GENETIC VARIATION IN EARLY GROWTH, STEM STRAIGHTNESS AND SURVIVAL IN *ACACIA CRASSICARPA*, *A. MANGIUM* AND *EUCALYPTUS UROPHYLLA* IN BUKIDNON PROVINCE, PHILIPPINES

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Key words: *Acacia mangium* - *A. crassicarpa* - *E. urophylla* - provenance variation - heritability - genetic improvement - genetic gain

ARNOLD, R. J. & CUEVAS, E. 2003. Variasi genetik dalam pertumbuhan awal, kelurusan batang dan kemandirian dalam *Acacia crassicarpa*, *A. mangium* dan *Eucalyptus urophylla* di wilayah Bukidnon, Filipina. Keputusan dicatatkan daripada tiga percubaan famili provenans, satu daripada *Acacia crassicarpa*, satu daripada *A. mangium* dan satu daripada *Eucalyptus urophylla*, yang didirikan di wilayah Bukidnon, selatan Filipina, di pulau Mindanao. Kesemua percubaan mengandungi lot biji benih yang mewakili pelbagai geografi semula jadi spesies. Lot biji benih percubaan *A. mangium* juga termasuk beberapa lot biji benih kebun. Pertumbuhan purata pada umur hampir tiga tahun berjulat antara ketinggian 9.3 m dan diameter aras dada (dbh) 8.0 cm bagi *E. urophylla* sehingga ketinggian 10.9 m dan dbh 12.2 cm bagi *A. mangium. Eucalyptus urophylla* mempamerkan purata kelurusan batang yang baik manakala *A. mangium* dan *A. crassicarpa* mempunyai batang yang tidak lurus secara relatif. Terdapat perbezaan bererti dalam dbh dan kemandirian antara kedua-dua provenans dan famili di dalam provenans bagi *A. crasicarpa.* Dalam *A. mangium* terdapat perbezaan bererti antara kawasan, provenans di dalam kawasan dan famili di dalam provenans bagi dbh, dan antara kawasan dan famili di dalam provenans bagi kelurusan batang. Satu-satunya perbezaan bererti bagi kemandirian *A. mangium* ialah antara provenans di dalam kawasan. Perbezaan bererti didapati antara provenans *E. urophylla* bagi dbh, kelurusan batang dan kemandirian. Bagaimanapun, perbezaan ini adalah lebih kecil berbanding perbezaan antara famili di dalam provenans bagi ciri-ciri ini. Anggaran keterwarisan bagi ciri-ciri pertumbuhan dan kelurusan batang adalah rendah hingga sangat rendah (0.07 hingga 0.15) bagi ketiga tiga spesies, dengan pengecualian dalam kelurusan batang bagi *A. crassicarpa* yang sederhana (0.25).

Introduction

Forest cover and available timber resources have declined rapidly in the Philippines in recent years, due largely to the pressure of rapid population growth and economic development. Recent surveys indicate that of 15 million ha of legally classified forest lands, approximately 50% are now mostly barren and dominated by grasses (primarily cogon—*Imperata cylindrica*—and bagokbok —*Themeda triandra*) or scrub vegetation (Umali-Garcia 1995). To help address problems arising from declining natural forests and diminishing supplies of timber, the government of the Philippines initiated a National Forestation Program in the mid 1980s. This programme identified 10 priority forest trees for plantation development including *Acacia crassicarpa, A. mangium* and *Eucalyptus urophylla* (Rosario & Abarquez 1995).

Acacia crassicarpa is one of the fastest-growing acacias for planting on degraded sites in the seasonally-dry tropics (CABI 2000). Its advantages include tolerance of a wide range of soil types, particularly those of low fertility, fire resistance and an ability to compete favourably against weed species such as cogon. It has the potential to produce a dense hardwood that can be used in industrial pulp production, as sawn or round timber for construction or as fuelwood (CABI 2000). Whilst plantations for pulpwood production are managed on rotations varying in length from four to eight years, those for timber production will extend up to 20 years and incorporate thinning from as early as age three years (Doran & Turnbull 1997).

Acacia mangium is now a major plantation species in the humid tropical lowlands of Asia for production of pulpwood and, to a lesser extent, timber. Its success is due to its vigorous growth, tolerance of acidic and low nutrient soils, ability to grow reasonably well where competition is severe (such as on cogon grasslands), versatile wood acceptable for a wide range of end uses, and ease of establishment (CABI 2000). Plantations for pulpwood are usually harvested at six to seven years, or about the point of maximum mean annual increment. For sawlog production with this species rotations of around 15 to 20 years are envisaged (Mead & Miller 1991).

Eucalyptus urophylla and its hybrid combinations are important forest plantation species for wood production in lower latitude seasonally-dry tropical areas of numerous countries (Pryor *et al.* 1995). Its favourable attributes include fast growth, coppicing ability, adaptability to a range of environments, relative resistance to pests and diseases, and suitability for a variety of wood products. Rotation lengths in *E. urophylla* pulpwood plantations range up to eight to 10 years, whilst those for sawlogs and other solid wood products range up to 25 years and incorporate thinning at intermediate ages (CABI 2000).

Much of the work on genetic improvement of these and other priority forest plantation species in the Philippines has been undertaken by the government's Ecosystems Research and Development Bureau (ERDB) along with organisations undertaking large scale industrial plantation programmes. One of these organisations, Bukidnon Forests Incorporated (BFI), has a 39 000 ha estate of government-managed land in the province of Bukidnon in the central northern region of Mindanao. This estate typifies a large proportion of the lands available in the Philippines for forestation, i.e. degraded steep land with shallow soils that have long been dominated by cogon and other tropical grasses.

