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Growth Performance and Heritability Estimation of *Acacia crassicarpa* in a Progeny Trial in eastern Thailand

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Abstract

Growth performance and heritability were studied in a progeny trial of *Acacia crassicarpa* in Chacheongsao province, eastern Thailand in order to provide information on suitable families for seed improvement and production. A randomized complete block design (originally 8 blocks, 80 family plots/block, 4 trees/plot) of the best 80 half-sib families selected from 7 provenances was thinned at ages 2.5, 4 and 5 years based on growth and tree form and so that there was one tree/plot remained at the stage of present study. All remaining trees were measured for diameter at breast height (DBH), tree height (H), individual volume (VOL) and stem form (straightness and forked height) at ages 12, 12.5, 13 and 13.5 years, respectively. Narrow sense heritability (h^2) based on family was estimated for each characteristic. Analysis of variance showed that there were highly significant differences among families at the four ages for DBH, H and VOL. Stem straightness and forked height were not significantly different among families. The heritability of DBH was increased as trees were mature (h^2 = 0.236, 0.285, 0.288, and 0.291) but those of H and VOL were a little decreased. The heritability of stem straightness was very low (0.013) and that of forked height was also low (0.138). The results implied that the tree breeding of *A. crassicarpa* could improve DBH, H and VOL considerably. Further selection testing is required to increase the heritability of stem form. The measured data would be useful for tree improvement and seed orchard establishment of *Acacia crassicarpa*.

Keywords: *Growth performance, Heritability, Progeny trail, Selection gain, Acacia crassicarpa*

Introduction

Natural forest resources are used for the economic development of country and are often destroyed by people who do not have any arable land. As the consequences, forests have been transformed into agricultural land, resulting in loss of habitats and in particular, loss of commercial tree species. To address the lack of commercial species, many countries, including Thailand, have planted exotic, fast-growing trees that have adapted well to their new environment. Furthermore, such exotic plantations will reduce the relentless pressure to obtain commercial wood products by the ongoing clearing of Thai native ecosystems.

In Thailand, tree improvement has been used to preferred species for increasing the production and quality of wood products based on controlling the hereditability from the parents to their progeny. Forest management may then benefit from the incorporation of the genetically improved progeny in seeds and hedge orchards to provide seeds for future plantations.

Acacia crassicarpa A.Cunn. ex Benth. is a fast-growing tree species that is endemic to Australia, Papua New Guinea and Indonesia which has been trialed and subsequently planted in many parts of Thailand (Luangviriyaseang, 2001). This tree has high potential to be developed as an economic species because it can grow and adapt to many different environments and fix nitrogen from the air to improve the soil. It is tolerant to climatic extremes, and its wood is strong and has many uses such as for furniture, housing and industrial pulp (Jangtrakul et al., 1993).

Progeny testing is an important process in tree improvement programs for the selection of families which have good

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characteristics. Thus, the current study has investigated the growth performance and estimated heritability of *A. crassicarpa* using progeny testing of different families to develop a database for the program of tree improvement and the establishment of a future seed orchard. This study would also provide important information regarding this species' use for plantations, restoration works and industrial raw materials.

Material and Methods

Origin of seedlots

The *A. crassicarpa* progeny trial was containing a total of 80 open-pollinated families representing 7 provenances from CSIRO (Australian Tree Seed Centre) based on selecting one plus tree per family consisting of three families in a provenance in Indonesia, 22 families from two provenances in Queensland, Australia and 55 families from four provenances in Papua New Guinea (Table 1).

Data collection

1. Growth performance

For each tree, the diameter at breast height over bark (DBH) was measured using a diameter tape and the total height of tree (H) was measured using a Haga altimeter at ages 12, 12.5, 13 and 13.5 years and the stem volume over bark (VOL) of each tree was estimated using the formula:

$$\mathrm{VOL}=\frac{1}{3}\pi\left(\frac{\mathrm{DBH}^2}{4}\right)\mathrm{H}$$

2. Stem form

The same researcher scored the stem form of all plus trees of *A. crassicarpa* based on the stem straightness using a visual 4-point scale according to Pinyopusarerk (1990) as follows:

1 = very crooked, two or more serious bends.
2 =slightly crooked, one serious bend and/or >two small bends.
3 = almost straight, one-two small bends.
4 = completely straight.

