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Original Article

Growth variation and heritability in a second-generation *Eucalyptus urophylla* progeny test at Lad Krating Plantation, Chachoengsao province, Thailand

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A B S T R A C T

In Thailand, *Eucalyptus urophylla* was introduced with the main purpose of supplying raw material for pulp and chip wood production. The demand for genetically improved seed is increasing to support high productivity plantation establishment. One of the tree improvement activities established to meet the high demand for improved seed was a second generation progeny test at Lad Krating Plantation, Thailand to provide the best material for the successful plantation program. The aim of the current study was to compare growth variation of the first and second generation of *Eucalyptus urophylla* progeny that could provide information on suitable families for improved quality seed. The progeny test comprised the best 45 half-sib families selected from 80 half-sib families of the first-generation progeny test. The design of the progeny test was a randomized and complete block design (16 trees/plot × 45 plots/block × 9 blocks), with 4 rows of 4 trees at a spacing of 2 m × 1 m. Growth was assessed at age 3 yr. The average height and diameter at breast height over bark (DBH), was 13.72 m, and 8.75 cm, respectively. There were highly significant ($p < 0.01$) differences among provenances and families in both height and DBH. The individual heritability values for height and DBH were 0.48 and 0.60, respectively. The family heritability values for height and DBH were 0.98 and 0.99, respectively. These 45 half-sib families proved to be genetically superior ensuring higher productivity and contributing to the success of the Forest Industry Organization plantation at Lad Krating.

Introduction

Eucalyptus urophylla S.T. Blake is native to islands of the Indonesian Archipelago, Timor, distributed in the southeast, scattered around the islands of Timor and Flores and is exotic to Australia, Brazil, Cameroon, China, Congo, Cote d'Ivoire, French Guiana, Gabon, Madagascar, Malaysia, Papua New Guinea, and Vietnam where it has also been planted (Orwa et al., 2009; Li et al., 2015). *E. urophylla* occurs over a wide altitudinal range from about 300 to about 3000 m in areas with an annual rainfall of 700–2500 mm and a mean annual temperature range of 2–28 °C and a mature tree can reach 25–45 m and under favorable conditions can reach 50 m in height and a diameter at breast height over bark (DBH) of over 2 m (Joker, 2004).

In tropical regions, *E. urophylla* is grown in industrial plantations to produce wood for a diverse range of products such as pulp, sawn timber and fuel wood (Joker, 2004). In Thailand, *E. urophylla* was introduced with the main purpose of supplying raw material for pulp and chip wood production (Maid and Bhumibhamon, 2009). The demand for genetically improved seed is increasing to support high productivity plantation establishment but insufficient seed supply of suitable species is often seen as a major bottleneck for the development of planting programs (Granhof, 1991). To meet the high demand for improved seed, the Forestry Industry Organization (FIO) in its Lad Krating Plantation started a tree improvement program for *E. urophylla* in 1988. The seeds from 188 selected plus trees from *E. urophylla* provenance trials were planted and tested for initial survival and growth rates. In 2002, a progeny test (first generation) was established from the best-performing, 80 half-sib families which were selected from the 188 plus trees. A second-generation progeny test was established in 2012 with early

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selections from the first-generation progeny test with the best 45 half-sib families selected from the 80 half-sib families.

Although *E. urophylla* has become an important species in Thailand's forestry industry, there is a lack of improved quality seed and reliable genetic information to support a future successful plantation program in Thailand. Genetic information is required to assist in formulating the efficient operation of a breeding program through which the quality and productivity of plantations may be improved. The aim of the current study was to compare growth variation in the first and second generations of *E. urophylla* progeny tests that could provide information on suitable families for improved quality seed.

Materials and method

Study area

The second generation progeny test of *E. urophylla* was established at Lad Krating Plantation (13°42' N, 101°06 E; altitude above mean sea level, 180 m; annual rainfall, 1220 mm; and mean annual temperature, 28 °C) in Chachoengsao province, Thailand. The soil was a sandy clay loam of the Clayey-skeleton, Kaolinite, Aeric Kanhapustult Series.

