

TREND OF REALIZED GENETIC GAIN OBSERVED IN SECOND-GENERATION SEEDLING SEED ORCHARDS OF *ACACIA MANGIUM* IN SOUTH KALIMANTAN, INDONESIA

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ABSTRACT

Comprehensive tree improvement program for *Acacia mangium* has been started since 1992 by establishing a series of first-generation Seedling Seed Orchards (SSO) in Indonesia. Selection procedures in the first-generation of SSO have completely finished, and subsequently it was continued for second-generation improvement. This paper examines a trend of realized genetic gain as a response of selection practiced in the first-generation SSO. The observation was carried out in three sub-lines of the second-generation SSO (namely Sub-line B, C and D). Parameters recorded included tree height, diameter at breast height (dbh) and stem straightness that were recorded periodically up to 4 years growth. The realized genetic gain was calculated as a percentage of improved plus trees population in the first-generation of SSO compared to those of unimproved trees. The results showed that the improved population was consistently better than those of unimproved one until 4 years of age. There were variation in terms of realized genetic gain parameters recorded depending on the sub-lines and ages. The tree height varied from 1.1% to 5%, while dbh and stem straightness were in the ranges of 2.8% to 6.7% and from 1.8% to 8.4%, respectively. Across the three sub-lines, the tree height varied from 2.2% to 3.1%, while dbh and stem straightness were in the ranges of 4.3% to 5.2% and 4.3% to 6%, respectively. In general, the trend of the realized genetic gains slightly decreased for dbh and tree height with the increasing of ages, while it slightly increased for stem straightness.

Keywords: *Acacia mangium*, Realized Genetic Gain, Seedling Seed Orchard, Second Generation

I. INTRODUCTION

In the last few years, genetically improved seed demand of *A. mangium* increased sharply to support plantation forest in Indonesia. Comprehensive tree improvement program has been started since 1992 by establishing first-generation of *A. mangium* seedling seed orchards (SSO) in Indonesia (Hashimoto *et al.*, 1996). The SSO was initially established as a progeny test using superior provenances collected from Papua New Guinea and Far North Queensland-Australia.

In 2000, selection procedures in the first-generation SSO of *A. mangium* have completely finished, and subsequently it was continued for the second-generation improvement (Kurinobu

and Rimbawanto, 2002). The primary objective of selection practiced in the seedling seed orchards was to select individual trees and families which had the most desirable characters for use as parents in breeding and improved seed production. Selection procedures were started by within-plot selection, followed by family or in combining with within-family selection, and finally plus trees selection. Significant amount of genetic gain could then be obtained from each step of selections, although the amount of improvement will vary among them (Wright, 1976).

Prediction of genetic gain obtained from progeny test is commonly practiced in tree improvement program, which is mainly dependent on the degree of heritability and selection differential between the selected population and original population. In case of *A. mangium*, Kurinobu *et al.* (1996) has reported that

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total prediction of genetic gain in *A. mangium* SSO from within-plot and family selection based on early growth data was less than 5% for both of growth and stem straightness. However, the amount of genetic gain prediction may differ from those of realized genetic gain. The difference might be due to the weakness of juvenile-mature correlation, the presence of competitive interaction, pollen contamination, unequal contribution of parents to the improved population, and interaction between genotypes and silvicultural practices (St. Clair, 1993). Therefore, comparison study of improved and unimproved population to evaluate the amount of actual genetic gain is necessary. The result obtained from the study is also useful to observe the response to selection practiced in a SSO which is initially set up as progeny test.

Nirsatmanto *et al.* (2004) reported that realized genetic gain brought by the first-generation tree improvement using data observed in three second-generation SSO were positive at the first year of age. The realized genetic gains were around 3% for height, 5% for dbh, and 4% for stem-straightness, and confirmed that the series of selection procedure practiced in first-generation SSO had been done properly. However, the one year age data as used in that study was still very young and probably provides different result if the trees getting older. According to Eldridge *et al.*, (1993) and Zobel and Talbert (1984), realized genetic gain tends to reduce with increasing stand development and competition. Therefore, the present study was conducted to observe the trend of realized genetic gain using data until four years of age in the second-generation SSO of *A. mangium* in South Kalimantan, one of the representative regions for *A. mangium* plantation in Indonesia.

