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Wood density prediction using near-infrared hyperspectral imaging: an application for early selection of *Eucalyptus grandis* trees.

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Introduction

Wood density is related to pulp and paper quality (Rana et al., 2011) and could decrease with future fast-growing varieties, as higher growth rates are moderately related to lower wood densities. Although improving wood density of Eucalyptus trees is not yet in demand in breeding programs, it is important to anticipate future needs to select varieties not only for high growth rates but also for lower growth/wood density ratios. The strong correlations between wood densities at juvenile and mature stages assure the suitable selection of the best varieties at juvenile stage. Due to its biological nature, wood density is highly variable across age (Miranda et al., 2001). Soil water availability has been shown to affect the density of the wood. Mapping wood density over the whole cross section allows measuring the inter-annual (between tree rings) variation and calculating juvenile-mature correlations.

Commonly, wood density radial variation is performed using X-ray microdensitometry (XRD). Although this technique provides a high spatial resolution and accuracy on wood density estimation, it is time-consuming and only allows analyzing a small region from wood disks. Near-infrared hyperspectral imaging (NIR-HSI) allows the spectral and spatial information of the whole disk to be obtained quickly. If an efficient calibration model is constructed, NIR-HSI can be a valuable and practical tool for mapping wood density and estimating inter-annual variation.

In this context, the objective was to evaluate the performance of use NIR-HSI to estimate wood density variation across the age of *Eucalyptus grandis* trees and estimate the juvenile-mature correlations on wood density under different soil water conditions.

Material and Methods

The samples came from 6-year-old *E. grandis* trees from São Paulo, Brazil, subjected to two treatments: 37% throughfall reduction (–W) and non-throughfall reduction (+W). Twenty-seven trees by treatment were sampled randomly, and a cross-sectional disk (3 cm height) at breast height was cut from each tree.

The NIR-HIS images of polished disks were obtained using a stationary chemical imaging camera (SisuCHEMA, SWIR, Specim®) with a resolution of 625 µm/pixel. We used 226 spectral channels comprising between 1048 nm to 2456 nm wavelength. Then, wood density profiles of 15 disks determined by XRD images were used as NIR-HSI reference values. Pixels of NIR-HIS and XRD images were averaged and matched (Fig. 1). As a result, a data set with 2478 hyperspectral reflectance measurements and corresponding wood density values were created to construct calibration models.

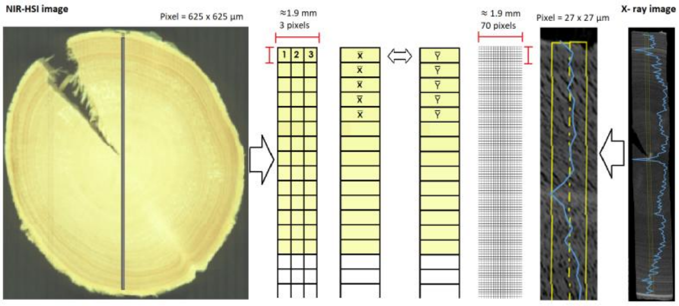

Fig. 1: Schematic representation of the pre-processing of NIR-HSI. From the left to right, the NIR-HSI images were analyzed into a region of three pixels width (≈1.9 mm).

A principal component analysis (PCA) was applied to identify abnormal spectra. Two models, PLSR (partial least squares regression) and LWPLSR (locally weighted partial least squared regression) with several pre-treatments of spectra, were tested for calibration using the cross-validation method (CV). The models with the minimum root mean square error of cross-validation (RMSECV) were selected to perform independent validation. Models were performed in R software.

The best calibration model was applied in the NIR-HIS images to create a wood density map of 42 whole discs (Fig. 2A). Juvenil-mature correlations of wood density were evaluated using two approaches: correlation between individual growth rings (ring-ring correlations) (Fig. 2B) and correlation between aggregated growth rings, i.e., area of all the rings from pith up to a given age (age-age correlations) (Fig. 2C).

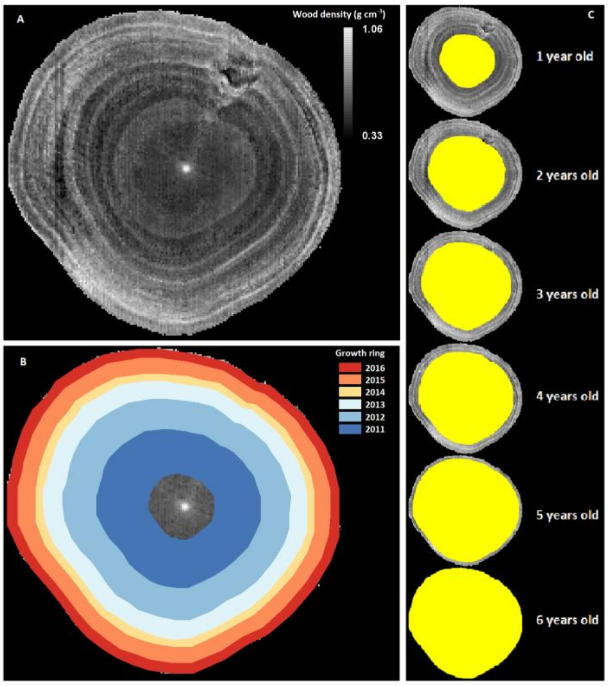

Fig. 2: Wood density map of a disk predicted with the best calibration model (A), the annual growth rings (B), and transversal area delimitation at each year old (C).

