Provenance variation in growth and wood properties of A. mangium and A. auriculiformis in Central Java, Indonesia : selecting potential hybrid parents for good performance

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https://doi.org/10.15017/17049

出版情報：九州大学農学部演習林報告. 90, pp.25-37, 2009-03. 九州大学農学部附属演習林

九大演報 (Bull. Kyushu Univ. For.), 90：25-37, 2009

Original Ariticle

Provenance variation in growth and wood properties of *A.mangium* and *A.auriculiformis* in Central Java, Indonesia*: selecting potential hybrid parents for good performance

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Abstract

Wood variations among regional and local provenances of 11-year old *Acacia mangium* and *Acacia auriculiformis* in Central Java, Indonesia were investigated to obtain the basis data for selecting for superior trees. The regional provenances of Am and Aa were from Papua New Guinea (PNG) and Queensland-Australia (QLD), respectively. Wood cores were extracted at the breast height of each candidate plus trees, and used for measuring the wood properties.

First, a quick and effective method for evaluation of fiber length in an individual tree was investigated. The means at two different positions (F_t) were statistically related to the area weighted fiber length. F_t could be used as the value for the individual tree. Second, provenance variation in wood properties was evaluated by analysis of variance. Among Am provenances, both fiber length and lignin content differed significantly between PNG and QLD at the 1% level. Fiber length of PNG (1.09mm) was longer than that of QLD (1.06 mm), and lignin contents of PNG (29.9%) was lower than that of QLD (30.6%). All provenances were classified into three groups (good, medium, and poor performance) according to the mean values for fiber length, air-dried density, and lignin content. Aa provenances could not be classified into the good group. These results suggested some Am provenances might provide superior trees with good performance.

Key words：Provenance variation, Wood property, Fiber length, Lignin content, Density, *Acacia mangium, Acacia auriculiformis*

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* 長谷川益己・脇元理恵・吉田絵美・清水邦義・近藤隆一郎・アントニウス ウィディアットモコ・アリフ ニルサトマント・白石進：インドネシア産アカシアマンギウムとアウリカリフォーミスの成長と木材性質の産地間変動

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1. Introduction

Indonesian forests total 88 million ha and cover nearly 50% of total land area; this forest area is the 8th largest in the world (FAO, 2006). But this forest has been reduced by 2 million ha/yr from 1990 to 2005 due to deforestation. Forest plantations are expected to be alternative resources for forest industries. Indonesian plantation areas have increased by about 1 million ha from 1995 to 2005 (FAO, 2006). Some exotic fast-growing species, that is, *Acacia* spp. and *Eucalyptus* spp. have been rapidly planted. *Acacia* is a large genus with over 1300 species, which is widely distributed in the tropics and subtropics (Lemmens et al., 1995). The main plantations of *Acacia mangium* and *Acacia auriculiformis* have been established in Indonesia, Malaysia, Vietnam, Papua New Guinea, India, and other countries for pulp and timber production (Turnbull et al., 1998; Yelu, 1998). In Indonesia, *A. mangium* is the main species, planted in more than 80% of the plantations (Rimbawanto, 2002).

There have been enthusiastic efforts to research an acacia hybrid since the discovery of the natural hybrid *A. mangium* × *A. auriculiformis* in Sabah, Malaysia in the 1970s (Nguyen et al., 2008; Yamamoto et al., 2003; Kha, 2000; Royampaeng et al., 1998). The hybrid has superior characteristics compared with its parents. In particular, hybrids between *A. mangium* and *A. auriculiformis* appear to grow better than their parents. It is necessary to select parents with good performance for growth and wood properties.

In this study, the assessment of wood properties of *A. mangium* and *A. auriculiformis* was carried out to obtain the basis data for selecting a superior individual tree. First, we investigated a quick and effective method to estimate the fiber length of individual trees. Second, the effect of provenance variations on wood properties were estimated by using the prepared method.