II. MATERIAL AND METHOD

A. First and Second-generation Seedling Seed Orchard (SSO)

Detailed description and field experiment in the first and second-generation SSO were described by Nirsatmanto *et al.* (2004), and it is summarized in Table 1. Six of the first-generation SSO of *A. mangium* were established in January 1994 in two locations: South Sumatra and South Kalimantan. They were established according to the sub-line system (McKeand and Beineke, 1980), which were accomplished by establishing small breeding groups of SSO separately according to their original provenances. Owing to poor survival and fire disaster at two orchards, plus trees selection was made only in the four orchards representing four sub-lines, namely sub-lines A, B, C and D (Table 1).

Beyond strategy towards advanced generation breeding program using sub-line system, four second-generation SSO representing the four sub-lines were established in January 2001 in South Kalimantan, Indonesia. Family tested in the second-generation SSO consists of 24-49 open-pollinated families of selected plus trees in first-generation SSO and 3-39 newly infused families selected from natural forest. In this study, the plus trees families and the infused families were then referred to as the improved population and the unimproved one, respectively. During the four years measurement, within-plot selections were practiced twice in the four sub-lines of SSO: at two years for the first selection and at three years for the second one, with culling rate of 50 % for each stage of selection.

Table 1. Summary of description and field experiment of seedling seed orchards

Sub-line	Provenance	First-generation			Second-generation	
		Location	Number of Family	Number of Candidate Plus tree	Location	Number of Family
A	PNG	South Kalimantan	65	107	South Kalimantan	52
B	PNG	South Sumatra	58	32	South Kalimantan	55
C	FNQ	South Kalimantan	55	55	South Kalimantan	68
D	FNQ	South Sumatra	62	35	South Kalimantan	55

Remarks : PNG: Papua New Guinea; FNQ: Far North Queensland

B. Measurements and Data Analysis

Periodical measurements were conducted at two, three, and four years of age involving traits of tree height, diameter at breast height (dbh) and stem straightness. Tree height and dbh were recorded in metric scale, while stem straightness was scored from 1 (worst) to 5 (best) according to the method of Keiding *et al.* (1984). In this study, the data from the sub-line A was excluded from the analysis due to a large imbalance in the number improved families and unimproved one. Therefore, the subsequent analysis was made with the data from the three SSO: sub-lines B, C and D.

Analysis of variance was made for each sub-line using individual tree data (y_{ijk}) with the following linear model:

$$y_{ijk} = \mu + P_i + B_j + P/F_{ik} + BF_{jk} + e_{ijk} \dots\dots\dots(1)$$

where, μ = population mean, P_i = the effect of improved and unimproved population, B_j = the j -th replication effect, F/P_{ik} = the k -th family effect in i -th population, BF_{jk} = the k -th plot error in the j -th replication and e_{ijk} = within plot deviation with y_{ijk} , respectively.

In order to examine the amount of genetic improvement across the three sub-lines, analysis of variance was made using replication x population mean across the three sub-lines (y_{ijk}) with the following linear model:

$$y_{ijk} = \mu + S_i + B/S_{ij} + P_k + S*P_{ik} + e_{ijk} \dots\dots\dots(2)$$

where, μ = population mean, S_i = the sub-line

effect, B/S_{ij} = the j -th replication effect in the i -th sub-line, P_k = the k -th population effect, $S*P_{ik}$ = the effect of sub-line x population interaction, and e_{ijk} = experimental error associated with y_{ijk} , respectively.

The realized genetic gains were calculated as the differences between the improved population and unimproved ones, both of which were the least square estimates of the linear model given in Equation 1 and Equation 2. Then the relative gain was calculated as a percentage rate of the gain into the mean of unimproved population. The results were then compared with those studied by Nirsatmanto *et al.*, (2004) to obtain more complete results and to make comprehensive discussion.