There has been large scale establishment of forest plantations with a number of the priority species by BFI and other organisations since the mid 1980s. However, a baseline study of forest tree improvement in the Philippines in mid 1990s found that genetic resources available within the Philippines of *A. mangium* and other important exotic forest species were generally too limited in diversity and quality to support ongoing genetic improvement programmes (Umali-Garcia 1995). In more recent times, BFI has become involved in a number of Australian-Philippine collaborative projects to address this problem (Simpson & Dart 1996, Arnold *et al.* 1998).

In 1996 large provenance-family trials of *A. crassicarpa*, *A. mangium* and of *E. urophylla* were established at BFI. These three trials, a collaborative initiative between BFI and CSIRO Forestry and Forest Products' Australian Tree Seed Centre (ATSC), were all designed to be thinned at later ages for conversion into seedling seed orchards. This report presents the results from growth and stem form assessments of these three trials carried out at approximately age three years.

Materials and methods

Trial sites

The trials are located in the central portion of Bukidnon province on the southern Philippine island of Mindanao. The region's climatic seasons are not very pronounced though there is a drier period from November to April and it is wetter during the rest of the year. However, no months have mean rainfall of less than 100 mm. In nearby Malaybalay City, mean annual rainfall is approximately

2500 mm, mean annual temperature is 23.9 °C, and the mean minimum and maximum temperatures are 18.5 °C and 29.2 °C respectively (data provided by Philippine Atmospheric, Geophysical and Astronomical Services Administration based on climatic records for period 1961 to 1995 from their Malaybalay Bukidnon Synoptic Station).

The three trial sites are adjacent to each other at around 8° 25' N and 124° 57' E with an elevation of approximately 600 m asl. The trial sites are on the highest plateau of the Siloo Station, a parcel of the BFI estate where the elevation ranges from 500 to 900 m asl.

Soils in the trials are deeply weathered, predominantly ultisols and undifferentiated hill soils with heavier textures (high clay contents), and are of volcanic origin. Over most of the sites roots are able to extend several metres down into B and weathered C horizons. These soils are generally low in available phosphorus (P) and sulphur (S) and are deficient in potassium (K) and boron (B) (Dell 1999).

Seedlots

The *A. crassicarpa* trial contained 164 open-pollinated families representing 13 provenances from the species natural range in Queensland and Papua New Guinea (PNG) (Table 1). In the *A. mangium* trial, there were 150 open-pollinated families representing 15 natural provenances in PNG, four natural provenances in far north Queensland, three natural provenances from the Cairns region in Queensland and two from seedling seed orchards (Table 2). One of the seedling seed orchards, located in Fiji, was developed from a large number of open-pollinated families sourced from natural stands in far north Queensland and the western part of PNG. The other seed orchard, located near Cardwell in Queensland, was developed from open-pollinated families sourced from natural stands in various locations in south-western PNG.

The *E. urophylla* trial contained 208 open-pollinated families representing a total of 16 provenances obtained from native stands of the species located across four separate Indonesian islands, namely, Alor, Flores, Pantar and Wetar (Table 3). In 1995, Pryor *et al.* suggested the provenances from Wetar island may in fact be a separate species, *E. wetarensis,* which would include 73 families representing seven of the provenances included in the trial. However, this newer classification has not been widely accepted internationally (CABI 2000). In this report all provenances will be referred to as *E. urophylla.*

All seedlots were provided by the Australian Tree Seed Centre, part of CSIRO Forestry and Forest Products, Australia.

Trial design

Designs for each of the trials were developed using the field trial design software package ALPHA+ 1993, Version 1.0. The family seedlots in each trial were represented as four-tree row plots in each of six complete replicates. Randomisation

Table 1 Provenance means for diameter at breast height over bark (DBHOB), height (HT), stem straightness (STR) and survival at age three years in the *Acacia crassicarpa* provenance-family trial at BFI in Bukidnon

Seedlot	No. of families	Provenance/seed source details					DBHOB	HT #	STR	Survival
		Location	Country/ state	Latitude (S)	Longitude (E)	Altitude (m asl)	(cm)	(m)	(1–4)	
16986	6	Oriomo DPI, WP	PNG	8° 51'	143° 11'	35	10.9	9.8	2.1	85.5%
17548	19	Oriomo Old Zim, WP	PNG	8° 48'	143° 06'	20	10.8	9.7	2.0	76.0%
15646	6	Wemenever	PNG	8° 56'	141° 17'	20	10.7	9.6	2.0	66.3%
16597	16	Gubam Village,WP	PNG	8° 37'	141° 55'	25	10.6	9.6	2.0	76.8%
18947	17	Bensbach, WP	PNG	8° 53'	141° 17'	25	10.5	9.6	2.0	73.3%
18940	16	Bimadebum, WP	PNG	8° 38'	142° 03'	40	10.5	9.5	2.0	77.0%
18937	16	Oriomo, WP	PNG	8° 52'	143° 03'	30	10.4	9.6	2.0	78.5%
18931	15	Wipim, WP	PNG	8° 46'	142° 48'	45	10.4	9.6	2.1	78.8%
13683	13	Woroi Wipim, WP	PNG	8° 49'	143° 00'	20	10.4	9.5	2.1	71.3%
17948	10	Chilli Beach	QLD	12° 38'	143° 23'	3	10.1	9.5	2.0	71.8%
17944	19	Claudie River	QLD	12° 48'	143° 18'	20	9.4	9.1	2.1	80.0%
18405	4	12 km S of Bamaga	QLD	11° 00'	142° 22'	40	8.4	8.7	1.8	84.8%
16128	7	Jardine River	QLD	11° 02'	142° 22'	20	8.0	8.5	1.9	62.0%
Standard error of differences between means				Average			0.27	##	n.s.	4.9%
				Maximum			0.39	##	n.s.	7.5%
				Minimum			0.19	##	n.s.	3.4%