Experimental design

The second generation progeny test consisted of 45 half-sib families selected from the first generation progeny test of *E. urophylla* as shown in Table 1. The second generation progeny test was laid out using a randomized complete block design in nine replications or blocks, with each block consisting of 45 plots with 45 families in a plot, planted with 4 rows of 4 trees at a spacing of 2 m between trees and 1 m between rows. Initially, there were 16 trees per plot. The rogueing in the first year retained 8 trees in each plot out of 16 trees, at age 2 yr, 4 trees per plot were retained out of 8 trees, and at age 3 yr, the 2 best trees per plot were retained out of the 4 trees.

Data collection

Assessments of total height and DBH were conducted at age 3 yr. The total height was measured using a Haga, while DBH was measured at 1.3 m above the ground for each standing tree using a measuring tape.

Data analysis

All statistical analyses were carried out using Statistical Analysis Systems software (SAS Inst. Inc., 2004). The data were subjected to analysis of variance using the statistical model to investigate variations in provenance, family and their interactions. Duncan's new multiple range test was used for the comparison of means at a significance level of $p < 0.01$. The statistical model for family differences is shown in Eq. (1) (Espahbodi et al., 2008):

$$Y_{ijkl} = \mu + \beta_i + \eta_j + \alpha_{k(j)} + \eta_j\beta_i + \alpha_{k(j)}\beta i + \rho_{ijkl} \quad (1)$$

where Y_{ijk} is the phenotype value of the sth progeny of the kth family with the jth provenance in the ith block; μ is the overall mean; β is the effect of the ith block; η_j is the effect of the jth provenance; $\alpha_{k(j)}$ is the effect of the kth family within the jth provenance; $\alpha_{k(j)}\beta i$ is the interaction effect of the ith block and kth family within the jth provenance; and ρ_{ijkl} is the within plot variation.

Heritability assessment

Individual tree heritability of height and diameter were also estimated across and within each planting zone. The progenies of each mother tree are half-sibs and additive genetic variances σ_A^2 were estimated as $\sigma_A^2 = 4\sigma_f^2$, where σ_f^2 is the genetic variance among families within a population (Falconer and Mackay, 1996). The effects of progeny nested in mother trees were included in the phenotypic variance. The formula used for the individual tree base and family base narrow sense heritability is shown in Eqs (2) and (3), respectively, (Sebbenn et al., 2003):

$$h_1^2 = \frac{4\sigma_{F(P)}^2}{\sigma_w^2 + \sigma_{F(P)B}^2 + \sigma_{F(P)}^2} \quad (2)$$

$$h_F^2 = \frac{\sigma_{F(P)}^2}{\frac{\sigma_w^2}{bps} + \frac{\sigma_{F(P)B}^2}{bp} + \sigma_{F(p)}^2} \quad (3)$$

where h_1^2 is individual base heritability; h_F^2 is the family base heritability; σ_w^2 is the random error variance; $\sigma_{F(P)B}^2$ is the within family variance components; and $\sigma_{F(P)}^2$ is the among family variance components.

To identify the best and the worst overall provenance at 3 yr, ordinal ranking was developed based on the method described by Edward et al. (2014). This was done as follows, For each variable evaluated, provenances were assigned ranks from the best (assigned 1 point) to the worst (assigned 45 points) performing provenance. Thereafter, ranks were added, then averaged and the overall score was taken as a basis of the overall provenance ranking.

Results

Growth performance

The results from the analysis of variance are presented in Table 2. At 3 yr, the average height of all trees was 13.72 m and the mean height ranged between 11.75 m in family 5 (Mandiri Flores) to 15.37 m in family 27 (Lelogama Timor). The variation in height performance among provenances and families was highly significant ($p < 0.01$). The average DBH of all trees was 8.75 cm and ranged from 6.71 cm in family 15 (Mt Egon, Flores) to 10.04 cm in family 4 (Wasbilla Panter). The variation in DBH was highly significant ($p < 0.01$) among provenances and families. There were also significant ($p < 0.05$) differences in the DBH values among blocks.

Heritability

The results of individual and family tree heritability are presented in Table 3. At age 3 yr, the individual heritability values for height and DBH were 0.48 and 0.60, respectively. Family heritability values for height and DBH were 0.98 and 0.99, respectively.

