ESTIMATION OF BASIC DENSITY AND MODULUS OF ELASTICITY OF EUCALYPT CLONES IN SOUTHERN CHINA USING NON-DESTRUCTIVE METHODS

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WU SJ, XU JM, LI GY, RISTO V, LU ZH, LI BQ & WANG W. 2011. Estimation of basic density and modulus of elasticity of eucalypt clones in southern China using non-destructive methods. Wood properties were assessed on 23 eucalypt clones in southern China using non-destructive methods. They were sampled at 51 months. Correlations between three traits assessed using non-destructive methods and basic density measured on increment core showed that genotypic correlation between Pilodyn penetration and basic density was significantly negative (r = -0.83), indicating that basic density could be predicted using Pilodyn. The correlation between basic density and modulus of elasticity was significantly positive (r = 0.74). Stress wave velocity was unfavourably correlated with Pilodyn penetration (r = -0.20) but correlated with basic density (r = 0.52) and modulus of elasticity (r = 0.96). This indicates that basic density and modulus of elasticity can be predicted using stress wave velocity.

Keywords: Genotypic correlation, Pilodyn, stress wave velocity

WU SJ, XU JM, LI GY, RISTO V, LU ZH, LI BQ & WANG W. 2011. Anggaran ketumpatan asas dan modulus kekenyalan klon *Eucalyptus* di selatan negara China menggunakan kaedah tak memusnah. Sebanyak 23 klon *Eucalyptus* di selatan negara China diuji ciri kayunya menggunakan kaedah tak memusnah. *Eucalyptus* disampel pada usia 51 bulan. Korelasi antara tiga ciri yang dikaji menggunakan kaedah tak memusnah dengan ketumpatan asas yang disukat pada tokokan teras menunjukkan bahawa korelasi genotip antara penembusan Pilodin dengan ketumpatan asas adalah signifikan dan negatif (r = -0.83). Ini menunjukkan yang ketumpatan asas boleh diramal menggunakan Pilodin. Korelasi antara ketumpatan asas dengan modulus kekenyalan adalah signifikan dan positif (r = 0.74). Kelajuan gelombang tegasan kurang berkorelasi dengan penembusan Pilodin (r = -0.20) tetapi berkorelasi dengan ketumpatan asas (r = 0.52) dan modulus kekenyalan (r = 0.96). Ini menunjukkan bahawa ketumpatan asas dan modulus kekenyalan boleh diramal menggunakan kelajuan gelombang tegasan.

INTRODUCTION

Eucalypts play an important role in forestry in southern China, particularly in Guangdong, Guangxi and Hainan (Qi 2002). In the past, many eucalypt breeding programmes have focused on developing clones to enhance plantation productivity and product uniformity. In this context, the estimation of basic genetic parameters is crucial in determining the best strategies for clonal breeding and testing and in predicting genetic gains from developing the best clones (Osorio et al. 2001).

Improving both productivity and product quality of plantations is a goal of research and tree improvement in particular (Kube et al. 2001). Historically, improving productivity has been the main priority. However, little work has been done to improve wood properties (Wei & Borralho 1999, Kube et al. 2001). Wood density is important in the value of timber and pulpwood. It is highly correlated with major strength characteristics, and pulp and paper properties (Hansen 2000, Pliura et al. 2007, Yin et al. 2008, Wu et al. 2010). Basic density measured on increment core taken at breast height is the most common technique (Jacques et al. 2004). However, measurement of wood density is constrained by various factors such as high cost, time consuming and it is a destructive

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operation (Wei & Borralho 1997, Hansen 2000, Wu et al. 2010). Non-destructive evaluation methods have contributed considerably towards reducing these limitations (Wang et al. 2000) and have been applied for a variety of purposes, particularly for the evaluation of wood properties (Ilic 1998). By definition, non-destructive evaluation method is the science of identifying physical and mechanical properties of a piece of material without altering its end-use capabilities (Ross & Pellerin 1994). Such evaluations rely upon non-destructive testing techniques to provide accurate information pertaining to the properties, performance or condition of the material in question (Ross & Pellerin 1994).

The Pilodyn wood tester measures the degree of soft rot in wooden telephone poles by fixed energy, generally 6 J (Hansen 2000, Jacques et al. 2004, Yin et al. 2008). The depth to which the pin penetrates is indicated on the instrument and is inversely proportional to wood density (Wei & Borralho 1997, Hansen 2000, Jacques et al. 2004, Yin et al. 2008, Wu et al. 2010). Pilodyn, a hand-held instrument which fires a flat-nosed pin into a tree with a fixed force, has been recommended as an effective tool to measure wood density in eucalypts (MacDonald et al. 1997, Wei & Borralho 1997, Raymond & MacDonald 1998, Kien et al. 2008) and other species (Hansen 2000, Jacques et al. 2004, Pliura et al. 2007, Ishiguri et al. 2008).