Results

Both in PLSR and LWPLSR, calibration models with raw spectra showed higher performance than with treated spectra. LWPLSR showed a better performance than PLSR (Fig. 3).

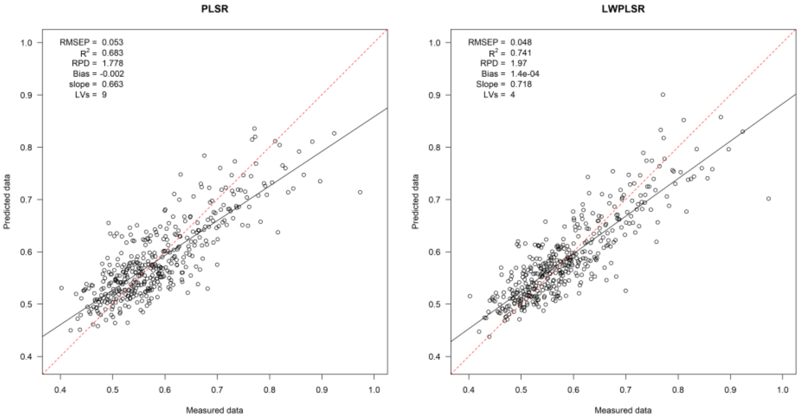

Fig. 3: Results of the independent validation of the PLSR and LWPLSR. R^2 is the coefficient of determination; RMSEP is the root quadratic square error of prediction.

We observed moderate ring-ring correlations between the first and lasts growth rings (r = 0.54 to 0.7). Age-age correlations were stronger than ring-ring correlations over 6 years. Overall, ages 6 and 1 was highly correlated (r = 0.72 to 0.93).Correlation increased until 0.87-0.94 when correlated ages 6 and 3 (Fig. 4). Ring-ring and age-age correlations were higher in +W than in –W.

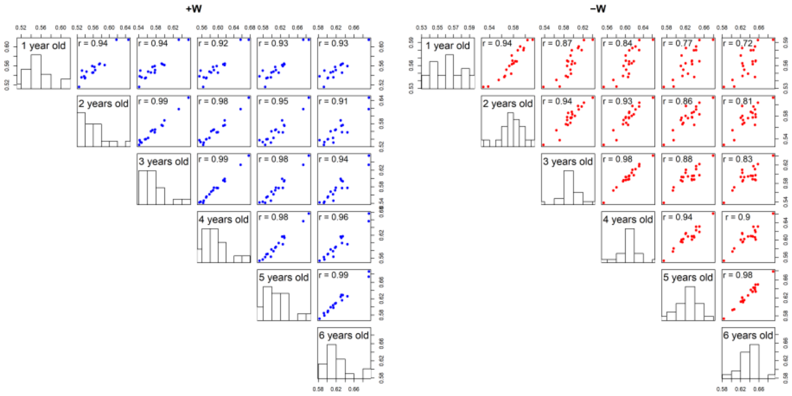

Fig. 4: Age-age correlation matrix plot by treatment.

Discussion

Calibration with the LWPLS model demonstrated better performance than the PLS model for wood density prediction on *E. grandis* trees. In addition, our LWPLS model produced lower RMSECV than PLS model in *Pinus pinea* (Fernandes et al., 2013).

At 3 years of age, which is the standard selection age for growth (Bouvet et al., 2003), the wood density was strongly correlated with 6 years of age (r=0.9). Also, the correlation between 1 year of age and 6 years of age was 0.85, indicating that selection at ages under 3 is also feasible. These results agree with breeding improvement studies in Eucalyptus species. (Greaves et al., 1997; Osorio et al., 2003). As expected, ring-ring correlations were not as large as the age-age correlations over 6 years. However, correlations between rings 1-2 and ring 5-6 were moderate-high varying from 0.51 to 0.7, indicating that trees with high densities at young ages tended to form denser wood in subsequent years.

Selection studies in different water regimes are essential to know if increasing tree stress affects juvenile-mature correlations for tree selection. The correlations between ages 1-2 and 5-6 were lower in –W than in +W. However, even under water stress conditions, the selection at 3 years old is efficient (r=0.81). This point is important to consider in the framework of tree breeding programs when tests are made in regions with water deficits.

Conclusions

The use of NIR-HSI demonstrates good performance to predict wood density using LWPLSR model calibration and be helpful to build wood density maps of the whole cross-section. The age-age and ring-ring correlations showed that juvenile selection of trees under 3 years is feasible to predict wood density at 6 years. In non-water-limited sites, tree selection can be highly accurate even at 1 year of age. Juvenile-mature correlations are slightly reduced in sites under 37% water deficit.

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