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RESEARCH PAPER

Use of the pilodyn for assessing wood properties in standing trees of *Eucalyptus* clones

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Abstract: The effectiveness of pilodyn was tested in evaluating wood basic density, outer wood density, heartwood density, and modulus of elasticity (MoE) at 22 four-year-old eucalyptus clones in Guangxi, China. Results indicated that the mean value ranged from 9.44 to 15.41 mm for Pilodyn penetration, 0.3514 to 0.4913 g·cm^{-3} for wood basic density, and 3.94 to 7.53 Giga Pascal (GPa) for MoE, respectively. There were significant differences (1% level) in pilodyn penetration between different treatments, different directions and among the clones. Generally strongly negative correlations were found between pilodyn penetration and wood properties, and the coefficients ranged from -0.433 to -0.755. Our results, together with other studies, suggest that the use of pilodyn for assessing wood density and MoE was confirmed as a possibility.

Keywords: correlation; eucalyptus; modulus of elasticity; pilodyn; wood density

Introduction

Eucalyptus, a major timer production species in the world, is characterized by fast-growing and high-yield. The species is well adapted to different flat and mountainous environments with extreme low temperature of -5°C (Qi 2007). Most of eucalypts species are naturally distributed in the continental Australia of Oceania, and a few native to the Timor Island of Indonesia and Papua New Guinea (Qi 2007). Identification and selection of superior trees in forest management and breeding programs provide a means for improving the properties and value of future wood products (Knowles et al. 2004). In recent years, breeding objectives in tree improvement have moved from volume per hectare alone to an incorporation of wood properties and their impact on industrial end products (Wei and Borralho 1997). Wood basic density is considered as one of the most important wood properties, which has a major impact on the freight costs, chipping properties, pulp yield per unit mass of wood and paper quality (Pliura et al. 2007; Schimleck et al. 1999). Wood basic density generally shows a high heritability and responds well to genetic improvement. However, the genetics of wood density has not been studied in great detail (Macdonald et al. 1997). Currently, the available information on genetic variation in wood basic density in eucalyptus is very limited (Nguyen et al. 2008; Lu 2000; Luo 2003).

Measurement of wood density is expensive and time consuming, and also creates varying degrees of damage to experimental materials, which has restricted the number and accuracy of the studies published (Hansen 2000; Wei et al. 1997). Pilodyn sampling is faster, cheaper, and not destructive, thus resulting in overall higher expected gains for selection of trees or culling of seedling seed orchards in comparison with the more destructive direct assessment of density (Greaves et al. 1996). Kube and Raymond (2002) reported that core sampling for basic density is assumed to cost $10.5 per tree, which includes field collection and laboratory processing, whereas the cost of pilodyn measurements is assumed to be $1.5 per tree. The pilodyn wood tester is an instrument originally developed in Switzerland for determining the degree of soft rot in wooded telephone poles (Raymond et al. 1998; Hansen 2000). Pilodyn penetration, as an indirect method for determining wood basic density, has been demonstrated to be effective in assessing large number of trees in eucalyptus (Wei et al. 1997; Nguyen et al. 2008; Macdonald et al.

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1997; Raymond et al. 1998) and other species (Ishiguri et al. 2008; Pliura et al. 2006).

In the present study, we test the effectiveness of pilodyn for evaluating wood basic density, modulus of elasticity (MoE) and other traits of eucalyptus clones in standing trees, with an objective to provide information for developing appropriate selection strategies of eucalyptus breeding programs in southern China.

Materials and methods

Trial description

The trial was established at Shankou town in Guangxi (21°34' N, 112°42 E, 29 m asl.), China. The study area is characterized by the north tropical monsoon, with annual mean temperature of 23°C and annual mean rainfall of 1,589 mm. The lateritic red earth was derived from sandstone and contains 0.15% of organic matter (0−20 cm). Previous vegetation was a plantation of Eucalyptus. Indigenous vegetation was found on site. Twenty-two eucalypts clones (table 1) were planted in April 2004. Field design was randomized complete blocks with seven replications and 5-tree plot in a spacing of 4 m × 2 m. Measurements and increment cores were collected in December 2008, at which time the trial was aged 56 months.

