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Early Growth of *Acacia mangium* × *Acacia auriculiformis* Hybrid Clonal Trials Established at Three Different Sites in Indonesia

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Abstract

Understanding how Acacia mangium × A. auriculiformis hybrid clones respond to different environments through a multi-site test is necessary. This study observed the early growth of the hybrids in clonal trials established in Central Java, Riau, and Jambi. The trials were laid out in a randomized complete block design: 20−44 clones (nine clones in common), 4−20 replications, tree spacing of 3 × 3m or 3 × 2m. Height, diameter at breast height and stem volume were assessed at two years of age. The results show that the growth rates of hybrid clonal trials in Riau and Jambi are higher than the rates in Central Java. Several significant differences were found among the clones for all traits with high clone repeatability (0.91−0.97) and ramet repeatability (0.49−0.69). Clone × site interaction was highly significant and affected a lower multi-site clone repeatability (0.30−0.70) and ramet repeatability (0.07−0.24). The top two clones and consistent ranking order across the three sites of clonal trial for volume were Clones 44 and Clone 42. The results implies the important strategies for deploying Acacia hybrid clones, but it will take more than two years for a clear pattern of differences between clones to emerge.

Keywords: clones × site interaction, repeatability, multi-site analysis, Acacia hybrid

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Introduction

Large areas in the commercial plantations of *Acacia mangium* in Indonesia have recently been destroyed by pest and disease, and now species planted in most of the areas were being replaced by *Eucalyptus pellita* (Brawner *et al.* 2015; Hardiyanto *et al.* 2015; Harwood *et al.* 2015). Exploring and developing other alternative species are then still necessary in which one of the potential species is *Acacia* hybrids. Crosses among *Acacia* species have been developed from natural or artificial hybridization between *A. mangium* and *A. auriculiformis*, which have been reported showing good growth potential and are being wide adapted to a range of sites and environments (Kha 2001; Le & Ha 2017). *Acacia* hybrids have been commercially grown in plantations in Malaysia (Ibrahim 1993) and Vietnam (Bueren 2004), and become a promising species in Thailand (Luangviriyasaeng 2007).In Indonesia, besides over coming in pests and diseases that attack the *A. mangium*, the *Acacia* hybrids are being developed as one of the potentially adaptive species in some adverse environment conditions (Sunarti *et al*. 2013).

The exploration of hybrid vigour for the *Acacia* hybrids is commonly associated with the better growth, a straighter main stem, lighter branches, softer bark, and being more tolerant to pests and diseases than the parent species of *A. mangium* (Galiana *et al.* 2003; Nikles *et al.* 1998). Moreover, some studies have reported that basic density, cellulose content, lignin content, and pulp yield are also considered more suitable for the pulp and paper industry than those found in *A. mangium* (Kato *et al.* 2014; Kato *et al.* 2012; Khalid *et al.* 2010; Rokeya *et al.* 2010; Sunarti *et al.* 2014; Yahya *et al.* 2010).

Studies in developing *Acacia* hybrids through control crossed between *A. mangium* and *A. auriculiformis* revealed that the growth performance widely varies among the hybrid progenies (Sunarti *et al*. 2013). In this case, clonal propagation of hybrid trees selected from a hybrid vigor trial seemed to be the best way to capture the hybrid vigor of *Acacia* hybrid. However, before mass scale propagation and commercial are released, the hybrid clones should undergo the extensive screening and selection based on those that perform the best across many sites, as some can be sensitive to site condition (Frampton & Foster 1993; Sein & Mitlohner 2011). A well-planned clonal trial is then necessary to find the promising clones, which show stable and best growth performances in various site conditions (Frampton & Foster 1993). While this practice is well-developed in Vietnam (Kha *et al.* 2012), no parallel examination of potential *Acacia* hybrids have been reported for Indonesia.

In some management practices, plantation establishment through clonal forestry provides some advantages, such as increasing stand productivity, uniform plantation to reduce the costs of harvest, and produce uniform products (White *et* *al*. 2007). However, to capture these management advantages, the selection of planting stock that genetically performs well in the target sites of the plantation is necessary during the establishment. Therefore, the exploitation of genotype × environment interaction through the site-specific deployment of tested clones to edaphoclimatic conditions should be conducted (White *et al.* 2007).