Table 1
Detail information of the progeny trial of *Acacia crassicarpa* at Ladkrating plantation, Chachoengsao province, Thailand

Region	Family ID	CSIRO seed ID	Origin of mother tree	Latitude		Longitude		Alt. (m)	No. of parent trees
				°	′	°	′		
Indonesia	4-6	17489	Smalleber, Irian Jaya	8	20	141	0	40	3
Queensland Australia	7-10	17943	Oliver River	12	19	142	50	60	4
	11-28	17944	Claudie River	12	48	143	18	20	18
Papua New Guinea	1-3	16597	Gubam Village, WP	8	37	141	55	25	3
	29-43	18937	Oriomo	8	52	143	3	30	15
	44-58	18940	Bimadebum, WP	8	38	143	3	40	15
	59-80	18947	Bensbach, WP	8	53	141	17	25	22

Study site and experimental design

A second generation progeny trial of *A. crassicarpa* was estab lished at Ladkrating plantation, Chachoengsao province, Thailand at latitude13°42′*N* and longitude 101°06′ *E*. The location is rather flat with an elevation of about 80 m above sea level. The soil is a sandy clay loam (sand 48 %, silt 26 % and clay 26 %) and the pH was 3.4-5.4. The mean annual temperature is approximately 28.4°C and the annual rainfall is 1,200 mm. There is a drier period from November to February and the maximum rainfall is in September.

A randomized complete block design was established with 8 blocks in July, 2002 and each block was consisting of 80 plots (families) and each plot was containing 4 trees with spacing of 2m × 4m. One tree per plot was cut when the trees were aged 2.5, 4 and 5 years, respectively. The selection was based on the information of tree form and growth, resulting in 1 tree per plot remaining.

The same researcher estimated the forked height (reflecting the ability of the tree to retain its primary axis) using a visual 6-point scale as follows:

1 = double or multiple leaders (fork) from ground level.
2 = fork in the first (lowest) quarter of the tree.
3 = fork in the second quarter of the tree.
4 = fork in the third quarter of the tree.
5 = fork in the fourth quarter of the tree.
6 = no fork.

3. Total scoring of traits

For combing five traits, all measured data of DBH, H, VOL, stem straightness and forked height were sorted by descending order. The data were standardized relatively to the highest value (= $x_i/x_{highest}$) so that the highest value of each trait was transformed as one. The standardized values for each trait were summed and ranked for the total ranking of growth characteristics at 13.5 years.

Statistical analysis

Analysis of variance was undertaken on DBH, H, VOL, stem straightness and forked height using an *F*-test to determine significance between family means. Duncan's new multiple range test procedure was used to test the significance of the differences between family means. Estimated variance components were determined using the SAS software program (version 9.4; SAS Institute Inc.; Cary, NC, USA).

Heritability estimation

Heritability was originally defined as the proportion of phenotypic variance among individual in a population that is due to heritable genetic effects (Nyquist, 1991). The progenies of each mother tree are half-sibs and the additive genetic variance (V_A) was estimated as $V_A = 4\sigma_f^2$ and the genetic variance among families was σ_f^2. The effects of progeny nested in mother trees were included in the phenotypic variance (V_P). The formula used for the family base and the narrow sense heritability was estimated followed by Lee and Hong (1998) as follows:

$$h^2 = \frac{4\sigma_f^2}{\sigma_f^2 + \sigma_e^2} = \frac{V_A}{V_P}$$

where h^2 is the family base heritability, σ_f^2 is the genetic variance among families and σ_e^2 is the random error.