The core sampling for basic density collected on *Eucalyptus nitens* is estimated to cost USD10.5 per tree (Kube & Raymond 2002), which includes field collection and laboratory processing, whereas the cost of Pilodyn measurement is estimated at USD1.5 per tree. A strong positive correlation between stress wave velocity (SWV) and modulus of elasticity (MOE) was found in most species, e.g. pine (Chauhan & Walker 2006), Sitka spruce (Wang et al. 2000), Japanese larch (Ishiguri et al. 2008) and eucalypts (Dickson et al. 2003).

The objective of this study was to investigate the effectiveness of the Pilodyn and Fakopp microsecond timer in evaluating basic density (BD) and predicting MOE in eucalypt clones.

MATERIALS AND METHODS

Site

The trial was established at the Luokeng town of Jiangmen City in Guangdong (22° 22' N, 112° 52' E, 45 m asl). The site experiences the north tropical monsoon with mean annual temperature of 21.8 °C and rainfall of 1800 mm. The mean January temperature is 13.4 °C and July, 28.3 °C. The minimum temperature is 0.3 °C. The annual frost-free period is 339 days. The mean annual accumulated temperature is 7959 °C. It has red lateritic earth, which is derived from sandstone and contains 30 mg kg^{-1} total N, 1 mg kg^{-1} total P and 29 mg kg^{-1} total K. The soil pH is 4.9. The site was formerly planted with *Acacia*. The dominant plants in the undergrowth of the original tree canopy included *Dicranopteris pedata*, *Mussaenda pubescens* and *Rhodomyrtus tomentosa*. Twenty-three eucalypt clones (Table 1) were planted in May 2004. The widely planted U6 clone was used as control. The field design was a randomised complete block with six replications and five tree-line plots planted in a spacing of 3 × 2 m.

Data collection

Measurements were taken in August 2008, at which time the trees were 51 months old. All clones were assessed for Pilodyn penetration (PP) and SWV using Pilodyn and Fakopp microsecond timer tools respectively.

Assessments of wood properties

Pilodyn penetration

Pilodyn penetration was measured using a 6-J Pilodyn fitted with a 2.5 mm steel pin by removing a small section of the bark (approximately 40 × 20 mm) at 1.3 m and making two Pilodyn shots in this bark window. Pilodyn penetration was recorded on each of the four directions (north, south, east and west) for a tree within each plot with average diameter at breast height (dbh) over bark (1.3 m).

Acoustic velocity

The Fakopp microsecond timer is used to measure SWV on standing trees (Wang et al. 2000, Knowles et al. 2004). The resulting signals travelling between start and stop transducers were recorded using an oscilloscope and the distance between them was used to calculate the SWV (Wang et al. 2000, Chauhan & Walker 2006).

Table 1 Identity and origin details of the clones assessed

No.	Clone identity	Parental combination	Origin of clone	Type of propagule
1	DH32-26 F2	U × G	RITF	Cutting
2	W5	ABL 12 × Unknown	Dianbai Forest Bureau	Tissue culture
3	DH32-29	U × G	Dongmen Forest Farm	Cutting
4	M1	U × T	RITF and Leizhou Forest Bureau	Tissue culture
5	DH32-28	U × G	Dongmen Forest Farm	Cutting
6	SH1	LZ No.1 × Unknown	Leizhou Forest Bureau	Tissue culture
7	DH33-9	U × G	Dongmen Forest Farm	Cutting
8	GL 9	G × U	Guangxi Academy of Forestry Sciences	Tissue culture
9	DH32-25	U × G	Dongmen Forest Farm	Cutting
10	DH42-6	U × G	Dongmen Forest Farm	Cutting
11	THD3	U × C	RITF	Tissue culture
12	DH196	U × G	Dongmen Forest Farm	Cutting
13	DH32-28	U × G	Dongmen Forest Farm	Tissue culture
14	DH30-10	U × G	Dongmen Forest Farm	Cutting
15	TH9224	U × C	RITF	Tissue culture
16	DH33-27	U × G	Dongmen Forest Farm	Cutting
17	TH9211-LH1	U × T	RITF and Leizhou Forest Bureau	Tissue culture
18	DH201-2	G × T	Dongmen Forest Farm	Cutting
19	DH32-22	U × G	Dongmen Forest Farm	Tissue culture
20	DH32-13	U × G	Dongmen Forest Farm	Tissue culture
21	GL 4	U	Guangxi Academy of Forestry Sciences	Tissue culture
22	DH32-29	U × G	Dongmen Forest Farm	Tissue culture
23	U6 (CK)	U × Unknown	Zhanjiang Forest Bureau	Tissue culture

U = *E. urophylla*, G = *E. grandis*, T= *E. tereticornis*, C = *E.camaldulensis*; ABL 12 = *E. ABL 12*, LZ No.1 = *E. leizhou* No.1; GL 9 = Guanglin 9, GL 4 = Guanglin 4; The male parents of U6, W5 and SH1 were not clear; RITF = Research Institute of Tropical Forestry, Chinese Academy of Forestry.

$$SWV = L / t \quad (1)$$

where

L = distance between start and stop probes (1500 mm)
t = transmission time (μs)

The SWV may be used as an indicator of stiffness in itself or combined with density measurements to give an estimate of dynamic MOE (Knowles et al. 2004, Wu et al. 2010).

$$MOE = \rho\omega^2 \quad (2)$$

where

MOE = dynamic modulus of elasticity (GPa)
ρ = average green density of the stem by water displacement method (g cm^{-3})
ω = SWV (m s^{-1})

Basic density

Five millimetre pith to bark increment cores were removed at dbh from an average tree per plot in the north–south orientation which corresponded to the direction of the planted rows. The increment cores were immediately stored in plastic tubes with both ends sealed using the methods described by Kien et al. (2008). Water displacement method was adopted in this study to determine BD (Wei & Borralho 1997, Schimleck et al. 1999, Kien et al. 2008).

