Estimating wood properties of green radial strips by near infrared spectroscopy

L.R. Schimleck[a], C. Mora[b] and R.F. Daniels[a]

[a]*Warnell School of Forest Resources, University of Georgia, Athens GA, 30602, U.S.A.*

[b]*Department of Forestry, North Carolina State University, 3125 Jordan Hall, Raleigh, NC, 27695, U.S.A.*

Introduction

The wood properties of trees grown in plantations are the product of a number of variables including genetics (eg. species, provenance, clone), environmental factors (eg rainfall, soil type, altitude) and silvicultural practices (eg. fertilization, pruning, thinning). Owing to the unpredictable nature of the interaction between these variables the wood properties of plantation grown trees are also quite variable. Considerable interest exists in improving the wood properties of plantation grown trees but owing to the wide variation that exists in plantations many trees have to be sampled. To measure the large numbers of trees rapid non-destructive methods are required, ideally these methods would also be applicable to standing trees.

SilviScan-1 and SilviScan-2[1-3] have been designed to rapidly measure a range of wood properties including cell cross-sectional dimensions, density, microfibril angle (MFA) and stiffness (determined using SilviScan-2 diffractometric data and measured density). These properties are measured using a combination of scanning X-ray microdensitometry, X-ray diffractometry and image analysis. Measurements are made at high resolution on wooden strips cut from 12 mm increment cores. However the SilviScan instruments are laboratory based and are not applicable for use in the field. In addition, the wooden strips have to carefully cut and conditioned at a temperature of 20ºC and a relative humidity of 40% prior to testing.

Data generated by the SilviScan instruments can be used to calibrate a near infrared (NIR) spectrometer. It has been shown that calibrations developed for air-dry density, MFA, stiffness and a number of fiber properties provide strong relationships between SilviScan measured values and NIR-estimates for *Pinus radiata* D. Don (Radiata pine) cores[4-7]. NIR spectroscopy has been successfully applied to green (or wet) wood[8,9] and potentially it could be used to estimate properties measured by SilviScan using samples that have not been dried but it is unknown what impact the high and variable moisture content[10] of green wood would have on those calibrations reported for conditioned samples[4-7]. Hence the aim of this study was to investigate the development of air-dry density, MFA and stiffness calibrations based on NIR spectra collected from the surface of green *Pinus taeda* L. (loblolly pine) wood samples.

Materials and methods

Sample origin

P. taeda wood samples examined in this study were obtained from a regeneration trial established by the North Carolina State Forest Nutrition Cooperative in 1979 on a poorly drained site in Williamsburg County, South Carolina, U.S.A. The study received a factorial combination of

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two levels of each site preparation, fertilization and herbicide treatment at establishment. A complete description of the treatments is given elsewhere[11]. Breast height (1.4 m) discs representing twenty trees from five different treatments were utilised in this study. All samples were frozen after sampling for storage. Radial samples representing pith to bark variation were cut from each breast height disc while frozen. The dimensions of the radial samples were 12.5 mm tangentially and 12.5 mm longitudinally, radial length was determined by the pith-bark length of each sample.

Sample preparation for near infrared spectroscopy and SilviScan analysis

The frozen radial samples were defrosted and any loose sawdust present on the surface of the samples removed. NIR spectra were collected from the radial-longitudinal and transverse surfaces of the green radial samples but only results for the radial-longitudinal surface will be reported here.

Measurement of wood properties using SilviScan

Radial strips for analysis by SilviScan-1 and -2 were cut from the samples when dried to a moisture content of approximately 7% using a twin-blade saw. Strip dimensions were 2 mm tangentially and 7 mm longitudinally, radial length was determined by the pith-bark length of the samples.

Air-dry density was measured in 50-micron steps using x-ray densitometry on SilviScan-1[1]. MFA was measured in 1-mm steps on SilviScan-2 using scanning x-ray diffractometry[2,3]. Wood stiffness (at the same resolution as MFA) was determined using x-ray densitometry and x-ray diffraction data. All measurements were made in a conditioned atmosphere maintained at 40% RH and 20°C. For correlation with the green wood spectra wood property averages were determined over 10.5-mm sections to account for the radial shrinkage (4.8%[10]) of the green samples when they were dried.

