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Assessing specific gravity of young *Eucalyptus* plantation trees using a resistance drilling technique

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Abstract: The resistance drilling technique has been in focus for assessing the specific gravity (SG) of young *Eucalyptus* trees from plantations for pulpwood production. Namely, the data of 50 34-month-old and 50 62-month-old trees from *Eucalyptus grandis* × *Eucalyptus urophylla* clonal plantations was evaluated, while the relative resistance profiles were collected with the amplitude in a scale from 0 to 100% of each tree at the breast height. For laboratory determination of SG and moisture content (MC), 3-cm-thick disks were taken at breast height. The average resistance amplitude of a full drill penetration or a half-diameter penetration showed weak correlations with SG for both 34-month-old and 62-month-old trees. However, when the two age classes were combined, the strength of the relationship was improved significantly, with a correlation coefficient ranging from 0.71 to 0.77 with respect to SG determined from strip samples and from 0.59 to 0.72 with respect to SG determined from wedge samples. The drill penetration depth had a significant effect on the relationship between average amplitude and SG. A clear trend of weakening correlation was observed with increasing drill penetration. As a result, the average resistance amplitude of a half-diameter drilling (from bark-to-pith) is more advantageous for assessing the SG of young *Eucalyptus* trees than a whole-diameter drilling.

Keywords: amplitude, density, drill penetration depth, plantation trees, resistograph, specific gravity

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Introduction

The genus *Eucalyptus* with a wide range of wood properties is an important source of wood supply for many applications, and also for the Brazilian cellulose pulping sector. According to Colodette et al. (2012), the area planted with eucalypt reached around 4.9×10^6 ha in 2011, which accounts for 68% of the total plantation forests in Brazil. The wood production has been elevated to around 50 m^3 per ha and year on the commercial scale, by means of tree breeding programs (Gomide et al. 2005), but in some regions the productivity of *Eucalyptus* spp. can reach up to 100 m^3 ha^{-1} $year^{-1}$ (Colodette et al. 2012; Fantuzzi 2012). The high productivity – achieved mainly through cloning techniques – contribute much to the development of the pulp and paper sector. The research work begins with evaluation of silvicultural aspects followed by a preliminary selection, in the course of which the wood properties of hundreds of clones has to be assessed. The suitable clones are multiplied and homogenous forests are created. Then, after 5–7 years of rotation, the plantations with high forest productivity deliver high wood quality for pulp production (Ohshima et al. 2000).

The specific gravity (SG) is one of the key properties affecting of wood performance, which is also inherently related to other wood and fiber properties, while the tissue composition consisting of fibers, tracheids, vessels, axial and radial parenchyma, etc. and their dimensions and the cell wall thicknesses influence the SG (Kollmann and Cotê 1968; Stewart and Polak 1975; Ponneth et al. 2014; Mansfield et al. 2016). In case of 7-year-old *Eucalyptus* trees, the anatomical characteristics have more influence on the SG than did chemical characteristics, and the cell wall thickness and lumen diameter of the fibers had the strongest influence (Shimoyama and Barrichelo 1991). Apart from genetic heritage, the parameters; age, forest site, and environmental conditions influence the SG. There are variations among trees and the within-tree variation in both radial and longitudinal directions is pronounced (Tomazello 1985a; Oliveira 1998). In the radial direction, there is a well-defined increasing tendency from the pith to bark

(Rezende and Ferraz 1985; Tomazello 1985a,b; Lima 1995; Carmo 1996; Lima et al. 2000). Silva (2002) studied SG variation in *Eucalyptus grandis* grown in the State of Paraná, Brazil, at ages of 10, 14, 20, and 25 years in four radial positions, and increasing values were found at higher age and a small reduction was seen at 25 years. The average SG was 0.41 g cm^{-3} with the lower limit of 0.31 g cm^{-3} (10 years, near the pith region) and the upper limit of 0.59 g cm^{-3} (20 years, near the bark region).

Age dependent SG increment was observed for various species of *Eucalyptus* (Ferreira and Kageyama 1978; Bath et al. 1990). Lima et al. (2000) found a rapid SG increment in young trees, and a gradual SG increase in trees at intermediate age and eventually the SG became relatively stable at maturity. In a study on *E. grandis*, Hillis and Brown (1978) reported that at the tree base, the wood formed between 16 and 20 years, a 25% SG increment is typical compared to the wood formed between 1 and 5 years. A 40% SG difference was seen for *Eucalyptus pilularis* between 1 and 31 years.

