties such as density (Gindl and others 2001, Hoffmeyer and Pedersen 1995, Thygesen 1994, Via and others 2003); mechanical properties such as modulus of elasticity (MOE) and modulus of rupture (MOR) (Gindl and others 2001; Hoffmeyer and Pedersen 1995; Kelley and others 2004a, 2004b; Thumm and Meder 2001; Via and others 2003) and wet chemistry (Kelley and others 2004b). Similarly, NIR spectroscopy has been very successfully applied to wood property data obtained from SilviScan. This instrument utilizes a combination of X-ray diffractometry, X-ray densitometry, and image analysis for the rapid determination of a range of wood properties at high spatial resolution. Schimleck, Evans, and coworkers, have used NIR spectra combined with SilviScan data to plot the variation of density, MFA, and MOE across increment cores (Jones and others 2005; Schimleck and Evans 2002a, 2002b, 2003; Schimleck and others 2002).

A system for the automated property assessment of increment cores, known as Near InfraRed Visual and Automated Numerical Analysis (NIRVANA), has been developed using this technique. This process utilizes a NIR spectrometer and a motorized stage linked together via various software and hardware systems. A software program was written to integrate the apparatus and is controlled by a user-friendly interface. For real-time property determination, various control settings (including choosing appropriate PLS models) must be input prior to scanning. The spectral data are collected and processed through the PLS models from which property values are instantaneously predicted. These are displayed in the form of real-time plots showing the variation of the selected properties as a function of distance along the core.

There is a range of applications suited to NIRVANA, one of which is to relate the wood quality of longleaf pine to growth and yield data. Since longleaf pine can exhibit relatively slow growth rates, intensive silvicultural treatments such as weed control, fertilization, thinning, and pruning may be needed to increase productivity. While these practices can result in large gains, questions arise over the quality of the wood that is produced by accelerated growth. NIRVANA aims to develop integrated information on growth, yield, and wood quality of longleaf pine subjected to varying levels of silvicultural inputs.

METHODS

The longleaf specimens used in the models for MOE and MOR were obtained from 10 longleaf trees selected from a plantation in Harrison Experimental Forest, Saucier, MS, located at longitude 89°10' W and latitude 30°60' N. The sample preparation and mechanical testing methods are fully described elsewhere (Via and others 2004).

The prediction set of 58 cores with unknown properties was collected from a variety of longleaf pine stands throughout the Southeastern United States (table 1). These stands represent ages between 20 and 100 years with site indices between 50 and 80. Some of these stands are part of the Regional Longleaf Pine Growth Study (RLGS), established in the Gulf States by the U.S. Forest Service, in which the original objective was to obtain a database for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine stands. The cores were air dried, mounted, and surfaced with the radial face protruding.

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Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

Table 1—Stand descriptions for longleaf cores used for prediction

Site	Site location	No. of cores	Site index	Basal area	Latitude (N)	Longitude (W)
Cyrene	Cyrene Turpentine Co., GA	16	80-85	30, 60, 90, 130 or 150	30°86'	84°38'
Southlands	Southlands Exp. Forest, GA	7	85-89	120 or 150	30°48'	84°42'
Escambia	Escambia Exp. Forest, AL	23	low 70s	60s	31°01'	87°04'
Flomaton	Flomaton Natural Area, AL	9	Unknown	Unknown	31°01'	87°14'
McClellan	Fort McClellan, AL	3	low 50s	40s	33°40'	84°45'

The cores were then placed on a Newport motorized stage (Newport, Irvine, CA), and spectra were collected at 2-mm intervals along the cores using an ASD Field Spec Pro (Analytical Spectral Devices, Boulder, CO) spectrometer. The spot size at the sample surface was approximately 2 mm with the spectra collected at wavelengths between 350 and 2,500 nm. This was achieved using a fiber optic probe oriented perpendicular to the sample surface while illuminated with a DC lamp oriented at 30° above the surface. The calibration specimens were scanned more than a year earlier using a similar method.

Partial least squares (PLS) analysis of the NIR data was performed using Unscrambler (version 8.0) software (CAMO, Corvallis, OR). The NIR data were reduced to 10 nm wavelength spacing by averaging prior to analysis. The calibration models for MOE and MOR were generated using full cross-validation (Martens and Naes 1989). The 469 calibration specimens were separated into a calibration set of 352 and a validation set of 117.

RESULTS AND DISCUSSION

The longleaf models employed in this study have been used to predict MOE and MOR values for a set of longleaf cores harvested from various sites in the southeast. This parallel study, when compared to the work on the Harrison Experimental Forest, will help establish more general trends and indicate the utility of such models across broader geographic areas. The relationship between the predicted and measured MOR and MOE is shown in figures 1(a) and 1(b), respectively. It can be seen that the R^2 values for both the calibration (352 specimens) and the validation (117 specimens) sets were high. The models obtained from the calibration sets were then used to predict the mechanical properties of the 58 cores in the prediction set.