In this paper, the early growth of *Acacia* hybrids was observed in clonal trials established in three different sites in Indonesia: Central Java, Riau, and Jambi. The effect of clone × site interaction was then assessed through a multi-site analysis across the three sites of trial enabling the selection of stable and optimum clones across the trials and the best clones within atrial. To maximize the benefit of these trials and to best understand the relationship between clonal performance and environment, the site of trials were selected to ensure differences in climate and soil condition.

Methods

Forty-four clones developed from artificial hybrids between the parental species of *A. mangium*×*A. auriculiformis* were propagated through shoot cuttings and used as the genetic material for clonal trials. The hybridization was done in a breeding garden at the Centre for Forest Biotechnology and Tree Improvement (CFBTI) in Yogyakarta. *A. mangium* was used as the female (*pollen receptor*) and *A. auriculiformis* as the male (*pollen donor*). The parental species trees were selected from plus trees in first-generation seedling seed orchards (SSO) of *A. mangium* (3.5 ha) and *A. auriculiformis* (2.1ha) in Wonogiri, Central Java; each of which had been established in 1994 and 1995, respectively (Ministry of Forestry 2004). Control crossed and clonal propagation procedure for the *Acacia* hybrids was described by Sunarti *et al.* (2013). Some ramets from each hybrid clones propagated in CFBTI were then delivered to other two sites of the trial, namely Riau and Jambi for further multiplication to obtain adequate ramet number as the determined clonal trial experiment design. However, of 44 clones, it was only 25 clones that could be successfully propagated in Jambi, and 20 clones in Riau for clonal trials establishment.

Sites The clonal trials were undertaken in three sites, in Central Java, Riau, and Jambi (Table 1). There were some differences in soil type; Ultisols both in Riau, Jambi (Sumatera) and Vertisol in Central Java. Based on the Schmidt and Fergusson classification, the climate types were B and C (Badan Pusat Statistik 2015) respectively; the site in Java has less rainfall (Table 1). The clones were planted manually by digging a 40 × 40 × 40 cm hole. The basal fertilizer was placed in the bottom of the hole and covered with a ± 10 cm layer of soil (Table 1). In all sites, the fertilizer NPK 15:15:15 was applied for three months after planting (100 g plant^{-1}), and the same fertilizer was re-applied in the rainy season when the trees were aged 1 (150 g plant^{-1}) and 2 (200 g plant^{-1}) years-old. All post-planting applications were buried in several holes around the trees.

Experimental design The experimental design of the clonal trial was a randomized complete block in all sites. All forty-four clones were represented at clonal trial in Central Java, and it was only 25 and 20 clones in Jambi and Riau, respectively, and nine clones were common to all trials. Also in each of these trials, respectively, there were 20, five and four replications (blocks) of single-, five- and four-tree line plots (Table 1). The three clonal trials were planted in two different spacing, 3 × 3 meters for Central Java, and 3 × 2 meters for Riau and Jambi.

Measurement and analysis

Total height (*H*) [m] and diameter at breast height (*D*) [cm]of all individual trees were measured at age 2 years with a 20-m height pole (to 0.01 m) and a phi-band (to 0.1 cm), respectively. Tree volume(*V*) was then assessed as stem volume index (m^3), and it was calculated as a function of *H* and *D* with the following Equation *[1]*:

$$V(\mathrm{m}^3) = 0.25\times\pi\times D^2\times H\times 10^{-4} \qquad [1]$$

The linear model of analysis of variance for single-site analysis is described as Equation *[2]*:

Table 1 Site condition, silvicultural treatment and experimental design of the *Acacia* hybrid clonal trials at three different sites in Indonesia

Site	Central Java	Riau	Jambi
Latitude (South)	7°32’	1°07’	1°36’
Longitude (East)	110°41’	102°52’	103°36’
Altitude (m asl)	141	7	27
Climate(Schmidt & Ferguson)	C	B	B
Mean annual rainfall (mm)	1878	2629	2347
Min-max temperature (°C)*	22.0Z33.6	21.8Z35.1°C	23.5Z31.9
Soil type	Vertisol	Ultisol	Ultisol
Design	RCBD	RCBD	RCBD
Number of trees per plot	single	4	5
Number of clones	44	20	25
Number of replications	20	4	5
Spacing (m)	3 × 3	3 × 2	3 × 2
Fertilizer at planting (per tree)#	100g SP_{36}	150g NPK	150g NPK

note: SP_{36} : Superphosphate fertilizer consisting of 36% of P_2O_5; NPK: fertilizer consists of 15% N, 15% P_2O_5 and 15% K_2O_5. *The data was based on daily weather-station collections of minimum and maximum temperature in 2014 (Statistik Indonesia 2015).