Basic density (Wei & Borralho 1997, Kien et al. 2008) was calculated as:

$$BD\ (g\ cm^{-3}) = w_2\ /\ w_1 \quad (3)$$

where

w_1 = volume of water displaced by immersion of core (cm^3)
w_2 = oven-dry weight (g)

Statistical analysis

Results for the individual ramets of each sampled clone were subjected to variance and covariance analyses based on the linear model of Hansen and Roulund (1996):

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

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

The genotypic correlation r_{Axy} of traits x and y was calculated as (Pliura et al. 2007)

$$r_{Axy} = \frac{\sigma^2_{axy}}{\sqrt{\sigma^2_{ax} \times \sigma^2_{ay}}} \quad (5)$$

where σ^2_{ax} is the clone variance component for the trait x, σ^2_{ay} is the clone variance component for the trait y and σ^2_{axy} is the clone covariance component.

RESULTS AND DISCUSSION

Analysis of variance of studied traits

Table 2 shows that there are significant differences (1% level) in all studied traits between clones, with F value ranging from 2.59 to 4.62. The differences (5% level) in studied traits between blocks were also significant except for PP, with F values ranging from 0.68 to 3.38. A possible explanation could be the relatively variable site conditions.

Correlations between non-destructive methods and basic density

Genotypic correlation (Table 3) between PP and BD was significant and negative (r = -0.83). This is in accordance with previous studies (Hansen & Roulund 1996, MacDonald et al. 1997, Wei & Borralho 1997, Hansen 2000, Knowles et al. 2004, Kien et al. 2008, Yin et al. 2008, Wu et al. 2010). This shows that PP is generally reliable as an indirect measure of BD.

The correlation between BD and MOE (r = 0.74) was significantly positive but less than the correlation between SWV and MOE. Stress wave velocity was unfavourably correlated with PP (r = -0.20) but was relatively strongly correlated with BD (r = 0.52) and MOE (r = 0.96), indicating that BD and MOE could be predicted using SWV. The correlations between traits assessed using non-destructive field methods and wood property assessment indicated that BD and MOE could be predicted using Pilodyn and Fakopp microsecond timer tools. The Pilodyn and Fakopp microsecond timer tools provide an effective and efficient means of ranking genotypes for BD and MOE. The overall wood quality of young eucalypt clones could be improved by selection based on a combination of these two parameters.

However, Pilodyn is useful for ranking genotypes or for grouping genotypes or sites into density classes but does not accurately predict individual tree values (Cown 1981, Moura et al. 1987, Raymond & MacDonald 1998). Consequently, a two-step selection process seems to be a practical approach for eucalypt clonal selection: a preliminary rapid evaluation using Pilodyn to rank clones for PP and then, based

Table 2 Variance analysis of basic density (BD), Pilodyn penetration (PP), stress wave velocity (SWV) and modulus of elasticity (MOE)

Source	Df	BD	PP	SWV	MOE
Clone	22	2.59**	3.85**	4.62**	2.84**
Block	5	2.50*	0.68	2.96*	3.38*

*, ** = Significant differences at 5 and 1% levels respectively

Table 3 Genotypic (G), phenotypic (P) and environmental (E) correlations with basic density (BD), Pilodyn penetration (PP), stress wave velocity (SWV) and modulus of elasticity (MOE)

Trait	Factor	BD	PP	SWV
PP	P	-0.31		
	G	-0.83**		
	E	0.08		
SWV	P	0.32	-0.16	
	G	0.52**	-0.20	
	E	0.01	-0.14	
MOE	P	0.67**	-0.27	0.86**
	G	0.74**	-0.41*	0.96**
	E	0.61**	-0.14	0.58**

*, ** = Significant differences at 5 and 1% levels respectively

on these results, using the Fakopp on a small number of preselected clones for MOE.

Eucalypt plantations in southern China are being established mainly for pulping. Published studies concluded that traits with greatest impact on increasing pulping mill capacity or reducing cost are volume, basic density and pulp yield (Wei & Borralho 1999). There have been some reports on the genetics of growth for eucalypts, but the genetics of wood properties remains poorly understood in China. Therefore, growth and wood properties affecting the pulping process need to be studied in order to carry out efficient breeding strategies. Furthermore, it is vital to include rapid and inexpensive non-destructive evaluation technologies, such as Pilodyn and the Fakopp microsecond timer, in eucalypt breeding and improvement programmes.

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