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Genetic Variation and Correlations of Energy Use Traits in Clone Of *Eucalyptus urophylla* × *E. grandis*[1]

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ABSTRACT

DH32-29, a clone of *Eucalyptus urophylla* × *E. grandis*, has become most widely planted in southern China. We assessed growth traits, wood basic density and calorific value traits measured at the age of 2 to 6 years. Analysis of variance showed that there were significant differences in individual tree volume over bark, individual tree wood weight and individual tree calorific value among ages whereas the differences for basic density and calorific value among ages were not significant. The basic density of DH32-29 at 6-year fall below the most suitable range of basic density for pulpwood in eucalypts and joint analysis the age trends of studied traits revealed that rotation length of DH32-29 should be more than six years or longer for pulpwood and energy use. The basic density, the individual tree wood weight and the individual tree calorific value at 5-year were all lower than that at 4 and 6-year implying more tending should be carried out at 5 year after plantation. Phenotypic correlations among traits indicated that the individual tree volume over bark and individual tree wood weight could play important role to predict individual tree wood weight and individual tree calorific value respectively.

Keywords: eucalypt; age trends; energy use; wood properties; correlation;

INTRODUCTION

As one of the three most quickly growing genera, trees from the genus *Eucalyptus* have been widely planted in the tropical, sub-tropical and temperate climatic regions around the world (Li *et al.* 2011). Eucalypt plantations now cover an estimated area of more than 4.0 million hectares in China (Chen and Chen 2013), principally in Guangdong, Guangxi, Hainan Island, Yunnan, Sichuan and Fujian provinces with more than 1.4 million hectares in Guangxi alone (Liley 2014). There has been remarkable progress in terms of wood volume improvement in China and the mean clone annual increment in volume of eucalypt plantations in China has been near the mean annual yield of eucalypt plantations in tropical and subtropical region of the parts of the world at more than 20 m^3 ha^{-1} $year^{-1}$ (Mo *et al.* 2002; Toit *et al.* 2010; Wu *et al.* 2014). DH32-29 is a hybrid clone of *E. urophylla* × *E. grandis* selected by Dongmen Forest Farm in 1980s (Qi *et al*. 2007). It is widely planted in southern China due to its stable growth and well adaptability. The annual yield of this clone is frequently reported by more than 30 m^3 ha^{-1} $year^{-1}$(Wu *et al.* 2011).

The energy mix worldwide is primarily based on consumption of fossil fuels, which not only are not renewable but have also been regarded as a major cause of the climate changes on record (Andrade *et al.* 2013). As renewable resources, biomass and especially wood is the most common form of renewable energy sources (Kumar *et al.* 2010). Estimations of the calorific value of different *Eucalyptus* species have been published in China. Numerous studies have also been conducted in an attempt to understand difference of calorific values of different *Eucalyptus* species (Chen *et al.* 2007; Zhou *et al*. 2009; Zhou *et al.* 2012; Han *et al.* 2013) and different stand densities (Han *et al.* 2009; Xu and Chen 2012). However, less studies have been focused on the energy use of most widely used clone.

The objectives of this study were to: (1) compare annual energy use traits in order to determine the rotation length of DH32-29, (2) look at the relationships between energy use traits with age trends. Theses information will be used to develop appropriate selection strategies for eucalypt breeding programs in southern China.

MATERIALS AND METHODS

Trial Description

The data and samples were collected from Luokeng town of Jiangmen City in Guangdong (22°22′N, 112°52′E). This province has a subtropical humid monsoon climate-there is a summer rainfall maximum and winters are genrally dry and cool. The rainfall is 1750 mm year. The soil is classified as Lateritic red earth and contains 30mg • kg^{-1} total N, 1mg • kg^{-1} total P, 29mg • kg^{-1} total K. The soil pH is 4.9. The dominant plants in the undergrowth of the eucalypt plantation of DH32-29 were *Dicranopteris pedata* (Honutt.) Nakaike, *Mussaenda pubeseens* Ait and *Rhodomyrtus tomentosa* Hassk.. Planting pits (50 cm × 50 cm × 40 cm) were prepared and 0.5 kilogram compound fertilizer was applied. Spacing was 2.3 m × 2.5 m.