The variation of predicted MOE along a typical longleaf core is shown in figure 2, with its corresponding image (inset). A general trend was observed of low MOE near the pith with higher values towards the bark. However, the values appear to peak near the transition region from wide to much narrower rings. Each NIR spectrum collected, after the transition region, is an average over many narrow growth rings as compared with those collected near the pith. Furthermore, the localized variation of MOE with earlywood and latewood bands is clearly evident in the pith region. This plot was repeated for each of the cores and also replicated for MOR. The NIRVANA system can produce these plots in real time, thus making it suitable for use in quality control applications. It was also observed that the inverse of the mechanical properties closely mirrors the annual growth of the tree. Both factors exhibit large variability during the formation of juvenile wood, followed by a sharp reduction in variability as growth continues (fig. 3).

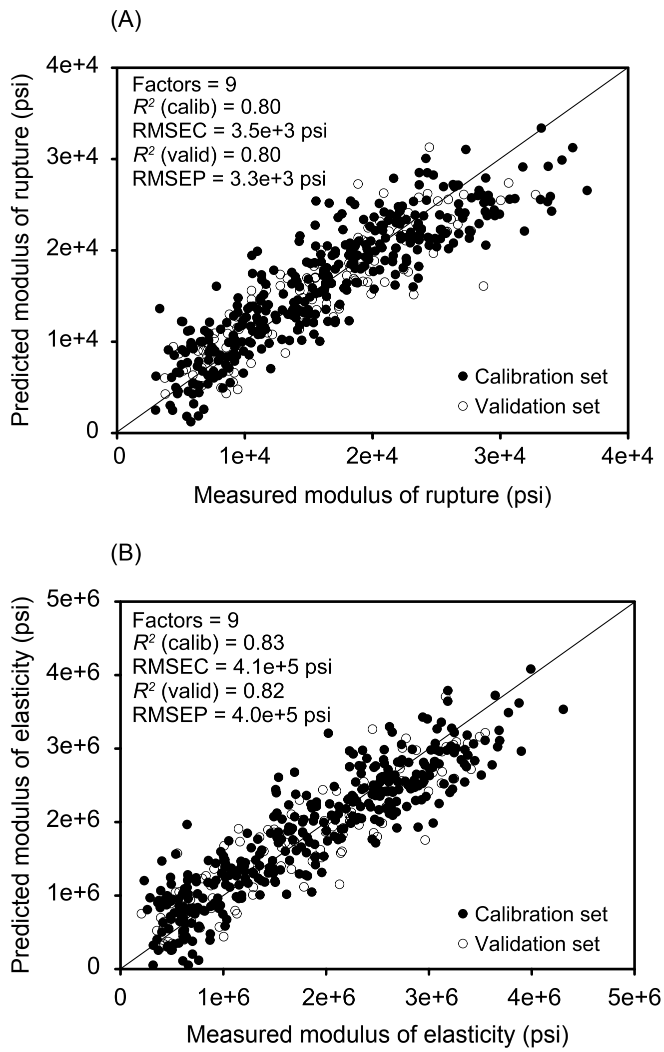

Figure 1—Relationship between predicted and measured (A) Modulus of Rupture and (B) Modulus of Elasticity.

This can be related to the image in figure 2 in which wide growth rings were present during juvenile wood formation followed by much narrower rings with the development of mature wood.

The determination of a single average value for each core may often be necessary for silivicultural or genetic studies in which thousands of increment cores may be extracted. This was carried out for MOE and MOR using both an area-weighted average as well as a simple numerical average. It was concluded that both methods yielded similar results for these

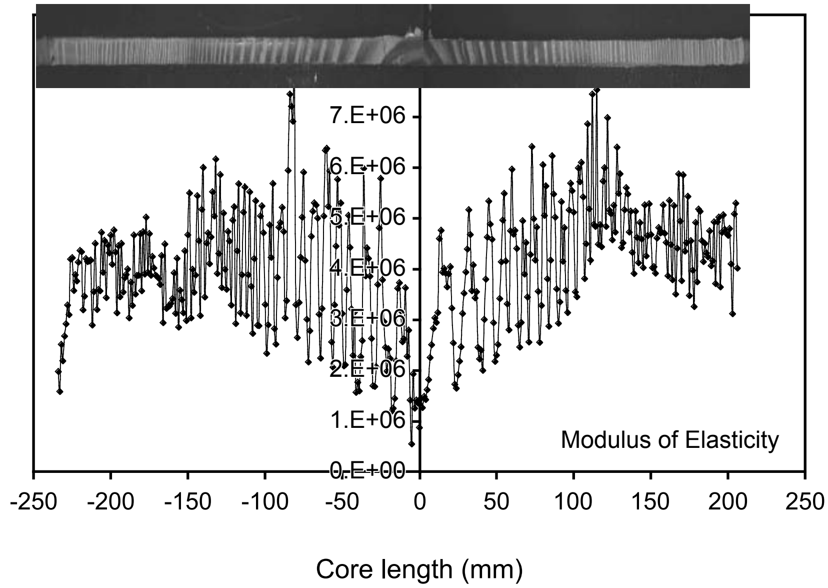

Figure 2—Modulus of Elasticity variation across an increment core.