$$Y_{ijk} = \mu + b_i + c_j + \varepsilon_{ijk} \qquad [2]$$

where Y_{ijk} is the observed phenotypic measurement of the $k^{\text{-th}}$ ramet of the $j^{\text{-th}}$ clone at the $i^{\text{-th}}$ block, μ is the overall mean, b_i is the fixed effect of the $i^{\text{-th}}$ block, c_j is the random effect of the $j^{\text{-th}}$ clone on a given variable, and ε_{ijk} is the residual error. Phenotypic variables were represented by individual *H*, *D*, and *V*.

Analysis of variance for multi-site was based upon the randomized complete block design for nine common clones in three trials. The clone was considered as a random effect, while site and block were as the fixed effect. Clones × sites interactions were tested using a cross-classification (Karlson & Hogberg 1998). The mixed linear model of analysis of variance for multi-site analysis can be described as Equation *[3]*:

$$Y_{ijkl} = \mu + s_i + b(s)_{ij} + c_k + c_* s_{ik} + \varepsilon_{ijkl} \qquad [3]$$

where Y_{ijkl} is the observed phenotypic measurement of the $l^{\text{-th}}$ ramet of the $k^{\text{-th}}$ clone at the $j^{\text{-th}}$ block within the $i^{\text{-th}}$ site, s_i is the fixed effect of the $i^{\text{-th}}$ site, $b(s)_{ij}$ is the fixed effect of $j^{\text{-th}}$ block nested in the $i^{\text{-th}}$ site, c_k is the random effect of $k^{\text{-th}}$ clone, $c_* s_{ik}$ is the random effect of interaction between the $k^{\text{-th}}$ clone and the $i^{\text{-th}}$ site, and ε_{ijkl} is the residual error. A Duncan's Multiple Range Test was used to examine the ranking of the clones that were common to each trial.

Clone (H^2_c) and ramet (H^2_r) repeatability for each site of the trial were estimated as Equation *[4]* and Equation *[5]* (Falconer 1960):

$$H_c^2 = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_e^2/nb} \qquad [4]$$

$$H_r^2 = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_e^2} \qquad [5]$$

and for multi-site of trials as Equation *[6]* and Equation *[7]* (Karlsson & Hogberg 1998):

$$H_c^2 = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_{cs}^2/s + \sigma_e^2/nbs} \qquad [6]$$

$$H_r^2 = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_{sc}^2 + \sigma_e^2} \qquad [7]$$

where σ^2_c, σ^2_{cs} and σ^2_ε are the clonal, clone × site and residual variance components, respectively. While *n*, *b*, and *s* is the harmonic mean number of ramet, blocks and sites, respectively.

In this study, *V*, as a function of *H* and *D*, was then used as the basis for observing the rank order of clones to find the clones showing a solid performance across the three trials. Moreover, the *V* is one of the main final targets for improving the productivity of the *Acacia* hybrid.

Results and Discussion

Growth At the age of two years, the general mean of growth across three *Acacia* hybrid clonal trials were 7.3 m, 7.1 cm and 42.9 (× 10^{-3} m^3) for *H*, *D*, and *V*, respectively (Table 2). Growth rates were found profoundly greater in Jambi and Riau compared with those in Central Java. While between those two sites in Sumatra, clonal trial in Jambi showed a better growth, particularly for *H* and *V*. Site's conditions of the trials are the probable cause (Frampton & Foster 1993). The main differences between the sites in Sumatra and the one in Central Java are related to soil type, annual rainfall, and climate type. The vertisol in Central Java is dominated by clay which cracks in the dry season, and in the rainy season, it is sticky and sometimes flooded because of poor drainage. These properties are linked to root damage and reduced nutrient uptake (Foth 1988), both of which may have contributed to the low growth rates of the clones. Conversely, Ultisols have no shrink-swell property, free draining and well-suited to *Acacia* hybrids plantation forestry (Kijkar 1992), mainly if supported by high annual rainfall as occurred in Riau and Jambi (Sein & Mitlohner 2011).

