WOOD BASIC DENSITY OF *EUCALYPTUS GRANDIS* FROM PLANTATIONS IN CENTRAL RIFT VALLEY, KENYA: VARIATION WITH AGE, HEIGHT LEVEL AND BETWEEN SAPWOOD AND HEARTWOOD

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GITHIOMI JK & KARIUKI JG. 2010. Wood basic density of *Eucalyptus grandis* from plantations in Central Rift Valley, Kenya: variation with age, height level and between sapwood and heartwood. Basic wood density was studied in 4–10-year-old *Eucalyptus grandis* to provide information on variation in basic density between and within trees and at various ages. Wood discs were taken from six height levels of each tree for determination of basic wood density. The density was significantly influenced by age and tree height. It increased with age and was lowest at age 4 years (0.414 g cm^{-3}) and highest at age 10 years (0.517 g cm^{-3}). An equation, $y = 0.0017x^2 - 0.007x + 0.4159$ to predict the basic density of *E. grandis* grown in similar conditions and for ages up to 10 years was derived, where y is the basic density and x is the age. There were significant differences ($p < 0.05$) in basic density between heartwood and sapwood. The basic density of ages 4, 5, 6 and 7 years were also closely related while that of ages 8, 9 and 10 were distinctly different from one another. Therefore, the rotation age of *E. grandis* for fuelwood plantations cannot be reduced from 10 years to 8 or 9 years since higher basic density at 10 years gives higher calorific values unless other growth and yield factors are considered.

Keywords*:* Fuelwood, plantation, wood properties

GITHIOMI JK & KARIUKI JG. 2010. Ketumpatan asas kayu *Eucalyptus grandis* dari ladang di Central Rift Valley, Kenya: variasi disebabkan usia, ketinggian dan antara kayu gubal dengan kayu teras. Ketumpatan asas kayu *Eucalyptus grandis* yang berusia antara empat tahun hingga 10 tahun dikaji untuk mendapatkan maklumat tentang variasi ketumpatan asas dalam pokok pelbagai usia dan perbandingan nilainya di antara pokok. Cakera kayu diambil daripada setiap pokok pada enam aras ketinggian untuk menentukan ketumpatan asas kayu. Ketumpatan dipengaruhi dengan signifikan oleh usia dan ketinggian pokok. Ketumpatan meningkat apabila usia meningkat dan nilainya paling rendah pada usia empat tahun (0.414 g cm^{-3}) dan paling tinggi pada usia 10 tahun (0.517 g cm^{-3}). Dengan mengandaikan y = ketumpatan asas dan x = usia, satu persamaan iaitu $y = 0.0017x^2 - 0.007x + 0.4159$ telah digubal untuk meramalkan ketumpatan asas *E. grandis* yang sama usia dan ditanam dalam keadaan yang serupa. Terdapat perbezaan signifikan ($p < 0.05$) dalam ketumpatan asas antara kayu teras dengan kayu gubal. Terdapat hubungan rapat antara ketumpatan asas pokok berusia empat tahun, lima tahun, enam tahun dan tujuh tahun sementara bagi pokok berusia lapan tahun, sembilan tahun dan 10 tahun, ketumpatannya berbeza dengan ketara antara satu sama lain. Justeru, usia kitaran *E. grandis* bagi tujuan ladang kayu api tidak boleh dikurangkan dari 10 tahun ke lapan tahun atau sembilan tahun. Ini kerana ketumpatan asas yang lebih tinggi pada usia 10 tahun menghasilkan nilai kalori yang lebih tinggi kecuali apabila faktor pertumbuhan serta faktor hasil yang lain dipertimbangkan.