Results

Diameter at breast height (DBH)

There were highly significant differences in DBH among families (Table 2). The top and low ranking 5 families based on the age 13.5 years are presented in Table 2. The average growth of DBH based on the 80 half-sib families were explained the heterogeneous intervals of 0.35, 0.87 and 0.38 cm at ages 12-12.5, 12.5-13 and 13-13.5 years, respectively. Family number 36 from Oriomo, Papua New Guinea had the largest DBH at all measured ages. On the other hand, the family number 27 from Claudie River, Queensland Australia had the smallest DBH at all measured ages.

At all ages there was an acceptable average of DBH increase and the highest and the lowest families were showing the consistent rank. The DBH of the largest family 36 was increased 0.30, 1.51 and 0.43, and that of the smallest family 27 was increased 0.31, 0.26 and 0.33, respectively, at ages 12-12.5, 12.5-13 and 13-13.5 years. At age 13.5 year, the average DBH of best 5 families was 35.41 cm, which is 58.3 % superior, compared to the average (22.37 cm) of worst 5 families.

Tree height (H)

The general trend for height growth (H) corresponded closely with that for DBH (Table 3 shows the top and low ranking 5 families). The height of family 36 was regarding to the degradation of DBH, showing that family 36 was the best for DBH but

Table 2.
Average of the diameter at breast height (± standard error) of *Acacia crassicarpa* for top and low ranking 5 families based on the age 13.5 years (*F*-value based on overall ranking of 80 half-sib family) at different ages in the progeny test at Ladkrating plantation, Chachoengsao province, Thailand.

Family ID	Rank	Diameter at breast height (cm)			
		12 years	12.5 years	13 years	13.5 years
36	1	35.18±2.56	35.48±2.60	36.99±3.00	37.42±3.07
3	2	33.46±3.46	33.58±3.47	35.27±3.68	35.71±3.56
62	3	33.40±4.91	33.69±4.90	34.63±4.77	34.89±4.73
58	4	33.30±2.96	33.60±2.83	34.25±3.26	34.73±3.33
37	5	32.63±4.66	32.89±4.68	33.90±4.78	34.32±4.72
25	76	22.22±5.12	22.46±5.15	23.08±5.32	23.26±5.34
18	77	21.97±4.61	22.32±4.45	22.89±4.73	23.14±4.80
16	78	21.59±3.64	22.11±3.26	22.46±3.29	22.80±3.24
9	79	21.50±1.75	21.67±1.67	22.11±1.75	22.30±1.76
27	80	19.46±3.76	19.77±3.89	20.03±3.84	20.36±3.72
Average		28.03	28.38	29.25	29.63
F-value		5.56**	5.59**	5.93**	5.96**

** = highly significant at 1% level

Table 3
Average of height (± standard error) of *Acacia crassicarpa* of top and low ranking 5 families based on the age 13.5 years (*F*-value based on overall ranking of 80 half-sib family) at different ages in progeny test at Ladkrating plantation, Chachoengsao province, Thailand.

Family ID	Rank	Height (m)			
		12 years	12.5 years	13 years	13.5 years
64	1	24.65±3.70	24.95±3.83	25.06±3.81	25.20±3.68
57	2	24.24±4.10	24.41±4.04	24.67±4.25	24.72±4.24
2	3	23.97±3.55	24.39±3.37	24.75±3.54	24.87±3.32
3	4	23.76±3.17	24.06±3.24	24.24±3.30	24.38±3.19
62	5	23.70±2.35	23.95±2.5	24.19±2.67	24.35±2.49
36	76	19.63±4.53	20.23±4.23	20.38±4.14	20.19±3.88
14	77	17.55±3.62	17.79±3.64	18.01±3.58	18.16±3.49
27	78	17.03±2.46	17.34±2.36	17.65±2.5	17.79±2.49
18	79	16.56±2.43	16.74±2.5	16.94±2.5	17.13±2.42
25	80	16.27±3.59	16.42±3.57	16.84±3.46	16.94±3.46
Average		20.84	21.12	21.32	21.49
F-value		2.08**	2.17**	2.1**	2.23**

** = highly significant at 1% level

very poor in tree height. There were highly significant differences in H among families. The average differences of H based on the 80 half-sib families were explained the heterogeneous intervals (0.28, 0.20 and 0.17 m) at ages 12-12.5, 12.5-13 and 13-13.5 years, respectively. Family number 64 from Benbach WP, Papua New Guinea had the tallest H at all measured ages and family number 25 from Claudie River, Queensland, Australia had the shortest H at all measured ages.