Table 1. Details of clones in the analysis

Clone number	Clone Identity.	Parental Combination	Style of Seedling
1	GRDH32-26	*E.urophylla ×E.grandis*	Cuttings
2	W5	ABL 12×Unknown	Tissue culture
3	GRDH32-29	*E.urophylla ×E.grandis*	Cuttings
4	M1	*E.urophylla ×E.grandis*	Tissue culture
5	GRDH32-28	*E.urophylla×E.grandis*	Cuttings
6	SH1	Leizhou NO.1×Unknown	Tissue culture
7	GRDH33-9	*E.urophylla ×E.grandis*	Cuttings
8	U6	*E.urophylla* x *E.tereticornis*	Tissue culture
9	GRDH32-25	*E.urophylla×E.grandis*	Cuttings
10	DH32-29	*E.urophylla×E.grandis*	Tissue culture
11	GRDH42-6	*E.grandis ×E.urophylla*	Cuttings
12	RGD3	*E.urophylla×E.camaldulensis*	Tissue culture
13	DH196	*E.urophylla×E.grandis*	Cuttings
14	DH32-28	*E.urophylla×E.grandis*	Tissue culture
15	GRDH30-10	*E.urophylla×E.grandis*	Cuttings
16	TH9224	*E.urophylla×E.camaldulensis*	Tissue culture
17	GRDH33-27	*E.urophylla×E.grandis*	Cuttings
18	LH1	*E.urophylla×E.tereticornis*	Tissue culture
19	TH9224	*E.grandis* x *E.camaldulensis*	Cuttings
20	DH32-22	*E.urophylla×E.grandis*	Tissue culture
21	DH32-13	*E.urophylla×E.grandis*	Tissue culture
22	DH32-25	*E.urophylla×E.grandis*	Tissue culture

Note: Male parents of U6, W5 and SH1 were not clear.

Pilodyn penetration

Pilodyn penetration was measured using a 6-J Forest pilodyn with 2.5 mm steel needle, by over the bark and removing a small section of bark (approximately 40 mm × 20 mm) at 1.3 m, respectively, and taking two pilodyn shots on each of four aspects (north, south west and east) from an average tree per plot. The pilodyn is attractive in that it is rapid, does not require the use of an increment borer (destructive sampling), and is, in principle, free of operator bias (Cown 1978; Hansen 2000). To avoid introducing additional sources of error, all clones were sampled by the same team of people, minimizing the potential for operator error (Raymond et al. 1998).

Modulus of elasticity

FAKOPP microsecond timer is able to measure acoustic velocity in standing trees, by timing the acoustic wave as it travels along the stem between points a known distance apart (Knowles et al. 2004; Chauhan et al. 2006). The results signals were engendered by starting and stopping transducers, and recorded on an oscilloscope. Stress wave velocity (SWV) was then calculated by dividing the test span by the measurement stress wave transmission time (Wang et al. 2000).

$$SWV = L/t \tag{1}$$

where L = 1,500 mm is the distance between two probes, t is the transmission time in microseconds (μs).

The *SWV* is combined with density measurements to give an estimation of dynamic MoE (Knowles et al. 2004).

$$MoE=\rho\omega^2 \tag{2}$$

where *MoE* is the dynamic modulus of elasticity, ρ the average green density of the stem, and ω the *SWV*.

Wood basic density

Wood basic density was defined as oven-dry wood mass per unit volume of green wood, and was measured using the water displacement method (Kube and Raymond 2002; Tappi 1989). The 5-mm increment cores from pith to bark were extracted at a height of 1.3 m in the south-north orientation from an average tree per plot, immediately stored in plastic tubes with both ends sealed (Nguyen et al. 2008). Wood basic density was determined using the water displacement method, with two weights for every sample: weight of water displaced by immersion of wedge (w_1) and oven dry weight (w_2) (Nguyen et al. 2008). Basic DEN was then calculated as:

$$Basic\ DEN\ (g \bullet cm^{-3}) = w_2 / w_1 \tag{3}$$

Wood basic density, outer wood basic density and heartwood basic density were tested, respectively.

Statistic analysis

The SAS software package was used to analyze the variance of different pilodyn penetration and the relationship between the pilodyn penetration and wood density or MoE. The mean by ramet at each clone of sampling was submitted to a variance and a covariance analysis according to the following linear model (Hansen et al. 1997):

$$y_{ij} = \mu + \alpha_i + \beta_i + \varepsilon_{ij} \quad (4)$$

where, y_{ij} is the performance of ramet of i^{th} clone within j^{th} block, μ the general mean, α_i the random effect of the i^{th} clone, β_j the random effect of the j^{th} block, ε_{ij} the random error.

Results and discussion

Comparison between pilodyn penetration and wood properties

The mean values of pilodyn penetration and wood properties of 22 clones were listed in Table 2. The mean value ranged from 9.44 to 15.41 mm for pilodyn penetration, 0.3514 to 0.4913 g·cm^{-3} for wood basic density, and 3.94 to 7.53 GPa for MoE, which were smaller than previous studies on the same species (Knowles et al. 2004; Nguyen et al. 2008; Wei et al. 1997) as well as other species (Jacques 2004; Zhu et al. 2008; Zhu et al. 2009). The most suitable range of basic density for pulpwood in eucalyptus is 0.48 to 0.57 g·cm^{-3} and pulp yield decreases sharply when basic density falls below 0.4 and exceeds 0.60 (Dean 1995; Ikemori et al. 1986). There were considerably lower density values than those found in this study. Consequently, wood basic density should be improved substantially to about 0.55 g·cm^{-3}, and this would benefit pulp production in southern China (Nguyen et al. 2008). Clones of M1, RGD3 and TH9224 had higher basic density and MoE, meanwhile, clones of DH32-28, GRDH42-6 and DH196 had lower basic density and MoE.

