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Full Length Research Paper

Genotype and environment interactions in Moe and Mor of Acacia Mangium

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This paper presents the effects genotype by environment interaction (GXE) on the wood strength properties of a 13-year-old Acacia mangium established at five sites in the state of Sarawak, Malaysia. The objective of this paper is to examine GXE interactions on the modulus of elasticity (MOE) and modulus of rupture (MOR) of five provenances planted at the five sites. Effects of provenance and site were found to be significant for both MOE and MOR. GXE interaction was highly significant in both traits which involved changes in ranking, indicating a strong influence on both MOE and MOR. GXE interaction has the highest component of variance relative to site and provenance component of variances i.e. 30.5% and 37.8% for MOE and MOR, respectively

Keywords: Acacia mangium, modulus of elasticity, modulus of rupture, Provenance, variance component.

INTRODUCTION

Genotype-by-environment interaction (GXE) arises when the relative performance of genetic entries is not consistent in different environments (Falconer 1989). Hence, testing series of genotypes over a wide range of environments is vital due to environmental and the interaction effect on various characters of trees. This is very important due to its major implications in testing and selection in breeding program, resulting in reduced overall genetic gains. The patterns of response across environments involve both or either changes in the ranking of genotypes and/or alterations in scale. The former type of GXE interaction is of particular since it determines critical decisions in developing optimal breeding strategies and realizing genetic gains. GXE interactions tree species are extensive (McKeand et al. 1990).

When GXE interaction is present breeders either develop breeding for performance stability across wide ranges of environments or defining regions with relatively uniform impacts on genotypes (McKeand et al; 1990). The approach to this problem requires the estimation of the level and the causes of the GXE interaction. The provenance - site interactions on growth characteristics in Acacia mangium has been recognized. (Lokmal et al; 1995) reported

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significant variation in height and diameter among provenances as well as a significant interaction between site and provenance. Similar studies of such interaction have also been reported by (Gonscalves et al. 2003) in Brazil.

Modulus of elasticity (MOE) and modulus of rupture (MOR) are among the most important properties of the wood associated with structural quality (Johnson and Gartner 2006). It is commonly used to evaluate the stiffness and strength of the wood. It is impacted strongly by wood density and microfibril angle (Cave and Walker 1994). Modulus of elasticity (MOE) is the ratio of stress to strain within the elastic limit of the material i.e. initial slope of the linear stress-strain relationship of the wood. High MOE indicates a stiff material, necessitating a greater applied stress to achieve a given amount of strain.

Acacia mangium Willd. is a leguminous tree species of the family Leguminosae. It is a fast growing pioneer species and has been planted extensively in Malaysia due to its fast growth, good form, and its suitability for general utility timber as well as for pulp and paper. The wide range of seed sources used in the early introduction of the species, created genotype by environment interaction in growth characteristics (Lokmal et al. 1995; Lokmal and Mohd-Noor 2008), and specific gravity (Lokmal and Mohd-Noor 2009) in the species. These variabilities suggest that attractive gain could be obtained through selection. Among the hardwood species, great variation in both MOE and MOR were observed in both MOE and MOR (Firmanti et al. 2007), but very little information is available in the literature on the variation of MOE in Acacia mangium.

This paper forms part of a larger study of the influence of genetic and environmental, and their interaction on growth, wood properties and mechanical properties in Acacia mangium. A separate paper examines within tree variation in wood properties of Acacia mangium. This paper examines genotype x environment interactions in MOE and MOR of the five provenances.

MATERIALS AND METHODS

This section is divided into subsections that describe the trials, selection of trees for wood samplings, and the testing and measurements of wood properties.

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Provenance trials

A set of provenance trials of Acacia mangium was established in 1985 at five sites in the state of Sarawak, Malaysia (Table 1). Five provenances (Table 2) were planted at each of the five sites using a randomised complete block design with five blocks. The total number of trees planted in this set of trials was 6,125 (5 sites x 5 blocks x 5 provenances x 49 trees).

Sampling for wood properties

Three trees aged 13 years were selected and cut from each treatment plot for wood sampling. A total number of 375 trees were cut. Eleven (11) trees with heart-rot problem were not used. Two clear specimens were prepared (from east and west directions) from each tree at 1.3 m height and at the midpoint between pith and bark.

Prior to the test, all samples were placed in a conditioning room with an average room temperature of 20±3oC and relative humidity of 65±2%. The samples were kept in the conditioning room until the moisture content reached 12±2%.