2. Materials

2.1 Trial site

The site was located in the Wonogiri trial area at the Indonesia Forest Biotechnology and Tree Improvement Center in Indonesia (Fig. 1). The location of the trial site (7°32' S - 8°15' S, 110°4' E - 111°18' E) is in central Java. This site was established for a seedling orchard of *A.mangium* (Am) and *A.auriculiformis* (Aa) in 1995 (3.53 ha). They were planted in a randomized complete block design with 7 replications of 4 tree, 4 × 2 plots. Provenances of Am and Aa were used from 68 families from Papua New Guinea (PNG) and Queensland-Australia (QLD), respectively. In November 2006, 11-year old Am and Aa were selected from the candidate plus trees by their stem straightness and form and were used as sample trees for this study. Data on the diameter at breast height (Dbh) and the height for all local provenances are shown in Table 1 and 2.

Fig.1 Trial site of *A. mangium* at Wonogiri, Central Java.

Table 1 Growth of the selected provenance for *A. mangium*.

Provenance	Region	N*	Dbh [cm]	Dbh Rank	Height [m]	Height Rank
Cassowary Ck-Iron Range	QLD	21	31.9	9	27.5	7
Claudie R & Iron Range		7	31.0	13	28.4	2
Claudie River		35	32.0	7	26.6	13
Claudie River (Ex Aceb)		17	30.8	14	26.8	11
Nne Coen		7	31.6	10	27.4	8
Pacoe Rer Area Sl 35815		6	31.3	11	26.9	10
Pascoe River		15	32.6	3	28.4	3
Arufi Vilage WP	PNG	6	32.7	2	26.3	15
Bimadebum WP		16	32.0	8	27.8	5
Boite Ne Morehead WP		18	32.4	5	28.3	4
Derideri Ne Morehead		5	30.1	15	29.6	1
Dimisisi WP		7	32.2	6	27.7	6
Gubam Ne Morehead WP		12	32.4	4	26.3	14
Kini WP		20	31.3	12	27.3	9
Wipim District WP		11	33.4	1	26.7	12

* N indicates the number of provenance sample.

Table 2 Growth of the selected provenance for *A. auriculiformis*.

Provenance	Region	N*	Dbh [cm]	Dbh Rank	Height [m]	Height Rank
Boggy Dreek	QLD	3	29.6	1	24.3	8
Kennedy River		9	29.2	2	25.3	1
Lower Poscoe River		18	28.3	7	24.6	5
Morehead River		6	26.8	8	23.5	9
Olive River		18	28.9	5	24.8	4
R Orchard Melville Int		4	26.6	9	25.1	2
Wenlock River		38	29.1	3	24.5	7
Bensbach R	PNG	18	28.5	6	24.5	6
Morehead R Rouku WP		9	28.9	4	25.0	3

* N indicates the number of provenance sample.

2.2 Sampling Method

In January 2007, at the breast height, 2 wood cores per sample tree were extracted by using a wood corer (Trecor HW300, CSIRO, AUS) and motor drill (BT450, Stihl) as shown in Fig. 2 (Downess et al., 1997). The dimensions of the extracted core were 12 mm diameter and 200 mm length. After extraction, the core hole was sealed by spraying with thiophanate-methyl solution for preventing fungal infection. The hole was plugged with expanding polystyrene, and vinyl acetate resin was applied to the surface.

Fig.2 Sampling wood cores with motor drill attached wood corer.

3. Determination of measurement method for fiber length

3.1 Methods

Ten wood cores each of Am and Aa were randomly selected from the all provenances. Six small pieces were cut from the wood cores at a relative distance from the pith (10%, 30%, 50%, 70%, 90%, and 100%). They were macerated by a treatment of a 1:1 mixture solution of glacial acetic acid and 30% hydrogen peroxide for 24h at 80℃. After staining with safranin, 30 fibers at each position were measured with a light microscope (4 objective lens) and an image analysis system (WinROOF, Mitsuya Co. Ltd).