\# = Heights estimated from only replicate one, other parameters estimated using data from the full six replicates.
\## = Differences between provenances not analysed; data available only from replicate one.
n.s. = Differences not significant ($p \leq 0.05$)
WP = Western Province
PNG = Papua New Guinea
QLD = Queensland

Table 2 Region and provenance means for diameter at breast height over bark (DBHOB), height (HT), stem straightness (STR) and survival at age three years in the *Acacia mangium* provenance-family trial at BFI in Bukidnon

Region	Seedlot	No. of families	Provenance/seed source details: Location	Region	Latitude (S)	Longitude (E)	Altitude (m asl)	DBHOB (cm)	HT # (m)	STR 1–4	Survival
Region means											
Seed Orchards (SSO)		44						12.8	11.2	2.38	84.5%
Papua New Guinea (PNG)		73						12.2	10.9	2.27	83.0%
Far North Queensland (FNQ)		21						11.7	10.6	2.35	82.8%
Queensland - Cairns Region (QCR)		12						10.6	10.1	2.35	79.0%
Standard error of differences between means -				Average				0.17	##	0.04	n.s.
				Maximum				0.21	##	0.05	n.s.
				Minimum				0.11	##	0.03	n.s.
Provenance means											
	18194	4	SW of Boset, WP	PNG	7° 17'	141° 05'	100	13.6	11.54	2.27	71.3%
	17866	3	Lake Murray	PNG	6° 51'	141° 29'	55	13.0	11.19	2.20	77.0%
	19286	33	Seed Orchard in QLD	SSO	18° 16'	146° 02'	80	12.9	11.21	2.39	84.5%
	17550	7	Bensbach, WP	PNG	8° 53'	141° 17'	25	12.7	11.11	2.12	76.3%
	18765	5	Cassowary Ck Iron Range	FNQ	12° 34'	143° 16'	40	12.4	11.03	2.35	82.5%
	16590	1	Dimisisi, WP	PNG	8° 31'	142° 13'	50	12.4	10.75	2.20	76.5%
	16999	2	Oriomo Sawmill, WP	PNG	8° 49'	143° 06'	10	12.3	11.05	2.37	90.3%
	19256	11	Seed Orchard in Fiji	SSO	18° 00'	178° 01'	10	12.3	10.96	2.38	85.8%
	16991	6	Gubam NE Morehead, WP	PNG	8° 37'	141° 54'	25	12.2	10.95	2.31	85.3%
	16931	4	Makapa, WP	PNG	7° 56'	142° 35'	15	12.2	10.84	2.23	84.0%
	16992	5	Bimadebun, WP	PNG	8° 38'	142° 03'	40	12.2	10.77	2.31	84.5%
	16589	5	Pongaki E of Morehead, WP	PNG	8° 40'	141° 50'	30	12.1	10.83	2.29	84.8%
	16997	8	Boite NE Morehead, WP	PNG	8° 37'	141° 58'	25	12.0	10.83	2.24	81.3%
	16971	7	Wipim District, WP	PNG	8° 47'	142° 52'	45	12.0	10.76	2.35	85.0%
	16938	9	Kini, WP	PNG	8° 05'	142° 58'	12	12.0	10.86	2.30	91.3%
	16987	5	Pongaki E Morehead, WP	PNG	8° 40'	141° 50'	30	11.9	10.72	2.29	87.3%
	19214	5	Claudie River	FNQ	12° 44'	143° 16'	30	11.9	10.68	2.40	83.5%
	15643	4	Wemenever	PNG	8° 43'	141° 29'	40	11.8	10.69	2.31	83.5%
	16939	3	Duaba, WP	PNG	8° 13'	142° 58'	25	11.8	10.66	2.22	74.0%
	19212	6	Pascoe River	FNQ	12° 34'	143° 06'	15	11.4	10.53	2.36	85.3%
	15700	4	S of Cardwell	QCR	18° 32'	146° 05'	55	11.0	10.34	2.36	83.0%
	15687	4	SE of Daintree	QCR	16° 16'	145° 22'	12	11.0	10.11	2.33	72.0%
	18249	5	Captain Billy Road	FNQ	11° 41'	142° 42'	100	10.9	10.19	2.30	81.0%
	18764	4	Kuranda	QCR	16° 44'	145° 30'	390	9.9	9.69	2.38	84.3%
Standard error of differences between means				Average				0.41	##	n.s.	5.8%
				Maximum				0.73	##	n.s.	10.3%
				Minimum				0.21	##	n.s.	3.0%

\# = Heights estimated from only replicate one, other parameters estimated using data from the full six replicates.
\## = Differences between regions and between provenances-within-regions not analysed; height data available only from replicate one.
n.s. = Differences not significant ($p \leq 0.05$)
WP = Western Province

Table 3 Provenance means for diameter at breast height over bark (DBHOB), height (HT), stem straightness (STR) and survival at age three years in the *Eucalyptus urophylla* provenance-family trial at BFI in Bukidnon