Table 2. The mean value of pilodyn penetration and wood properties

Clone number	Mean value of pilodyn penetration (mm)	Wood basic density (g.cm^{-3})	Modulus of elasticity (GPa)
1	12	0.4614	5.88
2	10.66	0.4145	4.93
3	12.22	0.4237	5.52
4	10.03	0.4913	7.42
5	15.41	5	0.3514
6	11.44	0.4295	5.25
7	14.03	0.4164	5.47
8	11.15	0.362	3.94
9	12.97	0.4106	5.32
10	11.63	0.4627	6.33
11	14.94	0.3924	4.45
12	10.28	0.4638	7.53
13	15.34	0.3899	4.35
14	12.69	0.3938	5.48
15	10.81	0.4384	6.14
16	9.44	0.4395	6.48
17	13.5	0.4266	5.92
18	11.47	0.4371	5.85
19	11.03	0.4302	6.31
20	11.41	0.4236	5.76
21	11.47	0.4262	5.84
22	13.09	0.4172	5.65

Variance analysis of pilodyn

The variation coefficient of pilodyn penetration over the bark ranged from 9.15% to 11.83%, whereas those measured by removing the bark ranged from 13.40% to 14.45% (Table 3). One possible explanation could be that bark thickness and branch cluster frequency could affect this value. This agreed well with previously published results by Wei (1997) and Yin (2008).

Table 3. The mean value and variation coefficient of pilodyn penetration (PP) on four directions

Treatment	Index	Mean PP (mm)	C V (%)
PP over the bark	East	14.5	10.42
	West	14.99	11.83
	South	14.59	9.15
	North	14.62	10.94
	Mean	14.67	10.41
PP with bark removal	East	12.04	14.4
	West	12.33	14.45
	South	12.15	13.4
	North	12.02	14.06
	Mean	12.14	13.57

The analysis of variance of pilodyn presented in Table 4. There were significant (1% level) differences between pilodyn penetration of different treatment, different directions and different clones, indicating that selection of clones for pilodyn would be effective.

Table 4. Variance analysis of pilodyn

Source	DF	F Value	Pr≥F
Treatments	1	16.47	< 0.0001
Directions	6	21.13	< 0.0001
Clones	21	8.10	< 0.0001

The correlations between pilodyn and wood properties

The regression equations and phenotypic correlations between pilodyn penetration and wood properties are given in Table 5 and Table 6, respectively. Generally strongly negative correlations were found between pilodyn and wood properties, ranging from -0.433 to -0.755, slightly lower than previously published study (Wei et al. 1997; Chapola 1994). The possible explanation could be at least in part to the relatively small age of materials or less pilodyn penetration and pith taken from clones. The results indicated that pilodyn penetration was generally reliable as an indirect measure of wood basic density. The correlations between pilodyn and MoE were significantly and negative. However, the relationship between pilodyn and MoE does not seem to be documented, and is needed to clarify in further. The correlations between pilodyn and heartwood density were slightly positive to strongly positively, lower than the correlations between pilodyn and other wood properties because of the short length of steel needle

Table 5. Regression analysis of wood properties (y) to pilodyn penetration (x) over the bark on four directions

