GENOTYPE X ENVIRONMENT INTERACTION AND ITS STABILITY IN *ACACIA MANGIUM*

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LOKMAL, N., AB. RASIP, A.G., NORWATI, M. & EARNEST, C.O.K. 1995. Genotype x environment interaction and its stability in *Acacia mangium*. Five provenances of *Acacia mangium* were used to establish provenance trials at five locations, namely Sabal, Jakar, Oya Road, Labang and Sawai Forest Reserves in Sarawak. The provenances were Broken Pole, Cassowary, Piru Ceram, Rex Range and Sidei. Plot means of each provenance were subjected to joint regression analysis using height and diameter growth. Location, provenance and interaction between provenance and location effects were significant. Provenances Piru Ceram, Rex Range and Sidei were found to be stable in their response to different locations while Broken Pole and Cassowary were unstable. Hence, the former provenances were expected to give an average response to various locations while the latter were more suitable for good locations only.

Keywords: Provenance - genotype x environment interaction - joint regression - analysis - genotypic stability - *Acacia mangium*

LOKMAL, N., AB. RASIP, A.G., NORWATI, M. & EARNEST, C.O.K. 1995. Saling tindak genotip x persekitaran dan kestabilannya dalam *Acacia mangium*. Lima provenan *Acacia mangium* digunakan untuk menubuhkan percubaan provenan di lima Hutan Simpan di Sarawak iaitu Sabal, Jakar, Oya Road, Labang dan Sawai. Provenan-provenan tersebut adalah Broken Pole, Cassowary, Piru Ceram, Rex Range dan Sidei. Purata (ketinggian dan diameter) plot bagi setiap provenan digunakan dalam analisis regresi bersama. Kesan lokasi, provenan dan saling tindak antara provenan dan lokasi adalah ketara. Provenan-provenan Rex Range, Piru Ceram dan Sidei didapati stabil di semua lokasi, manakala Broken Pole dan Cassowary didapati tidak stabil. Oleh itu, ketiga-tiga provenan terdahulu dijangka tumbuh dengan konsisten di berbagai lokasi, manakala dua provenan terkemudian lebih sesuai di lokasi yang baik sahaja.

Introduction

Acacia mangium is a legume of the subfamily Mimosoideae. It is native to northern Queensland, Papua New Guinea and the Molucca Islands of eastern Indonesia. It is a fast growing species, and reaches 30 m with a trunk of 40 cm in diameter at breast height within 14 years (Anonymous 1983). It was first introduced to Sabah in 1966 and is now the fast growing species selected for intensive reforestation programmes in Sabah, Sarawak and Peninsular Malaysia. Initially, for plantation establishment, seeds were obtained from various sources in Australia (Yong 1984). As a result, the trees in plantations in Peninsular and East Malaysia showed variability in growth performance, form (Rac'z & Zakaria 1986), vigor and resistance to diseases and insect attack. This may be due to variation in seed sources and environmental conditions. In consequence, an intensive programme of research on *A. mangium* was conducted.

Among the studies, the provenance trials were carried out in various places: i) to determine the most suitable provenance for a large scale planting programme; ii) to determine the average provenance which can perform consistently at various sites; and iii) to evaluate the genotype and environment interaction.

The genotype of an individual can be measured only from its phenotype, or that of its parents or relatives. The effects of the genotype and the environment are not independent and thus genotypes differ in their phenotypic response. The variation between genotypes in their response to different environmental conditions is called genotype x environmental interaction (GEI).

Changes in gene expression with changes in environment have long been recognized by plant breeders as an important source of phenotypic variation (Immer *et al.* 1934). These effects reduced genetic gains in breeding programmes. In general plant breeders agree that GEI has an important bearing on the breeding of better varieties or clones.

Several methods have been developed to analyze GEI and one of the most successful ones is the joint regression technique. This technique was pioneered by Yates and Cochran (1938), modified by Finlay and Wilkinsons (1963), refined by Eberhart and Russell (1966) and given genetical credence by Perkins and Jinks (1968). Joint regression or stability analysis with its several variations (e.g. Finlay & Wilkinson 1963, Perkins & Jinks 1968, Eberhart & Russell 1966) allows for a degree of interpretation of the type of genotype x environment interaction (whether linear) for each of the tested genotypes.

Sometimes, a genotype x environmental reaction in a particular genotype manifests itself in either of the following two ways:

a) a difference in magnitude of response in relation to the population mean,
b) cross-over effects where a genotype may perform better in poorer environments but worse in better environments (or vice versa).

These differences have been pointed out by various workers (Haldane 1946, Gail & Simon 1985, Gregorius & Namkoong 1986, Baker 1988).

