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Variation of Specific Gravity in *Acacia mangium*

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ABSTRACT

The study involved 13-year old provenance trials of *Acacia mangium* which were established at five sites in Sabal, Jakar, Oya, Labang and Sawai in Sarawak, Malaysia. Five provenances were planted in the trial. Three provenances were from Australia and two from Indonesia. The main objectives of this study are to establish a radial trend of specific gravity from pith to bark and to establish the extent of variation contributed by planting site, provenance, tree, orientation and radial position on specific gravity. Radial variation in specific gravity increased from pith to bark. It ranged from 0.20 at pith to 0.80 at bark with a mean and coefficient of variation of 0.56 and 17.05%, respectively. Site, provenance and radial contributed significantly towards specific gravity in *Acacia mangium*. Interaction between provenance and site was highly significant which involved a change in provenance ranking across the sites. Radial was the largest contributor to the total variance component in specific gravity.

Keywords: *Acacia mangium*, provenance trial, genotype and environment interaction, specific gravity, radial variation, pith to bark

ABSTRAK

Percubaan provenan *Acacia mangium* berumur 13 tahun yang telah ditubuhkan di lima kawasan iaitu di Sabal, Jakar, Oya, Labang dan Sawai di negeri Sarawak, Malaysia telah dicerap bagi kajian ini. Lima provenan telah ditanam dalam percubaan ini. Tiga provenan adalah dari Australia dan dua dari Indonesia. Tujuan utama kajian ini adalah untuk menilai corak perubahan graviti spesifik dari tengah ke bahagian kulit kayu. Juga untuk menilai tahap variasi yang disumbangkan oleh persekitaran, provenan, pokok, orientasi dan posisi jejari pada graviti spesifik. Variasi sepanjang jejari bagi graviti spesifik dalam kajian ini menaik dari bahagian tengah ke kulit kayu dengan julat antara 0.20 di bahagian tengah dan 0.80 dibahagian kulit kayu. Purata dan pekali variasi adalah 0.56 dan 17.05%. Persekitaran, provenan dan posisi jejari menyumbang dengan bererti terhadap graviti spesifik dalam *Acacia mangium*. Salingtindak antara persekitaran, dan provenan adalah sangat bererti dan melibatkan perubahan tahap di setiap persekitaran. Posisi jejari merupakan penyumbang terbesar pada komponen varian dalam graviti spesifik.

Kata kunci: *Acacia mangium*, percubaan provenan, saling tindak genotip dan persekitaran, graviti spesifik, variasi jejari, bahagian tengah ke bahagian kulit kayu

INTRODUCTION

Acacia mangium is a fast growing pioneer species. It has been planted extensively in Malaysia due to its fast growth, good form, suitability for general utility timber as well as for pulp and paper. The species is also capable of producing viable seeds every year. In its early introduction into Malaysia, seeds from various sources were introduced thus creating a variation in growth form and other morphological characters (Lokmal *et al.,* 1993; Lokmal *et al.,* 1995). The variations are attributed to the seed sources and the seeds themselves. Other variations were also present within the trees such as growth characteristics, and physical and mechanical properties of the wood. These changes occur as the tree trunk increases in girth as the trees grow. Most wood properties show variation from the centre of the tree outward, from the base to the top of the tree, within an annual ring and sometimes between opposite radii. Specific gravity also varies within trees, longitudinally and radially (Taylor, 1979; Wilkes, 1988; Bhat *et al.,* 1989; Zhang and Zhong, 1990). Variation in specific gravity is directly related to variation in fibre cell wall percentage, and such variation is dependent mostly on fibre cell wall thickness, lumen diameter and fiber proportions (Aung, 1962; McDonald *et al.*, 1995). The number of fibres has a major effect on wood strength.

Specific gravity is one of the most important wood characteristics which has a direct impact on wood stiffness and strength (Cave, 1969; Harris *et al.,* 1976; Cave and Walker, 1994). It may vary among trees of the same species due to genetic and environmental influences (Wyatt-Smith, 1958; Omolodun *et al.,* 1991; Butterfield *et al.,* 1993). The relationship between specific gravity and site differences in growth rate is complex and is still being disputed (Taylor and Wooten, 1973; Zobel and Van Buijtenen, 1989).

