# RAPID ASSESSMENT OF THE FUNDAMENTAL PROPERTY VARIATION OF WOOD

**Chi-Leung So, Leslie H. Groom, Timothy G. Rials, Rebecca Snell, Stephen S. Kelley, and Robert Meglen**[1]

**Abstract—**Genetic variation, site conditions, silvicultural treatments, seasonal effects, and their complex interaction are all vitally-important factors accounting for the variability and quality of the raw material produced - wood. Quality can be measured in several ways that generally influence the end use. The most desirable measure is the fundamental properties. The physical properties and strength characteristics at selected locations in the bole have been determined for three loblolly pine trees obtained from the Crossett Experimental Forest (Crossett, AR). The range and variation of properties within and between the trees has been summarized in the form of wood property maps. The creation of such property maps via traditional test methods require much time and expense. However, a new rapid assessment technique combining near infrared (NIR) spectroscopy with multivariate statistical techniques to predict these fundamental properties has shown great potential. This paper introduces the application of this developing methodology to wood quality issues by highlighting early results from a larger program that will define the range of properties for southern pine. The results from the standard test methods have been compared with those predicted from NIR spectra/multivariate analysis, and have been shown to provide excellent correlations.

## INTRODUCTION

An improved understanding of genetic factors and silvicultural treatments on the chemical, physical, and mechanical properties of wood is important for producing raw materials that are optimized for specific material systems. Paper and pulp operations require sensitive measurement of chemical composition of wood chips to control processing conditions. It is reasonable to assume that manufacturers of wood composite products can derive similar benefits from data on physical and mechanical properties of the wood. This type of information is not routinely available because of the time and expense required to obtain the data.

Recent research has addressed the issue of rapid assessment methods that are capable of affordably evaluating fundamental wood characteristics. Near infrared (NIR) reflectance spectrometry (1,000 - 2,500 nm, 10,000 - 4,000 $cm^{-1}$) combined with multivariate statistical techniques has now been demonstrated to provide spectra of sufficient quality to permit chemical analysis of solid wood without sample preparation (Schimleck and others 1997; Meder and others 1999). The application of multivariate analysis to the NIR spectra of wood has reduced much of the problem of overlapping signals from the three main polymer constituents: cellulose, hemicellulose and lignin (Wallbacks 1991). NIR spectra have also been used to provide quantitative, non-destructive measurement of physical properties such as density (Meder and others 1999).

Several studies have been performed comparing the use of near infrared (NIR) and Fourier transform infrared (FTIR) with multivariate analysis for predicting chemical composition (Schultz and Burns 1990; Wallbacks and others 1991a,b; Meder and others 1999). It was observed that although both NIR and FTIR could be used to predict chemical composition, it was the NIR spectra which generally produced better correlations and was clearly the simpler and much faster technique.

This technique found acceptance in the pulp and paper industry and has been used to predict paper properties from the spectra of pulp (Wallbacks and others 1991a,b) as well as paper ageing studies in which the age of paper in service could be estimated (Ali and others 2001). Similarly this technique has been gaining use for online process monitoring in particleboard manufacture. In particular, it can facilitate the reduction in standard deviation of the board quality by adjusting the process settings accordingly, thus leading to substantial cost savings (Engstrom and others 1998; Johnsson and others 2000).

## MATERIALS AND METHODS

The trees selected in this study are part of a larger program to study the variability and development of properties for southern pine. Three trees were selected from each site. The majority of this paper is concerned with a set of 55-yr old loblolly pine (*Pinus taeda* L.) trees felled from a natural regeneration stand in the Crossett Experimental Forest, Crossett, AR. Periodic understory control was conducted via a series of prescribed burns. Trees were also collected in

[1]Research Scientist, Research Scientist, Project Leader, USDA-Forest Service, Southern Research Station, Pineville, LA; Research Scientist, BioComposites Center, Bangor, Wales; Senior Chemist, Senior Chemist, National Renewable Energy Laboratory, Golden, CO, respectively.