At all ages there was an acceptable average H range with the families having the highest and the lowest H remaining consistent throughout with the tallest being family 64 was increased 0.30, 0.11 and 0.14 m, respectively and the shortest being family 25 was increased 0.15, 0.42 and 0.10 m, respectively. At age 13.5 years, the average height of best 5 families was 24.70 m, which is 36.9 % superior, compared to the average (18.04 m) of worst 5 families.

Tree volume (VOL)

There were highly significant differences in volume growth (VOL) among families (Table 4). The averages of VOL based on the 80 half-sib families were explained the heterogeneous intervals (0.02, 0.03 and 0.02 m^3) at ages 12-12.5, 12.5-13 and 13-13.5 years, respectively. Family number 3 from Gubam Village, WP, Papua New Guinea had the largest VOL at all measured ages and family number 27 from Claudie River, Queensland, Australia had the smallest VOL at all measured ages.

At all ages there was an acceptable average of VOL range with the families having the highest and lowest VOL remaining consistent throughout with the largest being family 3 was increased 0.014, 0.080 and 0.023 m, respectively and the smallest being family 27 was increased 0.010, 0.008 and 0.008 m^3, respectively. At age 13.5 years, the average volume of best 5 families was 0.75 m^3, which is 200.1% superior, compared to the average (0.25 m^3) of worst 5 families.

Stem form (stem straightness and forked height)

Stem straightness of *A. crassicarpa* was not significantly different among families (Table 5). The average stem straightness score for all 80 half-sib families was 2.96. At age 13.5 years, family number 21 from Claudie River, Queensland, Australia showed the best stem straightness whereas family number 23 from Claudie River, Queensland, Australia (the same provenance) had the poorest stem straightness.

Forked height of *A. crassicarpa* also was not significantly between families (Table 6). The average forked height score for all 80 half-sib families was 3.21. At age 13.5 years, family number 56 from Benbach WP, Papua New Guinea showed the best forked height whereas family number 11 from Claudie River, Queensland, Australia had the poorest stem straightness.

Total ranking of growth characteristics

The score summation of growth characteristics of *A. crassicarpa* families at 13.5 years indicates that the best ranking family was Family 31 and the order of ranking is shown in Table 7. All of the top ranking families were originated from the provenance of Papua New Guinea.

Table 4
Average of tree volume (± standard error) of *Acacia crassicarpa* of top and low ranking 5 families based on the age 13.5 years (*F*-value based on overall ranking of 80 half-sib family) at different ages in progeny test at Ladkrating plantation, Chachoengsao province, Thailand.

Family ID	Rank	VOL (m^3)			
		12 years	12.5 years	13 years	13.5 years
3	1	0.698±0.15	0.712±0.15	0.792±0.17	0.815±0.16
62	2	0.686±0.13	0.705±0.12	0.752±0.12	0.769±0.12
37	3	0.660±0.17	0.678±0.17	0.726±0.19	0.747±0.19
38	4	0.627±0.23	0.651±0.23	0.704±0.27	0.727±0.27
44	5	0.624±0.25	0.655±0.26	0.696±0.28	0.714±0.29
16	76	0.240±0.14	0.255±0.14	0.269±0.15	0.276±0.15
25	77	0.236±0.14	0.243±0.14	0.264±0.15	0.270±0.15
9	78	0.233±0.05	0.239±0.05	0.252±0.05	0.257±0.05
18	79	0.217±0.09	0.225±0.09	0.241±0.10	0.249±0.10
27	80	0.179±0.08	0.189±0.08	0.197±0.09	0.205±0.09
Average		0.45	0.47	0.50	0.52
F-value		4.69**	4.93**	5.08**	5.09**

** = highly significant at 1% level

Table 5
Average of stem straightness (± standard error) of *Acacia crassicarpa* of top and low ranking 5 families (*F*-value based on overall ranking of 80 half-sib family) at 13.5 years in progeny test at Ladkrating plantation, Chachoengsao province, Thailand.