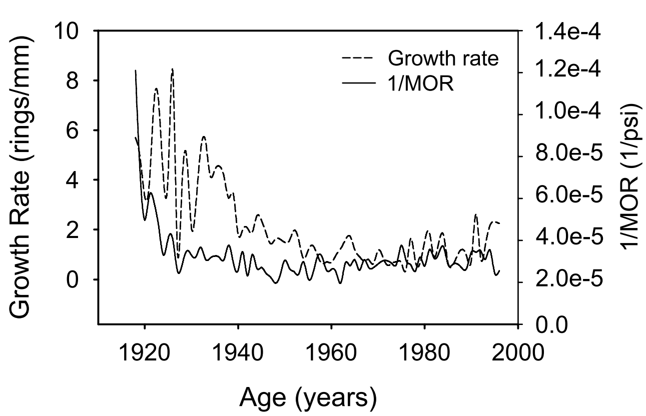

Figure 3—Variation of 1/Modulus of Rupture and growth by year.

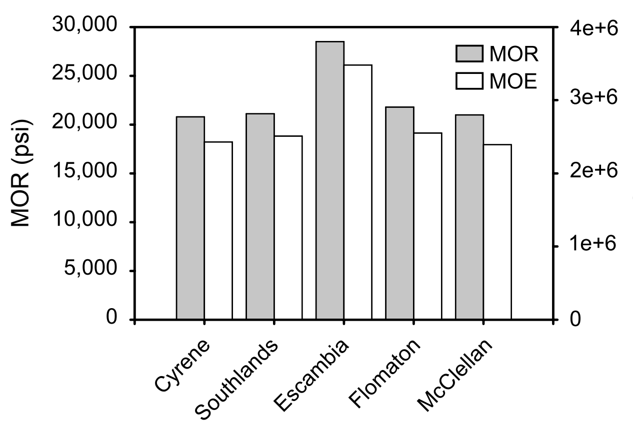

Figure 4—Summary of average mechanical properties by site.

cores. This data was further summarized by averaging these properties by site. The initial results indicate there are relatively large differences in mechanical properties between the cores from the Escambia Experimental Forest compared with those from the other sites (fig. 4). Further analysis of the growth and yield data is required to understand these results.

The predicted results for this initial study were based on a calibration set obtained from longleaf pine stands in the Harrison Experimental Forest, Saucier, MS. This sample set, however large, does have limited variation. It must be determined whether this variation is large enough to encompass that of the prediction set, i.e., cores from the sites listed in table 1. The mechanical properties for the prediction set are unknown and have only been predicted using the models from the calibration set. It was observed that a significant number of MOE values in figure 2 were greater than those for the calibration samples in figure 1(b). This indicates that the calibration set may not provide enough variation to produce robust calibration models that can be applied to the prediction set. It has been reported that the addition of a single specimen from the prediction set significantly decreased the error in the wood property predictions (Jones and others 2005). The authors concluded that the enhancement was not so much due to the increase in variability of the wood properties in the calibration, but rather to the slight variability in the spectra from each stand due to the unique growing conditions at each site. These studies utilized Silviscan to determine the measured wood properties for both the calibration and prediction sets. However, in this study, it was not possible to obtain measured mechanical properties from trees used in the prediction set.

The purpose of this paper was to demonstrate the applicability of the NIRVANA system for wood quality studies and relating these results to growth and yield data. The NIRVANA software is presently undergoing an upgrade from a visual basic- to a Labview™-based program, greatly enhancing its functionality. The incorporation of a high-resolution video camera, integrated into the new software, will permit the automated visual recognition of individual growth rings, thus allowing the property variation along the core to be determined on a growth ring basis. This can be carried out simultaneously with the collection of growth and yield data from the core.

CONCLUSIONS

The rapid assessment of solid wood properties using NIR has broad implications in relation to wood quality and ultimately, tree improvement. The NIRVANA system provides data rapidly and economically and thus is ideally suited to both silviculture and genetic programs with their use of large-scale sampling. It can also be used for real-time monitoring of property changes along an increment core. While NIRVANA has been successfully applied to this study, in order to produce robust calibration models for the prediction of wood properties, good sampling techniques must be employed, which, in this case, may mean the inclusion of a few samples from each of the sites into the calibration models.

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