In this study, the area-weighted average was used for estimating the fiber length. The area-weighted average of fiber length (*Fa*) was calculated using the measurement values at the different radial positions (Jorge et al., 2000):

$$F_a = \frac{\sum_{j,k=1}^{6} f_j (S_j - S_k)}{\sum_{j,k=1}^{6} (S_j - S_k)},$$

where f_j is the fiber length measured at each position along the radius (j = 1 to 6, corresponding to relative distance from the pith, that is, 10%, 30%, 50%, 70%, 90%, and 100%). S_k is the area of the circle with radius (k = 1 to 6, corresponding to 0%, 20%, 40%, 60%, 80%, 90%).

3.2 Results and discussion

3.2.1 Radial variations in fiber length

Figure 3 shows the radial variation in fiber length for Am and Aa. The fiber length tended to increase from about 0.8 mm near the pith (relative distance 10%) to almost 1.2 mm at the bark (relative distance 100%) (Table 3). As shown in Table 3, the average fiber lengths were 1.04 mm (Am) and 1.02 mm (Aa), respectively. The fiber length was longer for Am than for Aa. There were no significant differences in fiber length between Am and Aa. Lim SC and Gan KS reported that the fiber length for 14-year-old Am in Malaysia varied from 0.96 to 1.20mm (Lim and Gan, 2000). Wu SC and Wang YC reported that fiber lengths for 8-year-old Am and Aa in Taiwan were 0.80 mm and 0.68 mm, respectively (Wu and Wang, 1988). Yamada et al. reported fiber lengths for 9-year-old Am and 6-year-old Aa in India were 0.78 mm and 0.84 mm (Yamada et al., 1990). Fiber length for 8, 10, 13-year-old Aa in India increased with age (Rao et al., 2007). Wood properties varies depending on the plantation environment (rainfall, latitude, soil, and so on). Both of them cannot be made easy comparisons, the measured values in this study were close to the previous ones.

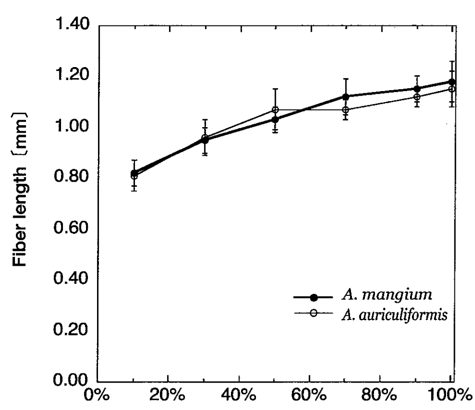

Fig.3 Radial variations in fiber length for *A. mangium* and *A. auriculiformis*.

Table 3 Radial variations of fiber length in *A. mangium* and *A.auriculiformis*.

	Radial relative distance from the pith						Average	
	10%	30%	50%	70%	90%	100%	*F**	*Fa***
A. mangium	0.82	0.95	1.03	1.12	1.15	1.18	1.04	1.12
	(0.05)	(0.05)	(0.05)	(0.07)	(0.05)	(0.08)	(0.04)	(0.05)
A.auriculiformis	0.81	0.96	1.00	1.07	1.12	1.15	1.02	1.08
	(0.06)	(0.07)	(0.08)	(0.04)	(0.04)	(0.07)	(0.04)	(0.04)

Numbers in parenthetic are the standard deviations.
* *F* is the average values at the all relative distance (10%, 30%, 50%, 70%, 90%, 100%).
** *Fa* is the area-weighted average.

3.2.2 Comparison of area weighted fiber length and average fiber length

The mean area weighted fiber length (F_a) is shown in Table 3. For Am and Aa, these were 1.12 mm and 1.08 mm, respectively. F_a was significantly longer than the average fiber length, because the area occupied by fiber length increased with the distance from the pith. The relation between F_a and F_t were investigated to figure out whether the fiber length can be estimate at as possible a little measuring position. F_t is expressed as the average value of fiber length at 2 different positions. These positions comprise the five combinations, which are between 10% and 30%, 30% and 50%, 50% and 70%, 70% and 90%, and 90% and 100%. Table 4 shows the correlations between F_t and F_a for Am and Aa. The averages of 50%–70% and 70%–90% for Am have strong correlations ($P < 0.001$), those of 30%–50%, 50%–70%, and 70%–90% have strong correlations ($P < 0.001$) for Aa. Comparing between the two species, the averages of 50%–70% and 70%–90% relative distance were good combinations. It is sufficient only to measure the 2 different positions for estimation of the fiber length in individual tree. These findings show that there is a quick and effective method for estimating fiber length.