Seedlot	No. of families	Provenance/seed source details					DBHOB	HT #	STR	Survival
		Location	Region	Latitude (S)	Longitude (E)	Altitude (m asl)	(cm)	(m)	1–4	
17836[W]	16	SW of Uhak	Wetar	73° 9'	126° 29'	350	8.3	9.54	3.12	81%
13011	16	Mt Lewotobi	Flores	83° 2'	122° 47'	500	8.2	9.40	3.18	81%
14532	16	Mt Lewotobi	Flores	83° 1'	122° 45'	398	8.2	9.55	3.09	86%
17565	16	Lewotobi	Flores	83° 2'	122° 48'	375	8.2	9.46	3.25	83%
17564	7	Mandiri	Flores	81° 5'	122° 58'	410	8.1	9.32	2.91	79%
17841	11	Piritumas	Flores	81° 9'	124° 31'	355	8.1	9.28	2.72	79%
17835[W]	6	1 km N of Carbubu	Wetar	75° 6'	125° 53'	175	8.0	9.26	3.19	86%
17831[W]	16	N of Ilwaki	Wetar	75° 2'	126° 27'	515	8.0	9.35	3.19	87%
17567	32	Egon	Flores	83° 8'	122° 27'	450	8.0	9.18	3.17	82%
13012	13	Mt Egon	Flores	84° 1'	122° 27'	515	7.9	9.27	3.16	89%
14531	17	Mt Egon	Flores	83° 8'	122° 27'	515	7.9	9.12	3.07	92%
17834[W]	6	N of Telemar	Wetar	75° 4'	125° 58'	180	7.9	9.25	2.89	71%
17832[W]	15	6 km N of Arnau	Wetar	74° 9'	126° 10'	315	7.8	9.34	2.96	79%
17838[W]	9	Lalikki Mine	Wetar	74° 2'	126° 21'	220	7.8	9.25	3.24	88%
17843	7	Baubillatung W	Pantar	82° 0'	124° 02'	285	7.6	8.91	2.96	83%
17837[W]	5	4 km NW Old Uhak	Wetar	73° 6'	126° 37'	215	7.6	9.09	2.94	86%
Standard error of differences between means			Average				0.21	##	0.12	5%
			Maximum				0.30	##	0.17	6%
			Minimum				0.14	##	0.14	3%

W = Indicates seedlot is classified as '*E. wetarensis*' according to Pryor *et al.* (1995).
\# = Heights estimated from only replicate one, other parameters estimated using data from the full six replicates.
\## = Differences between provenances not analysed; height data available only from replicate one.

within replicates was constrained to provide a row and column structure for incomplete two-dimensional blocking within each replicate. Trees were spaced at 4.5 m (between rows) × 2.0 m (within rows).

Site preparation, planting and establishment

Seedlings were propagated in BFI's nursery near the town of Malaybalay. The eucalypt seedlots were sown into individual germination trays and the seedlings were raised in these for about one month under shade. They were then dibbled into root trainer tubes (approximate volume 100 cm^3) and placed under high shade. When approximately 10 cm tall, they were moved to outside holding areas to grow on and then harden. The seedlots of both acacia species were sown directly into root trainer tubes. All three trials were planted in July and August 1996, with seedlings generally in the range of 20 to 30 cm tall.

The trial sites were occupied by mainly cogon grass and bagokbok before trial establishment. They received intensive site preparation followed by regular weed control during the first two years. The weed control measures included spraying with glyphosate herbicide one month before planting and again at 10 to 12 months after planting. Manual ring weeding and brushing were performed at both one month and five months after planting.

Tree nutrition was closely monitored and fertiliser was applied in line with the regime routinely used by BFI in its commercial plantations. One week after planting 60 g $tree^{-1}$ of diammonium phosphate (DAP, 18-46-0) and 20 g $tree^{-1}$ ulexite (boron) were applied. This was followed at two months after planting with 100 g $tree^{-1}$ of DAP. During the second year, a further 200 g $tree^{-1}$ of DAP and 20 g $tree^{-1}$ of ulexite were applied. At the end of the second year, 100 g $tree^{-1}$ of muriate of potash (K), 400 g $tree^{-1}$ of phoscal plus (mainly P) and 5 g $tree^{-1}$ of zinc sulphate (Zn) were applied.

No form pruning or stem pruning were carried out in the trials prior to the three-year assessment.

Assessments

All three trials were assessed in February till March 1999, at approximately three years of age (32 months). Diameter overbark at a height of 1.3 m (i.e. diameter at breast height over bark—DBHOB) and stem straightness (STR) were measured on all living trees. Due to limited resources for the assessments, total heights (HT) could only be assessed on all trees in the first replicate of each trial.

Stem straightness was assessed using a visual four-point score by one person. Score "4" was assigned to trees whose stem (excluding the top one metre or so of new growth) was essentially completely straight. Score '1' was used for very kinked or otherwise deformed stems that were potentially non-merchantable. Score "2" was for trees of inferior straightness but not as extremely so as those with score 1, and score "3" trees were of better than average straightness but with some minor noticeable defects.

Data analyses

In each of the three trials very small trees (DBHOB $\leq$ 1.5 cm and/or HT $\leq$ 2.0 m), which could have either been suppressed, genetic runts (i.e. stunted due to substantial genetic inferiority) or planted in a locally poor microsite, were deleted from the data used for analysis (less than 30 trees in each trial).

Results from each trial were processed and analysed separately. The software package DataPlus 1997 was used to pre-process the data and screen for outlying values. Plot means, variances and counts for DBHOB and STR were calculated by DataPlus. Screening provenance plot variances served a second check of data for outliers or irregular plots. The plot counts were used to calculate plot mean survival percentages. Analyses of variance were carried out on plot means for the trees retained in the data set for each trial, using the statistical analyses software package GENSTAT 1987, Version 5.3.2.