Non-cross-over effects are of practical value because genotypes which exhibit such effects are generally adapted (or non-adapted) to a range of environmental conditions for a specific trait. Cross-over effects make it difficult to predict the reaction of a particular genotype to contrasting environments. Such genotypes have to be recommended for specific adaptation to certain designated environment.

The stability of genotype across a range of environment has been measured by its among-environment variance (Plaisted 1960, Shukla 1972), the regression of its mean to an environmental index (Finlay & Wilkinson 1963, Perkins & Jinks 1968) and the residual mean square from the regression (Eberhart & Russell 1966, Tai 1971).

To date, no successful techniques have been specifically developed to evaluate GEI in forest trees. However, joint regression analysis has been used successfully in forest tree experiment (Morgenstern & Teich 1969, Mergen *et al.* 1974) to explain a large part of provenance or family interaction with sites.

The objectives of this paper are to examine the extent of GEI and its stability in some provenances of *Acacia mangium.*

Materials and methods

Trial

In 1985, a provenance trial of *A. mangium* was established in Sarawak. The seeds of three of the provenances were obtained from CSIRO, Australia, while two others were from Indonesia (Table 1). They were planted at five different sites, viz. (1) Sabal Forest Reserve, (2) Jakar Forest Reserve, (3) Oya Road Forest Reserve, (4) Labang Forest Reserve and (5) Sawai Forest Reserve, using a randomized complete block design with five replications. Each treatment plot consisted of 49 trees at 3 × 3 m spacing.

The assessments of height and diameter at breast height (dbh) of 25 trees in the central part of each plot were carried out at four years after planting.

Table 1. Sources of the different provenances of *Acacia mangium* used in the trial

Provenance	Seedlot no.	Latitude (South)	Longitude (East)	Altitude (m)
Broken Pole Creek, Queenslands	13241	18° 21'	146° 03'	50
Cassowary Range, Queenslands	13534	16° 32'	145° 25'	60
Piru Ceram, Indonesia	13621	3° 04'	128° 12'	150
Rex Range NR Mossman, Queensland	12992	16° 30'	145° 32'	306
Sidei, Indonesia	13622	0° 46'	133° 34'	30

Statistical analysis

The mean of each treatment plot was subjected to analysis of variance using random model as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \delta_k + \theta_{ik} + \varepsilon_{ijk}$$

where

- Y_{ijk} - plot mean of *k*th provenance in *j*th block in *i*th site
- μ - overall mean
- α_i - effect of the *i*th site
- $\beta_{j(i)}$ - effect of *j*th block in *i*th site
- δ_k - effect of *k*th provenance
- θ_{ik} - effect of interaction between *i*th site with *k*th provenance
- ε_{ijk} - random error associated with *k*th provenance in *j*th block in *i*th site

Joint regression analysis was performed using the method after Perkins and Jinks (1968). The sum of squares for the pooled error is extracted from the combined analysis of variance. The sum of squares for heterogeneity between regressions is derived by totaling the regression sum of squares of individual genotypes on environments. The remainder sum of squares is then the balance from subtracting the heterogeneity between regressions sum of squares from GEI sum of squares extracted from the combined analysis. The heterogeneity between regressions and remainder mean squares are tested against the pooled error. Heterogeneity between regressions is also compared against the remainder or deviation term to determine if it accounts for a significantly large part of the observed GEI.

Results and discussions

Table 2 presents results of the joint regression analysis for height and diameter growth. Main effects, i.e. provenances and sites, were highly significant. Interactions between provenances and sites were highly significant at $p \geq 0.01$ for height and diameter. Similar observations were reported in *Pinus caribaea* (Binet 1963, Gibson 1982).

Table 2. Mean squares for height and diameter for combined and joint regression analysis

Source of variation	d.f.	Mean square	
		Height	Diameter
Site	4	229.0^{**}	136.8^{**}
Block (Si)	20	3.0^{ns}	2.5^{ns}
Prov	4	20.2^{*}	53.0^{**}
Prov x Si	16	7.6^{**}	6.7^{**}
Heterogeneity of regression	4	$9.4^{*\ ns^a}$	$5.5^{*\ ns^a}$
Deviation from regression	12	7.0^{**}	7.1^{**}
Pooled error	80	2.3	2.1
Total	124		

Note:

ns, **, *** : not significant at $p \leq 0.05$, significant at $p \geq 0.05$ and $p \geq 0.01$ respectively;

ns^a : not significant at $p \leq 0.05$ when tested against mean square of deviation from regression.