Family ID	Rank	Stem straightness
21	1	3.63±0.92
63	2	3.57±0.79
19	3	3.50±0.84
8	4	3.50±1.62
12	5	3.50±0.76
43	76	2.43±0.53
67	77	2.43±0.79
38	78	2.38±0.74
10	79	2.38±0.74
23	80	1.75±0.46
Average		2.96
F-value		0.79ns

ns = not significant

Table 6.
Average of forked height (± standard error) of *Acacia crassicarpa* of top and low ranking 5 families (*F*-value based on overall ranking of 80 half-sib family) at 13.5 years in progeny test at Ladkrating plantation, Chachoengsao province, Thailand.

Family ID	Rank	Forked height
56	1	4.43±0.53
67	2	4.43±0.96
31	3	4.00±0.53
32	4	4.00±0.82
76	5	3.86±0.38
23	76	2.50±0.53
26	77	2.38±0.52
9	78	2.38±0.52
7	79	2.33±1.37
11	80	2.28±0.49
Average		3.21
F-value		0.96^{ns}

^{ns} = not significant

By selection of top 10 superior families of *A. crassicarpa*, genetic response (selection gain) could be achieved as 15.66% for DBH, 6.92 % for H, 37.74% for VOL and 9.38 % for forked height, which were considerably high compared to stem straightness (Table 7).

Heritability estimation

Estimates of family base heritability for DBH, H, VOL, stem straightness and forked height were moderately high at all ages (Table 8). At age 12 years, the heritability of DBH, H and VOL were 0.236, 0.421 and 0.361, respectively. Those were generally consistent with the other three measured ages which also showed similar trends (0.285, 0.403 and 0.361 at 12.5 years; 0.288, 0.401 and 0.355 at 13 years; and 0.291, 0.403 and 0.338 at 13.5 years, respectively).

However, the heritability of stem straightness was very low (0.013) and that of forked height was also low (0.138), which was measured at age 13.5 years is presented in Table 8.

Table 7
The scoring of each traits and ranking of top 10 *Acacia crassicarpa* families at 13.5 years and selection gain when the 10 families are selected in the progeny test at Ladkrating plantation, Chachoengsao province, Thailand.

Family ID	Provenance	DBH	H	VOL	Stem straight-ness	Forked height	Total score*	Total rank
31	Oriomo	0.904	0.915	0.860	0.895	0.903	4.477	1
36	Oriomo	1.000	0.801	0.921	0.906	0.806	4.434	2
37	Oriomo	0.917	0.959	0.917	0.826	0.790	4.410	3
3	Gubam village WP	0.954	0.967	1.000	0.826	0.650	4.398	4
54	Bimadebum WP	0.925	0.928	0.901	0.826	0.763	4.344	5
62	Bensbach WP	0.932	0.966	0.944	0.689	0.790	4.322	6
39	Oriomo	0.886	0.863	0.797	0.887	0.828	4.262	7
58	Bimadebum WP	0.928	0.882	0.846	0.895	0.707	4.258	8
56	Bimadebum WP	0.844	0.863	0.717	0.826	1.000	4.251	9
57	Bimadebum WP	0.868	0.981	0.863	0.826	0.652	4.191	10
Average		0.916	0.912	0.876	0.840	0.793	4.333	
Grand mean		0.792	0.853	0.636	0.816	0.725	3.821	
Selection gain (%)		15.66	6.92	37.74	2.94	9.38		

* Total score : sum of all scores from traits (DBH, H, VOL, Stem straightness and Forked height)

Table 8
Families base heritability estimates of *Acacia crassicarpa* at different ages in the progeny test at Ladkrating plantation, Chachoengsao province, Thailand.