In this study, the mean *H* of *Acacia* hybrid clonal trial in Central Java (Table 2) was lower than the referenced *A. mangium* grown in the same site, around 7.1 m (Handayani *et al*. 2017). But, the growth in Riau and Jambi were higher than *A. mangium* grown in South Sumatra, around 9.4 m (Krisnawati *et al*. 2011). The lower *H* growth of trial in Central Java might be due to a large growth variation among the *Acacia* hybrid clones. Moreover, *A. mangium* used as a referenced control in Central Java was derived from the advanced generation breeding cycles of third-generation seedling seed orchard. However, some best clones in this trial showed a comparable growth with the *A. mangium*. In another comparison, the mean annual *H* increments in Riau and Jambi were similar to those observed during the first three or four years of growth in a comparison of 27 *Acacia* hybrid clones grown in Yen Thanh and Long Thanh, Vietnam (Kha *et al*. 2012). The poorest *H* growth in the previous study in Ba Vi (3.0 m yr^{-1}) may also have been associated with the soil type, a rhodic ferrasol which has low porosity and hydraulic conductivity (Beadle *et al*. 2013). Matching selected clones to the site can, therefore, be important with *Acacia* hybrids if high productivities are required.

Another possible reason for the lower mean growth of the clones in Central Java is related to the more number of tested clones. The number of clones in Central Java was almost twice more (44 clones) than those tested in Riau and Jambi. The greater number of tested clones for the *Acacia* hybrids leads to increase the growth variation among the clones. This is because the hybrid clones tested in this study were derived from F-1 control crossed progenies between *A. mangium*×*A. auriculiformis* (Sunarti *et al*. 2013). The selected hybrid progenies at the seedling stage were then propagated through

Table 2 Mean *H* (height), *D* (diameter at breast height) and *V*(volume) from the 2-year-old *Acacia* hybrid clonal trials at three sites in Indonesia

Traits	Central Java	Riau	Jambi	General mean
H (m)	3.9	9.9	11.6	7.3
D (cm)	4.7	9.5	8.8	7.1
V (× 10^{-3} m^3)	6.8	63.8	70.5	42.9

shoot cutting without a prior hybrid vigor test. It was reported that such breeding selection for *Acacia* hybrids would commonly provide a large variation in growth performance of progenies from very poor to superior growth after planting in field test (Sunarti *et al*. 2013). Another study was also reported that the F-1 hybrid progenies were quite variable and produced a high proportion of plants of extremely poor vigor (Potts *et al*. 2000).

Genetic parameters At each trial, there were highly significant differences ($p<0.01$) among all clones tested for *H*, *D*, and *V* (Table 3). High clone repeatability was consistent for all measured traits (>0.91), and was less in Central Java compared to the ones in Riau and Jambi. The high value of repeatability is one of the important factors for further development of hybrid clones. In another study on two-year-old *E. grandis* clones in Portugal, clone repeatability was also high (0.87–0.91) (Borralho *et al.* 1992). Such result indicates that growth can be strongly influenced by genetic and that clonal selection based on growth, which was variable between clones in this experiment, will be effective in a breeding program (Maniee *et al*. 2009). However, it should be noted that within a genus, clonal repeatability can be low. For example, in three-to-five-year-old *E. camaldulensis* in Vietnam, it was 0.18–0.42 (Kien *et al*. 2010). In case of the estimation of ramet repeatability, it was also high for all variables (0.48–0.69) with the lowest one found in Central Java (0.48–0.49), except for *H*. The lower ramet repeatability in Central Java was probably due to a lower variability among the ramets within each of 44 tested clones which was aggravated by a higher proportion variance of error (Table 3).

For the multi-site analysis, there were some significant differences ($p<0.01$) among the clones tested, sites, and clone × site interaction for *H*, *D*, and *V* (Table 4).Unlike the single site analysis, the multi-site analysis of the nine common clones grown at all three trials showed lower clone repeatability and ramet repeatability. Clone repeatability for all measured traits were 0.29–0.70; ramet repeatability was in the range of 0.07–0.24 (Table 4). The diminished repeatability in the multi-site analysis might be related to the site variability among the three clonal trials. From the two

Table 3 Mean squares from a single-site analysis of variance, component of variance, clone repeatability (H^2_c) and ramet repeatability (H^2_r) for *H* (height), *D* (diameter at breast height), *V* (volume) from the 2-year-old *Acacia* hybrid clonal trials at three sites in Indonesia

