

REALIZED GENETIC GAIN AND SEED SOURCE X SITE INTERACTION ON STAND VOLUME PRODUCTIVITY OF *ACACIA MANGIUM*

Arif Nirsatmanto^{1*}, Teguh Setyaji¹ and Reny Setyo Wahyuningtyas²

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ABSTRACT

Following the results of the comprehensive tree improvement programs for *Acacia mangium*, it is necessary to estimate the real amount of genetic improvement and to develop an improved seed deployment strategy. This study was aimed to verify realized genetic gain on stand volume productivity attained by the first-generation Seedling Seed Orchards (SSO) of *A. mangium* and to identify the magnitude of seed sources x site interaction as a basis for improved seed deployment. Seeds from five SSOs were tested together with seeds from seed stand in genetic gain trials which were established in South Kalimantan and Central Java. Realized gains were calculated from the percentage improvement of respective SSOs compared with seed stand at two and four years of age. Seed source x site interaction was investigated through analysis across the two sites. Results of the study showed that trees derived from the five SSOs produced better stand volume than those from seed stand. At four years of age, stand volume of the best SSO reached around 127 m³/ha in South Kalimantan and 84 m³/ha in Central Java. Realized genetic gain were around 66% at two years and 59% at four years in South Kalimantan, and around 136% at two years and 81% at four years in Central Java. Seed source x site interaction was not significantly different indicating superiority of improved seed were consistent across the two sites with the average realized gain ranging from 18% to 79% and 24% to 62% at two and four years, respectively. The best three SSOs were SSO-1 located in Pleihari-South Kalimantan, SSO-2 in Pendopo-South Sumatra and SSO-5 in Wonogiri-Central Java, all of which originated from Papua New Guinea provenances. Improved seed from the orchards could be used at plantation sites without any significant change of the order in their superiority for stand volume productivity.

Keywords: *Acacia mangium*, genetic gain trial, realized genetic gain, seedling seed orchard, stand volume

ABSTRAK

Studi ini bertujuan untuk mengetahui besarnya perbaikan genetik aktual terhadap produktifitas volume tegakan dan interaksi sumber benih x lokasi pertanaman. Benih unggul *A. mangium* dari lima kebun benih diuji bersama benih dari tegakan benih di plot uji perbaikan genetik di Kalimantan Selatan dan Jawa Tengah. Hasil penelitian menunjukkan bahwa benih unggul dari kebun benih memiliki produktifitas volume tegakan yang lebih tinggi dibandingkan benih kontrol dari tegakan benih. Tingkat perbaikan genetik aktual di Kalimantan Selatan mencapai 66% umur dua tahun dan 59% umur empat tahun, sedangkan di Jawa Tengah mencapai 136% umur dua tahun dan 81% umur empat tahun. Interaksi sumber benih x lokasi tidak menunjukkan pengaruh yang nyata dan superioritas benih unggul stabil dikedua lokasi. Benih unggul dari lima kebun benih yang diuji dapat digunakan untuk pembangunan pertanaman di Kalimantan Selatan dan Jawa Tengah tanpa ada penurunan superioritas terhadap produktifitas volume tegakan yang dihasilkan.

Kata kunci: *Acacia mangium*, uji perbaikan genetik, perbaikan genetik riil, kebun benih, volume tegakan

¹Center for Forest Biotechnology and Tree Improvement, Jl. Palagan Tentara Pelajar Km. 15, Purwobinangun, Yogyakarta 55582 - Indonesia

²Banjarbaru Forestry Research Institute, Jl Ahmad Yani Km.28,7 Landasan Ulin, Banjarbaru, South Kalimantan 70721 - Indonesia

*Corresponding Author: arif_nirz@yahoo.com

I. INTRODUCTION

Establishment of *Acacia mangium* plantations in Indonesia in the early years had been using seeds collected from seed stand. The oldest seed stand of *A. mangium* in Indonesia was established in 1979 at Subanjeriji, South Sumatra, and used combination of bulk seeds from Queensland and Indonesian provenances (Werren, 1991). This seed stand is well known as the land race of Subanjeriji, and its seed production had been widely used in the establishment of the first rotation *A. mangium* plantations. The use of seeds collected from such kind of seed source was commonly practiced in the beginning of the plantation programs before permanent seed orchards became available (Zobel and Talbert, 1984).