Tropical hardwoods have not been as well studied as the temperate species. However, a number of studies have indicated that specific gravity in tropical hardwoods changes considerably from pith to bark (Whitmore, 1973; Wiemann and Williamson, 1989a). The largest increase in specific gravity occurs in the shade tolerant pioneer species such as *Hampea appendiculata, Heliocarpus apendiculatus* and *Ochroma pyramidale* (Wiemann and Williamson, 1989b). In *Eucalyptus grandis*, density increases rapidly with increasing distance from the pith; especially in the zone of juvenile wood (Bhat *et al.,* 1990). Ismail *et al.* (1995) found an increasing pattern of specific gravity from pith to bark in 26 year-old Kelempayan (*Anthocephalus chinensis*). Investigation revealed that the pattern was associated with an increase in cell wall thickness and the transition from juvenile wood to mature wood. Hernandez and Restrepo (1995) found that some populations of *Alnus acuminata* from Southern and Central America showed no pith to bark variation in specific gravity, while others displayed an increase from pith to bark.

Variation in specific gravity in *Acacia mangium* due to sites, genotypes and their interaction has not been reported. Miranda *et al.* (2001) concluded that effects of provenances on wood density were highly significant. Little attention is given to the issue of radial variation in wood properties of tropical species.

The objectives in this study are to establish a radial trend of specific gravity from pith to bark, to establish extent of variation contributed by planting site, provenance, tree, orientation and radial position on specific gravity, to establish within tree variation in wood properties of *Acacia mangium,* and to examine genotype x environment interactions of five provenances; grown at five sites, in the state of Sarawak, Malaysia.

MATERIALS AND METHODS

Provenance Trials

Thirteen year old provenance trials of *Acacia mangium* which were established at five sites *i.e.* Sabal, Jakar, Oya, Labang and Sawai in the state of Sarawak, Malaysia, were sampled. At each site, five provenances were planted in five blocks by using randomized complete block design (RCBD) with factorial arrangement of five sites, five blocks and five provenances. Each provenance consisted of 49 trees with 3 m x 3 m spacing or 1111 trees per hectare (Tables 1 and 2).

Wood Sampling

From each plot (49 trees), 3 trees were selected and cut for the purpose of this study. A total of 375 trees (3 trees x 5 sites x 5 blocks x 5 provenances) were cut based on their closest diameter with the respective plot mean. However, due to heart-rot, only 362 trees were sent to the sawmill for subsequent processes. A diametrical strip 2.0 cm thick and 2.0 cm wide was cut from a disc, which was cut from every tree at the height of 1.3 m point, along the sample logs in an east-west direction.

Four radial position sub-samples were cut, making a total of 2896 (362 trees x 2 orientations x 4 radial positions). Four sub-samples of equal length were cut from pith to bark from each of the east and west radii of the strip. Tree sample numbers were written on these sub-samples.

Table 1. Provenance details.

Provenance	Seedlot Number	Latitude (South)	Longitude (East)	Altitude (m)
Rex Range NR , Mosman, Queensland	12992	16° 30	145° 32	306
Broken Pole Creek, Queensland.	13241	18° 21	146° 03	50
Cassowary Range, Queensland.	13534	6° 32	145° 25	60
Piru Ceram , Indonesia	13621	3° 04	128° 12	150
Sidei, Indonesia	13622	0° 46	133° 34	30

Table 2. Characteristics of the test sites in Sarawak.

Site	Latitude (N)	Longitude (East)	Altitude (m)	Mean annual precipitation (mm)	Mean annual rain days (day)	Soil types
Sabal	1° 03	109° 55	35	4014.3	243.0	Podzol (soft humus pan)
Jakar	2° 13	111° 30	30	3246.2	235.6	Thionic (Rajang) or Gley (Pendam)
Oya	2° 17	112° 00	30	3246.2	235.6	Grey White Podzolic imperfectly drained
Labang	3° 22	113° 37	35	3641.7	222.6	Red-Yellow Podzolic (clay loam to clay)
Sawai	3° 45	113° 49	170	2641.6	185.6	Red-Yellow Podzolic (clay or clay loam)

Determination of Specific Gravity

The sub-samples were oven dried at 100 °C until constant weight was achieved. The weight of each sub-sample was recorded. All sub-samples were removed from the oven and dipped in liquid wax. This was done to avoid water and moisture absorption by the sub-samples. Excessive wax was scraped from each sample using a razor blade. Specific gravity was measured by water displacement as described by ASTM (1997). A 30 cm^3 beaker of water was tarred on an electronic balance. Each of the waxed oven-dried sub-samples was submerged in the water inside the beaker with a dissecting needle, and the weight of water displaced from the beaker was recorded.

