# Nondestructive evaluation of wood properties of plantation grown *Pinus taeda* by near infrared spectroscopy

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## Introduction

*Pinus taeda* L. (loblolly pine) is the most important commercial timber species in southern USA. It is widely grown in plantations where the application of intensive silvicultural management and the incorporation of genetically improved planting stock have provided significant increases in growth and yield. While the growth of plantation trees has been improved it has been observed that the properties of the wood have declined. The wood quality of future plantations can be improved through silviculture, breeding and genetic engineering but access to basic wood property information will be required for this to occur.

Obtaining the basic wood property information needed for improvement requires the measurement of many thousands of trees and using existing analytical methods may be cost prohibitive. To overcome these limitations, rapid, nondestructive methods based on increment cores are desirable. The recent development of the SilviScan instruments[1–3] has made it possible to measure the wood properties of increment cores on a large scale.

Recently data provided by the SilviScan instruments has been used to calibrate a near infrared (NIR) spectrometer. Experiments conducted using *Eucalyptus delegatensis* R.T. Baker (alpine ash)[4] and *Pinus radiata* D. Don (Radiata pine)[5] samples, obtained strong relationships between SilviScan measured values and NIR-estimates for a range of wood properties including density, MFA and stiffness. Later studies based on *P. radiata* cores,[6–9] also provided strong relationships between SilviScan measurements and NIR-estimates for air-dry density, MFA, stiffness (determined using SilviScan-2 diffractometric data and measured density) and a number of fibre properties. The calibrations, apart from fibre perimeter and radial diameter, performed well when applied to a separate test set of two cores that were from the same population as the calibration samples.

However, the *P. radiata* core calibrations[6–9] were based on a relatively small sample set (eight breast height cores that provided a total of 119 NIR spectra collected at 10 mm increments). If these calibrations are to be used operationally then it will be necessary to develop calibrations using several hundred samples that include as much variation as possible. It is uncertain if the relationships would be as strong if large calibration sets are used.

In 2002, a study commenced at the University of Georgia investigating the non-destructive evaluation of plantation grown *P. taeda* wood properties using NIR spectroscopy. The aim of the work was to develop wood property calibrations that would be applicable to *P. taeda* increment cores obtained from plantations in Georgia. The preliminary findings of the study will be presented.

## Materials and methods

### Sample origin

Ninety breast height (1.30 m) increment cores were collected from nine *P. taeda* plantations in Georgia, USA. For each geographic region where *P. taeda* is grown (Lower and Upper Atlantic Coastal Plain and Piedmont) three plantations were sampled. The selected sites had a range of site qualities (low, medium and high). For each site ten trees with a range of breast height diameters were sampled. All samples were frozen after sampling. The samples were defrosted and dried to a moisture content of 7% prior to sending the samples to Australia for SilviScan analysis.

### Measurement of wood properties using SilviScan

Radial strips for analysis by SilviScan-1 and -2 were cut from the samples 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. Wood property averages were determined over 10 mm sections for correlation with the NIR spectra.

### Near infrared spectroscopy

Eighty-nine radial strips were available for analysis by NIR spectroscopy. These samples represented *P. taeda* trees grown on nine sites. One sample could not be analysed by SilviScan and was excluded from the set. NIR diffuse reflectance spectra were obtained from the radial-longitudinal face of each core sample using a NIRSystems Inc. Model 5000 scanning spectrophotometer. Samples were held in a custom made holder.[4] A 5 mm × 10 mm mask was used to ensure collection of spectra from a constant area. The spectra were collected at 2 nm intervals over the wavelength range 1100–2500 nm. The instrument reference was a ceramic standard. Thirty-two scans were accumulated for each 10 mm section and the results averaged. One average spectrum was obtained per section. All NIR measurements were made in a conditioned atmosphere maintained at 40% RH and 20°C.

### Calibration development

A total of 730 spectra were obtained from the radial strips available for NIR analysis. Initial calibrations were developed using all available samples. WinISI II (version 1.50) software package (Infrasoft International, Port Matilda, PA, USA) was then used to select samples, at random, for the calibration (365 spectra) and prediction sets (365 spectra). A statistical summary of the calibration and prediction sets is given in Table 1.

The spectra were converted to the second derivative mode using the WinISI II software. A gap width of 4 nm was used for the conversion. The wavelength range was limited to 1108 to 2492 nm for calibration development. The wood property calibrations were developed using modified partial least squares (MPLS) regression and the second derivative treated spectra. Calibrations were developed with four cross-validation segments. The standard error of cross-validation (*SECV*) (determined from the residuals of each cross-validation phase), the standard error of calibration (*SEC*) (determined from the residuals of the final calibration) and the co-efficient of determination ($R^2$) were used to assess calibration performance.

**Table 1.Statistical summary of each wood property for the calibration and prediction sets.**

| Wood | Calibration set | | | | | Prediction set | | | |
|---|---|---|---|---|---|---|---|---|---|
| Property | Min. | Max. | Av. | Std. dev. | | Min. | Max. | Av. | Std. dev. |
| Air-dry density (kg/m$^3$) | 350. | 807.8 | 575.5 | 99.6 | | 337. | 832.6 | 578.8 | 97.8 |
| MFA (deg) | 11.0 | 45.2 | 27.0 | 7.5 | | 11.2 | 43.1 | 26.3 | 7.4 |
| Stiffness (GPa) | 2.4 | 23.0 | 9.5 | 5.0 | | 2.4 | 23.0 | 9.7 | 4.8 |

The standard error of prediction (*SEP*) was used to give a measure of how well a calibration predicted the parameter of interest for a set of unknown samples.

## Results and discussion

### *P. taeda* wood property calibrations—730 spectra

MPLS regression calibrations developed for air-dry density, MFA and stiffness using all available samples, are shown in Figure 1(a)–(c).