Near infrared spectroscopy

NIR diffuse reflectance spectra were obtained from the radial-longitudinal face and transverse face of each sample when green. All spectra were obtained using a NIRSystems Inc. Model 5000 scanning spectrophotometer. Samples were held in a custom made holder described in an earlier publication[12]. The holder was modified to hold larger samples. A 5-mm x 10-mm mask was used to ensure a constant area was tested. Several samples were slightly twisted and a small gap between the spectrometer window and sample was occasionally observed permitting stray light to interfere with the NIR measurements. To minimize stray light the samples were tested in a light proof environment. The spectra were collected at 2 nm intervals over the wavelength range 1100-2500 nm. The instrument reference was a ceramic standard. Fifty scans were accumulated for each 10-mm section and the results averaged. One average spectrum was obtained per section.

Calibration development

Fifteen cores, three per silvicultural treatment, were selected at random for calibration development. The remaining five cores (one per silvicultural treatment) were used to test the predictive ability of the calibrations. Table 1 gives a statistical summary of each wood property for the green wood calibration and prediction sets.

WinISI II (version 1.50) software package (Infrasoft International, Port Matilda, PA) was used to develop the wood property calibrations. The wavelength range was limited to 1108 to 2492 nm for calibration development. Calibrations were developed using Modified Partial Least Squares (MPLS) regression with second derivative spectra (gap 4 nm).

Table 1. Range of each parameter for the green wood calibration and prediction sets.

Wood	Calibration set (98 samples)				Prediction set (32 samples)			
Property	Min.	Max.	Av.	Std. dev.	Min.	Max.	Av.	Std. dev.
Air-dry density (kg/m^3)	394.4	784.1	589.6	91.9	405.1	852.8	613.2	109.6
MFA (deg.)	10.8	38.6	25.6	7.3	10.4	34.0	23.5	7.6
Stiffness (GPa)	3.1	21.0	10.1	5.1	3.2	25.5	12.0	6.2

Results and discussion

Variation in NIR spectra collected from the radial-longitudinal surface

NIR spectra collected from the radial-longitudinal surface of each *P. taeda* core were averaged to give a single NIR spectrum per core (Figure 1). The NIR spectra shown demonstrate wide variation in terms of their moisture content (approximately 100 to 154%), air-dry density (519.1 to 686.3 kg/m^3), MFA (16.2 to 31.4 deg.) and stiffness (7.5 to 15.9 GPa).

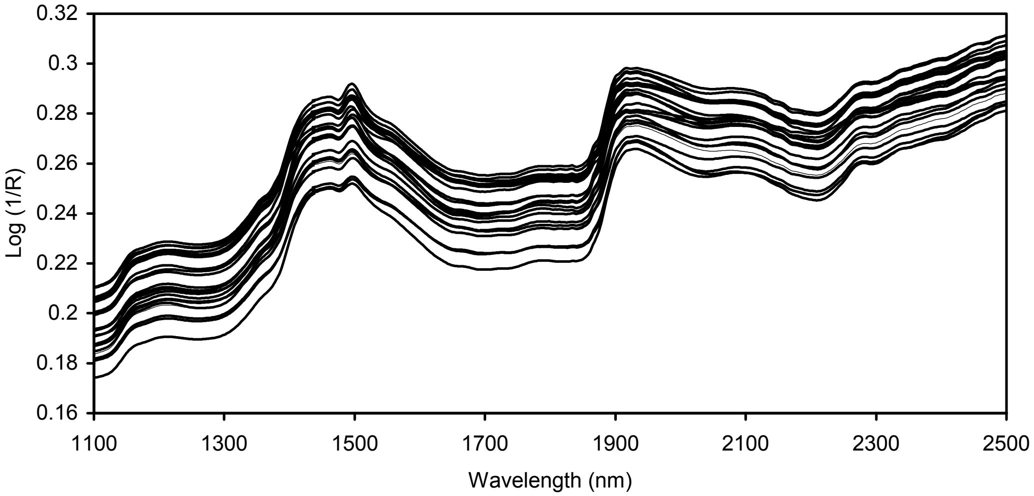

Figure 1. NIR diffuse reflectance spectra of twenty *P. taeda* increment cores over the range 1100-2500 nm.

The relationship between absorbance at each wavelength, for both untreated and second derivative spectra, was examined for air-dry density, MFA and stiffness using standard linear regression and all samples (130). Weak relationships were obtained for the untreated spectra. Stronger relationships were observed between each wood property and second derivative absorbance at individual NIR wavelengths. Wavelengths giving the strongest relationships are given in Table 2.