Due to the growing importance of *A. mangium* in large scale plantation programs, the demand of genetically improved seeds of this species was increasing to improve the productivity of the plantations. In order to fulfill the demand, first-generation seedling seed orchards of *A. mangium* were established in some regions in Indonesia under a comprehensive tree improvement program, such as in South Kalimantan, South Sumatra, West Kalimantan and Central Java (Hashimoto *et al.*, 1996). The seedling seed orchard was initially established as a progeny test using families collected from superior provenances in Papua New Guinea and Far North Queensland. In 2000, the selection procedures have completely finished, and the orchards were in the stage of production of improved seeds ready for plantation.

Studies designed specifically to estimate realized genetic gain will allow the tree breeder to show what has actually been achieved through selection and breeding (Zobel and Talbert, 1984). Such studies can be implemented by establishing genetic gain trials, where the improved seeds are tested against the unimproved seeds in a plot trial with the same silvicultural practices. Establishing genetic gain trials will be required if we want to be able to confidently obtain realized genetic gain from improved plantation (St. Clair, 1993).

Genetic gain trials can be established and replicated in several plantation locations, and thus it will be useful to identify the magnitude of seed source x site interaction which is important for the development of a genetically improved seed deployment strategy. This is needed because often a strong genotype x environment interaction for growth traits restricts the possible gains when one population is destined for use over wide areas of plantation (Zobel and Talbert, 1984). In addition, genetic gain is better to be presented as an expected amount of improvement in the form of volume productivity per unit area. This is because single tree volume is not always a good indicator to measure the potential of improvement in volume productivity.

Studies on realized genetic gains by first-generation tree improvement in forest tree species have been done for several pine species, for example, 16%-18% increase in stand volume at 10 years age (Matziris, 1974) and 7%-12% at rotation age (Li *et al.*, 2000) for loblolly pine; 32% increase in individual stem volume for black pine (Matziris, 2005). In the case of tropical forest species, Luangviriyasaeng and Pinyopusarek (2002) reported outstanding growth and form trait of improved families of *A. auriculiformis* at 36-40 months. With regard to *A. mangium*, although Nirsatmanto *et al.* (2004) has reported the realized genetic gain based on the one year age data observed in second-generation of seed orchard: increased around 3%, 5 % and 4 % for height, diameter and stem straightness respectively, the realized genetic gain was not yet verified in genetic gain trial. Therefore, the objective of this study is to verify the realized genetic gain for stand volume productivity attained by the first-generation seedling seed orchards of *A. mangium* in two genetic gain trials located in Central Java and South Kalimantan. As a basis to develop an improved seed deployment strategy, the effect and the magnitude of seed sources x site interaction were also investigated.

II. MATERIAL AND METHOD

A. Genetic Gain Trials

Following a comprehensive tree improvement program for *A. mangium*, three genetic gain trials were established in Central Java (7°32'S and 110°41'E), South Sumatra (3°15'S and 103°50'E), and South Kalimantan (3°30'S and 115°0'E) (see Table 1). The last two locations represent the regions with large scale operational plantations of *A. mangium* in Indonesia. The design of all genetic gain trials was similar using a randomized complete block design which was laid out as 100 trees in square plots (10×10 trees) of 4 - 5 replications with a spacing of 4×2 m. High mortality occurred in the trial in South Sumatera due to fire, thus this trial was excluded from the analysis. At four years of age, two replications in the trial in South Kalimantan was also destroyed by fire, thus at this age only three out of five replications from this trial were used for the analysis.

Basically, the genetic gain trials consisted of the same set of a mix open pollinated seeds collected from eight seed sources. However, for the purpose of this study, only six of the seed sources were used for the analysis: five seedling seed orchards (SSO) and one seed stand as the control (Table 2). The five seedling seed orchards (referred to as SSO-1, SSO-2, SSO-3, SSO-4, SSO-5) were established using family originating from Papua New Guinea and Queensland-Australia provenances as part of a comprehensive breeding program for *A. mangium* (Hashimoto *et al.*, 1996). While one control was the seed stand from the local land race of Subanjeriji (Werren, 1991).