INTRODUCTION

Large areas of different *Eucalyptus* species are being planted in many parts of the world due to the rapid growth rate of this species and increasing demand for wood. In Kenya, *Eucalyptus* species are among the most successful exotic hardwoods accounting for about 10% of tree plantation establishment (KFMP 1994). Eucalypts were introduced in Kenya in 1902 to supply fuelwood for the Kenya–Uganda railway locomotives. *Eucalyptus* is the third most commonly grown tree genus in Kenya, after pine and cypress. Most of the area under eucalypts is dominated by three species, namely, *E. grandis*, *E. saligna* and *E. camaldulensis*. Eucalypts are grown in most agro-ecological zones by the Kenya Forest Service, private sector and small-scale farmers for various uses such as firewood, poles, posts, pulp and timber. In Kenya, *Eucalyptus* plantations grown for poles and firewood have a rotation age of up to 10 years and for pulp, posts and timber,

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18 years. The mean annual increment (MAI) of eucalyptus crop in Kenya has been reported to be between 20 and 30 m^3 ha^{-1} $year^{-1}$ (James 1983, Oballa & Giathi 1996).

The density of eucalyptus wood is a complex characteristic since the tissue is made up of different types of cells with varying properties such as cell wall diameter, wall thickness and length and contains variable amounts of non-structural materials such as extractives and tyloses. The density is further reported to vary depending on harvesting age; young eucalyptus plantation trees have lower density wood than that of mature wood (Hillis 1984). Wood density is closely correlated with many wood properties. In the absence of other actual test data, it can be used to give a broad indication of mechanical strength, hardness, shrinkage, heating value of wood and other properties (Keith 1961). In this study, density was used as an indicator for the heating value of *E. grandis* fuelwood plantations.

The main objective of this study was to determine the variation in wood density within and between trees of *E. grandis* at different ages ranging from 4 to 10 years. The specific objectives were to (1) determine the relationship between stand age and wood basic density in *E. grandis*, (2) determine variation in basic density between sapwood and heartwood and at different tree heights, and (3) predict wood basic density at a particular age using data generated from the study.

MATERIALS AND METHODS

A total of 14 trees were sampled for testing, with two trees from each plantation aged 4, 5, 6, 7, 8, 9 and 10 years old. The plantations, designated as K1, T1, K2, T2, C1, S1 and C2 respectively, are located in Kericho District in Central Rift Valley. All the plantations had the same stocking level and were from the first crop of direct planting. The altitude of the region where samples were obtained varied from 1945 to 2075 m asl. Before selection, and to minimise the effects of differences in growth, a general visual examination of trees in each of the age class was conducted to determine the range of their diameters at breast height (dbh). Only trees with straight boles and no visible defects were sampled.

The sampled trees were felled using a chain saw and their total heights and dbh were measured (Table 1). For each of the 14 trees, six short logs measuring 300 mm in length were then removed at the base, breast height, 20, 40, 60 and 80% of the total tree height and labelled. The 84 logs were the transported to the Forest Products Research Centre, Karura for testing.

Table 1 Tree height, age and dbh of the sampled *Eucalyptus grandis* trees

Plantation	Age (years)	Tree height (m)	*Dbh (cm)
K1	4	17.3	12.0
K1	4	17.6	13.4
T1	5	24.2	15.6
T1	5	24.0	16.1
K2	6	30.0	22.4
K2	6	29.5	20.1
T2	7	29.7	19.3
T2	7	26.9	19.1
C1	8	32.0	29.8
C1	8	32.9	26.5
S1	9	33.2	23.0
S1	9	29.0	23.9
C2	10	31.2	28.6
C2	10	29.9	23.9

*Over bark values

Each log was further cross-cut into three discs using a band saw. Disc A, measuring about 30 mm along the grain was cut from the bottom of each log for assessment of sapwood and heartwood area (not reported here). Disc B, 100 mm along the grain, was cut at the centre of the log and used for basic density determination. The remaining portion, disc C was stored for other studies (Figure 1).

A radial strip of wood (width 30 mm) extending across the north–south and east–west axis of the disk was cut from disc 'B' of each sample for determination of basic density for all height levels. These strips were further cut to produce heartwood and sapwood blocks for each axis.