Table 4 The correlations for fiber length between the average of two different positions and area-weighted average.

Species		10%–30%	30%–50%	50%–70%	70%–90%	90%–100%
A.mangium	R*	0.42	0.72	0.87	0.97	0.67
	P**	NS	0.02	0.001	< 0.001	0.03
A.auriculiformis	R*	0.76	0.80	0.84	0.90	0.72
	P**	0.01	0.006	0.002	< 0.001	0.02

* R indicates the correlation coefficient between fiber length for area, weighted and average at two positions,
** P indicates the level of statistical significance of the between fiber length for area weighted and average at two positions.

4. Measurement of wood properties

4.1 Methods

The samples were cut from the wood core at the 30% to 100% relative distances from the pith. Using the water displacement method, the air-dried density was measured. After that, wood blocks for fiber length or lignin content were cut from wood samples as shown in Fig. 4. For cutting the samples for lignin content, we considered the sapwood width of the cores. The volume of sapwood in Acacia was low. It is difficult to measure the lignin content in sapwood. In this report, only lignin content in heartwood was measured. Some individuals had an indistinct border between heartwood and sapwood, and the wood blocks were cut from the typical heartwood location (Fig. 4). Lignin content was determined according to the Klason method. Samples milled to 60–80 mesh were treated with 72% sulfuric acid for 4 h at room temperature. The reaction mixture was diluted with water to a 3% concentration of sulfuric acid, and then heated in an autoclave at 121℃ for 1 h. Insoluble fractions separated by filter were washed by hot water and pure water. Their weights were measured after drying at 105℃ overnight.

As regards the fiber length, measuring positions were decided on the basis of both the results of the 3rd chapter and lignin content analysis as shown in Fig. 4. The 3rd chapter suggested that the 2 combinations (50%–70% and 70%–90%) were good for measuring fiber length. The area 90% from the pith was mostly sapwood. We decided on positions 50% to 70% relative distance from the pith in consideration of the measuring lignin content. The averages both them used as the value of individual tree. The maceration of fiber length and analysis were carried out in the same method as shown in the 3rd chapter.

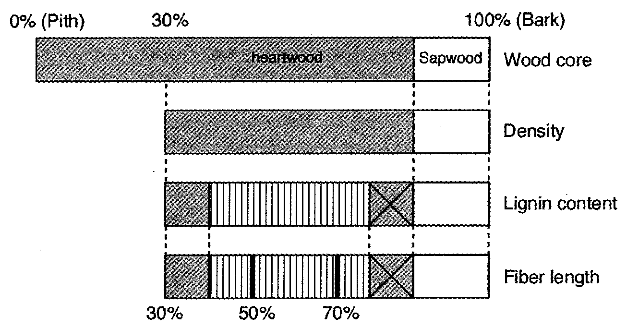

Fig.4 Dimensions of wood sample for measuring wood properties.