B. Measurement and Statistical Analysis

Investigation was done by analyzing stand volume productivity at two and four years of age. Individual stem volume was derived from the volume equation (Inose *et al.*, 1992) using height and diameter at breast height (dbh):

$$v = 0.000058806 \times D^{1.71772} \times H^{1.0809} \dots\dots\dots(1)$$

To get an accurate observation, only the inner 64 trees (8 x 8 trees) in each square plot were measured to stimulate the competition that would occur between individual trees of the same seed source. The stand volume on each plot was calculated by summing up the individual stem volumes of all surviving trees in each plot, which was then expressed as stand volume productivity per hectare (m³/ha) using the following equation:

$$\text{Stand Volume per Hectare} = \frac{\text{stand volume on plot}}{\text{area of plot in square meter}} \times 10000 \dots\dots\dots(2)$$

Analysis of variance was made at each site as well as across the two sites with the following linear equations (Hai *et al.*, 2008):

$$Y_{ij} = \mu + B_i + S_j + e_{ij} \text{ (for each site) } \dots\dots\dots(3)$$

$$Y_{ijk} = \mu + L_i + B / L_{ij} + S_k + S * L_{ik} + e_{ijk} \text{ (for across sites) } \dots\dots\dots(4)$$

Where, μ = population mean, B_i = the *i*th replication effect, S_j = the *j*th seed source effect, L_i = the *i*th site effect, B/L_{ij} = the *j*th replication effect in the *i*th site, S_k = the *k*th seed source effect, $S * L_{ik}$ = the effect of seed source×site interaction, e_{ij} and e_{ijk} = experimental error associated with *y_{ij}* and *y_{ijk}*, respectively.

The realized genetic gains were calculated as differences between the respective seedling seed orchard and the seed stand, all of which were the least square estimates of the linear model given in Equations 3 and 4. Then the relative gain was calculated as a percentage rate of the gain to the average seed stand.

III. RESULT AND DISCUSSION

A. Survival Rate and Stand Volume

The average number of surviving trees varied slightly among seed sources as indicated by the different average number of observations per plot (Table 3). Except SSO-4 in genetic gain trial in Central Java, which had the smallest number of observation (survival rate around 70 %), the average number of surviving trees per plot in each seed source at both ages and sites were more than 51 (survival rate was ranging from

80% to 97%). Difference in survival by seed sources over the two ages was small (less than 3%). In South Kalimantan, the data used for analysis at four years was only from three out of five replications (two damaged replications with low survival rates were excluded). As a result, the average number of trees per plot at four years increased from that at the two years age. The high survival rate would be sufficient to ensure an accurate comparison among the tested seed sources to examine the realized genetic gain and seed source x site interactions for stand volume productivity in genetic gain trial.

Stand volume productivity of genetic gain trial in South Kalimantan was much better than that in Central Java. The average stand volume in South Kalimantan was 18.62 m³/ha at two years and 108.43 m³/ha at four years, while the corresponding stand volume in Central Java was 6.76 m³/ha at two years age and 72.53 m³/ha at four years age (Table 3). The differences observed here are possibly associated with climatic characteristic, whereby rainfall in Central Java is lower than in South Kalimantan: 1,878 mm in Central Java and 2,043 mm in South Kalimantan (see Table 1). The natural distribution of this species can be found in areas with a range of rainfall from 1446 mm to 2970 mm and can tolerate a minimum annual rainfall of 1000 mm. *A. mangium* has performed well in site with higher annual rainfall. In addition, the growth seems to slow or cease in response to the combination of low rainfall and temperature (Mackey, 1996). Another

reason might be due to the differences in the geographic coordinates of the sites, where the latitude of test plantations decreases from 7°32' S in Central Java to 3°30'S in South Kalimantan. The same trend of faster early growth with decreasing latitude for *A. mangium* was also observed in trials and operational plantations in Vietnam (Kha, 2011) and in provenance trial in many tropical countries (Harwood and Williams, 1991). Besides the climate factor in general, soils property is also another important factor of plantation productivity. Despite *A. mangium* tolerates to the soil with low fertility, its growth more pronounced in a site with red and well drained soil properties such as Podzols, the similar type of soil as in the site of South Kalimantan in this study (Table. 1). Moreover, most of *A. mangium* plantation in Indonesia were also established in the regions dominated by the type soil of Podzols (Hardiyanto and Wicaksono, 2008; Golani *et al.*, 2009).