Analyses of data from the *A. crassicarpa* trial were based on the following linear model:

$$Y_{ijklm} = \mu + R_i + X_{j(i)} + Y_{k(i)} + P_l + F_{m(l)} + e_{ijklm}$$

where

Y_{ijklm} = the plot mean of the *m*th family within the *l*th provenance in the *k*th column-within-replicate *i* and the *j*th row-within-replicate *i*,
μ = the overall mean,
R_i = the effect of the *i*th replicate,
$X_{j(i)}$ = the effect of the *j*th row within replicate *i*,
$Y_{k(i)}$ = the effect of the *k*th column within replicate *i*,
P_l = the effect of the *l*th provenance
$F_{m(l)}$ = the effect of the *m*th family which is nested within the *l*th provenance;
e_{ijklm} = the residual error with a mean of zero.

Computations of analyses of variance (ANOVA) were carried out in two stages. The first stage involved mixed model analyses using the REML procedure in GENSTAT, for which families and replicates were treated as fixed effects while both rows-within-replicates and columns-within-replicates were treated as random. For the second stage, family means estimated from this first stage were analysed according to a nested treatment structure (families nested with provenances) using the ANOVA procedure in GENSTAT. The outputs from the two stages were then combined to produce composite ANOVA tables for testing the significance of provenance and family effects, following procedures described by Williams and Matheson (1994).

For the *A. mangium* and *E. urophylla* trial, a region effect was included in the model. For *A. mangium* the provenances were from one of four distinct regions: PNG, far north Queensland, Cairns region in Queensland, or a seedling seed orchard (SSO) (Table 2). For *E. urophylla*, each of the separate island sources namely, Flores, Alor, Pantar and Wetar, were treated as separate regions (Table 3).

REML analyses in GENSTAT, using a mixed-effects models, were used to produce estimates of mean DBHOB, STR and survival for families and provenances. These were adjusted for blocking structures within the trials (REML means).

For height, species means and provenance-within-species means were calculated as arithmetic means from the data obtained from the first replicate of each trial.

Genetic parameters

Appropriate variance components for genetic parameter computation were obtained separately for each species by mixed model analyses. Replicates and provenances were treated as fixed effects while columns-within-replicates, rows-within-replicates and families-within-provenances were taken as random effects (Williams & Matheson 1994). These analyses were conducted using the REML procedure in GENSTAT.

The family-within-provenance variance components (after declaring provenance as a fixed effect) were used to estimate mean within-provenance individual tree heritabilities (denoted h^2) separately for DBHOB and stem straightness in each species as follows (Williams & Matheson 1994):

$$h^2 = 1/r \times (\sigma_f^2 / \sigma_p^2)$$

where

r = coefficient of relationship
σ_f^2 = variance between families-within-provenances
σ_p^2 = phenotypic variance
= $(\sigma_f^2 + \sigma_m^2 + \sigma_t^2)$
σ_m^2 = variance between plots
σ_t^2 = variance between trees within plots

Standard errors of the heritability estimates were calculated according to Becker (1984).

In the case of *E. urophylla* the coefficient of relationship (r) used in computation of the individual tree heritabilities was taken as 0.30, rather than the value of 0.25 for half-sib families; House and Bell (1994) found outcrossing rates in natural populations of this species to be approximately 90%. For both acacia species, the coefficients of relationship used in computation of the heritabilities were taken as 0.25. Natural populations of *A. crassicarpa* from northern Queensland have high outcrossing levels and low amounts of inbreeding (Moran *et al.* 1989). Similarly, studies have found little evidence of inbreeding in populations of *A. mangium* in PNG (Butcher *et al.* 1999) where most of the seedlots of that species for the trial at BFI were sourced from.

Results

Overall survival was high for *E. urophylla* (83%) and *A. mangium* (83%) (Table 4). Survival for *A. crassicarpa* was lower (74%).

The best average growth was that of *A. mangium* with a mean height of 10.9 m and DBHOB of 12.2 cm. These equate to early age mean height and DBHOB increments of approximately 4.1 m $year^{-1}$ and 4.6 cm $year^{-1}$ respectively. Average growth in the *A. crassicarpa* trial was somewhat less, with mean height and DBHOB of 9.5 m and 10.2 cm respectively. *Eucalyptus urophylla* had the slowest growth with average height of 9.3 m and DBHOB of 8.0 cm.

Eucalyptus urophylla had the best average stem straightness of the three species (3.1 out of 4.0). *Acacia mangium* displayed poorer stem straightness with a mean of 2.3 as did *A. crassicarpa* with a mean score of only 2.0.

As the trials for the eucalypt and the two acacias were on separate sites, it is not possible to derive any rigid statistical comparisons between the three species.

Provenance variation

Significant differences ($p < 0.05$) were found between the *A. crassicarpa* provenances for DBHOB and survival but not for stem straightness (Table 5). The best three were Oriomo DPI, Oriomo Old Zim and Wemenever, PNG (Table 1). The four Queensland provenances, namely, Chilli Beach, Claudie River, 12 km S of Bamaga and Jardine River, were the poorest in DBHOB. The provenance which had the best survival (85.5%) was also that which had the best DBHOB, i.e. Oriomo DPI, whilst that with the poorest DBHOB was the one that showed the poorest average survival, i.e. Jardine River (62.0%). However Wemenever, which ranked third best by growth, had the second poorest average survival (66.3%).

Table 4 Species means for diameter at breast height over bark (DBHOB), height (HT)[a], stem straightness (STR) and survival at age three years in the trials/seedling seed orchards at BFI in Bukidnon

Species	Number of provenances tested	Number of families tested	DBHOB (cm)	HT (m)	STR 1–4	Survival
Acacia crassicarpa	13	164	10.2	9.5	2.0	74%
Acacia mangium	26	150	12.2	10.9	2.3	83%
Eucalyptus urophylla	16	208	8.0	9.3	3.1	83%

[a] = heights estimated from only the first replicate of each trial, other parameters estimated using data from the full six replicates in each trial.