Ordinal ranking of tree variables

The ranking of families for the two tree variables (average height and average DBH) were computed and the family provenances were ranked as shown in Table 4. The 10 best families were: No. 4, Mt. Wokoh Flores; No. 18, Mt. Egon Flores; No. 28, Kalabahi Alor; No. 25, Mt. Wasbilla Panter; No. 44, Mt. Wulogai Flores; No. 24, Ampui Alor; No. 19, Hatuloi Wetar; No. 26, Ermera Timor; No. 27, Lelogama Timor; and No. 43, Mt. Lewotobi Flores.

Table 1
Plus tree of *Eucalyptus urophylla* S.T. Blake provenances tested in the progeny tests, at Lad Krating Plantation, Chachoengsao Planted in 2012.

Family number	Progeny code	Block	Plus tree registration code	Provenances	Seed weight (g)
1	18	1	TK0114 Eu 0049	Mt. Lewotobi, Flores	25
2	24	1	TKO114 Eu 0056	Mt. Lewotobi, Flores	50
3	40	1	TKO114 Eu 0093	Mt. Sirungi. Pantar	350
4	55	1	TKO 114 Eu 0199	Mt. Wokoh, Flores	120
5	60	1	TKO 114 Eu 0129	Mt. Mandiri.Flores	20
6	71	1	TKO114 Eu 0151	Ermera, Timor	25
7	9	2	TKO114 Eu 0021	Mt. Egon, Flores	325
8	11	2	TKO114 Eu 0024	Mt. Sirungi. Pantar	100
9	23	2	TKO114 Eu 0055	Mt. Wasbilla, Panter	35
10	26	2	TKO114 Eu 0062	Mt. Egon, Flores	40
11	58	2	TKO114 Eu 0127	Mt. Kerbau. Lomblem	40
12	8	3	TKO114 Eu 0020	Ermera, Timor	30
13	10	3	TKO114 Eu 0023	Mt. Egon, Flores	20
14	60	3	TKO114 Eu0129	Mt. Mandiri. Flores	125
15	74	3	TKO114 Eu 0163	Mt. Egon, Flores	240
16	8	4	Tko114 Eu 0020	Ermera, Timor	55
17	10	4	TKO114 Eu 0023	Mt. Egon, Flores	25
18	29	4	TKO114 Eu 0067	Mt. Egon, Flores	20
19	50	4	TKO114 Eu 0111	Hatuloi. Wetar	35
20	60	4	TKO114 Eu 0129	Mt. Mandiri. Flores	85
21	31	5	TKO114 Eu 0072	Ermera, Timor	600
22	39	7	TKO114 Eu 0086	Remexoi. Timor	20
23	75	7	TKO114 Eu 0167	Mt. Egon, Flores	165
24	2	8	TKO114 Eu 0004	Ampui. Alor	50
25	14	8	TKO114 Eu 0030	Mt. Wasbilla, Panter	75
26	31	8	TKO114 Eu 0072	Ermera, Timor	40
27	66	8	TKO114 Eu 0140	Lelogama, Timor	15
28	78	8	TKO114 Eu 0175	Kalabahi, Alor	35
29	2	9	TKO114 Eu 0004	Ampui. Alor	320
30	12	9	TKO 114 Eu 0026	Mt. Sirungi. Pantar	85
31	12	9	TKO114 Eu 0041	Kalabahi, Alor	40
32	16	9	TKO114 Eu 0055	Mt. Wasbilla, Panter	30
33	32	9	TKO114 Eu 0074	Ermera, Timor	155
34	32	9	TKO114 Eu 0075	Mt. Wokoh, Flores	260
35	3	10	TKO114 Eu 0005	Ampui. Alor	60
36	18	10	TKO114 Eu 0049	Mt. Lewotobi, Flores	100
37	75	10	TKO114 Eu 0167	Mt. Egon, Flores	220
38	6	11	TKO114 Eu 0014	Mt. Lewerok, Flores	40
39	11	11	TKO114 Eu 0024	Mt. Sirungi. Pantar	80
40	24	11	TKO114 Eu 0056	Mt. Lewotobi, Flores	20
41	29	11	TKO114 Eu 0067	Mt. Egon, Flores	30
42	37	11	TKO114 Eu 0083	Mt. Wulogai. Flores	40
43	43	11	TKO114 Eu 0097	Mt. Lewotobi, Flores	60
44	49	11	TKO114 Eu 0110	Mt. Wulogai. Flores	40
45	28	12	TKO114 Eu 0066	Mt. Kerbau. Lomblem	55

Table 2
Results from analysis of variance for height and diameter in 3-year-old second generation progeny test of *Eucalpytus urophylla* planted in Lad Krating Plantation, Chachoengsao.