Specific gravity (SG) of the sample was calculated as;

SG = Oven-dry weight/weight of displaced water by oven-dried volume.

Data Analysis

ANOVA of specific gravity

Analysis of variance of specific gravity was performed using individual tree data with the following model:

$$Y_{ijklm} = \mu + \alpha_i + \delta_j + \upsilon_{ij} + \Omega_k + \theta_l + \Gamma_m + \eta_{kl} + \gamma_{km} + \rho_{lm} + \lambda_{klm} + \varepsilon_{ijklm}$$

Where;

Y_{ijklm} is the observation of the specific gravity of *m*th radial position in the *l*th orientation at the *k*th tree in *j*th provenance in *i*th site.
μ is the overall mean.
α_i is the effect of the *i*th site.
δ_j is the effect of the *j*th provenance.
υ_{ij} is the effect of the interaction between *i*th site and *j*th provenance.
Ω_k is the effect of the *k*th tree.
θ_l is the effect of the *l*th orientation.
Γ_m is the effect of the *m*th radial position.
η_{kl} is the interaction between the *k*th tree and the *l*th orientation.
γ_{km} is the interaction between the *k*th tree and the *m*th radial position.
ρ_{lm} is the interaction between the *l*th orientation and the *m*th radial position.
λ_{klm} is the interaction between the *k*th tree and *l*th orientation and the *m*th radial position.
ε_{ijklm} is the random error associated with the *m*th radial position in the *l*th orientation at the *k*th tree in *j*th provenance in *i*th site.

RESULTS AND DISCUSSION

Radial variation in specific gravity increased from pith to bark (Figure 1). Individual sub-sample ranged from 0.20 at pith to 0.80 at bark, with an overall mean and coefficient of variation of 0.56 and 17.05%, respectively. The specific gravity in *Acacia* increased radially from pith to bark (Figure 1 and Table 3). Increase in specific gravity from the innermost sample (SS1) to the outer most samples (SS4) was about 35% (Table 3). The same pattern was also shared by all provenances though the rates of change between provenances were different (Table 3). It was also found that specific gravity is dependent on distance from pith to bark. Specific gravity of the sample near the pith displays the highest variation as shown by its coefficient of variation of 14.9%. Specific gravity of the sample near the bark is the lowest in coefficient of variation which is 11.25%.

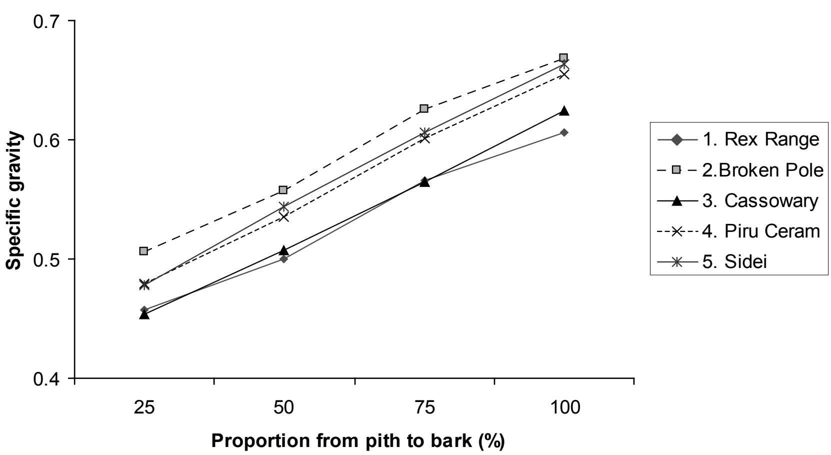

Fig. 1. Variation in specific gravity from pith to bark of five provenances of *Acacia mangium*.

Table 3. Variation of specific gravity from pith to bark in five provenances of *Acacia mangium*.