Trees planted using seed sources from five seedling seed orchards outperformed those from seed stand (Table 3). Stand volume from the five orchards in genetic gain trial in Central Java exceeded 5 m³/ha and 60 m³/ha at two and four years respectively, and those in South Kalimantan exceeded 15 m³/ha and 90 m³/ha at two and four years respectively. While the corresponding stand volume of the control seed source from seed stand at respective ages and sites were less than the observed values from the seedling seed orchards. Except at two years in Central Java, analysis of variance revealed that stand volume among seed sources

Table 1. Site location and experimental design of the genetic gain trail

Site location (Latitude, Longitude)	Altitude (m)	Mean annual rainfall (mm)	Temp. Max./Min. (°C)	Soil type	Planting	Design
Central Java (7°32'S and 110°41'E)	141	1,878	33.23/21.9	Vertisols	2002	RCBD/4 replications
South Sumatra (3°15'S and 103°50'E)	130	2,781	33 / 24	Podzolls	2002	RCBD/4 replications
South Kalimantan (3°30'S and 115°0'E)	150	2,043	33.7 / 26.2	Podzolls	2002	RCBD/5 replications

RCBD= Randomized Complete Block Design

Table 2. Six seed sources with different genetic levels and original provenances tested in genetic gain trial

No.	Seed source	Location	Latitude, Longitude, (Elevation)	Location of original provenance
1.	SSO-1	Pleihari-South Kalimantan	3°58'S and 114°37'E (15 m)	Dimissisi, PNG Derideri E Morehead, PNG Gubam NE Morehead, PNG Bimadebun, PNG Arufi Village, PNG Boite NE Morehead, PNG
2.	SSO-2	Pendopo-South Sumatra	3°31'S and 103°48'E (80 m)	Oriomo, PNG Wipim, PNG Kini, PNG
3.	SSO-3	Pleihari-South Kalimantan	3°58'S and 114°37'E (15 m)	Claudie River, FNQ 135K N, FNQ
4.	SSO-4	Pendopo-South Sumatra	3°31'S and 103°48'E (80 m)	Pascoe River, FNQ Claudie River, FNQ Cassowary CK, FNQ
5.	SSO-5	Wonogiri-Central Java	7°32'S and 110°41'E (141 m)	PNG ^(*) , FNQ ^(**)
6.	Seed Stand	Subanjeriji-South Sumatra	3°05'S and 104°25'E (80 m)	Queensland (bulk) IND (bulk)

PNG=Papua New Guinea; FNQ=Far North Queensland; IND=Indonesia

SSO=Seedling Seed Orchard

*) same as in seed source no.1, 2

**) same as in seed source no. 3, 4

Table 3. Average stand volume (m³/ha) and realized genetic gain (%) at two ages of measurements in genetic gain trial of *Acacia mangium*

Seed source ^{a)}	2 years age				4 years age			
	Central Java		South Kalimantan		Central Java		South Kalimantan	
	N	Volume	N ^{b)}	Volume	N	Volume	N ^{c)}	Volume
SSO-1	55	7.29 (+83)	59	19.92 (+46)	55	74.36 (+57)	62	127.79 (+59)
SSO-2	58	9.42 (+136)	58	22.61 (+66)	56	85.89 (+81)	60	118.41 (+47)
SSO-3	55	6.80 (+71)	59	18.40 (+35)	55	78.24 (+65)	61	111.80 (+39)
SSO-4	48	5.70 (+43)	56	15.36 (+13)	46	64.48 (+36)	60	92.01 (+14)
SSO-5	55	7.39 (+86)	59	21.76 (+59)	54	84.88 (+80)	60	120.02 (+49)
Seed Stand	53	3.98	55	13.65	51	47.34	57	80.57
Grand Mean	54	6.76	57	18.62	52	72.53	60	108.43