The green weight of each sapwood and heartwood block was measured using an electronic balance to the nearest 0.1 g. To calculate volume, dimensions of each block were measured using a pair of callipers. Samples were then oven dried at 103 °C until constant weight was achieved. The oven-dry weight and green volume of each of the wood blocks were used to calculate basic density:

$$\text{Basic density} = \frac{\text{oven dry weight (g)}}{\text{green volume (cm}^3\text{)}}$$

Data obtained were analysed using analysis of variance procedure in GenStat 6.1 (Payne *et al.* 2002). The initial analysis involved checking the data for normality and satisfying the conditions for validity of ANOVA by use of residual plots. Tests were carried out to determine whether or not the differences in means were significant. If the differences were significant, Tukey's-B test was used to determine which means were different. Further analysis was carried out using various graphs and plots and detailed analysis was carried out for each year separately.

RESULTS AND DISCUSSIONS

Basic densities of *E. grandis* differed significantly ($p < 0.05$) at various ages (Table 2). Significant differences were also apparent between various height levels and also between sapwood and heartwood. Significant interactions between these factors also indicated that there was no uniformity in basic density among height levels in the various ages and also between sapwood and heartwood of different ages and height levels.

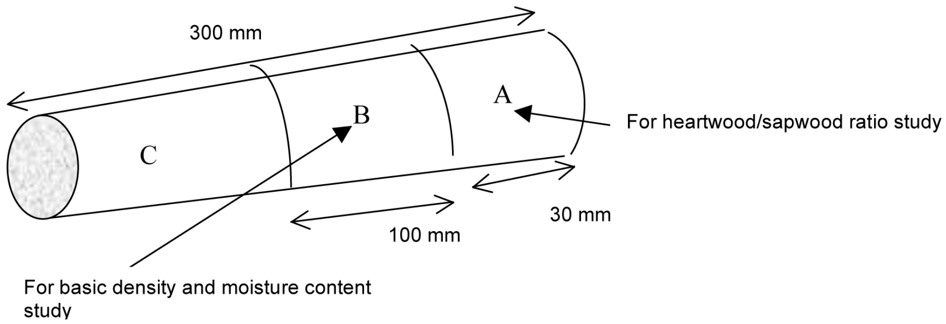

Figure 1 Illustration of the discs cut from the sampled log

Table 2 ANOVA of basic densities for 14 trees, six heights and two positions (sapwood and heartwood) of seven age classes (4–10 years) of *E. grandis*

Source of variation	DF (mv)	MS	VR
Age	6	0.12139	73.36**
Ht level	5	0.05725	34.60**
Position (sapwood, heartwood)	1	0.11519	69.61**
Age × ht level	30	0.00780	4.72**
Age × position	6	0.04273	25.82**
Ht level × position	4(1)	0.00444	2.68*
Age × ht level × position	24(6)	0.00157	0.95ns
Residual	531(54)	0.00165	

* = $p < 0.05$; ** = $p < 0.001$; ns = not significant; mv = missing values taken into account during ANOVA; MS = mean squares; VR = variance ratio, Ht =height

Variation of basic density with age

Basic wood density ranged from 0.414 to 0.517 g cm^{-3} for ages 4 to 10 years (Table 3). These differences were highly significant between all the seven age classes that were assessed. As expected, the younger trees generally had lower basic density, which increased with increasing age. However, further analysis indicated that trees of ages 4, 5, 6 and 7 were not significantly different in basic density whereas trees of ages 8, 9 and 10 were distinctly different from one another and from ages 4, 5, and 6 (see mean separation, Table 3). In a similar study in Central Highlands of Ethiopia, a weak but positive correlation was established between tree age and basic density of *E. grandis* (Mulugeta & Tsegaye 2004).

