Rapid assessment of pulpwood quality using near infrared spectroscopy

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Introduction

The Co-operative Research Centre for Hardwood Fibre and Paper Science (CRC-HFPS) was established in 1992. The mission of the CRC-HFPS is "the rapid and effective characterisation of the pulpwood quality and paper-making potential of plantation hardwoods to facilitate the development of resources on which to build the internationally competitive position of the Australian pulp and paper industry and to create new commercial opportunities".

This report presents a summary of research at the CRC-HFPS into the application of near infrared (NIR) spectroscopy to the characterisation of pulpwood quality, in particular the pulp yield of plantation grown eucalypts and its application to the investigation of the within-tree variation of pulp yield and wood chemistry.

Eucalypts for pulp and paper production

In Australia and overseas, eucalypt pulps are renowned for their ability to produce high-quality printing and writing papers. Eucalypt fibres are relatively short (0.7 to 1.5 mm), slender (0.015 to 0.025 mm) and thin-walled.[1] Brumby and Maddern[2] report that the combination of these properties leads to excellent sheet formation and to a paper that has high bulk, excellent surface properties and good density, stiffness and optical properties.

In south eastern Australia, the major plantation species are *Eucalyptus globulus* and *Eucalyptus nitens*.[3,4] Both species produce high-yielding kraft pulps with good paper-making properties.[5,6] *E. globulus* is preferred[7] as it gives kraft pulp fibres with a better balance of properties.[8] Both species demonstrate rapid early growth[4] and the ability to grow on a range of sites. *E. nitens* is more cold-tolerant and replaces *E. globulus* on sites subject to frequent frosts.[7]

Pulp yield

Pulp yield is an important measure of pulpwood quality that is used regularly by the pulp and paper industry. It is defined as the percentage of the original mass of wood fibre remaining after pulping to a given content of residual lignin. The typical range of yields observed in eucalypts is 45–53%.[9] Pulp yield is an important tree-breeding trait and small improvements in pulp yield can provide numerous benefits, including a reduction in wood requirement and hence wood costs, increased pulp production

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Table 1. NIR calibration statistics for pulp yield models.

Calibration	No. of factors	*R* value	*SEC*	*SEP*
Victoria				
1. *E. globulus*	4	0.95	0.69	1.31
2. *E. nitens*	3	0.89	0.70	0.85
3. *E. globulus* + *E. nitens*	5	0.93	0.76	1.01
Tasmania				
4. *E. globulus*	4	0.90	0.72	0.90
5. *E. nitens*	4	0.93	0.82	0.85
6. *E. globulus* + *E. nitens*	4	0.94	0.84	0.80

SEC = standard error of calibration and *SEP* = standard error of prediction.

capacity for a given level of wood intake, lower chemical demand and a reduction in fixed costs per tonne.[9]

Studies have shown that pulp yield is under moderate genetic control[10] and can, therefore, be improved through tree breeding. Current methods of assessment are time-consuming, costly and destructive, hindering future improvement. Researchers at the CRC-HFPS chose to evaluate NIR spectroscopy as an alternative method for estimating pulp yield. NIR spectroscopy is rapid, inexpensive and requires only small quantities of wood, such as is available from increment cores.

Collaborative research with Amcor in Victoria and North Eucalypt Technologies (NET, formerly Associated Pulp and Paper Mills Ltd) in Tasmania has been ongoing. Partial least squares (PLS) regression calibrations have been developed for both *E. globulus and E. nitens,* grown on a range of sites in both states (Table 1). A pulp yield calibration developed for *E. globulus* and *E. nitens* trees grown on

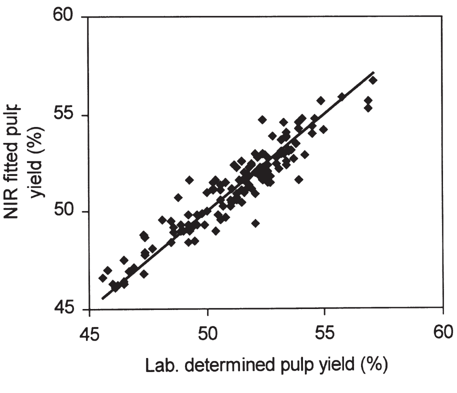

Figure 1. Plot of NIR fitted pulp yield v. laboratory determined pulp yield for *E. globulus* and *E. nitens* trees grown on a range of sites in Tasmania (*n* = 133).