In *A. mangium*, there were significant differences (p < 0.001) between regions for DBHOB and stem straightness, but not for survival (Table 6). Based on region means, seedlots of seed orchard origin showed the best growth (DBHOB = 12.8 cm) and stem straightness (2.38) (Table 2). For DBHOB, those from PNG and far north Queensland ranked second and third whilst those from the Cairns region in Queensland ranked last, averaging only 10.6 cm in DBHOB.

Natural stand provenances of *A. mangium* from within any one region showed significant differences (p < 0.05) in DBHOB as well as survival (Table 6). However, differences between their average stem straightness were small and not significant. The best provenance overall for growth (DBHOB) was from SW of Boset PNG, with Lake Murray PNG and the Seed Orchard in Queensland ranking second and third respectively. The provenances with the poorest DBHOB were Captain Billy Road in far north Queensland and Kuranda in the Cairns region of Queensland. The three provenances from the Cairns region were among the four poorest provenances in the trial for average DBHOB. The provenance with the best survival was Kini in PNG (91.3%). Of the 24 provenances tested 18 had survival exceeding 80% (Table 2). Interestingly though, the provenance that had the poorest survival of all (71.3%) was that which had the best growth, i.e. SW of Boset PNG.

Table 5 Analyses of variance of diameter at breast height over bark (DBHOB), stem straightness (STR) and survival based on plot means for the *Acacia crassicarpa* provenance-family trial at age three years at BFI in Bukidnon

Source of variation	Degrees of freedom	Mean Squares		
		DBHOB	STR	Survival
Provenance	12	25.626 ***	0.143 ns	987.5 *
Family-within-provenance	151	2.433 ***	0.223 ***	918.0 ***
Residual	589[a]	1.590	0.125	552.7

[a] = the degrees of freedom for the residual in the analyses of variance for survival differ from those given here as there were whole plots missing (i.e. all four trees had died in some plots).
n.s. = not significant
* = significant at p < 0.05
** = significant at p < 0.01
*** = significant at p < 0.001

Table 6 Analyses of variance of diameter at breast height over bark (DBHOB), stem straightness (STR) and survival based on plot means for the *Acacia mangium* provenance-family trial at age three years at BFI in Bukidnon

Source of variation	Degrees of freedom	Mean Squares		
		DBHOB	STR	Survival
Region	3	136.46 ***	0.739 ***	950.3 ns
Provenance-within-region	20	9.38 ***	0.137 ns	696.9 *
Family-within-provenance	126	2.54 **	0.139 ***	444.1 ns
Residual	551[a]	1.87	0.090	424.5

[a] = the degrees of freedom for the residual in the analyses of variance for survival differ from those given here as there were whole plots were missing (i.e. all four trees had died in some plots).
n.s. = not significant
** = significant at p < 0.01
*** = significant at p < 0.001

In *E. urophylla* the only trait that differed significantly ($p \leq 0.001$) between islands was stem straightness (Table 7). However, these differences were small ranging from 2.73 for Alor Island to 3.14 for Flores Island (data not shown). The provenances-within-islands showed significant differences ($p < 0.05$) for all three traits analysed (Table 7). The variations in DBHOB were relatively small and that of the best provenance was within 10% of the poorest provenance (Table 3). Even though the magnitude of variation in provenance mean survivals was greater, varying from 71 up to 92%, all but one provenance, North Telemar on the island of Wetar (71), would rate as having acceptable survival (≥ 79%).

No geographic patterns were apparent in the provenance variation in *E. urophylla* for DBHOB, stem straightness or survival. Provenances with better DBHOB, stem straightness and/or survival were from locations scattered across elevations ranging from 180 to over 500 m asl across the four Indonesian islands (Table 3), as were those that were inferior for these traits.

Family variation

In *A. crassicarpa*, differences between the families-within-provenances were highly significant ($p \leq 0.001$) for all three traits analysed (Table 5). The best 10 families for growth together averaged 11.8 cm in DBHOB while the poorest 10 families of *A. crassicarpa* for growth averaged only 7.9 cm in DBHOB. The better *A. crassicarpa* families for DBHOB were from a range of provenances with the top 10% (16 families) representing nine provenances, all of which were from PNG. All of the 40 families tested from Queensland provenances were relatively inferior for DBHOB.

The *A. mangium* families-within-provenances differed significantly ($p \leq 0.01$) in both DBHOB and stem straightness (Table 6). The range in family mean DBHOBs was from 8.2 to 14.4 cm and the top 10% (15 families) by this trait were dominated by just two provenances, SW of Boset PNG and the seed orchard in Queensland.

Table 7 Analyses of variance of diameter at breast height over bark (DBHOB), stem straightness (STR) and survival based on plot means for the *Eucalyptus urophylla* provenance-family trial at age three years at BFI in Bukidnon

Source of variation	Degrees of freedom	Mean Squares DBHOB	STR	Survival
Island	3	2.138 ns	3.206 ***	354.45 ns
Provenance-within-islands	12	2.267 **	0.819 *	1090.01 *
Family-within-provenance	192	2.004 ***	0.491 **	733.08 *
Residual	806[a]	1.029	0.378	574.30

[a] = the degrees of freedom for the residual in the analyses of variance for survival differ from those given here as there were a few whole plots missing (i.e. all four trees had died in some plots).
n.s. = not significant
* = significant at $p < 0.05$
** = significant at $p < 0.01$
*** = significant at $p < 0.001$

Families showing the poorest DBHOB were predominantly those from the Cairns region in Queensland. For stem straightness, more than half the top 10% of families (i.e. 9 of 15) were from the seed orchards.