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South Carolina and two sites in Mississippi for comparisons. A set of 15-yr old loblolly pine trees was collected from a rapid growth experimental plot near Summerville, SC, in which a 6 x 6 ft spacing was chosen for the first 5 years and then 12 x 12 ft thereafter. Three extremely-fast grown loblolly pine trees were chosen from a seed orchard in Eastabuchie, MS. These were felled from a 29-yr old clonal stand in which the conditions were primed for cone production. The last set in this study is a set of 30-yr old slash pine (*Pinus elliottii* Engelm) trees, grown on a wet site, in DeSoto National Forest, MS. Important tree data such as the height, diameter at breast height (d.b.h.) and height to live crown are listed in table 1.

#### Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

The bending specimens were taken from disks 14 inches in height that were cut at 15 ft separations along the tree height. Two parallel cuts were made along the disks, north to south, approximately 0.5 inches either side of the pith. These slabs were further cut according to the ring of interest, in which one ring either side was included, such that the specimen was 3 rings high and 1 inch wide. The specimens were cut to 12 inches in length for testing, under three-point bending, in an Instron testing machine. Care was taken to avoid any regions with defects, such as knots, where possible. A 1-inch cut-off piece was used for specific gravity testing.

### Near Infra-Red (NIR) Spectroscopy

NIR spectra were obtained using a FieldSpec FR (Analytical Spectral Devices Inc., Boulder, CO) at wavelengths between 350 and 2500 nm. Thirty scans were collected and averaged into a single spectrum. Two spectra were collected for each specimen.

### Multivariate Analysis

Multivariate analysis of the NIR data was performed using The Unscrambler® vsn. 7.5 software package (CAMO, Corvallis, OR). Partial least squares (PLS) analysis was conducted on the spectra after averaging. The models were generated using full cross-validation; this is a method in which one sample is systematically removed from the data set; a model is created from the remaining samples, and this model is used to predict a value for the extracted sample. This process is subsequently repeated for all remaining samples (Martens and Naes 1992). No further manipulation of the spectral data was employed.

**Table 1-–Summary of the tree height, diameter at breast height, and height to live crown for the trees**

| Site | Tree No. | Height of Tree, ft. | D.B.H., in. | Height to Live Crown, ft. |
|---|---|---|---|---|
| Crossett, AR | 1 | 92.7 | 16.4 | 73.6 |
| | 2 | 100.5 | 18.8 | 72.5 |
| | 3 | 98.1 | 20.9 | 78.6 |
| Summerville, SC | 1 | 59.7 | 10 | 24.3 |
| | 2 | 61.0 | 10.3 | 29.0 |
| | 3 | 59.3 | 9.8 | 29.5 |
| Eastabuchie, MS | 1 | 70.0 | 22.5 | 27.5 |
| | 2 | 75.0 | 23.3 | 26.0 |
| | 3 | 65.0 | 23.6 | 15.0 |
| Hattiesburg, MS | 1 | 47.5 | 6.2 | 31.0 |
| | 2 | 64.4 | 8.7 | 38.0 |
| | 3 | 56.5 | 8.4 | 45.7 |

## RESULTS AND DISCUSSION

### Tree Property Maps

Three trees were collected from each location and each of the following tree property maps (figures 1 through 4) is an average of the three trees taken. These tree property maps show the variation in a particular property within the tree. Figure 1 shows the variation of specific gravity in the 55-year-old trees from the Crossett site. The specific gravity for a given growth ring increases with tree height. The base of the tree provides the highest values of specific gravity, with the lowest derived within the juvenile core.

Although there exists a relationship between specific gravity and modulus of elasticity (MOE), this relationship is not strong as can be seen in figure 2. MOE appears to be more closely associated with juvenility, as pith-associated wood is more compliant than the corresponding mature wood. That is because MOE is more closely associated with microfibril angle (MFA) than with specific gravity (Megraw 1985). This strong relationship between stiffness and MFA also exists for strength as can be seen in figure 3.

The variation of MOE with tree location is not a constant from stand to stand (figure 4). Interactions such as live crown, specific gravity, and MFA result in a 3-dimensional maturation process that affects subsequent mechanical properties. These figures clearly show there is a large property variation within the tree. Thus, taking increment cores at breast height, a common technique, cannot be taken to representative of the whole tree.

### Near Infra-Red (NIR) Spectroscopy

The NIR spectra of juvenile (rings $< 8$) and mature (rings $> 24$) wood obtained from loblolly pine, between 350 – 2500 nm, is shown in figure 5. It is clear to see that differences cannot be noted visually; the characteristic peaks show broad overlapping absorption bands arising from secondary overtones and combinations X-H stretching vibrational modes. NIR is, most importantly, sensitive to hydrogen bonding, thus making it very applicable to wood. The use of multivariate statistical techniques improves the extraction of information from the spectra, revealing any differences.