Variance source	Mean Squares								
	Central Java			Riau			Jambi		
	H	*D*	*V*	*H*	*D*	*V*	*H*	*D*	*V*
Block	4.90	9.18	275.63	18.30	21.06	9,696.92	13.73	3.08	3,114.33
Clone	26.07**	29.94**	732.63**	73.12**	114.69**	44,855.15**	42.94**	18.20**	10,177.59**
σ^2_c	1.28	1.43	34.87	4.33	6.89	2,681.50	5.27	2.13	1,193.3
σ^2_e	0.63	1.51	37.40	3.23	5.24	22,445.60	2.39	1.74	835.74
H^2_c	0.97	0.95	0.95	0.96	0.95	0.95	0.95	0.91	0.92
H^2_r	0.66	0.49	0.48	0.57	0.57	0.52	0.69	0.55	0.59

** Significant at $\alpha=0.01$,σ^2_c= variance component of clone, σ^2_e= variance component of error

Table 4 Mean squares from a multi-site analysis of variance, component of variances, clone repeatability(H^2_c) and ramet repeatability (H^2_r) for *H* (height), *D* (diameter at breast height), *V* (volume) from the 2-year-old *Acacia* hybrid clonal trials at three sites in Indonesia

Source	Mean Squares		
	H	*D*	*V*
Clone	122.343**	106.030**	25,956.994**
Site	1,176.771**	393.891 **	125,556.354**
Block (Site)	4.911*	5.155*	1,669.918
Site× Clone	5.172**	7.714 **	11,009.160**
σ^2_c	0.98	1.57	150.17
σ^2_{sc}	2.15	1.72	978.21
σ^2_e	2.36	3.29	992.14
H^2_c	0.56	0.70	0.30
H^2_r	0.18	0.24	0.07

** Significant at $\alpha=0.01$, * Significant at $\alpha=0.05$, σ^2_c= variance component of clone, σ^2_{sc}= variance component of site ×clone, σ^2_e= variance component of error model analysis, single site and multi-site, the estimation of repeatability were categorized as high for all traits in the single site, while those in the multi-site generally varied ranging from low to moderate (Cotteril & Dean 1990).

The observed value of repeatability for *Acacia* hybrid clones in this study seemed to be different along the tree growth. Sunarti *et al.* (2013) reported that a slightly higher ramet repeatability of the hybrid clone grown in Central Java at one year of age for *H* was observed at around 0.59, but the clone repeatability was still similar as obtained in this study (≥ 0.90). The sensitiveness change of clone repeatability due to the increase of age were also observed in other studies for some species: *Acacia* hybrid in Vietnam (Kha *et al*. 2012), *E. camaldulensis* in Vietnam (Kien 2009), *Populus deltoides* in India (Dhillon *et al*. 2010), *Pinus radiata* in New Zealand (Baltunis & Brawner 2010), *Larix kemperi* in China (Lai *et al*. 2014), *Tectona grandis* in Sabah, Malaysia (Goh *et al*. 2013), *Peronema canescens* in West Java and Central Kalimantan (Kang *et al*. 2013), and white poplar in China (Zhao *et al*. 2012).

Ranking of clones Ranking changing order of clone is an essential factor to assess the stability of the clones at various tested site conditions. A significant effect of clone × site interaction commonly existed during the clonal test indicating the importance of interaction to the ranking change of clones among the trials. In this study, the clone × site interaction was statistically significant for all the traits (Table 4). The ranking of the nine common clones for *V* was different among the trials. Most of the tested clones showed an interactive ranking order across three trials, and only a few clones indicated a relatively consistent ranking performance among the trials (Table 5).

In each trial, the *V* was the greatest in Clone 44, Clone 4, and Clone 6, each for the trial in Central Java, Riau, and Jambi, respectively (Table 5). All of the best clones were statistically different from other remaining clones, except those in Riau in which the best Clone 4 was not different from the second top one of Clone 44. In the case of the lowest ranking order, Clone 10 was found at the lowest rank order, and stable across the three trials. The interactive clones between the trials based on *V* were mainly due to the changes in best ranking order in Riau and Jambi. The interactive ranking order of clones was observed in Clone 4 and Clone 6, the best rankings in Riau and Jambi respectively, but these two clones were dropped into at least third to seventh ranking order in other trials. However, in general, there were two clones: Clone 44 and Clone 42 that showed relative consistency as the top ranking across the three trials. Clone 44 consistently performed the best ranking in Central Java and Riau, and it was significantly different from other clones.