III. RESULT AND DISCUSSION

Growth, form traits and realized genetic gain until 4 years of age in the three sub-lines of the second-generation SSO were presented in Table 2. In general, trees planted in the three sub-lines showed good growth, exceeding 13 m for height and 13 cm for dbh at four years of age. Along the four year of ages, growth traits varied among the three sub-lines. Sub-line B performed slightly better in height growth with the average at four years exceeded 15 m, then followed by sub-line D. Conversely, sub-line D showed better in diameter than Sub-line B with the average exceeded 14 cm. Among the three sub-lines, sub-line C was

Table 2. Growth, form traits and gain (%) at 1, 2, 3 and 4 years measurement in the three sub-lines of the second-generation seedling seed orchard

Sub-Line	Type of Family	No. Family	Traits / Age											
			Height (m)				dbh (cm)				Stem-straightness			
			1 ¹⁾	2	3	4	1 ¹⁾	2	3	4	1 ¹⁾	2	3	4
B	Improved	31	4.58	8.06	13.61	15.28	4.64	8.26	13.38	14.41	3.12	3.20	3.42	3.60
	Unimproved	25	4.50	7.94	13.29	15.11	4.39	7.94	12.79	13.91	2.91	3.00	3.16	3.32
	Gain (%)		+1.7	+1.5	+2.4	+1.1	+5.6	+4.0	+4.6	+3.6	+7.2	+6.7	+8.2	+8.4
C	Improved	28	3.52	6.52	10.08	11.61	3.67	6.68	11.51	13.56	2.99	3.18	3.23	3.13
	Unimproved	40	3.39	6.25	9.60	11.36	3.50	6.36	11.20	13.05	2.89	3.06	3.03	2.90
	Gain (%)		+3.7	+4.32	+5.0	+2.2	+5.0	+5.0	+2.8	+3.9	+3.2	+3.9	+6.6	+7.9
D	Improved	24	4.45	8.27	12.68	14.71	4.74	8.33	13.54	15.38	3.21	3.32	3.36	3.66
	Unimproved	31	4.28	8.11	12.52	14.22	4.51	7.93	12.87	14.41	3.14	3.24	3.30	3.58
	Gain (%)		+3.9	+2.0	+1.3	+3.5	+5.3	+5.0	+5.2	+6.7	+2.4	+2.5	+1.8	+2.2
Mean	Improved		4.18	7.62	12.12	13.87	4.35	7.76	12.81	14.45	3.11	3.23	3.37	3.46
	Unimproved		4.06	7.43	11.80	13.56	4.13	7.41	12.29	13.79	2.98	3.10	3.16	3.27
	Gain (%)		+3.1	+2.5	+2.7	+2.2	+5.2	+4.6	+4.3	+4.7	+4.3	+4.3	+5.4	+6.0

¹⁾Nirsatmanto *et al.* (2004)

consistently the lowest in both of growth traits. As reported in previous study, the slower growth in Sub-line C was probably due to poor drainage of the site (Nirsatmanto *et al.*, 2004). Regarding the stem-straightness, all three sub-lines generally showed almost the same performance, exceeding score 3, with a tendency to be straighter with the increasing of ages. The possible reason of increasing stem straightness is due to the effect of within-plot thinning which have been practiced twice during the four years ages and the increases of diameter growth development. This phenomenon is similar with those reported by Hubert *et al.* (2003) in Sitka spruce, that thinning had a positive effect on the overall stem straightness of a stand. In addition, smaller trees in diameter tended to have poor stem straightness than larger diameter trees.