Table 3 Mean separation of basic density at various ages in *E. grandis* planted at Kericho, Kenya

Age (years)	Basic wood density (g cm^{-3})
4	0.414 a
5	0.428ab
6	0.431ab
7	0.442b
8	0.472c
9	0.495d
10	0.517e

Means with the same letter are not significantly different (Tukey's B test, $p < 0.05$)

Variation in basic density with height

Significant differences ($p < 0.05$) in basic density were detected among tree height levels with the highest average density of 0.4839 g cm^{-3} at 60% of total tree height and the lowest at breast height with 0.4292 g cm^{-3} (Figure 2). The combined density decreased from tree base to breast height and then increased to a maximum at the 60% height point before decreasing at 80%. A similar trend was observed when basic density was plotted against height for each age class separately, as shown in Figure 3, with the exception of age 4, which showed a slight decline at 60% of tree height and then an increase to 80%, and ages 6 and 8, which showed an upward trend right up to 80% level. A similar general trend was reported for 6- to 7-year-old trees of *E. grandis* and *E. urophyla* hybrid (Quilho *et al.* 2006). The maximum basic density at 60% of the total tree height and minimum at breast height that were observed in this study were also reported for 14-year-old *E. grandis* grown in South Africa (Taylor 1973)

Variation of basic density between sapwood and heartwood

Figure 4 shows significant variation in basic density ($p < 0.05$) between heartwood and sapwood. Basic density of the sapwood ranged from 0.4056 to 0.5432 g cm^{-3}, while that of heartwood ranged from 0.4227 to 0.4941 g cm^{-3}. Sapwood had higher basic density than heartwood in all ages except for ages 4 and 5. However, further analysis showed that these differences were only significant from ages 7 to 10 where the sapwood density was higher than that of the heartwood (Figure 4). At lower ages, there were no differences between the sapwood and heartwood basic densities as the wood was still in transitional stage with minimal chemical transformation. There is only a very small variation in basic density between sapwood and heartwood up to 65% height level (Gominho *et al.* 2001). In the current study, there was no heartwood present at 80% height level in all age classes.

Prediction of basic densities of plantation grown *E. grandis*

A polynomial regression was used to derive a predictive equation, which can be used in predicting the basic density of *E. grandis* grown in similar conditions and age range (Figure 5). The relationship had coefficient of determination of 0.99 and the following equation was derived:

$$y = 0.0017x^2 - 0.007x + 0.4159$$

where y is the basic density and x is the age of trees. A similar predictive model for basic density by Igartna *et al.* (2003) on *E. globulus* has a coefficient of determination of 0.91.

CONCLUSIONS

Basic density of *E. grandis* varied significantly with age of the tree with the lowest density at age

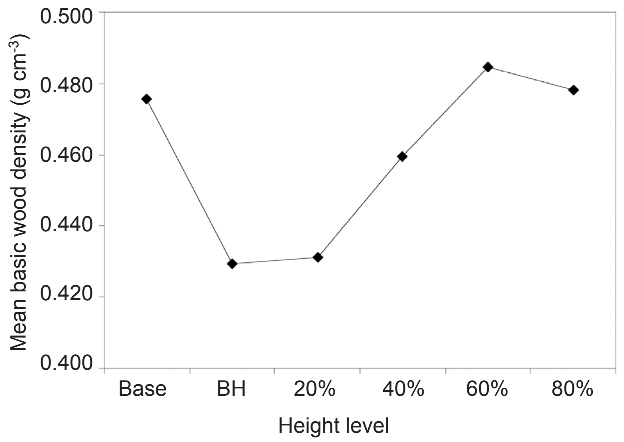

Figure 2 Variation in mean basic wood density of *E. grandis* at different height levels for all ages combined; BH = breast height