N=average number of observation per plot

a) Seed sources as described in Table 2.

b) number of observation based on five replications

c) number of observation based on three replications only or excluding two damaged replications

Value in parenthesis is realized genetic gain (%)

were significantly different at both ages and sites (Table 4). Separation the means showed that the significant differences among seed sources were mainly a result of differences

between the improved seeds from seedling seed orchards and the unimproved seeds from seed stand (Table 3). This result indicated that the improved seeds performed better than the

Table 4. Degree of freedom and mean square values for each component of stand volume at two ages of measurements in genetic gain trial of *Acacia mangium* analyzed in each site using Equation(3).

Source of variation	2 years volume		4 years volume	
	df	Mean square	df	Mean square
Central Java				
Replication	3	22.8797	3	284.9613
Seed source	5	13.2633ns	5	853.0961 **
Error	15	4.7358	15	173.0243

South Kalimantan				
Replication	4	58.2914	2	1614.3415
Seed source	5	62.8200 **	5	999.2511**
Error	20	14.0269	10	172.7574

**Significant at the 1% level, ns not significant

Table 5. Degree of freedom and mean square values for each component of stand volume at two ages of measurements in genetic gain trial of *Acacia mangium* analyzed across the two sites using Equation(4).

Source of variation	2 years volume		4 years volume	
	df	Mean square	df	Mean square
Site	1	1873.2697 **	1	13257.7816 **
Replication (site)	7	43.1150 **	5	816.7134 **
Seed Source	5	67.9251 **	5	1714.5543 **
Seed source x Site	5	8.1583 ns	5	137.7930 ns
Error	35	15.5567	25	172.9175

**Significant at the 1% level, ns not significant

control from unimproved seed regarding stand volume. Less inter-trees competition due to a slower growth in Central Java at two years probably reduced the magnitude of variance in seed sources level. As a result, stand volume among seed sources in such situation tends not to be significantly different.

Among the five seedling seed orchards, SSO-2 was ranked first for stand volume in Central Java at both ages (9.42 m³/ha and 85.89 m³/ha at two and four years, respectively), followed by the second ranked SSO-5 (7.39 m³/ha and 84.88 m³/ha at two and four years, respectively), while SSO-3 and SSO-1 was an intermediate. In South Kalimantan, SSO-2 was also ranked

first at two years (22.61 m³/ha), but it was replaced by SSO-1 at four years (127.79 m³/ha). The superiority of SSO-1 over SSO-2 at four years in South Kalimantan is probably due to the effect of the distance between seed source location and planting site. SSO-1 was located close to the trial site in South Kalimantan (50 km away) with probably more adaptive stand development at the trial site condition, while SSO-2 was located in South Sumatra (Table 2). The same as in Central Java, SSO-5 was second ranked at both ages (21.76 m³/ha and 120.02 m³/ha). While SSO-4 performed poorest in stand volume productivity over both sites and ages.

Table 6. Average stand volume across the two sites of genetic gain trial of *Acacia mangium* at two ages of measurements, followed by the ranking order

Seed source	2 years volume		4 years volume	
	Average (m ³ /ha)	Rank	Average (m ³ /ha)	Rank
SSO-1	14.30 <i>abc</i>	3	97.26 <i>ab</i>	3
SSO-2	16.75 <i>a</i>	1	99.83 <i>ab</i>	2
SSO-3	13.25 <i>bc</i>	4	92.62 <i>ab</i>	4
SSO-4	11.07 <i>cd</i>	5	76.28 <i>b</i>	5
SSO-5	15.38 <i>ab</i>	2	99.94 <i>a</i>	1
Seed Stand	9.35 <i>d</i>	6	61.58 <i>c</i>	6

Averages with the same letter in respective year indicate they are not significantly different at the 1% level

The superiority of SSO-1, SSO-2 and SSO-5 over SSO-3 and SSO-4 might be mainly due to the effect of provenances. This is because the first three superior seedling seed orchards as described above mostly consisted of families from Papua New Guinea (PNG) provenances, while the other two seedling seed orchards consisted of families from Far North Queensland (FNQ)-Australia (Table 1). The superiority of PNG provenances as resulted in this study was in agreement with the report of previous provenance trials (Harwood and William, 1991; Kari *et al.*, 1996).