In *E. urophylla* there were significant differences ($p \leq 0.05$) between the families-within-provenances for the three traits analysed (Table 7). For DBHOB the magnitudes of these variations were much greater than those between provenances; the poorest family had a mean DBHOB only 67% that of the best family and for straightness it was 57%. The best 10 families averaged 9.2 cm in DBHOB and 9.9 m in height whilst the poorest 10 averaged only 6.8 cm and 8.4 m in DBHOB and height respectively.

The *E. urophylla* families with the best DBHOB came from a wide range of provenances. The top 10% of families for this trait represented nine provenances, one of which was the provenance with the poorest average growth (Baubillatung W). Families of poor DBHOB were also from a wide range of provenances with the bottom 10% of families from 12 provenances.

Heritability

Estimates of individual tree heritabilities for growth traits and stem straightness were low to very low for all species tested, with the exception of stem straightness in *A. crassicarpa* which was moderate (0.25 ± 0.06) (Table 8). As the estimates presented are within-provenance heritabilities, they do not represent the total potential for genetic gain. Significant gains could also accrue from selection between provenances in each of the species.

Table 8 Individual tree heritability estimates, with standard errors (SE), for *Acacia crassicarpa*, *A. mangium* and *Eucalyptus urophylla* at age three years at BFI in the Philippines

Species	Trait	Individual tree heritability ± SE
A. crassicarpa	DBHOB	0.15 ± 0.05
	Stem straightness	0.25 ± 0.06
A. mangium	DBHOB	0.08 ± 0.05
	Stem straightness	0.10 ± 0.04
E. urophylla	DBHOB	0.13 ± 0.05
	Stem straightness	0.07 ± 0.04

Discussion

Species and provenances

Though accurate statistical comparisons cannot be made between the three species reported in this study, the trials suggest the acacia species were more productive at age three years in the Siloo environment under the silvicultural management applied. An important factor contributing to the results at Siloo may be that the acacias are leguminous species; associations of their roots with *Rhizobium* and *Bradyrhizobium* bacteria enable fixation of atmospheric nitrogen (N), whilst associations with arbuscular mycorrhizal fungi facilitate improved mineral absorption (Dart *et al.* 1991, Khasa *et al.* 1994). The degraded cogon grasslands, of which the Siloo sites are prime examples, are typically low in N (Turvey 1995, Simpson & Dart 1996). Even though substantial quantities of fertilisers which included N and P were applied to all three trials, it is likely that the acacias received some extra N benefit from their symbiotic relationships with the N-fixing bacteria. Visual inspections of roots in these acacia trials have shown abundant root nodulation with such N-fixing bacteria (Brown, pers. comm.). The eucalypts have symbiotic relationships with only mycorrhizal fungi.

Another important factor affecting the suitability of these acacia and eucalypt species for the Siloo sites is their ability to shade out competition. *Acacia mangium* and *A. crassicarpa* form denser crowns than *E. urophylla*. The heavier shade from the crowns of these acacias, and their earlier canopy closure, can reduce the competitive effect they experience from cogon grass present on such sites.

Despite the apparently lower growth of the eucalypts relative to the acacias, their average size at Siloo at age three years was similar to that reported by Wei & Borralho (1998) at the same age in four *E. urophylla* trials on red lateritic clay loams in southern China. The significant yet small magnitude of growth differences between *E. urophylla* provenances from across different islands found in the Siloo trial is also in general agreement with the results from China where provenance effects accounted for less than 10% of total phenotypic variance (Wei & Borralho 1998).

The results of the BFI trial do not enable any one-island occurrence of *E. urophylla* to be recommended over the others for either growth or stem straightness to age three years. In addition, the small magnitude of the provenance differences within islands means that no one single provenance nor group of provenances of this species can be singled out as superior for growth or stem form. These results are particularly noteworthy, as there have been few other reports published previously on comparative growth performance of provenances from Wetar. Good collections of seed from provenances and families on Wetar only became available in 1990 (Gunn & McDonald 1991) and thus material from that area was either absent or poorly represented in the many of the earlier *E. urophylla* trials established in various countries (CABI 2000).

It is possible that more substantial variation between island locations of *E. urophylla* will be found in other economically important traits such as wood properties or pest and disease resistance. In *E. globulus* for instance, important differences in wood density have been found between provenances from widely separated locations that have similar growth potential (Dutkowski & Potts 1999).

For the two acacia species the results presented clearly indicate appropriate provenances/seed sources, with respect to early growth and form, for future plantation establishment at Siloo and other sites of similar environment (Tables 1 and 2). In *A. mangium* there was a clear advantage (approximately 5%) for growth, form and survival of the seed orchard seed sources over those representing "average" natural provenances from PNG. Trials of *A. mangium* in a number of countries have also generally shown provenances from PNG and far north Queensland to be superior to those from Queensland's Cairns region (Harwood & Williams 1992, Harwood *et al.* 1993a, Khasa *et al.* 1995, Otsamo *et al.* 1996). For *A. crassicarpa,* provenances from the PNG region also proved significantly superior in growth and form to those from Queensland, as shown previously in an Australian trial (Harwood *et al.* 1993b, Arnold *et al.* 1995). Our results for provenance performance of both acacia species in the Siloo trials are also generally in accordance with those from trials in the Democratic Republic of Congo (formerly Zaire) (Khasa *et al.* 1995).

It must be emphasised that the results obtained at Siloo on species and provenance performance are limited to the environment typified by the Siloo site, which is only one of the many site types in the Philippines. The results presented cannot be used to extrapolate or predict performances in significantly different environments and/or under different silvicultural regimes. Nonetheless, Siloo is characteristic of a large proportion of the land available within the Philippines for reforestation (i.e. degraded lands with relatively infertile soils that have long been dominated by cogon and other tropical grasses), and the species tested are three of the 10 priority forest trees for plantation development in the Philippines (Rosario & Abarquez 1995). Thus, the results obtained in these trials are of wide relevance in the southern Philippines.