For 20 progenies of *E. grandis*, Wang et al. (1984) confirmed significant differences among trees within the same progeny, and a more recent study was dealing with the conversion of basic to apparent density of the same eucalypt species (Costa et al. 2014). Ribeiro and Zani (1993) assigned SG variations in *Eucalyptus* species which originated from Mogi-Guaçú, SP, Brazil to variations in soil and climate conditions between the forest sites. SG showed a decreasing trend from north to south as a result of better environmental conditions. Hillis and Brown (1978) reported extreme tree to tree SG variations. For instances, the SG of *E. pilularis* in Australia ranges from 0.59 to 0.81 g cm^{-3}. Within the *Eucalyptus* genus, SG ranges from 0.60 and 0.90 g cm^{-3} for mature trees and from 0.40 and 0.80 g cm^{-3} for younger trees (Hillis 2000).

Density prediction of wood is a current research topic (Chen at al. 2010; Kothiyal and Raturi 2011; Iliadis et al. 2013; Inagaki et al. 2014) and SG measurement on trees is still a challenge. The resistance drilling technique has a high application potential in this field. Rinn et al. (1996) stated that the gross density of dry wood closely correlates to the resistograph charts with R2 of ca. 0.8. In the meantime, several authors confirmed that this low cost and reliable technique is well suited for routine SG estimation on standing trees (Chan et al. 2010; Gao et al. 2012; Brashaw et al. 2013). An advantage is that SG profiles can be recorded through the tree diameter, which is difficult to achieve by other methods. For a mechanical drilling system it is typical that the relative resistance (torque moment) is measured against the introduction of a small diameter drill at a constant speed. The resistance amplitude (resAmp) is recorded in a scale from 0 to 100%, which is directly related to SG. Some early studies demonstrated strong linear correlations between mean drilling resistance and gross SG of dry wood (Görlacher and Hättrich 1990; Rinn et al. 1996). Isik and Li (2003) worked with a resistograph tool on standing loblolly pine (*Pinus taeda* L.) trees and confirmed the strong correlations between the average drilling resistance and SG. A strong genetic control of SG at the family level were assumed, while the individual phenotypic correlations were relatively weak (Lima et al. 2007; Gwaze and Stevenson 2008; Eckard et al. 2010; Gouvêa et al. 2011a). Isik and Li (2003) and Ukrainetz and O'Neill (2010) found that SG index is also sensitive to operator movement, tree moisture content, air temperature, and proximity of the sampling location to knots. Nonetheless, the handling variation and the other parameters could be minimized.

Resistance drilling as an inexpensive and user-friendly rapid method seems to be well suited for quality control of *Eucalyptus* trees. The objectives of this study were to determine the relationships between radial resistance drilling results as a function of SG on *Eucalyptus grandis*×*Eucalyptus urophylla* clones and to evaluate the applicability of this technique as a field tool.

Materials and methods

In focus were 100 clonal hybrid *Eucalyptus grandis*×*Eucalyptus urophylla* trees in a forest plantation located in Espírito Santo State, Brazil. Fifty trees were 34 months old (Tr_{34m}) and 50 trees were 62 months old (Tr_{62m}). The trees were randomly selected at each stand and marked. The diameter of the sampling trees were measured at breast height (DBH) by a diameter tape; two resistance drilling measurements were conducted in the trunk at breast height (BH) by means of an IML-RESI F300 tool (IML System GmbH, Wiesloch, Germany) illustrated in Figure 1. The drilling operation was set to "hardwood" mode (sensitivity stage 2 setting) with a fully charged battery. The feeding rate was approx. 22 cm min^{-1} and the drill bit rotating speed was 500–700 rpm. The maximum drilling depth for the IML-RESI F300 tool was 300 mm which was sufficient for the tree samples in this study. On each selected tree, two drilling measurements were made 3 cm apart at BH, both in the north-south direction. The resistograph chart was recorded electronically for each drilling measurement and the data were downloaded to a computer in Excel format for subsequent analysis.

Following field data collection, the sample trees were felled and the total tree height was measured on each stem. Three 3.0 cm thick disks were removed from each tree at BH. The disks were labeled and immediately put in sealed plastic bags to prevent moisture loss. A schematic for data collection and wood samples cutting is presented in Figure 2. Disks A and B corresponded to the two resistance drilling measurements and served for SG and MC determination in laboratory. Disk C was taken right below the Disk B and used for other laboratory evaluations.