Provenance	SS1	SS2	SS3	SS4	Percentage increase (%)
Rex Range	0.4568	0.4998	0.5654	0.6063	32.70
Broken Pole	0.5058	0.5574	0.6257	0.6687	32.21
Cassowary	0.4537	0.5072	0.5644	0.6248	37.71
Piru Ceram	0.4789	0.5355	0.6017	0.6553	36.83
Sidei	0.4776	0.5443	0.6061	0.6629	38.80

Notes: SS1 sample nearest to pith; SS4 sample closest to bark.

Differences in specific gravity between trees and orientations were not significant (Table 4). Effects of radial on specific gravity was highly significant and contributed to 51.0% of the total variances component and was the largest contributor among all effects under study (Table 4). All first and second degree interactions were not significant (Table 4).

Variation in specific gravity among provenance was also significant (Table 4). The same observations were made on other characteristics of *Acacia mangium*, such as modulus of elasticity (MOE) and modulus of rupture (MOR), diameter growth, and microfibril angle. However, no significant different was detected on height growth. Provenance Broken Pole displayed the highest specific gravity among provenances while provenance Rex Range displayed the lowest specific gravity (Table 5). The two provenances from Indonesia *i.e* Piru Ceram and Sidei were at the middle range while provenances from Australia showed the highest and the lowest value. Provenances contributed about 5% of the total variance in specific gravity (Table 4). The effect of site on specific gravity is not significant.

There were no apparent environmental factors that would account for the differences among trees or provenances; a large part of observed variation was probably attributed to the inherent potential of the individual tree or provenance to produce higher or lower specific gravity. Provenance Broken Pole from Australia came out as the highest specific gravity followed by Sidei, Piru Ceram, Cassowary and Rex Range (Table 5). Provenances from Australia covered a wide range of variation compared to provenances from Indonesia.

Table 4. Analysis of variance, variance component and its respective percentage for specific gravity

Source of variation	Df	Mean square	Variance Component	Percentage
Site (S)	4	0.03831 *	0.000020	0.19
Block (Site)	20	0.01128 *	0.000050	0.47
Provenance (P)	4	0.33965 **	0.000511	4.82
S x P	16	0.04516 **	0.000345	3.25
Tree (T)	2	0.00886 ns	0.000004	0.04
Orientation (OR)	1	0.00423 ns	0.000001	0.01
Radial position (SS)	3	3.93194 ***	0.005438	51.26
T x OR	2	0.01206 ns	0.000001	0.01
T x SS	6	0.00075 ns	0.000000	0.00
OR x SS	3	0.00224 ns	0.000000	0.00
error	2834	0.00425	0.004238	39.95
Total	2895	-	-	-

Notes: *, **, *** denote significant at P > 0.05, P > 0.01 and P > 0.001, ns denote not significant at P < 0.05.

An increase in specific gravity from pith to bark in *Acacia mangium* is consistent with work by Ani and Lim (1992), however the values were lower probably due to the small number of trees sampled compared to 362 trees in the present study. It was also probably due to many other variations such as different age, number of planting sites, and provenances. The need to have a larger sample size was stressed by Wiemann and Williamson (2002).

Tropical colonizers have long been recognized to produce wood of low specific gravity (Whitmore, 1984). With gain in height, an increase in specific gravity may be necessary to maintain structural stability. In some instances, the change in specific gravity from pith to bark is extremely high. Increase in specific gravity was associated with an increase in fibre length, diameter and wall thickness. In this study, the effect of the diameter growth rate on specific gravity could not be deduced due to the limitation of data available.

Efforts to relate growth rate, specific gravity and fiber length made by a number of researchers were not successful. Evans *et al.* (2000) concluded that the relationship between growth rate and specific gravity in hardwood has been contradictory.

Table 5. Mean of specific gravity for all provenances across all planting sites.

Site	Provenances					
	Rex Range	Broken Pole	Cassowary	Piru Ceram	Sidei	Overall
Sabal	0.51	0.59	0.53	0.56	0.59	0.562[b]
Jakar	0.52	0.58	0.52	0.58	0.56	0.559[b]
Oya	0.57	0.61	0.55	0.55	0.55	0.57[a]
Labang	0.51	0.57	0.54	0.59	0.58	0.562[b]
Sawai	0.52	0.57	0.53	0.53	0.55	0.548[c]
Overall	0.532[c]	0.589[a]	0.538[c]	0.569[b]	0.573[b]	

Note: Different letter is significant at P > 0.05 using Student-Newman-Keuls Test.