Absolute stand volume productivity in this study seemed lower as compared to the study reported by Otsamo *et al.*, (1996). In a previous study, mean annual increment (MAI) of stand volume at 41 months age in South Kalimantan reached around 39 m³/ha/yr and 28 m³/ha/yr for PNG and FNQ provenances, respectively. The corresponding MAI in the present study at 4 years was around 30 m³/ha/yr and 25 m³/ha/yr for PNG and FNQ, respectively. This discrepancy is probably due to the differences in site preparation and the practices of singling multi-stemmed trees. In a previous study, the trial plots were plowed twice which was recognized as the best method to support the initial growth in *Imperata cylindrica* grassland area (Otsamo, *et al.*, 1995), while in the present study the

preparation of the trial site was made manually, that is clear-felling followed by burning. The singling practiced in the present study was also a source for reducing the stand volume. Otsamo *et al.* (1996) has reported a statistical difference between singling and control (no singling), in which MAI of the singled tree population was only 71% of that of the control.

B. Realized Genetic Gain

Superiority of the five seedling seed orchards over the seed stands resulted realized genetic gains for stand volume in the two sites which ranged from 13% to 136% at two years of age and 14% to 81% at four years of age (Table 3). In general, realized genetic gain in Central Java was higher than in South Kalimantan. Among both ages, the realized genetic gain at two years was generally higher than that at four years. These trends were probably due to the effect of increasing inter-tree competition from more rapid stand development, either attributable to good site quality or older age, which then tend to reduce the amount of genetic gain. Site in Central Java was less productive as compared to South Kalimantan, as shown by the slower growth of the trees (Table 3), which then indicated that the inter-tree competition in Central Java was less intense compared to South Kalimantan. Eldridge (1982) has reported a

small genetic gain in productive site indicating the decreasing genetic gains with increasing stand development and competition.

Consistent with the superiority in absolute stand volume, realized genetic gain of seedling seed orchards originating mostly from PNG (SSO-1, SSO-2, SSO-5) were higher than those from FNQ provenances (SSO-3, SSO-4). At two years, realized genetic gains ranged from 35% to 136% for the orchards of PNG provenances, and from 13% to 71% for the orchards of FNQ, while at four years the gains ranged from 39% to 81% and from 14% to 65% for the PNG and FNQ, respectively. SSO-2 which consisted of Oriomo, Wipim and Kini region of PNG provenances (see Table 1) showed the highest realized genetic gain in Central Java: 136% increase at two years age and 66% at four years. *A. mangium* from Oriomo region was recognized as the most productive of the PNG provenances (Harwood and Williams, 1991, Kari *et al.*, 1996). While in South Kalimantan, the gain of SSO-2 was the highest at two years (81%), but it was replaced by SSO-1 at four years (59%). Similar to the absolute stand volume, SSO-4 has produced the poorest realized genetic gain among the seedling seed orchards at both ages and sites, which ranged only from 36% to 43% in Central Java and 13%

to 14% in South Kalimantan. However, the data used in this study was collected at half rotation age (rotation age assumed to be 8 years) and the actual genetic gain might become smaller amount when the stand is getting older. This is because the amount genetic gain tends to be reduced as the stand development is progressing (Zobel and Talbert, 1984).