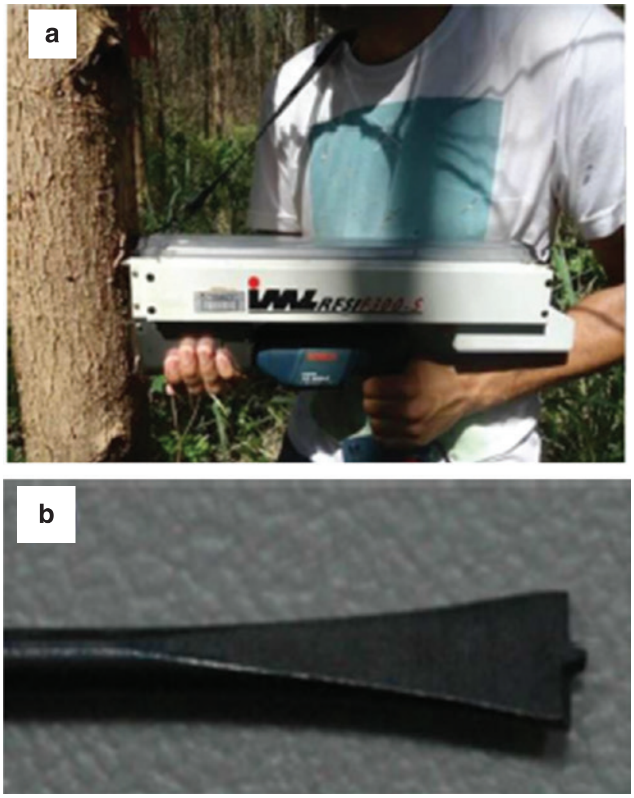

Figure 1: Photographs of the IML-RESI F300 tool (a) and a detail of drill bit (b).

In the laboratory, a 2.5-cm-wide center strip was cut from Disk A of each tree, and then each strip was sliced into 5-mm-thick samples through the whole length. Both MC and SG were determined for each individual sliced sample. The dimensions of the sliced samples were $5\times25\times30$-mm^3 (R×T×L). For Disk B, two opposite wedges were removed from the disk in the north-south direction that corresponds to the drill penetration of the resistance drilling measurement. SG was also determined for the two wedges. The volume of the samples under green conditions was determined according to ASTM D2395-14 (ASTM 2014) by replacing mercury with water. The green and dry masses were determined at a precision level of 0.01 g. The samples were then dried in an oven with forced ventilation and automatic temperature control at 103±20°C until mass constancy.

From the amplitude readings (%) of resistance drilling, an average resistance value was first calculated for every 5-mm penetration. Average amplitude was also calculated for each tree over a full penetration depth (through diameter) and half penetration depths (first radius and second radius). Data were first processed by Excel, and statistical analyses were performed with the S.A.G.E. program version 2012 (Federal University of Viçosa, Brazil).

Results and discussion

Resistance amplitude vs. SG of strip samples

Table 1 summarizes the statistics of tree DBH, tree height, and average values of MC, SG, and resistance amplitude (resAmp) at the tree level. Variations in MC and SG among trees were small within each age class. The mean values of SG were 0.40 and 0.42 for Tr_{34m} and Tr_{62m}, respectively, with coefficients of variation (COV) of 3.4 and 3.3%, respectively. In contrast, the average resAmp at tree level showed

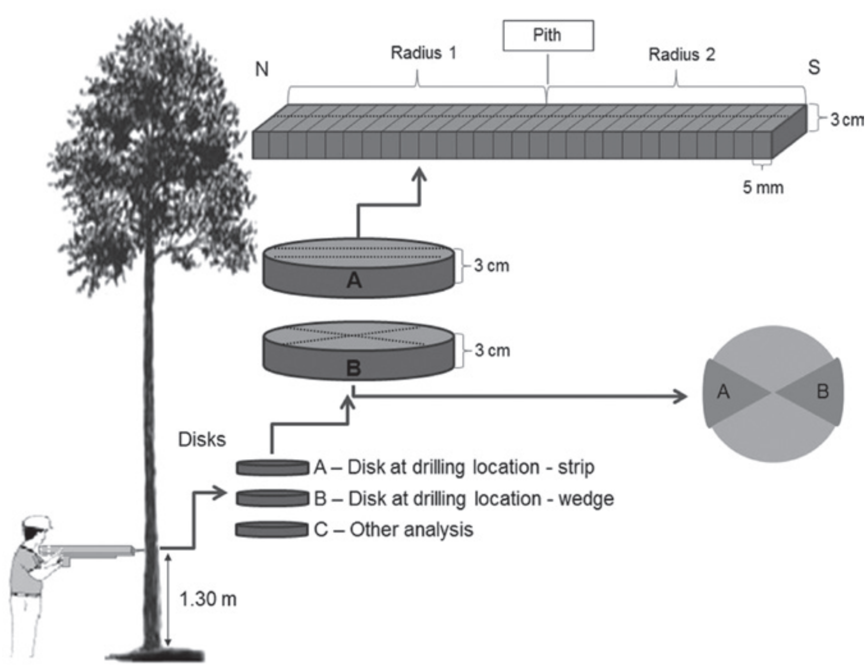

Figure 2: Field data collection and laboratory evaluation.