Contributions of site variance component in relation to the total variance components for height and diameter performances are the highest (Table 3; 69.0% and 51.2% respectively). The differences between provenances are significant at $p \geq 0.05$ and $p \geq 0.01$ for height and diameter respectively (Table 2). The GEI variance component for both traits, on the other hand, accounted for an average of 8.7% of the total variance components. It only explains about 4.0% and 18.2% of the total variance respectively (Table 3). The GEI is also significant for both traits, on the other hand, accounting for 8.3% and 9.1% of the total varience respectively.

Major variations (70%) in height were contributed mainly by the environmental effects, while major variations in diameter originated mainly from provenance (18%) and environmental effects (51%). It is also noted from Table 2 that mean square for heterogeneity between linear regression is significant for these traits when tested against the pooled error indicating a possible linear provenance response to environment and promising a degree of predictability of the provenance response.

Table 3. Variance components and their relative contributions (%) (in parentheses) for height and diameter

Components	height	diameters
S^2_s	8.83 (69.0)	5.19 (51.2)
$S^2_{b(s)}$	0.14 (1.1)	0.07 (0.7)
S^2_p	0.51 (4.0)	1.85 (18.2)
S^2_{ps}	1.06 (8.3)	0.92 (9.1)
S^2_e	2.25 (17.6)	2 .11 (20.8)

Note:

$S^2_s, S^2_{b(s)}, S^2_p, S^2_{ps}$ and S^2_e : variance for site, block within site, provenance, interaction and pooled error respectively.

However, the heterogeneity between regression was not significant when tested against the deviation from regression, and this indicated some doubt over the likelihood of prediction of provenance performance over environments. The above results suggested the possibility that the nature of GEI for height and diameter performances might be linear only for some particular provenances, in which case, their prediction performance in relation to environment might be possible.

Table 4 presents mean and regression coefficient (β) of individual provenance regressed on to the environmental mean. Based on the significant β value for height growth, all except provenance Piru Ceram showed a linear regression response to the environment.

Table 4. Overall mean and regression coefficient for height and diameter of all provenances

Provenance	Height (m)	β	Diameter (cm)	β
Broken Pole	11.4	1.14^{***}	12.1	1.20^{*}
Cassowary	10.1	1.22^{***}	10.2	1.10^{***}
Piru Ceram	9.6	0.69^{ns}	8.3	0.91^{ns}
Rex Range	9.4	0.97^{**}	10.2	0.91^{**}
Sidei	11.0	0.97^{**}	11.5	0.93^{*}

Note:
β: regression coefficient of individual provenance,
ns, *,**, ***: not significant at $p \leq 0.05$, significant at $p \geq 0.05$, 0.01 and 0.001 respectively.

Provenances Piru Ceram, Rex Range and Sidei were the most stable provenances in diameter and height with $\beta < 1$. Provenances Broken Pole and Cassowary were the most unstable but displayed high performances. These two provenances displayed higher diameter and height at the more productive sites. Lokmal *et al*. (1993), who examined the same provenances using coefficient of variation as a stability parameter (Francis & Kannenberg 1978), found Sidei to be a stable provenance.

Most tree species are out-crossing and are highly heterozygous. It is not known whether the amount of individual and populational buffering in tree species is insufficient or more than sufficient to stand against GEI. In view of the common detection of GEI in trees, it is probable that their stability can be improved.

If stability or lack of GEI for growth rate is a genetically controlled trait, it can be selected for, provided suitable methods are available to characterize it. There is growing evidence from plant breeding and some indications from trees that this is in fact the case. Finlay and Wilkinson (1963) were able to classify 277 barley varieties for relative stability when grown under varying environmental conditions.

Conclusion and recommendations

Provenances Piru Ceram, Rex Range and Sidei are stable provenances among the five provenances tested. Broken Pole and Cassowary are unstable. Piru Ceram, Rex Range and Sidei are stable and are not expected to show response to environmental change whereas Broken Pole and Cassowary are expected to give very strong response to environmental change, i.e. poor growth on poor soil and very good growth on good soil or otherwise. Hence, these two provenances are very good for good environments. Provenances Piru Ceram, Rex Range and Sidei can be planted on the average environment.

The presence of a strong provenance and environment interaction for these traits implies that special attention is required in planting various provenances at the present and new sites. Although this study clearly demonstrates the presence of GEI, further analysis is required to identify the causal factors of the GEI. If the causal factors were identified, performance of the provenance in untested sites could be predicted.

Besides height, diameter and girth, data on other traits such as stem form, forking habit, branching habit, wood quality, and general health are required. These traits are also important and have to be given some weight in determining the best provenance or the average provenance at all sites.

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