4.2 Results and Discussion

4.2.1 Histograms of wood properties

Figure 5 show the distributions of frequency of fiber length, air-dried density, and lignin content for Am and Aa. Data in these figures almost followed a uniform distribution. The coefficient variance ranged from 4.67% to 8.84% for Am and 6.48% to 7.04% for Aa. These results meant each factor is variable at an individual level. The mean of air-dried density for Aa (0.711g/cm^3) is larger than that for Am (0.615g/cm^3). Both are different at the 1% significant level. The air-dried density for Aa was distributed at the higher range. This tendency has been reported (Lemmens, 1995); the high density is a part of better wood character for Aa. The average fiber length is 1.08mm for Aa and 1.07mm for Am. There is no magnitude of correlation among them. Lignin content shows the mean for Am is 30.2% and for Aa is 30.9%. Am was significantly lower than Aa at the 1% level. The lignin content of tropical hardwood is higher than that of hardwood in temperate zones, varying from 17% to 25% (Sjöströn, 1981). For Acacia species, 7-year-old Am in Indonesia contain 27.1% lignin (Pinto et al., 2005). Dihn LK reported 4-year-old Aa and Am in Vietnam as containing 25.7% and 22.6% lignin, respectively (Dihn, 1999). And Xue et al. reported that the lignin content of Aa is higher than that of Am at three ages, 3, 6, and 9 year-old Acacia. (Xue et al., 2001). The lignin content of Aa may be higher than that of Am. The results in this study showed the same tendency, but the magnitude of lignin content for Am and Aa were higher than previously demonstrated.

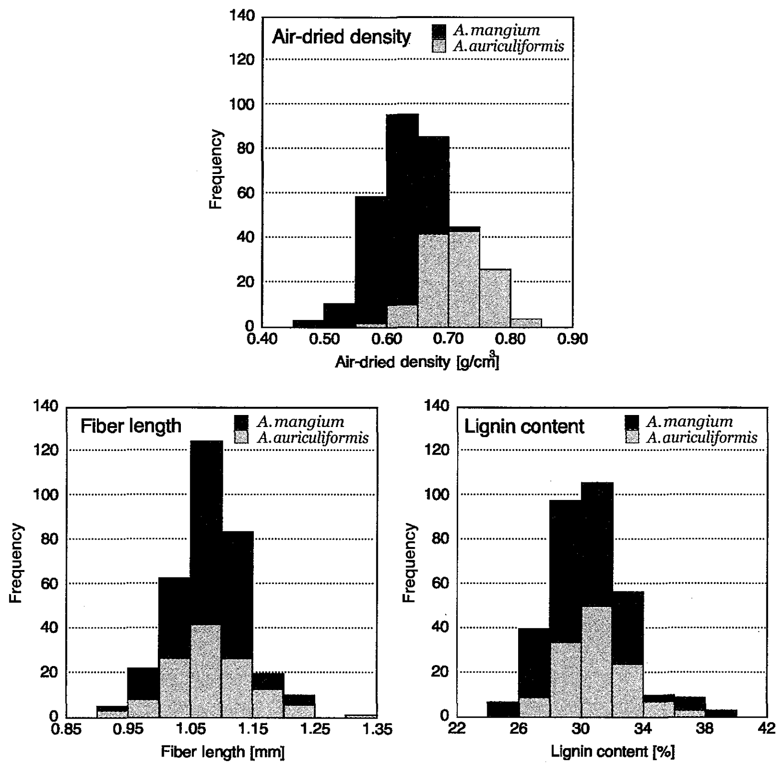

Fig.5 Histograms of wood properties for *A. mangium* and *A. auriculiformis*.

4.2.2 Variations among provenance in wood properties

Comparisons of wood properties between provenances of QLD and PNG, and among local provenances were made by analysis of variance. Among Am provenances, both fiber length and lignin content are significantly different between PNG and QLD at the 1% level as shown in Table 5. Fiber length is longer for the PNG than for the QLD provenance, and lignin content is lower for PNG than for QLD. Better performance of the PNG provenance, relative to the QLD provenance has also been reported in species/provenance trials in Thailand and Haian Island, China (Chittachumnonk and Sirilak, 1991; Yang and Zeng, 1991). On the other hand, in all wood properties there was no significant difference between the Aa provenance of QLD and PNG. Fiber length plays an important role in the tear index of a pulp sheet, and lignin content dose in pulp bleaching. The Am provenance of PNG has better performance than that of QLD.