Source	Degrees of freedom	Height (F value)	DBH (F value)
Block	8	81.21[b]	2.01[a]
Provenance	14	8.14[b]	10.33[b]
Block*Provenance	112	1.83[b]	1.56[b]
Family	44	8.84[b]	8.92[b]
Block*Family	352	2.34[b]	1.62[b]

[a] Significant difference at $p < 0.05$.
[b] Highly significant difference at $p < 0.01$.

Table 3
Individual heritability and family heritability for height and DBH at 3 yr for second-generation progeny test of *Eucalyptus urophylla* at Lad Krating Plantation, Chachoengsao.

	Heritability	
	Height	DBH
Individual heritability	0.48	0.60
Family heritability	0.98	0.99

DBH = Diameter at breast height over bark.

Discussion

The results of this study showed that the provenances and families in most cases were highly significantly different in growth variables. The families in the second-generation progeny test showed better growth variation than those from the first-generation progeny test, implying genetically inherent characteristics. Such variation would be expected from tree species with a wide geographical distribution (Ginwal, 2009). The selection of the superior families for further utilization can be effective at this stage. The average total height was high when compared with studies in other tropical countries (Arnold and Cuevas, 2003; Hodge and Dvorak, 2015). The DBH results agreed well with previously published studies on genetic variation in early growth, stem straightness and survival of *Acacia crassicarpa*, *A. mangium* and *Eucalyptus urophylla* in Bukidnon province, the Philippines (Arnold and Cuevas, 2003). The first generation of *Eucalyptus urophylla* at 3 yr at the same planting site had a low average height and high DBH compared with the current study Maid and Bhumibhamon (2009). The reason for these differences is that the growth height increment of a tree depends on the genetic improvement conducted on the tree (Dieguez-Aranda et al., 2006; Ngaga, 2011). The

Table 4
Ordinal ranking of tree variables showing differences between second-generation progeny test of *Eucalyptus urophylla* S.T. Blake at 3 yr after planting in Lad Krating Plantation, Chachoengsao.

Family	Provenance	Height	DBH	Mean	Overall rank
4	Mt. Wokoh, Flores	1	1	1.0	1
18	Mt. Egon, Flores	2	2	2.0	2
28	Kalabahi, Alor	5	3	4.0	3
25	Mt. Wasbilla, Panter	3	6	4.5	4
44	Mt. Wulogai. Flores	7	4	5.5	5
24	Ampui. Alor	4	8	6.0	6
19	Hatuloi. Wetar	8	5	6.5	7
26	Ermera, Timor	12	10	11.0	8
27	Lelogama, Timor	1	21	11.0	9
43	Mt. Lewotobi, Flores	10	13	11.5	10
23	Mt. Egon, Flores	6	18	12.0	11
39	Mt. Sirungi. Pantar	16	14	15.0	12
29	Ampui. Alor	22	9	15.5	13
3	Mt. Sirungi. Pantar	20	12	16.0	14
8	Mt. Sirungi. Pantar	16	16	16.0	15
12	Ermera, Timor	25	7	16.0	16
21	Ermera, Timor	17	17	17.0	17
10	Mt. Egon, Flores	24	11	17.5	18
34	Mt. Wokoh, Flores	15	20	17.5	19
31	Kalabahi, Alor	18	18	18.0	20
14	Mt. Mandiri. Flores	10	27	18.5	21
22	Remexoi. Timor	14	25	19.5	22
30	Mt. Sirungi. Pantar	13	26	19.5	23
17	Mt. Egon, Flores	23	22	22.5	24
42	Mt. Wulogai. Flores	31	14	22.5	25
16	Ermera, Timor	21	28	24.5	26
2	Mt. Lewotobi, Flores	19	31	25.0	27
36	Mt. Lewotobi, Flores	28	23	25.5	28
1	Mt. Lewotobi, Flores	26	30	28.0	29
33	Ermera, Timor	27	29	28.0	30
11	Mt. Kerbau. Lomblem	29	35	32.0	31
41	Mt. Egon, Flores	32	32	32.0	32
7	Mt. Egon, Flores	33	33	33.0	33
40	Mt. Lewotobi, Flores	35	31	33.0	34
35	Ampui. Alor	33	34	33.5	35
45	Mt. Kerbau. Lomblem	34	36	35.0	36
20	Mt. Mandiri. Flores	40	37	38.5	37
5	Mt. Mandiri. Flores	39	39	39.0	38
38	Mt. Lewerok, Flores	38	41	39.5	39
6	Ermera, Timor	40	40	40.0	40
32	Mt. Wasbilla, Panter	43	38	40.5	41
9	Mt. Wasbilla, Panter	41	42	41.5	42
15	Mt. Egon, Flores	39	45	42.0	43
37	Mt. Egon, Flores	42	43	42.5	44
13	Mt. Egon, Flores	44	44	44.0	45