Assessments of wood properties at later ages will also need to be considered in the *A. mangium* and *A. crassicarpa* trials. Significant variations have been found between *A. crassicarpa* provenances from PNG for a number of physical and mechanical wood properties including tangential shrinkage, radial shrinkage and shear parallel to the grain (Shukor *et al.* 1998). Investigations of such variations in the Mindanao environment will be very important in ongoing domestication and breeding work aimed at producing quality germplasm for production of solid wood products.

Family variation and heritability

In both *E. urophylla* and in *A. crassicarpa*, the differences between families within provenances were greater than differences between provenances. Again, these results are consistent with those reported from other field trials with these species (Harwood *et al.* 1993b, Arnold *et al.* 1995, Wei & Borralho 1998). Interestingly, isozyme studies on *E. urophylla* also suggested that most of the diversity in this species was located within, rather than between, provenances (House & Bell 1994).

Individual heritabilities reported here for DBHOB and stem straightness in all three species were generally low (from 0.08 to 0.15). However, they are similar to heritabilities reported from other open-pollinated family trials of *E. urophylla* and other eucalypt species (Eldridge *et al.* 1993, Wei & Borralho 1998) and of *A. crassicarpa* (Harwood *et al.* 1993b, Arnold *et al.* 1995). Stem straightness in *E. urophylla* at Siloo showed very low individual heritability (0.07 ± 0.04) but this is not a future constraint. This species already produced relatively straight stems (average score of 3.1 out of 4.0). However, the current stem form of *A. crassicarpa* (average stem straightness score at Siloo, 2.0 out of 4.0) is a significant limitation for that species (Arnold *et al.* 1995, Doran & Turnbull 1997). Therefore, improving its stem form will be important for increasing the utility of *A. crassicarpa* and the returns from its future plantations. As its heritability for stem straightness was found to be moderate (0.25 ± 0.06) at Siloo, there is potential to rapidly achieve significant improvements in the stem form of *A. crassicarpa* by selection and ongoing genetic improvement.

All three of the trials reported here were designed for multiple roles and could be classified as Breeding Seed Orchards (BSOs) (Barnes 1984, Matheson 1990). In such BSOs, provenance-family testing, selection, breeding and seed production can all occur with the one stand. Following selective thinnings at a later age to a single tree per row plot (25% of the establishment stocking), each tree will be surrounded by a group of unrelated neighbours, facilitating outcrossing and minimising cross-pollination between related trees. Additional thinnings, based on rigorous selection of superior families and individual trees-within-families, should provide for significant genetic improvement. Such thinnings will be heavy, both between and within families, to improve growth performance of seed obtained. Meanwhile, selection of superior trees for inclusion in advanced-generation breeding programmes can also be carried out in these BSOs.

Compromises are made in the design and management of provenance-family trials intended to function for such BSOs. Nevertheless they enable rapid and efficient progress in the domestication and improvement of tree species, with respect to time required and resources invested. Both the *A. mangium* and *A. crassicarpa* trials contained some clearly inferior provenances which are undesirable for future breeding and seed production. However, these will largely be eliminated by the selective thinning process. In the *E. urophylla* trial the differences between families-within-provenances were more important than those between provenances included in it. Thus, rather than attempting to define the best general area or group of provenances of *E. urophylla* for future breeding and seed production, emphasis will be placed on selecting the best families and individuals-within-families regardless of their provenance.

Genetic gains in BFIs tree improvement programmes may arise from both genetic differences between provenances and differences between families-within-provenances. The differences between provenances, as reported here, had already provided potential for gains as they had indicated better seed sources for Siloo and similar environments from where seed can be sourced for plantation establishment. In the medium to longer term, selection of the superior trees in the trials and selective thinning to remove poorer-performing families and individual trees will develop the trials into seedling seed orchards to provide local sources of genetically improved seed.

As the results presented here are from only age three years, less than half the envisaged rotation lengths for plantations of these species in the Siloo environment, they will need verification by later age assessments. The use of such results for both identification of preferred seed sources and for selection of seed orchard parents assumes that the traits assessed at this early stage will be well correlated with end of rotation volume and value. Clearly it will be important to quantify these correlations and verify early age selections with later age results through future assessments of these trials. The gains to be obtained from the future crossing between the selected individuals depend largely on the accuracy of selection of the superior trees to be retained in the orchard and the heritability of important traits.

Conclusions

This report presents early results of the first wide-ranging provenance-family trails of *A. crassicarpa, A. mangium* and *E. urophylla* in the Philippines. They emphasise the importance of careful selection of seed sources for plantation establishment. The known inferiority of *A. mangium* from Queensland Cairns region and of *A. crassicarpa* from Queensland was clearly demonstrated in the trials. As well-designed trials containing good genetic material, they provide a partial base for ongoing domestication and tree improvement for three of the Philippine's priority forest plantation species via advanced-generation seedling seed orchards.

However, the genetic variations for other important traits such as wood quality and pest and disease resistance have not yet been examined in these trials. Such variations warrant detailed examination in the Philippines, particularly as there is little information on these traits from this country.

In addition to the value of these provenance-family trails, some of their greatest benefits to both BFI and other exotic plantation initiatives in the Philippines are yet to be realised. Once they have been properly thinned, their future seed production will provide a local source of high quality germplasm for these priority species. This material should offer significant genetic gains over the average of that from good natural stands and local land races, and at a lower cost than imported unimproved natural provenance material.

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