### Multivariate Analysis

Figure 6 shows a prediction plot for the specific gravity in which the abscissa is the "true" specific gravity determined from standard test methods and the ordinate is the "NIR-predicted" specific gravity from the NIR spectra and multivariate analysis. It is clearly observed that the data follow the 1:1 line very well with a r-value of 0.82. Good correlations were also obtained for the mechanical properties as shown in figure 7 for the modulus of elasticity (MOE) and figure 8 for the modulus of rupture (MOR) with resultant r-values of 0.88 and 0.87 respectively. These findings are

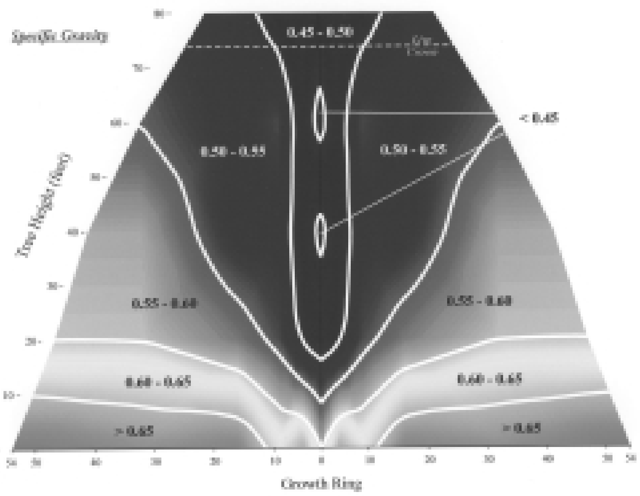


Figure 1—Specific gravity maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

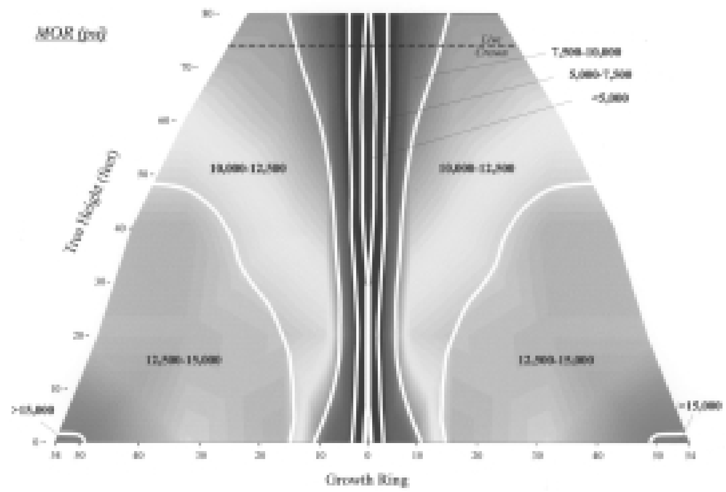


Figure 3—Modulus of rupture (MOR) maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

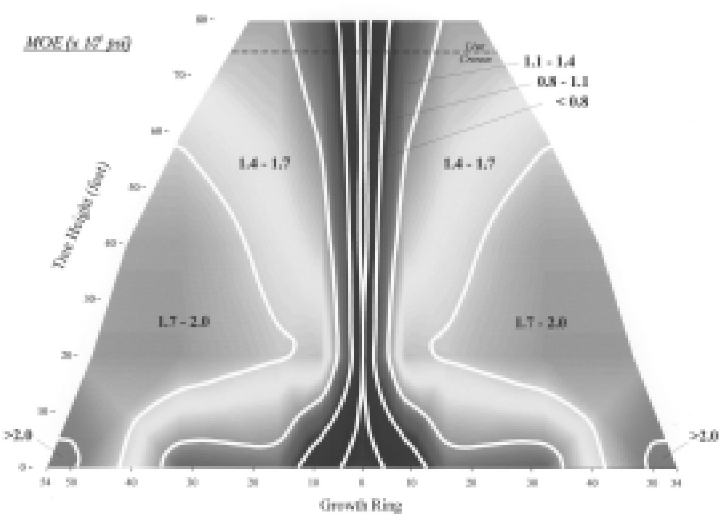


Figure 2—Modulus of elasticity (MOE) maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

consistent with Engstrom and others (1998) who obtained a similarly good correlation of 0.9 for particleboard MOR.