Clone 4 was the best ranking in Riau but performed poorly in Jambi. In contrast, Clone 6 was the best in Jambi, but it was at the middle ranking in Riau. It was clear that there were some differences in the ranking order of clones between Riau and Jambi, rather than being similar in the growing environment. In another case, although the site conditions differed between Central Java and two trials in Sumatra and its volume was five times greater in Riau. Clone 44 was the best performing concerning *V* at each of these trials. Clone 42 was not the best ranking, but it consistently performed better within a range of second top ranking at all trials (Table 5).

The growth of Clone 4, Clone 6, Clone 42 and Clone 44 in this study were promising based on the currently observed traits, but only Clone 44 showed a better performance in other important traits, such as stem form and branching (Sunarti 2013). In addition, Clone 44 followed by Clone 42 was the most stable in high-performance clones across the three trials under the given observed traits. These two clones were also confirmed as the top ranking among the total tested clones based on the respective single site analysis. Therefore, considering the adverse site conditions between Central Java and two trials in Sumatra, clone 42 and Clone 44 were the most promising clones for further detail observation as they performed relatively and equally had the high superiority on poor and good sites.

Ranking change in this study indicated that in general the growth of*Acacia* hybrid clones was sensitive to the change of site conditions. The change in sites could cause this, climate, soils, and even if in the similar climate and soils but in different geographical sites. The interactive growth performance of *Acacia* hybrid clones with the different site

Table 5 Ranking of nine common clones based on *V* (volume) from the 2-year-old *Acacia* hybrid clonal trials at three different sites in Indonesia.

Clones	V ($\times 10^{-3}$ m^3)*								
	Central Java			Riau			Jambi		
2	11.2	bc	(6)	31.3	cd	(7)	17.4	d	(8)
4	14.8	bc	(4)	140.0	a	(1)	33.0	d	(7)
6	13.8	bc	(5)	50.6	cd	(5)	135.7	a	(1)
8	10.1	bc	(7)	24.9	cd	(8)	51.6	bcd	(5)
10	7.9	c	(9)	18.6	d	(9)	16.3	d	(9)
26	9.2	c	(8)	32.3	cd	(6)	72.0	bc	(3)
40	15.1	bc	(3)	58.5	bc	(4)	35.4	cd	(6)
42	17.5	b	(2)	85.1	b	(3)	71.6	bc	(4)
44	26.9	a	(1)	134.1	a	(2)	86.7	b	(2)

*Means followed by the same letter are notsignificantly different as assessed by DMRt with $p< 0.05$.The number in parentheses is number of ranking.

condition was also reported in Vietnam (Kha *et al*. 2012; Sein & Mitlohner 2011). The interactive of clone deployment with the differing environments is probably due to a lack of homeostasis with clones (Bentzer *et al*.1988). However, comparing with the clones propagated from pure parental species, the clones from hybridization as practiced in *Acacia* hybrid in this study seemed to be more adaptive to site variabilities. Santos *et al*. (2016) reported that while clones from pure species performed well in specific environments, the hybrid presented better for broad adaptation to a range of environments.

Clone × site interaction effect was evident from this study as reflected by the changes of ordinary clone ranks across three different sites for most of the tested clones. It indicated that genotype by environment interaction was important for *Acacia* hybrids growth and should be taken into account in the clonal deployment. However, despite the early indications that some clones performed better at two years of age, it will be necessary to wait longer before decisions about which clones to deploy can be made.

The implication for breeding and deployment strategy

Observing the early growth of *Acacia* hybrid clones in three different sites in this study provided two implications for breeding process and clonal deployment strategy. Firstly, high clone variations had become an important factor in the clonal trial of *Acacia* hybrids. Such a high genetic variation accurately provides the genetic parameter estimation in the clonal trial. High genetic variation will also become a countermeasure to site variabilities for adaptive clones. However, hybridization process for *Acacias* to produce hybrid progenies is constrained by the difficulty of making controlled pollination between the pure parents' species: *A. mangium* and *A. auriculiformis*, due to a very tiny of flowers and polyad of pollen (Nghiem *et al.* 2011). In this case, time consumed for flowers emasculation is necessary, and it should be practiced carefully. The hybrid parents of *A. mangium* and *A. auriculiformis* for control crossed should be selected from the superior tree with considerable traits suitable for improving the final target of production, such as high growth, good stem form, good wood properties, and resistance to pests and diseases. Another simpler option to produce hybrid progenies is to employ open pollination by establishing hybrid seed orchard (HSO). However, the probability of hybrid seed progenies obtained from such HSO is limited to less than 1% (Sunarti *et al*. 2016). Moreover, morphologically, the identification of the hybrid seedling in the nursery stage is also time consuming. Regardless of these limitations, both option methods are the only currently available techniques to produce *Acacia* hybrid progenies.