Data Collection

Measurements of diameter at breast height over bark (DBH in cm), height (H in m), increment cores and wood samples were collected at age 2 to 6 years (Wu *et al.* 2012). Individual tree volume over bark (V in m^3) was calculated using the following formula as described by Lu *et al.* (2004):

$$V = H \times DBH^2 / 30\,000 \qquad (1)$$

The individual tree wood weight (WW, in kg) also can be estimated as the product of V and basic density (BD).

$$WW = V \times BD \times 1000 \qquad (2)$$

The individual tree calorific value (TCal, in GJ) was calculated by WW and calorific value (Cal, in KJ/g).

$$TCal = WW \times Cal \qquad (3)$$

Five millimeter thick increment cores, passing from bark to bark through the pith, were obtained at breast height (1.3 m) from the same trees that were sampled for wood samples. BD was determined using the water displacement method (Kien *et al.* 2008; Wu *et al.* 2011). All wood samples were oven-dried to constant weight at 80℃ and then chipped and ground into powder. One gram of wood powder was pelletized and burned in an oxygen calorimeter (WELL-9000) to determine calorific value.

Statistical Analysis

The significance of fixed effects was assessed using F-tests. The analysis of variance was performed using the PROC ANOVA in SAS. Results for the individual ramets were subjected to variance analysis based on the follow linear model (Hansen and Roulund 1996; Jacques *et al*. 2002):

$$y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

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

RESULTS AND DISCUSSION

Analysis of Variance of Studied Traits among Different Ages

The analysis of variance of the studied traits among ages is presented in Table 1. The results indicated that there were significant differences in V, WW and TCal, producing clear differences among ages. TCal was estimated from the product of WW and Cal and while there was no significant difference among ages for Cal, the TCal difference among ages was significant at the 0.01 level, suggesting a significant difference among clones in WW. Wu *et al.* (2014) reported that the WW differences among clones was significant ($P < 0.05$) for 60 *Eucalyptus urophylla* clones in southern China measured at ages 21, 52, 71 and 96 months. However, the differences for BD and Cal among ages were not significant in this study, indicating these two traits were stable during the whole research rotation. Kumar *et al.* (2010) reported that there was no significant variation in the basic density of wood for 2-6 year-old *Eucalyptus* hybrid. Zhou *et al.* (2014) found that the calorific value of *eucalyptus* hybrids among ages were also not significant.

Table1. *Variance analysis of studied traits among different ages*

Source	DF	SS	MS	F Value	Pr ＞ F
V (m^3)	4	0.27	0.07	57.60	＜ 0.0001
BD (g cm^{-3})	4	9.44	2.36	1.93	0.1063
Cal (KJ/g)	4	4.33	1.08	1.69	0.1654
WW (kg)	4	16554.56	4138.64	24.74	＜ 0.0001
TCal (GJ)	4	6.67	1.67	23.41	＜ 0.0001

Age Trends of Growth and Wood Properties in Clone Of DH32-29

Mean values and ranges for growth traits and wood properties at five ages are presented in Table 2. Over the period studied, the annual V increment among ages increased from 0.022 m^3 to 0.017 m^3, 0.02 m^3 and 0.037 m^3, respectively. This is relatively bigger than other studies in *E. urophylla* (Li *et al.* 2002), *E. camaldulensis* (Varghese et al. 2008; Kien et al. 2009) and *E. tereticornis* (Varghese et al. 2008) and slower than those reported in northern Tasmania where annual diameter increment was a mean of 17 mm at four years (Stackpole et al. 2010). Mead (2005) reported that rotation age should be when the peak of mean annual increment occurs. Together with the above variance analysis, the results indicated that rotation length of DH32-29 should be at least six years, agreeing with previous studies by Xu and Dell (2002) which reported that the rotation period of eucalypt should be extended from the current 4-6 to 6-8 years.