Testing of wood strength properties

Modulus of elasticity (MOE) and modulus of rupture (MOR) were measured using a three-point static bending test following the British Standard BS No. 373 (Anon. 1957). The tests were conducted using Instron Universal Testing Machine model M5500.

Statistical analysis

The mean values of MOE and MOR were calculated for each treatment plot. It is the average of two values of east and west direction over the three sampled trees in each treatment plot generated 125 data (5sites x 5 blocks x 5 provenances). Data were subjected to analysis of variance using the following model:

Table 1: Details of the trial sites.

Site	Lat. (North)	Long. (East)	Alt. (m)	Mean Annual precipitation (mm)	Mean Annual rain days (day)	Soil series
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 Podzoli 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)

Table 2: Provenance details.

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

Uijk= m + ai + bj(i) + dk + g(ik) + eijk,
Where
Uijkl is the observation of plot mean of the kth provenance in the jth block at the ith site.
m is the overall mean.
ai is the effect of the ith site.
bj(i) is the effect of the jth block within the ith site.
dk is the effect of the kth provenance.
gik is the interaction between the ith site and the kth provenance.
eijk is the error associated with the kth provenance in the jth block at the ith site.
All effects were treated as random.
Variance components were estimated using method of restricted maximum likelihood (REML).

RESULTS

Wood samples from all trees sampled for this study had MOE varied from 13049.31MPa to 18479.08 MPa with a mean of 15467MPa (Table 3). The MOR for individual tree varied from 2166.59 to 227.7 with a mean of 3442.76 (Table 4).

Site and provenance displayed significant effects on both MOE and MOR (Table 3). The interaction between provenance x site (GXE) was highly significant and involved changes of rank among provenances across sites (Table 3). All provenances displayed very inconsistent performance in MOE and MOR with respect to all the five sites, reflecting a lack of additivity between provenances and sites (Table 4 and 5).

Site, provenance and interaction accounted for 3.2, 23.8 and 30.1% of total variation in MOE, respectively (Table 6). In MOR, site, provenance and interaction (GXE) accounted for 1.5, 24.1 and 34.7% of total variation, respectively. In both traits, component of GXE interaction accounted for a very high proportion of total variation exceeding the component for genotype indicating

Table 3: Performance of all provenances across sites in modulus of elasticity (MPa)

Site	Provenance					Overall
	Rex Range	Broken Pole	Cassowary	Piru Ceram	Sidei	
Sabal	13049.31	14874.20	14110.48	15613.95	17242.08	**15008.01**
Jakar	14776.48	16545.55	13980.59	18479.08	15696.58	**15895.65**
Oya	14702.76	16284.05	13137.60	14350.55	14640.11	**14621.59**
Labang	13787.39	15238.02	16307.38	18374.56	16614.27	**16095.09**
Sawai	15267.03	14611.82	15020.52	17795.53	15562.10	**15661.27**
Overall	**14331.02**	**15500.28**	**14528.89**	**16975.90**	**15992.84**	**15473.28**

Table 4: Performance of all provenances across sites in modulus of rupture (MPa)

Site	Provenance					Overall
	Rex Range	Broken Pole	Cassowary	Piru Ceram	Sidei	
Sabal	2189.19	2650.43	2480.65	2226.84	3194.03	**2558.62**
Jakar	2369.58	3298.78	2183.91	3229.47	2862.79	**2788.91**
Oya	2572.25	3221.05	2166.59	2275.97	2671.97	**2580.37**
Labang	2327.08	2918.93	2966.01	3442.76	3040.31	**2947.29**
Sawai	2557.53	2707.15	2597.64	3315.11	2663.14	**2771.89**
Overall	**2402.45**	**2955.73**	**2481.63**	**2915.75**	**2895.51**	**2732.88**

Table 5: Analysis of variance for MOE and MOR across sites

Source of variation	df	MOE		MOR	
		SS	MS	SS	MS
Environment E)	4	35774935	8943733.8^{**}	5816.8	1454.2^{**}
Block(E)	20	37172634	1858631.7^{ns}	5458.6	272.9^{ns}
Genotype (G)	4	111371612	27842903.2^{*}	18738.9	4684.7^{*}
GXE	16	108246305	6765394.1^{***}	25128.6	1570.5^{***}
Error	80	114431655	1430395.7	23383.9	292.3
Total	124	406997142		78526.9	

Significant at $p \leq 0.05$, ** significant at $p \leq 0.01$, *** significant at $p \leq 0.005$, ^{ns} not significant at $p \leq 0.05$

Table 6: Component of variance of various factors on wood properties

Variance Component	MOE	MOE %	MOR	MOR %
Environment (E)	114784.0	3.2	11.0	1.5
Block within E	85647.2	2.4	0.0	0.0
Genotype (G)	843100.4	23.8	177.2	24.1
GXE	1066999.7	30.1	255.6	34.7
Error	1430395.7	40.4	292.3	39.7

great influence of GXE interaction on both traits under study.