Traits	Heritability			
	12 years	12.5 years	13 years	13.5 years
DBH	0.236	0.285	0.288	0.291
Height	0.421	0.403	0.401	0.403
Volume	0.361	0.361	0.355	0.338
Stem straightness				0.013
Forked height				0.138

Discussion

The results of this study showed that there were highly significant differences in growth performances among the 80 families of *A. crassicarpa*. All of four ages had a similar trend in terms of their DBH, H and VOL and the families at 13.5 years (the oldest in this study) showed the best growth performance.

The trees had adapted and were growing well in the suitable environmental and climatic conditions (i.e., rainfall, temperature, soil and altitude) of this study site. The ranking of the top 10 families was determined from five characteristics (DBH, H, VOL, Stem straightness and forked height). All of the top-10 families were from the Papua New Guinea provenance and family number 31 (Oriomo, Papua New Guinea) had the highest total score. These results are similar to those of Maelim (2012) who studied *A. crassicarpa* in Ladkrating plantation, Chacheongsao province, Thailand at age 5 years, He reported that family number 36 (Oriomo, Papua New Guinea) had the highest averages of DBH (21.23 cm) and volume (0.1897 m3). Furthermore, the study also reported that family number 56 (Bimadebum WP, Papua New Guinea) had the tallest average of tree height (17.63 m).

The results of the current study when compared with those from studies in other countries such as in Malaysia (Awang et al, 1995) and on Hainan Island, China (Minquan and Yutain, 1991) suggest that *A. crassicarpa* from the Papua New Guinea provenance grew better than the other provenances. Moreover, the current results indicated that the most families from Papua New Guinea could grow vigorously on the study site in Thailand.

In the current study, stem straightness had moderate scores. Although single-stemmed trees could be found, they tended to retain one or more upright branches, especially on the lower part of the stem. These upright branches were competing leaders at the early stage of development and, even after the main leader had assumed its dominance, they remained visible on the lower part of the main stem of mature trees. These characteristics are undesirable as far as utilization and timber quality are concerned.

The results indicated that forked height had ranking scores between 2 (the first quarter of the tree) and 4 (the third quarter of the tree) that were similar to those reported by Roongrattanakul et al. (1999) for *A. crassicarpa* in Kanchanaburi province, Thailand. Luangviriyasaeng and Pinyopusarerk (2002) discussed *Acacia* species tested in Thailand and noted they tended to produce multiple leaders and crooked stems, which limited their use as poles or others forms of timber that require reasonable length. They also noted that repeated forking often occurs with multiple stems which further reduce the usability of each individual stem.

Based on the need for increasing availability of suitable economic species that are suited to Thailand's climatic and edaphic conditions, the current progeny trial results on the heritability of the growth and form characteristics of *Acacia crassicarpa* have shown that there was considerable potential for further provenance selection to grow plantations with improved diameter at breast height (DBH), total height (H) and tree volume (VOL). Maelim (2012) reported similar heritability trends for the same five growth traits for the same species at the current study site at age 5 years. Specifically, he reported heritability values for DBH, H and VOL of 0.16, 0.23 and 0.14, respectively. Arnold (2003) reported the *A. crassicarpa* heritability value of growth was 0.15, which was less than for the current study, while his heritability value for stem straightness was 0.25, which was higher than in the current study.

Heritability values with the range of 0.2 to 0.4 or higher are considered to be worthwhile using in tree improvement programs (Holland et al., 2003). The ranges of heritability scores at the age of 12 to 13.5 years for DBH (0.236-0.291), H (0.401-0.421) and VOL (0.338-0.361) suggested that there was potential for improvement in these three parameters through a suitably designed tree improvement program. However, the low heritability values for stem straightness (0.013) and forked height (0.138) indicated a need for further research on stem form as other researchers have reported different values. There is sufficient merit in using these traits in future tree improvement programs to increase utility and returns from the future plantations of *A. crassicarpa*.

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