Over the period studied, mean values of BD increased from 0.391 g cm^{-3} at 2-year to 0.392 g cm^{-3} at 3-year, 0.422 g cm^{-3} at 4-year, 0.406 g cm^{-3} at 5-year and 0.445 g cm^{-3} at 6 year. The results in our study indicated that even the BD at 6 year fall below the most suitable range of basic density for pulpwood in eucalypts that has been suggested as 0.47 to 0.55 g cm^{-3}(Ikemori et. al. 1986; Dean 1995; Kien et al. 2008). It is interesting to find that the BD and WW at 5-year were all slower than that at 4 and 6-year, probably due to the competitive relationship between growth traits and wood properties at 5-year and so tending should be carried out at 5 year after plantation.

Table2. *Mean values and ranges for the studied traits at five years*

Age	Traits	Mean	Minimum	Maximum	Std. Dev.	s.e.	CV%
2-year	V (m^3)	0.034	0.011	0.065	0.013	0.002	38.57
	BD (g cm^{-3})	0.391	0.338	0.443	0.022	0.003	5.72
	Cal (KJ/g)	20.80	19.31	22.98	1.12	0.16	5.39

	WW (kg)	10.70	4.97	14.67	3.02	0.43	28.21
	TCal (GJ)	0.22	0.10	0.30	0.06	0.01	26.16
3-year	V (m^3)	0.056	0.011	0.102	0.022	0.003	38.65
	BD (g cm^{-3})	0.392	0.337	0.485	0.026	0.004	6.66
	Cal (KJ/g)	20.53	20.12	20.87	0.25	0.04	1.22
	WW (kg)	24.81	16.81	40.65	6.54	0.93	26.38
	TCal (GJ)	0.51	0.34	0.83	0.13	0.02	26.48
4-year	V (m^3)	0.073	0.017	0.188	0.037	0.005	51.14
	BD (g cm^{-3})	0.422	0.344	0.480	0.025	0.004	5.94
	Cal (KJ/g)	20.23	19.47	21.01	0.51	0.07	2.53
	WW (kg)	39.26	14.90	77.89	19.87	2.81	50.63
	TCal (GJ)	0.79	0.30	1.58	0.40	0.06	50.56
5-year	V (m^3)	0.093	0.026	0.173	0.040	0.006	43.71
	BD (g cm^{-3})	0.406	0.357	0.456	0.022	0.003	5.40
	Cal (KJ/g)	20.60	19.87	21.30	0.46	0.07	2.24
	WW (kg)	34.15	17.03	61.57	11.41	1.61	33.40
	TCal (GJ)	0.70	0.35	1.27	0.23	0.03	33.30
6-year	V (m^3)	0.130	0.042	0.223	0.049	0.007	37.40
	BD (g cm^{-3})	0.445	0.384	0.538	0.030	0.004	6.82
	Cal (KJ/g)	20.17	18.64	23.33	1.03	0.15	5.10
	WW (kg)	54.40	23.05	84.87	18.89	2.67	34.74
	TCal (GJ)	1.10	0.47	1.71	0.39	0.06	35.46

Mean values for Tcal at five ages are presented in Figure 1. The mean values of Tcal increased from 0.22 GJ at 2-year to 0.51 GJ at 3-year, 0.79 GJ at 4-year, 0.70 at 5-year and 1.10 at 6-year. Just like the BD and WW, the mean value of Tcal at 5-year were lower than that at 4 and 6-year because Tcal was the production of WW and Cal. The Tcal at 6-year was bigger than other years also showed the rotation length of DH32-29 should be at least six years.