Table 1: Height, DBH, basic physical properties and resistance amplitude (resAmp) of clonal hybrid *Eucalyptus grandis* × *Eucalyptus urophylla* trees (Disk A).[a]

Stand age (month)	No. of trees	Statistics	Height (m)	DBH (cm)	resAmp (%)	SG	MC (%)
34	50	Avrg.	16.58	12.24	6.3	0.40	179
		Min.	15.15	11.13	3.1	0.35	163
		Max.	17.40	13.87	11.2	0.42	195
		COV (%)	7.49	7.13	24.1	3.4	3.9
62	50	Avrg.	25.74	15.75	11.6	0.42	163
		Min.	23.70	13.98	8.7	0.39	143
		Max.	27.00	17.43	18.5	0.46	179
		COV (%)	4.07	7.10	15.5	3.3	4.2
Combined age 34 month and 62 month	100	Avrg.	21.16	14.00	8.9	0.41	171
		Min.	15.15	11.30	3.1	0.35	143
		Max.	27.00	17.41	18.5	0.46	195
		COV (%)	22.83	14.47	35.0	4.7	6.2

[a]Tree height based on 10 trees in each stand. DBH, Diameter at breast height; SG, specific gravity; MC, moisture content; StD, standard deviation; COV, coefficient of variation (%).

large variations within each stand and especially between the two stands (Tr_{34m} and Tr_{62m}). The data ranged from 3.1 to 11.2% for the Tr_{34m} and from 8.7 to 18.5% for the Tr_{62m}. The mean amplitude of the latter was almost twice that of Tr_{34m}. In the literature, the average amplitude of the resistance profile obtained at BH ranged from 10 to 17.4% for 7-year-old *Eucalyptus* clones (Lima et al. 2006) and from 12 to 33% for 16-years-old *Eucalyptus* clones (Lima et al. 2007). The increasing trend of average resAmp with age was likely caused by the SG increment in mature trees, but it could also be related to the DBH increase in the older stand. The friction on the shaft of the drill increases (particularly for hardwood species) as a function of drill penetration depth, which is, of course, well pronounced in the case of high tree diameters.

Figure 3 shows the variations of resAmp and SG across the diameter of the Tr_{34m} and Tr_{62m} trunks, respectively. Each point of the data represents the average resAmp of 50 trees at a specific location over a 5-mm width, and the corresponding SG of the 5-mm sliced sample at that location. For the Tr_{34m}, the SG was relatively constant across the diameter. In contrast, the resAmp increased through the first radius, then remained high in the second radius and gradually decreased as the drill bit moved out of the tree at the opposite side. This drilling characteristic implies that the friction force built up during the drilling process superimposes the individual drilling resistance amplitudes and weakens the correlation between the SG and resAmp.

For the Tr_{62m}, the trend of SG showed a concavity across the diameter. SG was relatively constant in core

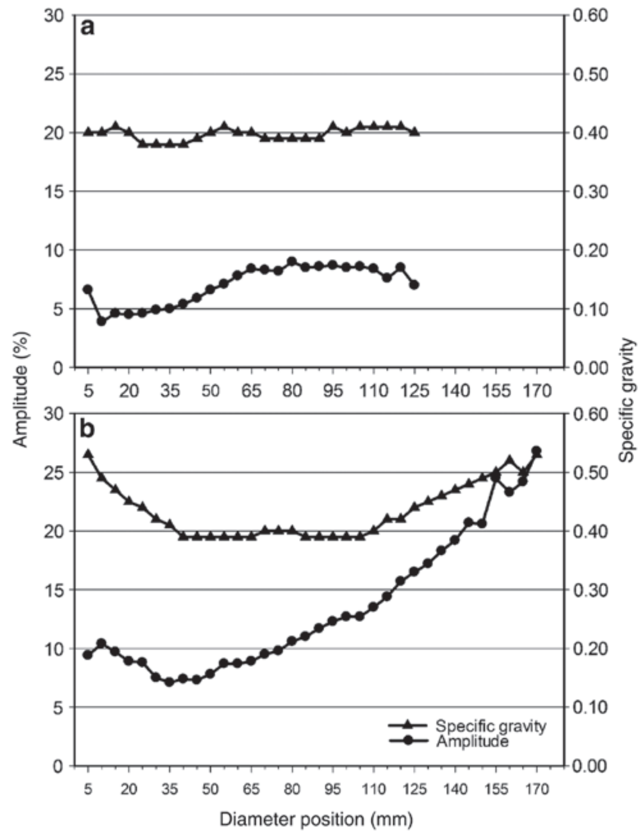

Figure 3: Changes of specific gravity and resistance amplitude across diameter.
(a) 34-month-old and (b) 62-month-old *Eucalyptus* trees.