## CONCLUSIONS

Property mapping of trees clearly reveals large variations with location within the tree. This was further extended to compare the MOE variation within trees from different stands. Naturally, differences were observed between the maps, with particular interest in the differences in their magnitude and their patterns. These maps show how growth conditions affect property variation within a tree and can be applied to silvicultural treatments to improve tree properties; however, the construction of such maps requires much time and expense with traditional test methods.

It has been shown that NIR spectroscopy, in conjunction with multivariate analysis, can be used to predict fundamental wood properties with excellent results, and in a much smaller time scale than by traditional testing. With further advances in technology, the development of a handheld portable field unit capable of assessing all major wood properties on standing timber may be possible.

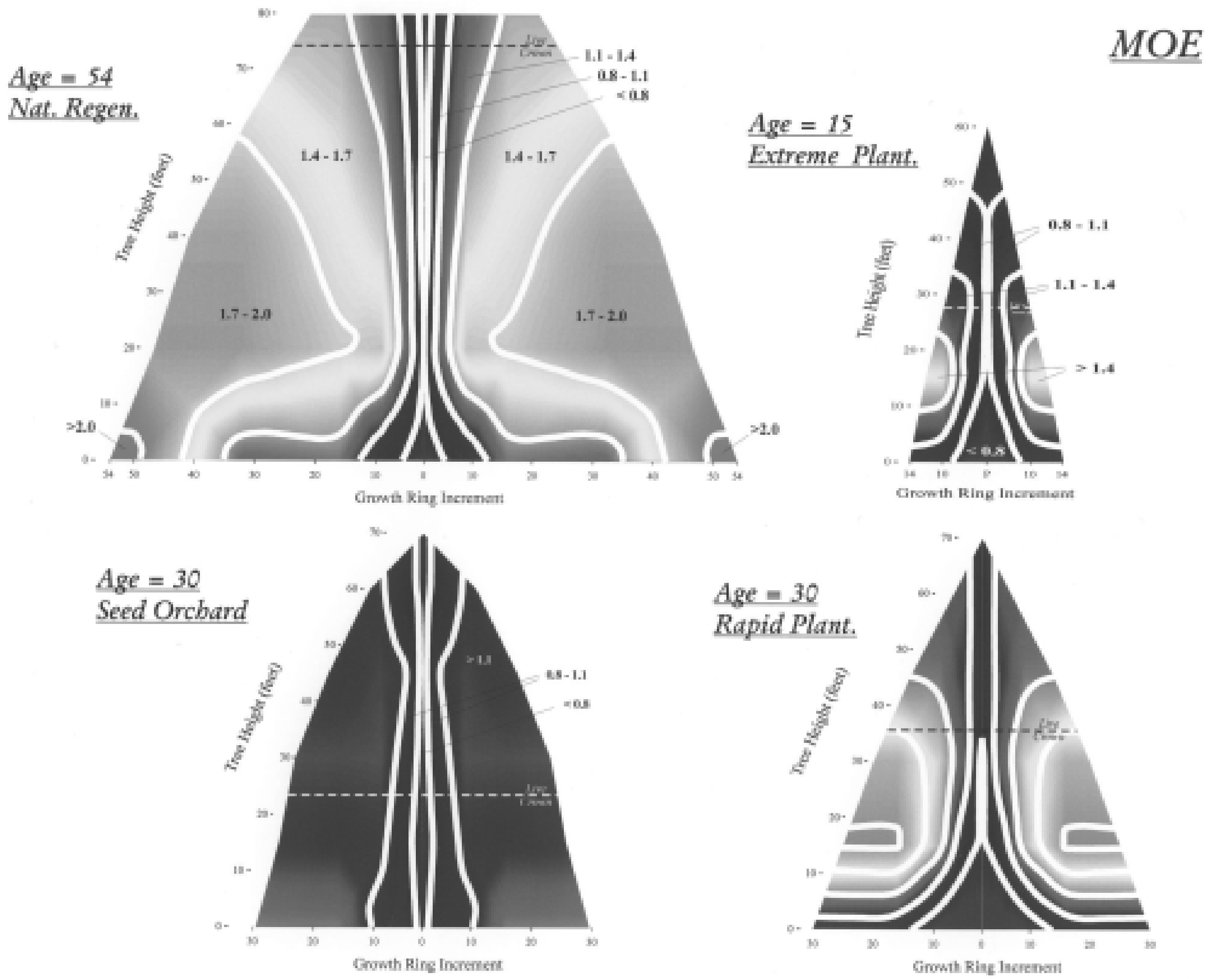


Figure 4—Modulus of elasticity (MOE) maps for trees harvested from (a) 55-year-old loblolly pine (Crossett, AR); (b) 15-year old-loblolly pine (Summerville, SC); (c) 30-year-old, seed orchard, loblolly pine (Eastabuchie, MS); and (d) 30-year-old slash pine (Hattiesburg, MS).

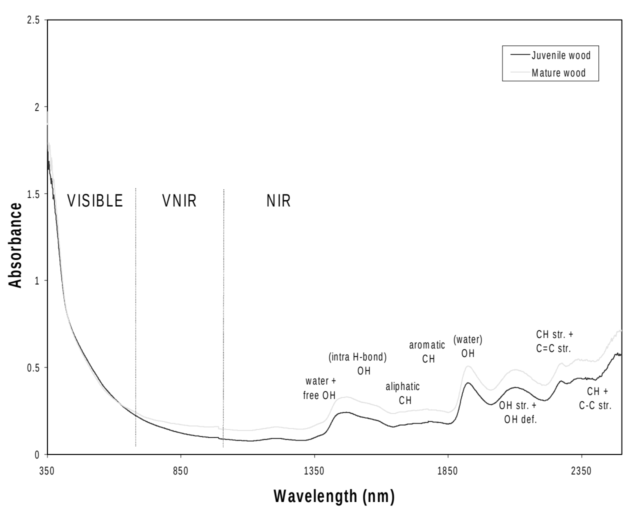


Figure 5—NIR spectra of juvenile and mature wood obtained from loblolly pine in the range of 350 – 2500 nm.

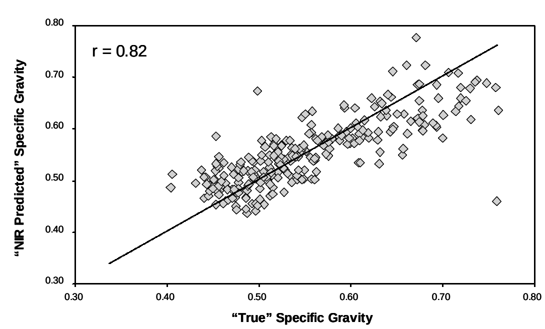


Figure 6—Comparison of “NIR-predicted” vs. “true” values for specific gravity.

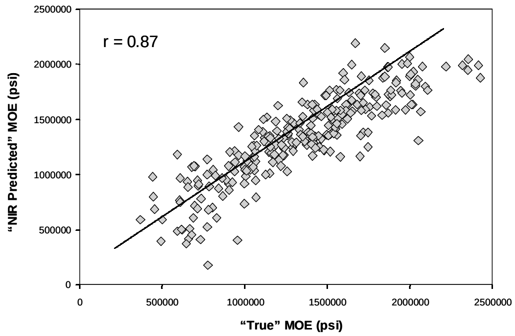


Figure 7— Comparison of "NIR-predicted" vs. "true" values for modulus of elasticity (MOE).

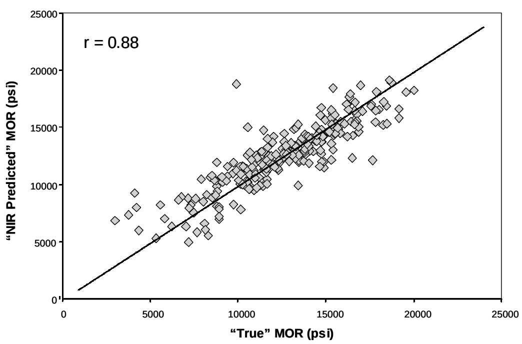


Figure 8—Comparison of "NIR-predicted" vs. "true" values for modulus of rupture (MOR).

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