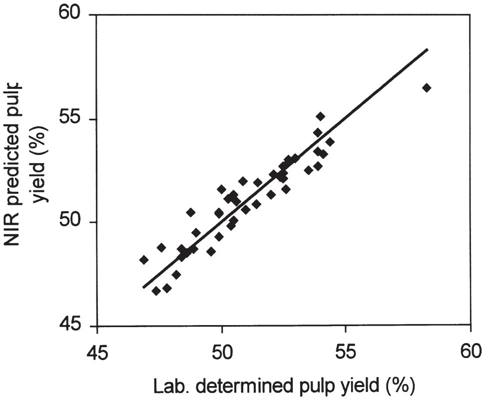

Figure 2. Plot of NIR predicted pulp yield v. laboratory determined pulp yield for *E. globulus* and *E. nitens* trees grown on a range of sites in Tasmania.

a range of sites in Tasmania is shown in Figure 1 (Calibration 6, Table 1). Note that the line of equivalence has been plotted. It is also plotted in Figures 2 to 5.

The calibration (Figure 1) was used to predict the pulp yield of 44 samples in a separate test set, giving an *SEP* of 0.80 (Figure 2). The low standard errors obtained for NIR-determined pulp yield indicates that NIR spectroscopy can estimate the pulp yield of plantation woods with sufficient accuracy to be of use for tree improvement programmes.

Cellulose

When conditions for pulp testing are held constant, the yield of a wood sample will depend upon its chemistry. Chemical components of the wood, such as cellulose and lignin, can be expected to be correlated with pulp yield. Holocellulose (cellulose plus hemicellulose) and alpha cellulose were found to be reliable indicators of pulp yield for eucalypt families and provenances.[11] Recent research conducted at the CRC-HFPS has shown that the relationship between pulp yield and cellulose content is strong.[12]

PLS calibrations for cellulose content, based on the NIR spectra of increment core samples, have been developed in collaborative research with the Co-operative Research Centre for Sustainable Production Forestry (CRC-SPF). Calibrations have been developed for *E. globulus* trees grown on several sites. A cellulose calibration developed for *E. globulus* trees grown on three sites (one in Tasmania, two in Victoria) is shown in Figure 3. Cellulose content was determined using the diglyme method described by Wallis *et al.*[13]

The calibration (Figure 3) was used to predict the cellulose content of 30 samples in a separate test set, giving an *SEP* of 0.88 (Figure 4). The low standard error obtained for NIR-determined cellulose indicates that NIR spectroscopy is a suitable method for the rapid estimation of the cellulose content of increment cores taken from standing trees.

Basic density

Another important pulpwood parameter is basic density. Basic density is a common measure of wood density and is the mass of oven-dry wood per unit volume of green wood. It is expressed in g cm^{-3} or kg m^{-3}. Basic density influences many aspects of the pulp and paper industry including freight costs, chipping properties, pulp yield per unit mass of wood and paper quality.[14]

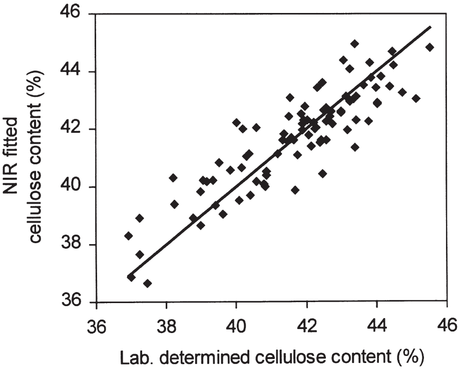

Figure 3. Plot of NIR fitted cellulose content v. laboratory determined cellulose content for *E. globulus* (*n* = 90, four factors, *R* value = 0.88, *SEC* = 0.95).

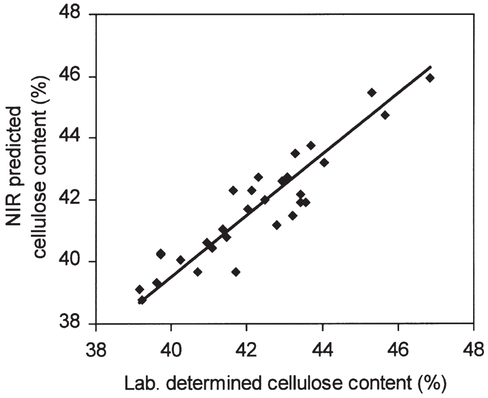

Figure 4. Plot of NIR predicted cellulose content v. laboratory determined cellulose content for *E. globulus*.