wood, which is similar to that of the Tr_{34m}; however, SG increased as the position moved towards the bark side. The resAmp, on the other hand, showed a slight decrease within the first 40-mm penetration depth, and then it gradually increased as the drill bit penetrated through the core wood. The rate of amplitude increment was much higher as the drill bit reached the opposite side of the trunk. Apparently, the friction has a non-linear effect on the resAmp measured.

Relationships between resAmp and SG

Table 2 shows the Pearson correlation coefficients (R^2) between average resAmp and SG of *Eucalyptus* trees. The experimental data were analyzed at tree level for each age class separately and for the combined age classes. The following scenarios were examined in the correlation analysis: 1. At tree level (average, $n=50$ or 100); 2. At sliced sample level, for entire strip ($n=2559$); 3. At sliced sample level, for first half of the strip (from bark to pith, $n=1303$); 4. At sliced sample level, for second half of the strip (from

Table 2: Pearson correlation coefficients (R^2) between resistance amplitude and SG of *Eucalyptus grandis* × *Eucalyptus urophylla* trees (Disk A).

Sample	Drilling depth (mm)	32-Month-old		62-Month-old		32+62-Month-old	
		n	R^2	*n*	R^2	*n*	R^2
Sliced disk	Entire strip	1089	0.35	1470	0.46	2559	0.49
Sliced disk	1st Half	566	0.10	737	0.48	1303	0.49
Sliced disk	2nd Half	523	0.45	733	0.65	1256	0.62
Tree	Diameter	50	0.28	50	0.35	100	0.71
Tree	1st Half	50	0.32	50	0.63	100	0.77
Tree	5	50	0.36	50	0.49	100	0.87
Tree	10	50	0.30	50	0.72	100	0.86
Tree	15	50	n.s.[a]	50	0.81	100	0.87
Tree	20	50	n.s.	50	0.58	100	0.74
Tree	25	50	n.s.	50	0.59	100	0.75
Tree	30	50	n.s.	50	0.42	100	0.53
Tree	35	50	n.s.	50	0.57	100	0.50
Tree	40	50	n.s.	50	0.67	100	0.38
Tree	45	50	n.s.	50	0.56	100	0.43
Tree	50	50	0.30	50	0.60	100	0.40
Tree	55	50	0.34	50	0.67	100	0.44
Tree	60	50	0.33	50	0.68	100	0.39
Tree	65	50	n.s.	50	0.64		
Tree	70	50		50	n.s.		
Tree	75	50		50	0.34		
Tree	80	50		50	0.30		

[a]n.s., Not significant at 5% confidence level.

pith to bark, $n=1256$); 5. At tree level, for various drill penetration depths with a 5-mm increment steps (5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, and 65 mm).

For the Tr_{34m}, the R^2 were weak for all scenarios considered, ranging from 0.10 to 0.45, and were not significant at 5% confidence level in some cases. Figure 4a shows the data plots of SG and average resAmp at sliced wood sample level (A) and at tree level (B). Clearly, at both sliced wood sample and tree levels, resAmp showed much larger variation (COV = 24.1%) than SG (COV = 3.4%), and there is no clear trend between the data sets. As pointed out above, the accumulated friction forces weaken the resAmp/SG relationship.

For the Tr_{62m}, the R^2 were improved in all scenarios (R^2 0.42–0.81) compared to those for the Tr_{34m}. The reason for this observation is not clear. Figure 4b shows the data plots of SG and average resAmp at sliced wood sample level (A) and at tree level (B). Similar to that observed in the Tr_{34m}, resAmp displays much larger variation (COV = 15.5%) than SG (COV = 3.3%). However, the Tr_{62m} had a much clearer trend between the two data sets with increasing resAmp as a function of SG. At the sliced wood sample level, the correlation between the data was improved compared to that for the Tr_{34m}. At tree level, the experimental data yielded moderate R^2 data between 0.42 and 0.81 (Table 2). In the case of combined age classes, the correlation was increased significantly at both slice sample level (R^2 0.49–0.62) and tree level (R^2 0.73–0.87). Figure 4c shows the situation for the combined data (Tr_{34m} and Tr_{62m}). Apparently, the greater variation in resAmp readings and SG improved the correlation. The results in the present study are in agreement with those of previous studies as already described above (Lima et al. 2006; Gouvêa et al. 2011b).