Table 6 and 7 show the variation in wood properties within Am and Aa provenances. For the fiber length of Am, four local provenances (Arufi Vilage WP, Boite Ne Morehead WP, Dinisisi WP, Pascoe River) were 1.10 mm at a maximum, and the provenance of NNE Coen was 1.03 mm at a minimum. Among Am provenances, the provenances of Boite Ne

Morehead WP and Pasoce River were significantly different in Cassowary CK-Iron Range (1.04mm) at the 1% level. These results indicate the fiber length of two local provenances (Pascoe and Boite) could be categorized as good performance; Cassowary was poor performance. As for the other properties (air-dried density and lignin content) of Am, they were not significantly different among the provenances. The fiber length of Aa varied between the minimum (0.96mm, R Orchard Melville Int) and the maximum (1.11mm, Morehead R Roku WP). Neither provenance had a significant difference. For other properties of Aa, there were no significant differences among the local provenances.

Secondly, an assessment of the local provenance with good performance was tried. The correlations among all wood properties were not significantly different. There were no provenances with long fiber length, high air-dried density, and low lignin content. Next, we tried to pick out the local provenances with above average wood properties. The four Am provenances (Arufi Vilage WP, Bimadebum WP, Gubam Ne Morehead WP, Kini WP from PNG) were above average in fiber length (1.07mm), density (0.615g/cm^3), and lignin content (30.2%) as shown in Table 6 and 7. They are good provenances in this site. On the other hand, the two provenances (Pascoe Rer Area SI 35815 and Cassowary Ck-Iron Range from QLD) were below average in all properties, and were divided into the poor group. The last nine provenances were divided into the medium group. For Aa, there were no provenances above or below average in all properties, but the provenance of Kennedy River was higher in fiber length and air-dried density. As mentioned, the local provenances of Am could be categorized into three groups (good, medium, poor) using the standard of the average values of wood properties.

Table 5 Variations of wood properties among provenances.

Species	Region	Fiber length [mm]		Air-dried density [g/cm^3]		Lignin content [%]	
		Ave.	SD	Ave.	SD	Ave.	SD
A.mangium	QLD	1.06	0.02	0.611	0.017	30.6	1.01
	PNG	1.09	0.02	0.621	0.020	29.9	0.49
	P*	0.001		NS		0.006	
A.auriculiformis	QLD	1.08	0.04	0.713	0.023	30.8	0.74
	PNG	1.09	0.06	0.706	0.019	31.1	0.31
	P*	NS		NS		NS	

* P indicates the level of statistical significance of the difference between QLD and PNG.

Table 6 The variations in wood properties for all provenances of *A. mangium*.

Provenance	Region	Fiber length		Air-dried density		Lignin content	
		[mm]	Rank	[g/cm^3]	Rank	[%]	Rank
Cassowary Ck-Iron Range	QLD	1.04	14	0.596	13	30.6	13
Claudie R & Iron Range		1.06	10	0.615	10	29.5	4
Claudie River		1.07	9	0.616	9	30.4	10
Claudie River (Ex Aceb)		1.05	12	0.617	7	30.4	9
Nne Coen		1.03	15	0.647	1	32.8	15
Pacoe Rer Area Sl 35815		1.05	11	0.610	11	31.0	14
Pascoe River		1.10	2	0.595	14	30.4	11
Average		1.06		0.611		30.6	
Arufi Vilage WP	PNG	1.10	4	0.625	5	29.6	5
Bimadebum WP		1.07	8	0.633	3	29.8	6
Boite Ne Morehead WP		1.10	3	0.616	8	30.5	12
Derideri Ne Morehead		1.05	13	0.643	2	29.3	3
Dimisisi WP		1.10	1	0.577	15	29.2	2
Gubam Ne Morehead WP		1.09	5	0.617	6	30.0	7
Kini WP		1.08	6	0.625	4	30.0	8
Wipim District WP		1.08	7	0.607	12	29.0	1
Average		1.09		0.621		29.9	
Total average		1.07		0.615		30.2	

Table 7 The variations in wood properties for all provenances of *A. auriculiformis*.