lower DBH in the second-generation progeny test may have been due to the stocking densities caused by thinning (Wei and Borralho, 1998). Thinning has a strong effect on DBH but less effect on height growth (West and Osier, 1995). Heritability for growth traits increases with age in the most widely planted *Eucalpytus* species (Wei and Borralho, 1998; Kien et al., 2009; Cappa et al., 2010). The estimated individual heritability and family heritability for height and DBH were higher when compared with the results found in Southeast China on genetic control of traits of *Eucalyptus urophylla* (Wei and Borralho, 1998) and variation in growth of *Eucalyptus camaldulensis* provenances in Thailand (Pinyopusarerk et al., 1996). The high heritability in the present study indicated that the best families can be precisely identified at age 3 yr and it also showed that genetic factors strongly influenced the amount of variation. The high heritability indicated that selection of superior families would be very efficient and effective at 3 yr (Ginwal, 2009). The selection of growth traits in *Eucalyptus urophylla* could be effective even when based on phenotypic selection. Santos et al. (2014) added that high heritability enables greater dynamism in the breeding program, allowing recombination of the best individuals in a shorter period of time. The estimated individual heritability and family heritability for height was lower than for DBH; similar results were observed in some tropical hardwoods (Maid and Bhumibhamon, 2009; Nirsatmanto, 2012; Naiem and Purnomo, 2014), though other studies reported that individual heritability for height was higher than for DBH in some other tropical hardwoods. (Hodge et al., 2002; Sotelo et al., 2006; Rochon et al., 2007). The family heritability estimate of the first-generation trial in the same planting zone was high (Maid and Bhumibhamon, 2009) when compared with the second-generation trial. Brawner et al. (2010) confirmed that fewer trees per plot reduced silvicultural intensity. The impact of differential outcrossing rates on heritability estimates has been discussed at length by Eldridge et al. (1993).

Ordinal ranking values showed that the 10 top families grew well under the climatic conditions of the study and they originated from the islands of Flores, Alor, Panter, Timor and Wetar. They also showed a great improvement from the first generation of *Eucalpytus urophylla*. Maid and Bhumibhamon (2009) reported that most promising families were from the islands of Flores, Alor and Lomblen. This indicated that the rainfall, temperature, soil and altitude of the study sites were within the optimal range for the survival and growth of the families. Numerous studies have reported on the good performance of the Mt. Egon and Mt. Lewotobi sources from Flores Island (Wei, and Borralho, 1998; Kien et al., 2009 and Hodge and Dvorak, 2015).

In the current study, families and provenances showed significant growth traits for the 45 families of *Eucalpytus urophylla*, indicating that each family had a different growth rate and this would provide an opportunity to support a breeding program in the future. The results obtained from this test indicated that genetic differences exist among the provenances, while the provenances from the islands of Flores, Alor, Panter, Timor and Wetar showed good performance. Heritability was high at the family level, suggesting that selection of the best families would be possible at an early stage. The final rogueing should be done in order to convert the progeny test to a seedling seed orchard and intensive management practices should be applied in order to increase the quality of planting materials. These 45 half-sib families have proved to be genetically superior and thus ensuring higher productivity and contributing to the success of the FIO-Lad Krating Plantation.

Conflict of interest

None.

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