For both traits, provenances Piru Ceram performed very well in MOE and MOR at al environments, except at Sabal and Oya. Provenances Rex Range and Cassowary performed poorly in all environments. Sidei did reasonably good in both traits at all environments. Broken Pole performed good in all but Labang.

DISCUSSIONS

Genotype x environment interaction constitutes important limiting factors that affect the efficiency of breeding program. When GXE is present and is quantitatively important, it cannot be ignored and breeders must decide between two major alternatives. The first is to identify stable and high performance genotypes across a wide range of environments as suggested (Finlay and Wilkinsons 1963). The second approach is to define breeding zones that fit group of genotypes with similar patterns of GXE interaction and select independently within each zone specifically adapted genotypes (Wright 1976).

Wood samples from 362 trees sampled for this study had modulus of elasticity varied from 7629.64MPa to 21497.03 MPa with a mean of 15467.69 MPa which is within the same range with the figures found by (Firmanti et al. 2005), but much higher than that reported by (Peh and Khoo 1984) 11671MPa and 12941MPa respectively. The same was observed for the MOR. The huge differences between these works were probably due to different moisture content and age of the wood samples and the small sampling size. Mature wood is known to be stronger and stiffer than juvenile wood (Burdon et al. 2004). (Peh et al. 1984) used woods with an average of 17% and 15.5% moisture content respectively. The moisture content for this study was determined at 12%±2. Moisture content was known to have a great influence on strength (Madsen 1975).

In another study by Mohd-Hamami et al. (1998) on six year old Acacia mangium, it was found that the MOE and MOR were 6286 MPa and 68.10MPa respectively. These are less than half the figures obtained from this study. The large difference between these two studies was probably due to differentiation in age of the sampled trees. The average MOR for Acacia mangium was recorded at 42.2 MPa (Firmanti et al. 2005). Takashi (1985) working on 67 specimens of three year old Acacia mangium found the range of MOE and MOR between 82.2-121.0 (103kg/cm2) and 443-1021 kg/cm2. The average of MOE and MOR for tropical wood are 103kg/cm2 and 756kg/cm2, respectively.

Effects of environment, provenance and the interaction between provenance and environment on MOE and MOR were significant. This is expected as the environments studied were especially diverse in soil properties (series, clay content and water-holding capacity ; see Table 1). These factors however could not be tested statistically as they were confounded with each other. Similar observations were reported by Mohd-Hamami et al. (1998). Effects of GXE interaction were also observed in other characteristics of Acacia mangium such as in specific gravity (Lokmal and Mohd-Noor 2010).

GXE interaction for both traits are highly significant and accounted for more than 30% of total variation, indicating great influence of GXE interaction on both traits under study. The contribution of the interaction is substantial enough to reduce the effectiveness of selection, hence reducing genetic gain. However, these effects could be reduced by dividing the planting regions into smaller planting zones on the basis of soil types, terrain and annual rainfall (Yu and Pulkkinen 2003). Effect of the interaction could also be reduced by selecting stable genotypes. Very large components of variance were accounted for experimental error i.e. about 40% for MOE and MOR. However, this is considerably low compared to another study which recorded about 70% experimental error as reported by (Yu and Pulkkinen 2003).

Selection for planting site is one of the major issues in forest plantation establishment, especially with the presence of strong interaction between genotypes and environments. Foresters are not given much choice to choose the planting site as better sites have been allocated for agriculture activities. Knowledge on the extent of GXE is therefore crucial in distributing plant genotypes to the appropriate planting sites in order to optimize yield, wood properties, or any other trait of interest.

CONCLUSION

The present study managed to separate effects of genetic and general site factors in MOE and

MOR. Genotype is an important factor influencing MOE and MOR of timber. Besides genotype, the influence of planting site on MOE and MOR is significant. Interaction between genotypes and environment also strongly affects both traits. All provenances used in the study performed very inconsistently across all the five sites. The patterns were unpredictable. However, the following conclusions can be made based on the patterns observed. Provenances Piru Ceram performed very well in good environments but poor in poor environments (at Sabal and Oya).

Provenances Rex Range and Cassowary performed poorly in all environments. Sidei behaves as an average provenance that performed reasonably well on either good or poor environments. The need to identify and produce stable genotypes across a range of potential allocated planting area should be explored. Stability analysis might give some indication.

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