Table 2. Wavelengths giving strong relationships with air-dry density, MFA and stiffness for second derivative NIR spectra. The coefficient of determination (R^2) for each wavelength is shown in parenthesises.

Wood property	Wavelength (nm) and R^2
Density (kg/m^3)	1232 (0.58), 1582 (0.69), 1606 (0.61)
MFA (deg.)	1582 (0.47)
Stiffness (GPa)	1582 (0.58), 1606 (0.56)

Moderate relationships were observed for air-dry density while the relationships for stiffness and MFA and were weaker. The strongest relationship for MFA ($R^2 = 0.47$) was much weaker than the MFA – individual wavelength relationships reported for *Pinus radiata*[5]. It is probable that the high and variable moisture content of the samples has weakened the relationships that exist between these wood properties and second derivative absorbance at individual NIR wavelengths.

Similar wavelengths were observed to have the strongest relationships for each wood property. The relationships between each of the wood properties were examined and it was found that MFA was strongly correlated with stiffness ($R^2 = 0.91$). Weaker relationships were observed between air-dry density and stiffness ($R^2 = 0.72$) and air-dry density and MFA ($R^2 = 0.51$).

Development and application of MPLS calibrations – green wood

MPLS regression calibrations were developed for air-dry density, MFA and stiffness using NIR spectra obtained from the radial-longitudinal face of the green *P. taeda* samples. The calibrations were then applied to a separate test set of 32 samples that represented five cores (one per treatment). Summary statistics for each calibration are provided in Table 3.

Table 3. Summary of calibrations developed for each *P. taeda* wood property using spectra collected from the radial-longitudinal face of green wood samples. When the number of factors reported and recommended by the software were different the number of factors recommended is shown in parenthesis.

Wood	Calibration set				Prediction set	
Property	# factors	R^2	SECV	SEC	R_p^2	SEP
Air-dry density (kg/m^3)	3	0.85	39.2	35.2	0.74	57.6
MFA (deg.)	5 (10)	0.82	3.9	3.1	0.68	4.2
Stiffness (GPa)	5 (6)	0.88	2.3	1.8	0.81	3.0

The calibrations developed for each wood property gave strong relationships with coefficients of determination (R^2) ranging from 0.82 to 0.88. For the MFA and stiffness calibrations developed using NIR spectra obtained from the radial-longitudinal fewer factors were used than actually recommended by the software.

A prediction R^2 (R_p^2) was calculated as the proportion of variation in the independent prediction set that was explained by the calibration. Predictions of the respective wood properties were good but the R_p^2 were noticeably lower for each wood property compared to R^2. The greatest reduction occurred for the MFA calibration.

Conclusions

This study demonstrates that calibrations for air-dry density, MFA and stiffness can be developed using NIR spectra obtained in 10 mm sections from the radial-longitudinal face of green *P. taeda* wood samples.

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References

1. Evans, in Microfibril Angle in Wood: Proceedings of the IAWA / IUFRO International Workshop on the Significance of Microfibril Angle to Wood Quality, Ed by B.G. Butterfield. University of Canterbury Press, Christchurch, NZ, p. 116 (1997).
2. R. Evans, Appita J. **52**, 283 (1999).
3. L.R. Schimleck and R. Evans, IAWA J. **23**, 217 (2002).
4. L.R. Schimleck and R. Evans, IAWA J. **23**, 225 (2002).
5. L.R. Schimleck and R. Evans, Appita J. (Accepted) (2003).
6. L.R. Schimleck and R. Evans, Holzforschung (Accepted) (2003).
7. L.G. Thygesen, J. Near Infrared Spectrosc. **2**, 127 (1994).
8. R. Meder, A. Thumm and D. Marston, J. Near Infrared Spectrosc. (Accepted) (2003).
9. J.G. Haygreen and J.L. Bowyer, Forest products and wood science: an introduction, 3rd Edition. Iowa State University Press, Ames, Iowa, USA, p. 167, 170, (1996).
10. U. Nilsson, and H.L. Allen, For. Ecol. Manage. **175**, 367 (2003).
11. L.R. Schimleck, R. Evans, and J. Ilic, Can. J. For. Res. **31**, 1671 (2001).