Effect of drill penetration depth

In the case of individual age classes, there was no clear correlation pattern visible. But when two age classes were combined, a clear trend of weakening correlation was observed with increased drill penetration depth. As Figure 5 shows, R^2 remained relatively high at penetration depths of 5, 10, and 15 mm ($R^2 \geq 0.86$), then it started to decrease as a function of drill penetration depth. The R^2 dropped to 0.53 at 35-mm penetration depth, which is explained by the detrimental effect of higher friction forces, which overlies the resAmp due to SG differences.

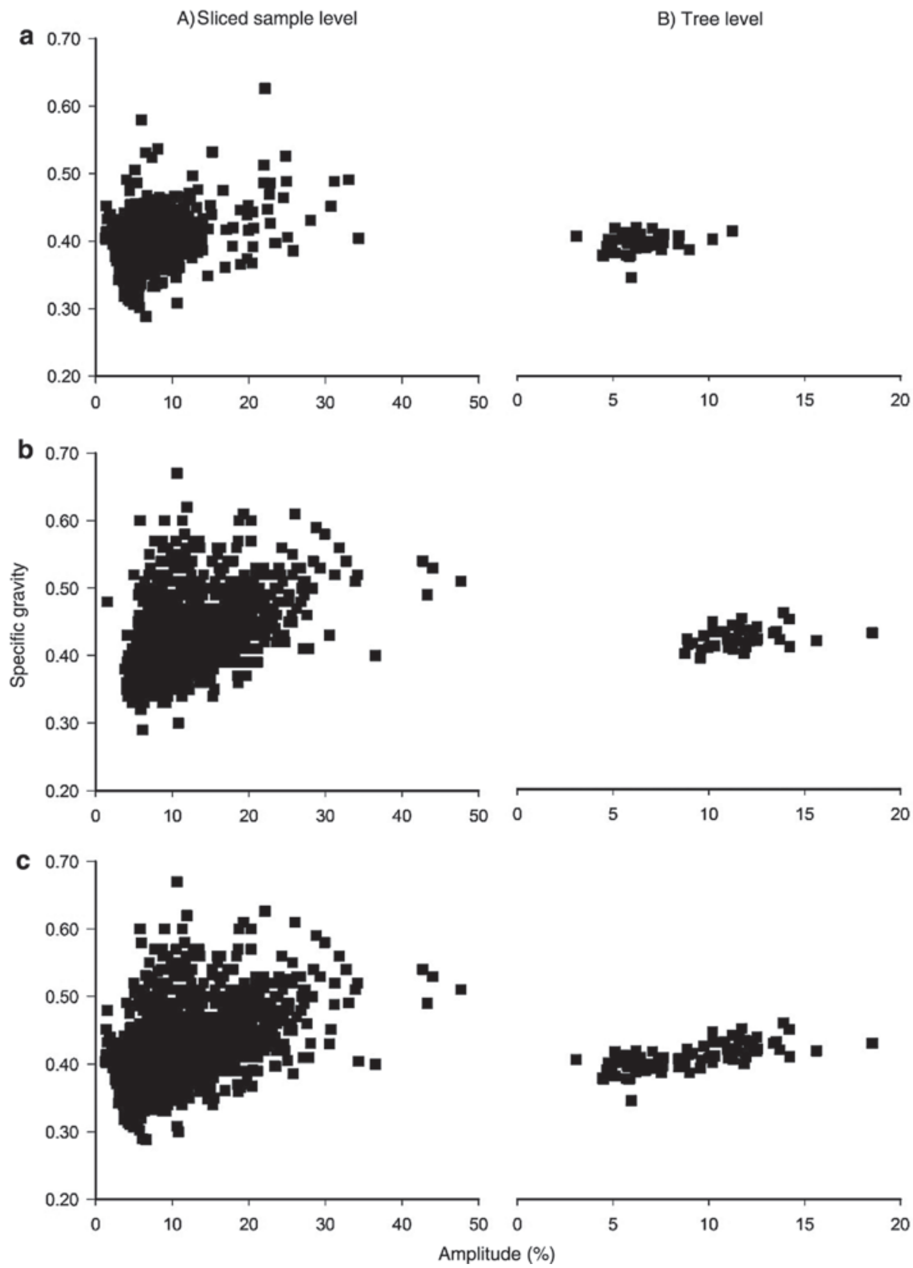

Figure 4: Plot of wood specific gravity and average resistance amplitude for the 34-month-old (a), 62-month-old (b) and 34 and 62-month-old (c) *Eucalyptus grandis* × *Eucalyptus urophylla* trees.
(A) At sliced sample level (entire strip); (B) at tree level.