By considering the fact that the stand volume is a function of height, diameter and stem form, the amount of realized genetic gains in this study seemed to be greater than the gain confirmed in 1 year's measurement of second-generation seedling seed orchards as reported by Nirsatmanto *et al.* (2004). In a previous study, the realized gain which was calculated as percentage increase of family from selected plus trees in the first-generation orchards to the newly added infused family were around 3%, 5%, and 4% for height, dbh, and stem straightness, respectively. This discrepancy might be mostly due to additional gain from the selected provenance that was accumulated in the amount of gain calculated in the present study. The gain by selected provenance of Papua New Guinea and Queensland-Australia for *A. mangium* was reported to be ranging from around 20% to 40 % for stand volume (Hardiyanto *et al.*, 2000; Nirsatmanto *et al.*,

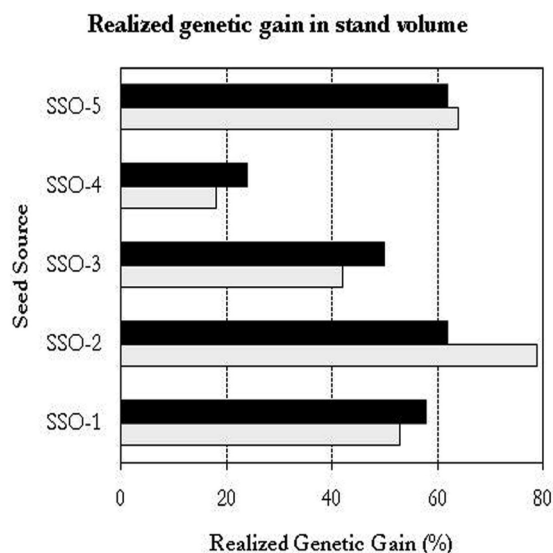


Figure 1. Realized genetic gain (%) for stand volume across the two sites of genetic gain trial of *Acacia mangium* at two years age (white bar) and four years age (dark bar)

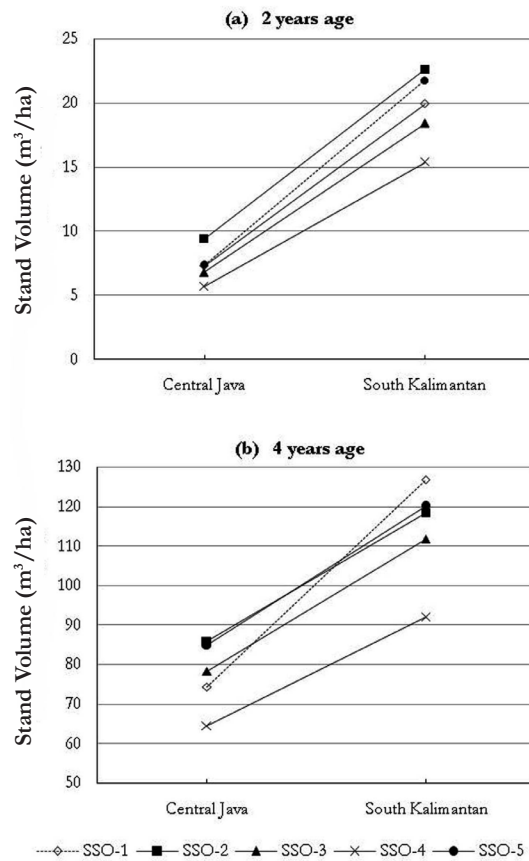


Figure 2. Ranking order of five seedling seed orchard (SSO) between two sites (Central Java and South Kalimantan) for stand volume observed at 2 years age (a) and 4 years age (b)

2003). Total realized genetic gain by the first-generation seed orchard as confirmed by this study was also higher as compared to other studies in pines species, e.g. 16%-18% increase in stand volume at 10 years age (Matziris, 1974) and 7%-12% at rotation age (Li *et al.*, 2000) for loblolly pine; 32% increase in individual stem volume for black pine (Matziris, 2005).

Selection of the productive provenance has become an important step for the success of the tree improvement of *A. mangium*. Butcher *et al.* (1998) has reported major differences in the level of genetic diversity of *A. mangium* in populations from the south of the species range (Daintree, Queensland) compared to levels in populations from Papua New Guinea using RFLPs. Higher level of genetic diversity, as shown by the population of Papua New Guinea ($He=0.16-0.21$), tended to produce superior growth in field trial.