Verified hybrid seedling produced from those two options above are then planted in hybrid vigor test to select the promising *Acacia* hybrid trees for further testing in the clonal trial. The effect of female and male parents in control crossed, and female parents in HSO should be then taken into account to drive the estimation of variation for target traits in the *Acacia* hybrid clones. This is important because the phenotypic performances of *Acacia* hybrid progenies potentially exhibited very large varying traits, and most of them are commonly exposed unexpected and adverse traits.

Although creating a pure line as in crops is difficult for *acacias* species, the variation in exhibited traits of the *Acacia* hybrid progenies should be controlled and directed into the appropriate manners of the target traits. Repeating selection in the breeding population of respective parents species into several successive advanced generations based on the target traits, and then followed by co-improvement hybridization among the selected trees within each parent breeding generation population seems to drive a desirable exhibited traits variation. The higher genetic variation in the desirable traits could be then expected to reduce the magnitude variation of clone × site interaction. As a result, the potential for selecting superior clones with high stability in various site conditions for the target traits could be increased simultaneously.

Regarding the second implication for clonal deployment strategy, a good understanding of the response of *Acacia* hybrid clones to grow in various site conditions is important. Observing the magnitude clone × site interaction is then necessary to identify the sensitiveness of the clones to various sites deployment. It is expected that the appropriately selected clones, whether should be planted in the specific site or could be planted in over a broader range of environments, will maximize its potential gain, and avoid the losses of its gain in the operational plantation

Superior hybrid clones with a high stability growth across the various site conditions would provide more benefits on the operational scale. However, the growth of *Acacia* hybrid clones seemed mostly interactive when growing in a different site, even if in some similar environments such as in Riau and Jambi in this study. In this case, there are two proposed strategies for the deployment. The first strategy is to regionalize the best-selected clones in respective specific site. It means that by nine common clones, Clone 44 should be planted for Central Java, Clone 4 for Riau and Clone 6 for Jambi. This strategy should be confirmed with the real best clone in respective site from total clones tested: 44 clones in Central Java, 20 clones in Riau and 25 clones in Jambi. The second strategy is a selection of the clones based on a range of desirable top ranking. In this strategy, clones with the consistent superior performances and stable ranking order across the sites could be recommended as the selected clones for all sites, although not the best one in each site. It means that Clone 44 and Clone 42 are among the two top-ranking clones across the trials; thus, they could be planted in all the three sites.

Another important aspect for the second implication for clonal deployment is the silvicultural practices. The plot configuration of clonal trials used in this study was a line tree-plot either by single tree-plot, four tree-plot or by five tree-plot (Table 1). In this configuration, inter-tree competition occurred mostly among the tree of different clones. This type of competition would be different in the operational of a clonal plantation in which trees from the same clones will be planted on the same plot block, and thus more intense inter-tree competition occurred mostly within the same clones. Considering this fact, observing the clone × site interaction from this study is necessary to be expanded into genetic gain trial plot allowing the comparison of the clones in similar with the real sylviculture practiced in the operational plantation. It could be implemented by establishing the promising selected clones from this study into a genetic gain trial in several sites which are laid out in large multiple tree-plot configurations, such as 100 or more squared tree-plot. This trial will minimize the bias between the growth superiority of selected clones observed in test plot and the realized one in operational scale.

Conclusion

The early growth of *Acacia* hybrid clones observed in three clonal trials is greater in Riau and Jambi rather than in Central Java which is probably caused by the difference of sites condition. The growth of clones revealed that the most of the tested clones of *Acacia* hybrid were interactive and susceptible to the different deployment sites for almost all measured traits. However, based on the growth of V it was found some clones which showed the best growth within each trial, and two superior and relative stable clones across the three trials. The results of the study provided some implications in respect to further breeding process and clonal deployment for *Acacia* hybrids.

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