ResAmp vs. SG obtained from wedge samples

Table 3 summarizes the statistic data from the Disk B. Similar to the results obtained from tree location A, the average resAmp at tree location B showed large variations among trees within each stand and between the two stands. The average resAmp at tree level ranged from 4.3 to 8.3% for the Tr_{34m} (COV = 17.4%) and from 10.0 to 14.0% for the Tr_{62m} (COV = 9.0%). The mean SG of the wedge samples was 0.40 for the Tr_{34m} (COV = 3.1%) and 0.45 for Tr_{62m} (COV = 3.0%). Obviously, there is no statistical difference between wedge SG and strip SG for the Tr_{62m} (P = 0.05).

The SGs determined in 1st half penetration and 2nd half penetration were basically the same (Table 3). However, the average resAmp in 1st and 2nd half penetration were found significantly different (P-value = 0.05). The resAmp of the latter is higher than that of the former, and this difference is more prominent in Tr_{62m} than that in Tr_{34m}. The bigger the tree diameter is, the longer the drill penetration,

Table 3: Statistics and correlation coefficients (R^2) of resistance amplitude and specific gravity for clonal hybrid *Eucalyptus grandis* × *Eucalyptus urophylla* trees (Disk B).[a]

Age (month)	No. of trees	Statistics	Resistance amplitude			Specific gravity			R^2
			Disk	1st Half	2nd Half	Disk	1st Half	2nd Half	
34	50	Avrg.	6.0	5.4	6.7	0.40	0.40	0.41	FP, n.s.
		Min.	4.3	3.8	4.5	0.37	0.37	0.34	1st Half, n.s.
		Max.	8.3	7.6	10.5	0.43	0.43	0.53	2nd Half, 0.57
		COV (%)	17.4	17.8	21.2	3.1	3.0	6.4	
62	50	Avrg.	11.6	9.3	14.0	0.45	0.45	0.45	FP, 0.24
		Min.	10.0	10.0	3.8	0.43	0.42	0.42	1st Half, 0.54
		Max.	14.0	13.8	18.1	0.49	0.49	0.52	2nd Half, 0.42
		COV (%)	9.0	16.1	16.6	3.0	3.9	4.5	
Comb. age	100	Avrg.	8.8	7.3	10.3	0.43	0.42	0.43	FP, 0.85
34+62		Min.	4.3	3.8	4.5	0.37	0.37	0.34	1st Half, 0.82
		Max.	14.0	13.8	18.1	0.49	0.49	0.53	2nd Half, 0.76
		COV (%)	33.9	31.7	39.7	6.2	6.6	7.4	

[a]Std. Dev., Standard deviation; COV, coefficient of variation (%); FP, full penetration; n.s., not significant at 5% confidence level.

and thus the higher are the friction forces with their negative effects. Lima et al. (2010) found similar increasing trend of resAmp for 7-year-old *Eucalyptus* clones.

Relationships between resAmp and SG

Table 3 also shows the correlation coefficients (R^2) between resistance amplitude and SG for different drilling penetrations. For the Tr_{34m}, no relationship was found in the scenario of full and 1st half penetration. A relatively weak relationship is seen for the 2nd half penetration. For the Tr_{62m}, a weak correlation (R^2 0.24) was found in the case of full penetration. A moderate correlation (R^2 0.54 and 0.42) was observed for the 1st and 2nd half of penetrations with a better correlation for the former than that for the latter. In case of combined data sets (Tr_{34m} and Tr_{62m}), the correlations are improved with R^2 of 0.85 (full penetration), 0.82 (1st half penetration), and 0.76 (2nd half penetration). This is probably due to larger sample sizes and wider range of measured properties concerning both resAmp and SG. It is also evident that the relationship found for 1st half penetration was higher than that in the 2nd half penetration. Clearly, the 1st half penetration is preferable for SG prediction of trees.