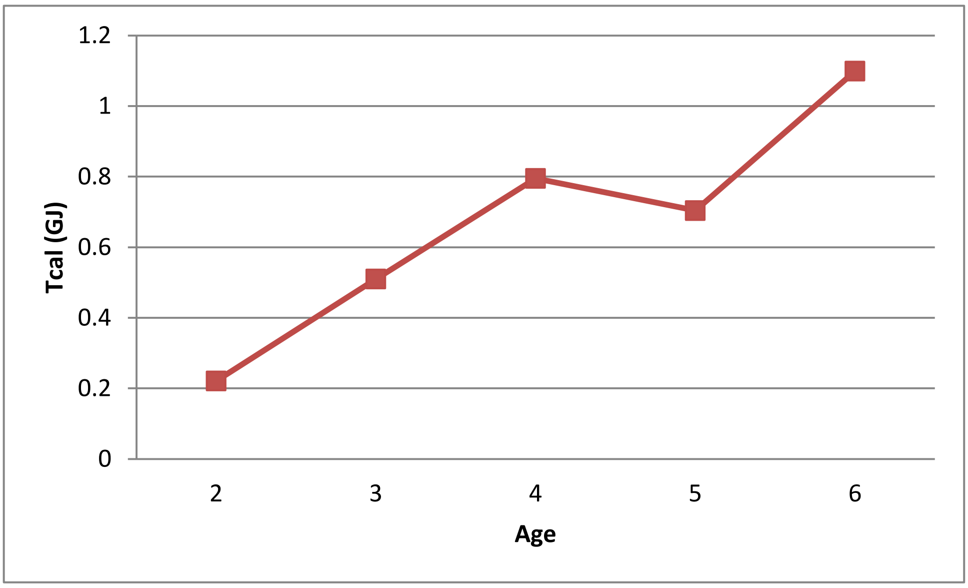

Figure1. *Mean values of Tcal of DH 32-29 at different years*

Phenotypic Correlations between Studied Traits at Different Ages

Phenotypic correlations among traits at individual ages are listed in Table 3.

The correlations between V and BD were positive, ranging from 0.11 to 0.34, at 3-year, 4-year and 6-year whereas negative correlations were found between V and BD, ranging from -0.09 to -0.52, at 2-year and 5-year, which is a very unfavorable result. This is in agreement with former findings, which reported that there was significant change in relationship between growth and wood density with increasing age in *E. globulus* because trees which initially are faster growing tend to produce less dense wood (Stackpole et al. 2010).

WW is the product of V and BD. The correlations between V and WW, however, were generally higher than for those between BD and WW on phenotypic levels, indicating the importance of V in selecting for improved stem volume. It is interestingly to find that the correlations between BD and WW were decreased from 0.59 at 2-year to -0.18 at 6-year, implying the importance of BD in selecting for improved stem volume decreased by age.

Tcal is the product of WW and Cal. There were significant positive correlations between WW and Tcal whereas the correlations between Cal and Tcal were ranged from -0.43 to 0.34, implying the WW could be used to predict Tcal.

Table3. *Phenotypic correlations among traits at individual ages (height = HGT, diameter at breast over bark = DBHOB, individual volume = V, basic density = BD and Pilodyn pin penetration = PPP)*

Age	Traits	V	BD	Cal	WW
2-year	BD	-0.09			
	Cal	-0.53**	-0.38		
	WW	0.99**	0.59**	-0.54**	
	TCal	0.98**	0.58**	-0.43*	0.99**
3-year	BD	0.34			
	Cal	0.27	0.25		
	WW	0.97**	0.38	0.30	
	TCal	0.97**	0.39	0.34	0.99**
4-year	BD	0.14			
	Cal	0.03	0.33		
	WW	0.99**	0.26	0.06	
	TCal	0.99**	0.27	0.11	1.00**
5-year	BD	-0.52**			
	Cal	-0.05	0.57**		
	WW	0.99**	0.23	0.03	
	TCal	0.98**	0.27	0.09	1.00**
6-year	BD	0.11			
	Cal	0.10	-0.22		
	WW	0.99**	-0.18	0.09	
	TCal	0.98**	-0.20	0.24	0.99**

Level of significance is denoted by: * = phenotypic correlations significant at 0.05 level; ** = phenotypic correlations significant at 0.01 level

MAJOR CONCLUSIONS AND IMPLICATIONS

Joint analysis of all the findings of this study, important conclusions and implications were follow. Firstly, rotation length of DH32-29 should be at least six years for pulpwood production and energy use. Secondly, the basic density of DH32-29 at 6-year fall below the most suitable range of basic density for pulpwood in eucalypts. Thirdly, The basic density, the individual tree wood weight and the individual tree calorific value at 5-year were all lower than that at 4 and 6-year, probably due to the competitive relationship between growth traits and wood properties at 5-year and so more tending should be carried out at 5 year after plantation. Finally, the individual tree volume over bark and individual tree wood weight could play important role to predict individual tree wood weight and individual tree calorific value respectively.

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