In the three sub-lines along the four year measurements, the growth and form traits of improved population were consistently better than those of the unimproved population. The realized genetic gain that were calculated as a difference between the improved population and unimproved one ranged from 1.1% to 5% for height, 2.8% to 6.7% for dbh, and 1.8% to 8.4% for stem straightness (Table 2). The amount of realized genetic gain for each trait varied among the sub-lines and ages. In general, the highest gain for height was found in Sub-line C, while those for

diameter was found in Sub-line D. Regarding the stem straightness, the highest gain was found in Sub-line B. The positive realized genetic gain for the three traits along the four year ages indicated that the series of selection practiced in the first-generation SSO was done properly. Realized genetic gain obtained as a response to selection in the orchard provided an improvement in growth and form traits productivity. In addition, despite the results of gain among the three sub-lines was not directly comparable because of the differences in genetic material of unimproved population, the respective sub-line showed higher realized genetic gain in specific characters: sub-line B for stem straightness, sub-line C for height and sub-line D for dbh. This result indicated that the magnitude of variation and improvement among the three sub-lines was different according to the trait. The possible reason of this discrepancy is mainly due to the differences of genetic materials used in each sub-line, where the three sub-lines consisted of family originated from different region of provenances: Papua New Guinea and Far North Queensland (Table 1).

Analysis of variance for each sub-line estimated using Equation (1) revealed that the differences between the improved and unimproved populations were statistically significant for all sub-lines and ages, except for height in Sub-line B and stem straightness in Sub-

Table 3. Mean of square for each component of three traits analyzed in each sub-line in four age measurements

Source of Variance	Traits and ages											
	Height				Dbh				Stem straightness			
	1 ¹⁾	2	3	4	1 ¹⁾	2	3	4	1 ¹⁾	2	3	4
Sub-line B												
Pop	3.3039 ^{ns}	7.0116 ^{**}	31.3773 ^{**}	4.4771 ^{ns}	32.6587 ^{**}	52.3458 ^{**}	99.2647 ^{**}	63.7748 ^{**}	23.6135 ^{**}	19.6828 ^{**}	19.9427 ^{**}	16.6693 ^{**}
Fam (Pop)	1.3163 ^{**}	3.2439 ^{**}	3.9072 ^{**}	11.4249 ^{**}	1.9453 ^{**}	3.5772 ^{**}	8.1386 ^{**}	7.9684 ^{**}	1.2178 ^{**}	0.9052 ^{**}	1.0834 ^{**}	0.9563 ^{**}
FamxRep	0.3537 ^{**}	1.445 ^{**}	2.0414 ^{**}	4.9786 ^{**}	0.8835 ^{**}	1.9825 ^{**}	6.531 ^{**}	5.1258 ^{**}	0.6330 ^{**}	0.4953 ^{**}	0.8015 ^{**}	0.7263 ^{**}
Error	0.1434	0.3008	0.8808	3.2600	0.4162	0.8341	3.2003	3.7957	0.4592	0.3939	0.5049	0.3987
Sub-line C												
Pop	9.7863 ^{**}	28.1001 ^{**}	58.7533 ^{**}	11.8443 [*]	19.0100 ^{**}	39.2248 ^{**}	21.0015 [*]	59.1287 ^{**}	5.5372 ^{**}	6.3050 ^{**}	11.3369 ^{**}	12.036 ^{**}
Fam (Pop)	1.0895 ^{**}	2.6824 ^{**}	4.6970 ^{**}	6.9314 ^{**}	2.2866 ^{**}	3.6943 ^{**}	8.8694 ^{**}	6.7542 ^{ns}	0.7612 [*]	0.7858 ^{**}	0.4815 ^{**}	1.2196 ^{**}
FamxRep	0.5698 ^{**}	1.9047 ^{**}	4.3067 ^{**}	5.5169 ^{**}	1.3649 ^{**}	3.1907 ^{**}	6.4205 ^{**}	8.4518 ^{**}	0.5541 ^{**}	0.4435 ^{**}	0.3597 ^{**}	0.8397 ^{**}
Error	0.1714	0.4840	1.4153	2.1451	0.5754	1.4226	4.2967	5.4802	0.3158	0.3450	0.2646	0.6462
Sub-line D												
Pop	15.4129 ^{**}	10.0759 ^{**}	6.5333 [*]	56.6723 ^{**}	29.7740 ^{**}	79.625 ^{**}	158.0852 ^{**}	229.3496 ^{**}	3.1594 ^{ns}	3.0669 ^{**}	1.2126 [*]	1.1639 ^{ns}
Fam (Pop)	1.5058 ^{**}	3.9006 ^{**}	5.8224 ^{**}	6.5302 ^{**}	2.8010 ^{**}	4.8159 ^{**}	8.8368 ^{**}	8.7092 ^{**}	1.6177 ^{**}	2.0796 ^{**}	1.2164 ^{**}	2.1371 ^{**}
FamxRep	0.4637 ^{**}	2.2462 ^{**}	3.1054 ^{**}	5.0175 ^{**}	0.9969 ^{**}	1.9446 ^{**}	4.2121 ^{**}	5.4074 ^{**}	0.6642 ^{**}	0.6103 ^{**}	0.3654 ^{**}	0.8016 ^{**}
Error	0.2108	0.4231	1.2443	1.7713	0.6031	1.4117	2.7864	3.5585	0.4480	0.3953	0.2668	0.4921