Provenance	Region	Fiber length		Air-dried density		Lignin content	
		[mm]	Rank	[g/cm^3]	Rank	[%]	Rank
Boggy Dreek	QLD	1.08	5	0.675	9	30.8	3
Kennedy River		1.08	4	0.720	3	30.9	4
Lower Poscoe River		1.08	7	0.702	6	30.1	2
Morehead River		1.08	6	0.728	1	30.0	1
Olive River		1.09	2	0.700	8	31.3	7
R Orchard Melville Int		1.05	9	0.711	4	31.8	9
Wenlock River		1.07	8	0.723	2	31.2	6
Average		1.08		0.713		30.8	
Bensbach R	PNG	1.09	3	0.707	5	31.1	5
Morehead R Rouku WP		1.11	1	0.701	7	31.3	8
Average		1.09		0.706		31.1	
Total average		1.08		0.711		30.9	

5. Conclusion

Variations among regional and local provenances in wood properties for pulping were estimated for Am and Aa in Central Java, Indonesia. For Am, fiber length and lignin content of PNG was significantly superior to those of QLD. For Aa, there were no significant differences between PNG and QLD. Among Am provenances, four local provenances were above average in mean of fiber length, air-dried density, and lignin content. They were shown to be the best group from all provenances. These findings show it is possible to pick Am provenances with the best properties. Aftertime, it is necessary to estimate other pulp properties except for fiber length, density, and lignin content. In terms of limitations, in this study, we investigated the variations among and within provenances at only one site. A comparison among sites may make it possible to select the provenances with the best performance for the Acacia hybrid in Indonesia.

Acknowledgements

This work was supported in part by a Grant-in-Aid for Scientific Research (A) (No.17208014) from Japan Society for the Promotion of Science.

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(*Recieved 20 October 2008 ; Accepted 17 February 2009*)

インドネシア産アカシアマンギウムとアカシアアウリカリフォーミスの成長と木材性質の産地間変動

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要 旨

パルプ特性に優れたアカシアハイブリッドの開発に向けて基礎資料を得ることを目的として，インドネシアジャワ島中部のオノギリ試験地の実生採取林に植栽された11年生アカシアマンギウムとアカシアアウリカリフォーミスの木材性質の産地間変動を検討した。種子の産地はパプアニューギニア（PNG）とオーストラリア・クィーンズランド（QLD）である。木材性質の計測は，繊維長，気乾密度，リグニン含有率の3つとし，供試木の胸高部より直径12mmの木材コアを取り出して使用した。まず，繊維長の簡便な評価方法を検討した。髄からの相対距離が異なる2箇所の繊維長の平均値は面積加重平均繊維長と1％水準で有意な正相関を示した。これより相対距離の異なる2箇所の平均値は個体の繊維長を評価する際に使用できることが明らかになった。次に，木材性質の産地間変動を検討した。マンギウムは，繊維長とリグニン含有率はPNGとQLDとの間に有意な差が見られた。繊維長は平均値でPNG（1.09mm）がQLD（1.06mm）より長く，リグニン含有率はPNG（29.9%）がQLD（30.6%）より低いことが分かった。繊維長，気乾密度，リグニン含有率の間には相関関係は見られず，繊維長が長く，気乾密度が高く，リグニン含有率が低いという，優良なパルプ特性を兼備した個体を選抜することは出来なかった。一方，繊維長，気乾密度，リグニン含有率の各平均値を基準値として分類すると，全て平均値を上回るもの，下回るもの，混在するものと，3つに分類することが出来た。3つの因子ともに平均値を上回る産地は4箇所あり，これらの産地由来のマンギウムは優良木として期待できる。アウリカリフォーミスに関しては，マンギウムとは異なり，PNGとQLDとの間には有意な差は見られず，平均値を基準として分類することも難しかった。以上のことから，マンギウムに関しては繊維長・気乾密度・リグニン含有率を基準として，優良なパルプ特性を備えた個体を選抜できる可能性が示唆された。

キーワード：産地間変動，繊維長，リグニン含有率，密度，*A.mangium*，*A.auriculiformis*