Figure 6 shows the plot of average resAmp and SG determined from Disk B samples (at tree level) for the Tr_{34m}

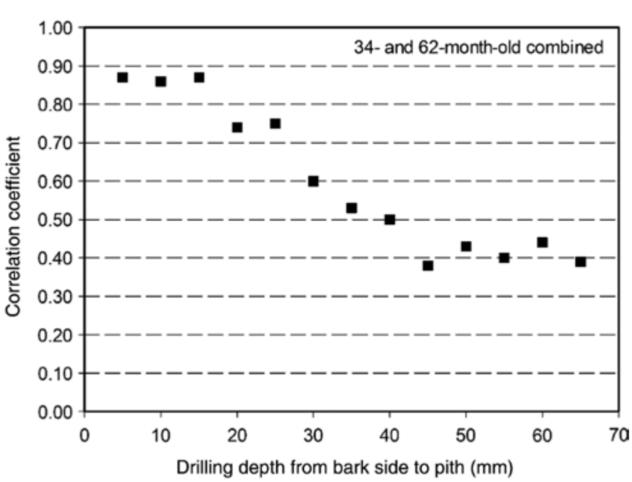

Figure 5: Correlation coefficient for the relationship between resistance amplitude and specific gravity of 34- and 62-month-old *Eucalyptus grandis* × *Eucalyptus urophylla* trees as affected by the drilling depth.

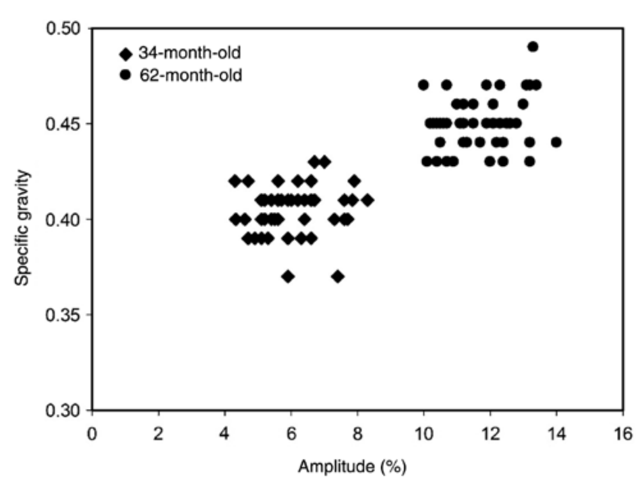

Figure 6: Plot of wood specific gravity and average resistance amplitude for the 34- and 62-month-old *Eucalyptus grandis* × *Eucalyptus urophylla* trees combined.

Table 4: Linear regression equations for calculation of specific gravity (SG) based on average resistance amplitude (rAmp) for 34- and 62-month-old *Eucalyptus grandis* × *Eucalyptus urophylla* trees (Disk B).

Age (months)	Drill penetr. at BH	Regression equation ($P<0.05$)	R^2
34	Full penetr.	n.s.[a]	–
	1st Half	n.s.	–
	2nd Half	SG = 0.3727 + 0.0046 rAmp	0.33
62	Full penetr.	n.s.	–
	1st Half	SG = 0.3929 + 0.0063 rAmp	0.29
	2nd Half	SG = 0.4038 + 0.0032 rAmp	0.17
34 + 62	Full penetr.	SG = 0.3598 + 0.0075 rAmp	0.72
	1st Half	SG = 0.3492 + 0.0107 rAmp	0.68
	2nd Half	SG = 0.3705 + 0.0053 rAmp	0.59

[a]Not significant at 5% confidence level.

and Tr_{62m}. Despite of the large variation within the data sets of each individual age class, there is a good general trend between resAmp and SG in case of combined data sets (Table 4), indicating the predictability of SG based on drilling experiments.

Conclusion

The average resAmp is distinctly different between Tr_{34m} and Tr_{62m} *Eucalyptus* plantation trees. The average resAmp obtained at tree position A (corresponding to Disk A and strip samples) ranged from 3.1 to 11.2% for the Tr_{34m} and from 8.7 to 18.5% for the Tr_{62m}. The average resAmp values obtained at tree position B (corresponding to Disk B and wedge samples) ranged from 4.3 to 8.3% for the Tr_{34m} and 10.0 to 14.0% for the Tr_{62m}, respectively.

With respect to SG of the strip samples, the average resAmp of a full penetration or a half penetration showed a relatively weak correlation with SG for both Tr_{34m} and Tr_{62m}. When two age classes were combined, the strength of the relationship was improved significantly, with R2 increased from 0.28 to 0.38 (Tr_{34m}) and 0.35–0.63 (Tr_{62m}) and 0.71–0.77 (combined Tr_{34m} and Tr_{62m}).

With respect to SG of the wedge samples, the average resAmp of a full penetration or a half penetration showed weak correlations with SG for both Tr_{34m} and Tr_{62m}. When the two age classes were combined, the R^2 data were improved significantly to 0.85. Drill penetration depth influences the results essentially. When two age classes were combined, the correlation was weakened as a function of drill penetration depth. The correlation is better for the first half of drill penetration, and therefor this approach should be used for SG prediction.

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