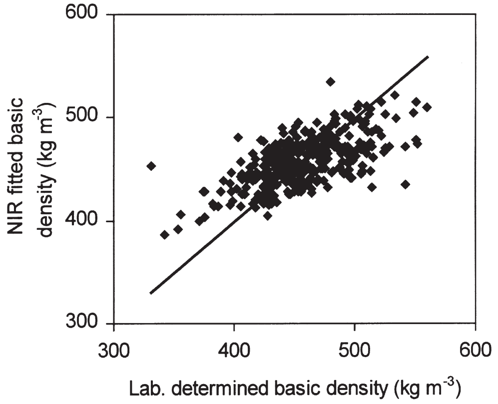

Figure 5. Plot of NIR fitted basic density versus laboratory determined basic density for *E. globulus* (*n* = 340, 6 factors, *R* value = 0.64, *SEC* = 29.2).

Our interest in the estimation of basic density by NIR spectroscopy arose from research at the CRC-SPF where experiments were conducted with the aim of examining the degree of genetic control of basic density and pulp yield in *E. globulus*.[15] Two cores were taken per tree, one for the determination of basic density and the other (which was milled) for the estimation of pulp yield by NIR spectroscopy. If NIR spectroscopy could be used to estimate basic density of a milled wood core, in conjunction with the estimation of pulp yield, then only one core would be required per tree providing a substantial reduction in labour.

PLS calibrations for basic density were developed using the averaged normal spectra of plantation-grown eight-year-old *E. globulus* samples taken from two sites (Site 37 and Site 38) in Gippsland, Victoria, Australia.[16] The calibration developed for Site 37 is shown in Figure 5.

The Site 37 calibration (Figure 5) was used to predict the basic density of 114 samples in a separate test set, giving an *SEP* of 31.6. Increment cores having relatively low basic densities were consistently overestimated and those having relatively high basic densities were consistently underestimated. The relatively high standard error indicates that NIR spectroscopy was less accurate than current techniques used to estimate the basic density of eucalypt increment cores.

The within-tree variation of pulp yield

Non-destructive sampling of standing trees can be achieved by taking increment cores that are representative of the whole tree. To facilitate the selection of representative sampling points, a detailed knowledge of pulp-yield variation within plantation trees is necessary.

A study conducted at the CRC-HFPS examined within-tree variation of pulp yield in fifteen plantation-grown *E. nitens* trees.[17] Maps demonstrating patterns of variation were developed and showed that yield was variable within trees and that each tree had a different pattern of variation. Generally, pulp yield increased from pith to bark and increased with height to a maximum at approximately 30% of tree height before decreasing.

Correlations between weighted NIR predicted pulp yield at various heights and whole-tree pulp yield for all trees were determined. The strongest correlation ($r = 0.91$) was for discs from 10% height (2.2 m). The correlation for 5% height (1.1 m) was lower (0.87) but provided a more convenient sampling height. The results indicate that good estimates of whole-tree pulp yield should be obtained by NIR spectral measurements on the milled wood of increment cores.

Identification of representative sampling heights

Recent collaborative research with the CRC-SPF has determined representative sampling heights for *E. globulus* and *E. nitens* across a range of sites in Tasmania, Western Australia and Victoria.[18] A sampling height of 1.1 m was recommended for *E. globulus* on all sites. Results for *E. nitens* were variable with large site differences. On good quality sites, a sampling height of 0.9 m was recommended. On poor quality sites, cores were poor predictors of whole-tree pulp yield and no recommendations were made.

Based on these recommendations, further research has been conducted by collaborators at the CRC-SPF. The effects of fertiliser application on NIR-estimated pulp yield has been examined.[19] On four sites, treatments of no fertiliser, nitrogen, phosphorus and nitrogen and phosphorus were compared. It was found that fertiliser addition decreased pulp yield to some degree on the sites examined. Research to estimate the heritability of pulp yield and investigate genotype by environmental interactions in *E. globulus* on a range of sites is in progress.

Conclusions

The low standard error of calibrations developed for pulp yield and cellulose indicates that NIR spectroscopy is a suitable method for the rapid estimation of these parameters.

Calibrations developed for basic density have higher standard errors and indicate that NIR spectroscopy was less accurate than current techniques used to estimate the basic density of eucalypt increment cores.

Representative sampling heights of 1.1 m for *E. globulus* and 0.9 for *E. nitens,* on good sites, were recommended.

Acknowledgements

The authors would like to thank Amcor, Bunnings Tree Farms, Forestry Tasmania and North Eucalypt Technologies for their provision of wood samples, Mr A. Bradley, Mr J. Lawson and Mr A. McDonald, CRC for Sustainable Production Forestry, for collecting the core and disc samples and Ms L. Nagy, CRC for Sustainable Production Forestry, for her assistance in obtaining the NIR spectra of the core and disc samples.

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