Directions	Wood properties	Regression equation	R^2	R
East	MoE	$y = 0.0341x^2 - 1.3743x + 18.331$	0.365	-0.604^{**}
	Basic density	$y = 0.0003x^2 - 0.0189x + 0.6422$	0.281	-0.530^{*}
	Outer wood density	$y = 0.0007x^2 - 0.0356x + 0.8051$	0.417	-0.646^{**}
	Heartwood density	$y = -0.0003x^2 + 0.0008x + 0.4794$	0.188	-0.433^{*}
West	MoE	$y = -0.0037x^2 - 0.1913x + 9.3565$	0.374	-0.611^{**}
	Basic density	$y = -2E\text{-}05x^2 - 0.0103x + 0.581$	0.363	-0.603^{**}
	Outer wood density	$y = 0.0009x^2 - 0.0409x + 0.8485$	0.482	-0.695^{**}
	Heartwood density	$y = -0.0005x^2 + 0.0076x + 0.4308$	0.274	-0.523^{*}
South	MoE	$y = 0.05x^2 - 1.9367x + 23.169$	0.424	-0.651^{**}
	Basic density	$y = 0.0019x^2 - 0.0735x + 1.0769$	0.395	-0.629^{**}
	Outer wood density	$y = 0.0031x^2 - 0.1139x + 1.4198$	0.521	-0.722^{**}
	Heartwood density	$y = 0.0011x^2 - 0.0459x + 0.8543$	0.289	-0.538^{**}
North	MoE	$y = -0.0105x^2 - 0.0191x + 8.1845$	0.357	-0.597^{**}
	Basic density	$y = -0.0003x^2 - 0.0042x + 0.5399$	0.357	-0.598^{**}
	Outer wood density	$y = 0.0014x^2 - 0.0579x + 0.9693$	0.464	-0.681^{**}
	Heartwood density	$y = -0.0012x^2 + 0.0255x + 0.3069$	0.284	-0.533^{*}
Mean value	MoE	$y = 0.0187x^2 - 0.9296x + 15.216$	0.389	-0.624^{**}
	Basic density	$y = 0.0006x^2 - 0.0313x + 0.7468$	0.359	-0.599^{**}
	Outer wood density	$y = 0.0022x^2 - 0.0823x + 1.1665$	0.493	-0.702^{**}
	Heartwood density	$y = -0.0003x^2 - 7E\text{-}05x + 0.4975$	0.262	-0.511^{*}

Table 6. Regression analysis of wood properties (y) to pilodyn penetration(x) with bark removal on four directions

Directions	Wood properties	regression equation	R^2	R
East	MoE	$y = 0.0429x^2 - 1.3872x + 15.992$	0.431	-0.656^{**}
	Basic density	$y = 9E\text{-}05x^2 - 0.0133x + 0.5688$	0.357	-0.598^{**}
	Outer wood density	$y = 0.0006x^2 - 0.0304x + 0.7061$	0.529	-0.727^{**}
	Heartwood density	$y = -0.0005x^2 + 0.0031x + 0.4548$	0.235	-0.484^{*}
West	MoE	$y = 0.0082x^2 - 0.5428x + 11.063$	0.431	-0.656^{**}
	Basic density	$y = 1E\text{-}05x^2 - 0.0117x + 0.5661$	0.414	-0.644^{**}
	Outer wood density	$y = 0.0008x^2 - 0.0367x + 0.7538$	0.530	-0.728^{**}
	Heartwood density	$y = -0.0005x^2 + 0.0033x + 0.4582$	0.313	-0.560^{**}
South	MoE	$y = -0.0063x^2 - 0.171x + 8.6605$	0.365	-0.604^{**}
	Basic density	$y = -0.0016x^2 + 0.0291x + 0.3081$	0.356	-0.596^{**}
	Outer wood density	$y = 0.0002x^2 - 0.0204x + 0.6545$	0.528	-0.727^{**}
	Heartwood density	$y = -0.0027x^2 + 0.0589x + 0.1055$	0.263	-0.513^{*}
North	MoE	$y = 0.0054x^2 - 0.4438x + 10.18$	0.344	-0.587^{**}
	Basic density	$y = -0.0007x^2 + 0.0061x + 0.453$	0.375	-0.613^{**}
	Outer wood density	$y = 0.0012x^2 - 0.045x + 0.7988$	0.541	-0.736^{**}
	Heartwood density	$y = -0.0018x^2 + 0.0353x + 0.2603$	0.282	-0.531^{*}
Mean value	MoE	$y = 0.0079x^2 - 0.5492x + 11.117$	0.418	-0.646^{**}
	Basic density	$y = -0.0008x^2 + 0.0084x + 0.4432$	0.404	-0.635^{**}
	Outer wood density	$y = 0.0006x^2 - 0.0326x + 0.7318$	0.569	-0.755^{**}
	Heartwood density	$y = -0.0018x^2 + 0.0341x + 0.2696$	0.295	-0.543^{**}

Conclusion

In the present study, the effectiveness of pilodyn for assessing wood properties of eucalyptus clones in standing trees was discussed. The results obtained are as follows:

(1) The mean value of pilodyn penetration, wood basic density and MoE ranged from 9.44 to 15.41 mm, 0.3514 to 0.4913 $g \cdot cm^{-3}$ and 3.94 to 7.53 GPa, respectively.

(2) There were significant differences between pilodyn pene-

tration of different treatments, different directions and different clones. The variation coefficient ranged from 9.15% to 11.83% for pilodyn penetration over the bark, and ranged from 13.40% to 14.45% for pilodyn penetration with bark removal.

(3) The correlations between pilodyn and wood properties were generally strongly negative, and the coefficients ranged from -0.433 to -0.755. The results indicated that wood basic density and MoE can be predicted by using pilodyn. Results from this study also tend to confirm those of Cown (1981) who concluded that pilodyn is not accurate equipment for measurement, but it does provide an effective and efficient means of estimating wood properties.

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