C. Seed Source x Site Interaction

Analysis of variance across the two sites showed that differences among seed sources were statistically significant for stand volume (Table 5). The average of pooled stand volume from the two sites by seed sources ranged from 9.35 m³/ha to 16.75 m³/ha and from 61.58 m³/ha to 99.83 m³/ha for two years and four years respectively, with the average values of control (seed stand) were always the lowest (Table 6). Therefore, the realized genetic gain based on across site analysis ranged from 18% to 79% at two years, and from 24% to 62% at four years (Figure 1). SSO-1, SSO-2 and SSO-5 which originated from PNG provenances were consistently found at the top three highest realized genetic gain with a slight change in the ranking order among them between the two sites at four years (Figure 2b). The positive realized genetic gain from all of the five

orchards through two types of analysis, single analysis (Table 3) and across site analysis (Table 6), suggested that the superiority of the five seedling seed orchards were evident for stand volume productivity.

Despite the fact that both sites were considerably different in climate and geographic coordinates, seed source x site interaction was not significantly different (Table 5), indicating there was not a strong GxE interaction among the two sites at seed source level. It means that at half rotation age, superiority of the five seedling seed orchards were consistent across the two sites of genetic gain trial for stand volume. This result supports our previously reported study where GxE interaction between South Sumatra and South Kalimantan was not strong to cause any apparent reduction in genetic gain (Nirsatmanto *et al.*, 2004). Thus, improved seed produced from the five seedling seed sources could be deployed into two tested sites of plantations without any serious change of order in their superiority.

The seed source x site interaction was slightly lower at two years than at four years, as demonstrated by the difference in changing of the ranking order (Figure 2a and Figure 2b). At two years, all five seedling seed orchards performance was relatively stable across the two sites, while at four years there was one seed source (SSO-1), which most responsive to the site difference. However this interactive effect was not so strong to appear as a significant seed source x site interaction. SSO-1 which is located in close distance from the trial site in South Kalimantan tended to be more productive for stand volume at older age when planted in a site that pronounced a similar environment, while SSO-2 and SSO-5 was relatively stable across the diverse environment.

The non significance of GxE interaction at the level of seed sources as resulted in this study was not in agreement with the report of previous GxE interaction study at the level of family (Setyaji, 2011). In the previous study, high significance of family x site interaction for growth traits were observed using data from

second-generation of progeny test of *A. mangium* in South Sumatra and South Kalimantan. This discrepancy might be due to the difference in magnitude of variations, where the increases of genetic variation tend to reduce the strength of GxE interaction. The five seedling seed orchards in this study were converted from progeny trials which were established using grouped sub-line system based on the original of natural population distribution. It is well known that genetic variation between populations for *A. mangium* was larger than the variation among individuals (family) within the population (Butcher *et al.*, 2000). Among some GxE interaction studies summarized by King (1964) it was also concluded that as the genetic diversity of material increases, the relative magnitude of the interaction decreases.

Result in this study through analysis in realized genetic gain and seed source x site interaction as described above suggested that genetic improvement in stand volume of *A. mangium* has been achieved through first-generation seedling seed orchards. Selection of productive provenance proved to be an essential factor to bring some amount of improvement from first-generation breeding program for *A. mangium*. This study revealed that seed orchards which were established using family originating from superior provenances of PNG and FNQ consistently produced higher productive stand as compared to the unimproved material.

IV. CONCLUSION

Realized genetic gains of five seedling seed orchards from first-generation breeding program of *A. mangium* were well verified at half rotation age in genetic gain trials established at two different sites. The genetic gains were high in relation to the stand volume productivity, although the magnitude varied depending on site quality and the age of the stand. Gain observed in poor site quality (Central Java) tended to be higher than that observed in high site quality (South Kalimantan). Across the two sites, the realized genetic gains were in the

range of 18% –79% at two years of age and 24%–62% at four years of age. Seedling seed orchards consisting of family originating from superior provenance (PNG) showed higher genetic gain. The effect of interaction between seed sources and sites was also weak which indicated that the superiority of improved seed was consistent across the two different sites. The results of the study implied that the genetically improved seed would increase stand volume productivity of *A. mangium* plantations and it could be potentially deployed in wider range of environments without any serious change of order in their superiority.

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