Some fast growing trees form higher sapwood than heartwood (Wilkes, 1988; Bosman *et al.,* 1994). The same pattern was reported by Wahyudi *et al.* (1998) for *Acacia mangium*. It is likely that this result is due to fast-growing trees requiring structure stability as they strive to get their canopy above ground to avoid competition in the early years of growth, hence channeling most of the resources to height development, and compromising its strength at the early stage of the growth. This caused the juvenile wood and the earlier part of the heartwood to be low in density and strength. Work to further reduce the proportion of heartwood by selection or breeding to further improve wood quality, has been done by Gapare *et al.* (2006).

Butterfield *et al.* (1993) detected differences in fiber length among geographic areas, but could not quantify the amount of variation, which is due to genetic and environmental factors.

All trees from the provenances planted at five different sites exhibited radial increase in specific gravity from pith to the bark. The increase of specific gravity is known to increase the strength. The results suggest that *Acacia mangium* which is known as a fast growing pioneer tree in the tropics is capable of increasing specific gravity and decreasing microfibril angle as they grow. Within tree variation, radial position is the main factor affecting variation in specific gravity of *Acacia mangium* which accounted for 50% of the total variance. Substantial variation exists between provenances and between trees of *Acacia mangium* which could be utilized for selection of the provenances and trees within provenances. Such selection could deliver some gain in specific gravity of *Acacia mangium*. Interaction between provenances and sites needs consideration since it involved actual change in the ranking of provenances across the sites. Depending on available resources, two options are available, that is, either make use of best provenances at a particular site or breed for stable provenances which could do best or above average across a range of planting sites. The former requires the establishment of many breeding programs for each planting region and would produce provenances best only to a specific site. The later requires the establishment of only one breeding program which produces provenances suitable to a range of regions.

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REFERENCES

Ani Sulaiman & Lim Seng Choon. 1992. Variation in specific gravity of five year old *Acacia mangium* from the Batu Arang Plantation, Selangor, Malaysia. *Journal of Tropical Forest Science* **6(2):** 203-206.

ASTM. 1997. Standard test methods for specific gravity of wood and wood-base materials. ASTM D2395-93. In *Annual Book of ASTM Standards 4.10.* American Society for Testing and Materials. Philadelphia, PA, USA. p. 348–355.

Aung, M. 1962. Density variation outward from the pith of some species of *Shorea* and its anatomical basis. *Commonwealth Forestry Research* **41**: 48-56.

Bhat K. M., Bhat, K. V. & Dhamodaran, T. K. 1989. Radial patterns of density variation in eleven tropical Indian hardwoods. *Holzforchung* **43**: 45-48.

Bhat, K. M., Bhat, K. V. & Dhamodaran, T. K. 1990. Wood density and fibre length of *Eucalyptus grandis* grown in Kerala, India. *Wood and Fibre Sciences* **22(1):** 54–61.

Bosman, M. T. M., De Kort, I., Van Genderen, M. K. & Baas, P. 1994. Radial variation in wood properties of naturally and plantation grown light red meranti (*Shorea*, Dipterocarpaceae). *IAWA Journal* **15**: 111-120.

Butterfield, R. P., Crook, R. P., Adam, R. & Morris, R. 1993. Radial variation in wood specific gravity, fibre length and vessel area for two central American hardwood: *Hyeronima alchorneoides* and *Vochysia guatemalensis*. *Natural and Plantation Grown Trees*. *IAWA Journal* **14(2):** 153-161.

Cave, I. D. & Walker, J. C. F. 1994. Stiffness of wood in fast-grown plantation softwoods: The influence of microfibril angle. *Forest Products Journal* **44(5):** 43-58.

Cave, I. D. 1969. The longitudinal modulus of *Pinus radiata*. *Wood Science and Technology* **3:** 40-48.

Evans, R., Llic, J. & Matheson, A. C. 2000. Rapid estimation of solid wood stiffness using SilviScan. In: *Proceedings of the 26th Forest Products Research Conference.* 19-21 June 2000. CSIRO Forestry and Forest Products, Clayton, Australia. p. 49-50.