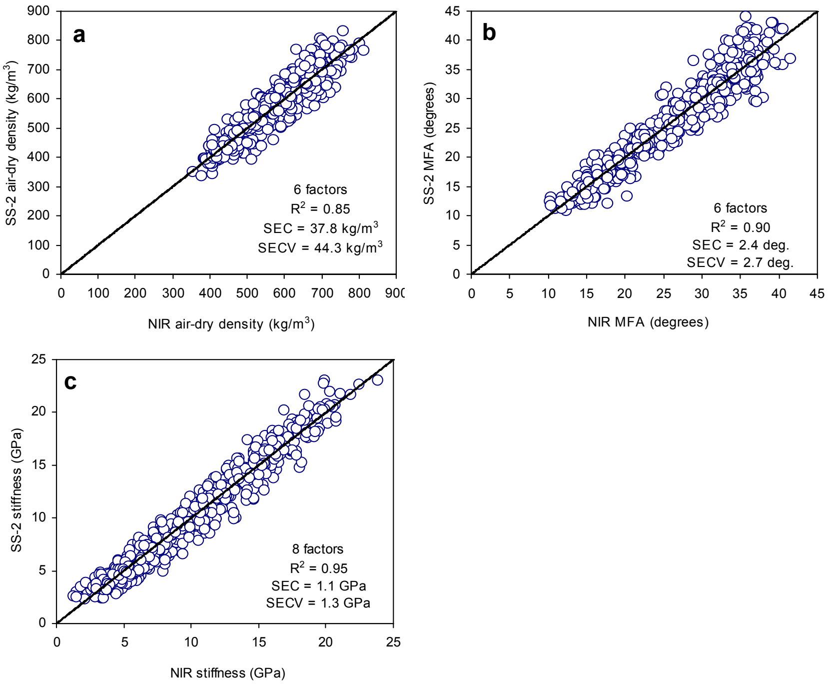


**Figure 1. Relationships between measured values and NIR-estimated values for (a) air-dry density, (b) MFA and (c) stiffness. Calibrations were developed using 730 spectra representing 89 radial wood samples.**

The calibrations developed for each wood property gave strong relationships with coefficients of determination ($R^2$) ranging from 0.85 to 0.95. The calibrations obtained show that it is possible to develop calibrations for important *P. taeda* wood properties using large data sets. Owing to the origin of the samples the variation represented in the calibration is extremely large.

## *P. taeda* wood property calibrations—calibration / prediction sets

MPLS regression calibrations were developed for air-dry density, MFA and stiffness using the samples that were selected at random by the WinISI II software, the calibrations and their predictive performance are summarised in Table 2.

**Table 2. Summary of calibrations developed for each *P. taeda* wood property. Samples for calibration and prediction were selected at random using WinISI II software.**

| Wood | Calibration set | | | | | Prediction set | |
|---|---|---|---|---|---|---|---|
| Property | # factors | $R^2$ | *SECV* | *SEC* | | $R_p^2$ | *SEP* |
| Air-dry density (kg/m$^3$) | 5 | 0.86 | 46.5 | 37.8 | | 0.80 | 43.3 |
| MFA (deg.) | 5 | 0.90 | 2.8 | 2.4 | | 0.88 | 2.5 |
| Stiffness (GPa) | 7 | 0.95 | 1.4 | 1.1 | | 0.93 | 1.3 |

The calibrations developed for each wood property again gave strong relationships ($R^2$ ranged from 0.86 to 0.95). The calibration developed for stiffness gave the strongest $R^2$ but was developed using an additional two factors compared to the air-dry density and MFA calibrations. For the three calibrations the *SECV* was approximately 20% higher than the *SEC*. When the calibrations were used to predict the wood properties of the separate test set the prediction $R^2$ (denoted by $R_p^2$) was similar to the calibration $R^2$, *SEP*'s for the respective properties were very similar to the SECV's. The strong predictive results demonstrate that the calibrations developed for air-dry density, MFA and stiffness can provide accurate predictions of these properties. The calibration developed for stiffness is shown in Figure 2(a), its performance on the separate test set of 365 spectra is shown in Figure 2(b).

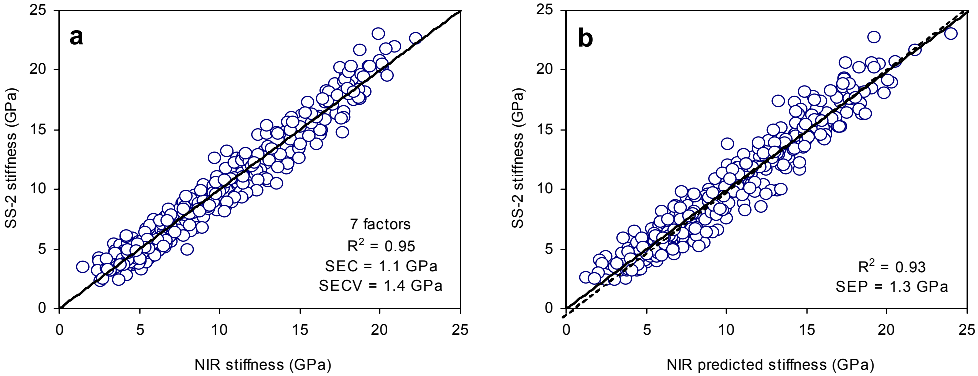


**Figure 2. Relationships between measured values and NIR values for stiffness (a) calibration set (365 samples) and (b) prediction set (365 samples).**

## Conclusions

The preliminary results of this study demonstrate 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 *P. taeda* wood samples.

It has also been demonstrated that it is possible to develop strong calibrations that perform well in prediction using large data sets that includes a wide range of environmental and genetic variation.

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