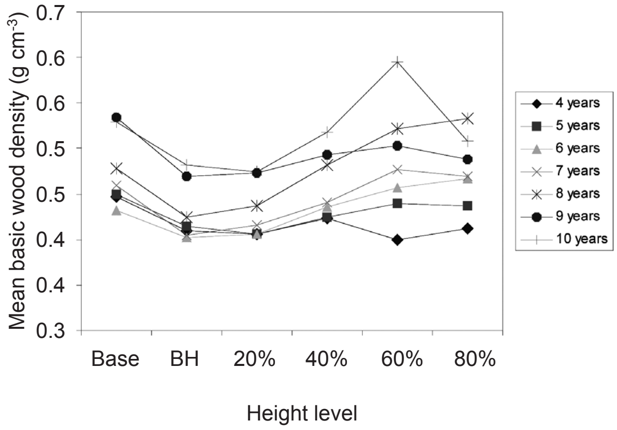

Figure 3 Variation of basic wood density at various height levels and different ages in *Eucalyptus grandis*; BH = breast height

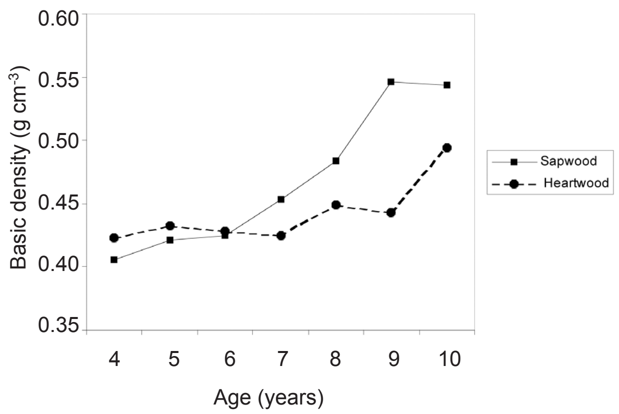

Figure 4 Variation in basic wood density between heartwood and sapwood at different ages of *E. grandis*

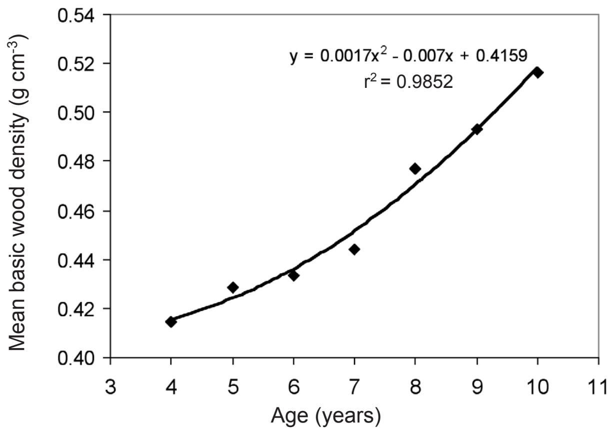

Figure 5 Regression equation and curve fitting for predicting the basic density at a particular age class of *E. grandis*

4 (0.414 g cm^{-3}) while the highest was at age 10 (0.517 g cm^{-3}). The basic density at ages 4, 5, 6 and 7 were similar while that of ages 8, 9 and 10 were distinctly different from one another. Therefore, the rotation age of *E. grandis* for fuelwood plantations cannot be reduced from 10 years to 8 or 9 years without compromising their heating value, which is related to the basic density of the wood since higher basic density gives higher calorific values.

The basic wood density varied significantly with tree height, with the highest average density at 60% of total tree height and the lowest at breast height. There was a general tendency for basic density to decrease from base to breast height and then increase to a maximum at 60% height point before decreasing at 80% with the exception of ages 6 and 8. The basic densities for sapwood and heartwood varied significantly. In general, sapwood had higher basic density than heartwood in all ages except for ages 4 and 5.

The regression equation, $y = 0.0017x^2 - 0.007x + 0.4159$ where y is the basic density and x is the age, can be used to estimate the density of *E. grandis* grown under similar condition as the sampled trees.

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