Gapare, W. J., Wu, H. X. & Abarquez, A. 2006. Genetic control in the time of transition from juvenile wood to mature wood in *Pinus radiata* D. Don. *Annual Forest Science* **63:** 871-878.

Harris, J. M., James R. N. & Collins, M. J. 1976. Case for improving wood desity in radiata pine. *New Zealand Journal of Forestry Science* **5(3):** 347-354.

Hernandez R. E. & Restrepo, G. 1995. Natural variation in wood properties of *Alnus acuminata* H. B. K. grown in Colombia. *Wood Fiber Science* **27(1):** 41–48.

Ismail, J., Jusoh, M. Z. & Sahri, M. H. 1995. Anatomical variation in planted Kelempayan (*Neolamarckia cadamba*, Rubiaceae). *IAWA Journ*al **16:** 277–287.

Lokmal, N., Darus, A. & Ernest, C. O. K. 1993. Genotype and environment interaction in *Acacia mangium*. In: *Proceeding of the International Symposium on genotype and environment interaction on perennial species.* V. Rao, I. E. Henson & N. Rajanaidu (eds.). 12-13 September 1991. Hilton Hotel, Kuala Lumpur, Malaysia.

Lokmal, N., Ab. Rasip, A. G., Ernest, C. O. K. & Norwati, M. 1995. Genotype and environment interaction and its stability in *Acacia mangium*. *Journal of Tropical Forest Science* **8(2):** 247-254.

McDonald, S. S., Williamson, G. B. & Wiemann, M. C. 1995. Wood specific gravity and anatomy in *Heliocarpus appediculatus* (Tiliaceae). *American Journal of Botany* **82(7):** 855-861.

Miranda, I., Almeida, M. H. & Periera, H. 2001. Provenances and site variation of wood density in *Eucalyptus globulus* Labill. at harvest age and its relation to a non-destructive early assessment. *Forest Ecology and Management* **149**: 235-240.

Omolodun, O. O., Cutter, B. E., Krause, G. F. & Mcginnes Jr, E. A. 1991. Wood gravity of *Hildergadia Barteri* (mast). Kossern, an African tropical pioneer species. *Wood and Fiber Science* **23(3):** 419-435.

Taylor, F. W. & Wooten, T. E. 1973. Wood properties variation of Mississippi delta hardwood. *Wood and Fiber Sciences* **5(1):** 2-13.

Taylor, F. W. 1979. Property variation within stems of selected hardwoods growing in the Mid. South. *Wood Sciences* **11(3)**: 193-199.

Wahyudi, I., Okuyama, T., Hadi, S., Yamamoto, H., Yoshida, M. & Watanabe, H. 1998. Growth stress and strain of *Acacia mangium*. *Proceeding of 1st International Conference on Acacia Species-Wood Properties and Utilization.* 16-18 March 1998. Penang, Malaysia.

Whitmore, J. L. 1973. Wood density variation in Costa Rican balsa. *Wood Science* **5**: 223-229.

Whitmore, T. C. 1984. *Tropical Rain Forests of the Far East. 2nd Ed.* Clarendon Press, Oxford, United Kingdom.

Wiemann, M. C. & Williamson, G. B. 1989a. Wood specific gravity gradients in tropical dry and montane rainforest trees. *American Journal of Botany* **76(6):** 924-928.

Wiemann, M. C. & Williamson, G. B. 1989b. Radial gradients in the specific gravity of wood in some tropical and temperate trees. *Forest Sciences* **35:** 197-210.

Wiemann, M. C. & Williamson, G. B. 2002. Geographic variation in wood specific gravity: Effects of latitude, temperature and precipitation. *Wood and Fiber* **34(1):** 96-107.

Wilkes, J. 1988. Variation in wood anatomy within species of *Eucalyptus*. *IAWA Bulletin* **9**: 13-23.

Wyatt-Smith, J. 1958. The habitat of *Shorea* species and its possible association with the grade of timber produced. *Malayan Forester* **21**: 83-84.

Zhang, S. Y. & Zhong, Y. 1990. Effect of growth rate on specific gravity of east-Liaoning oak (*Quercus liaotungensis*) wood. *Canadian Journal Forest Research* **21:** 255-260.

Zobel, B. J. & Van Buijtenen, J. P. 1989. *Wood variation: Its Causes and Control*. Springer Verlag, Berlin.