¹⁾ Nirsatmanto *et al.*, (2004)

Remarks: Pop : Population; Fam : Family; Rep : Replication

^{**}, significant at 1 % level

^{ns}, not significant

line D at one and four years of age (Table 3). The non significant difference was found mainly in the case where the realized genetic gain was lower. Besides the significant differences in population, almost all of the family variations on the three traits were also consistently significant along the four year measurements. This result indicated that the amount of genetic improvement could be continuously attained through the second-generation of tree improvement.

Analysis of variance by pooling data across the three sub-lines estimated using Equation (2) showed that the population difference was also statistically significant for all the three traits and ages, except for stem straightness at the first year of age (Table 4). As described in the previous study that this non significant for stem straightness was due to the evident of sub-line x population interaction (Nirsatmanto *et al.*, 2004). The result of analysis of variance across the three sub-lines was in line with the result of analysis of variance in each sub-line presented in Table 3. It indicated that the superiority of improved

population observed in this study was consistent, and thus, the amount of realized genetic gain from the first-generation selection was evident up to four years of age.

Mean of realized genetic gain across the three sub-lines varied depending on the ages, ranging from 2.2% to 3.1% for height, 4.3% to 5.2% for dbh and 4.3% to 6% for stem straightness (Figure 1). The realized genetic gain tended to be slightly decreased with the increasing ages for height and dbh, while they were increased for stem straightness. In the first and two years of ages, the greatest gain was dbh, then followed by stem straightness. By contrast, in the three and four year of ages, the greatest gain was stem straightness, then followed by dbh. Among the three traits, tree height was consistently low along four years growth. The greater genetic gain for stem straightness in the last two years might be due to the positive effect of within-plot thinning that was practiced twice in the orchards after two years of age. As reported by Hubert *et al.* (2003), thinning had a positive effect on stem straightness.

Table 4. Mean of square for each component of three traits analyzed across the three sub-lines in four age measurements

Source of df	Traits and ages											
	Height				Dbh				Stem straightness			
	1 ¹⁾	2	3	4	1 ¹⁾	2	3	4	1 ¹⁾	2	3	4
SL	2 6.7502**	23.0440**	90.3004**	88.1911**	6.4839**	19.9538**	29.6748**	13.8209**	0.2884**	0.0210**	0.2188**	1.9145**
Rep(SL)	27 0.1316 ^{ns}	0.7655**	1.2181**	4.4285**	0.2718 ^{ns}	0.4558**	0.7813**	0.8813**	0.0888 ^{ns}	0.0411**	0.0660**	0.3218**
Pop	1 0.2306*	0.3713**	1.1593**	1.0166**	0.7173*	1.5682**	2.4241**	6.3115**	0.2443 ^{ns}	0.2394**	0.4183**	0.4950**
SL X Pop	27 0.0106 ^{ns}	0.1727 ^{ns}	0.0811 ^{ns}	0.1881 ^{ns}	0.0084 ^{ns}	0.0187 ^{ns}	0.3560 ^{ns}	0.3374 ^{ns}	0.0258**	0.0196 ^{ns}	0.0644**	0.0489 ^{ns}
Error	59 0.0059	0.0241	0.0631	0.1271	0.0160	0.0396	0.1254	0.1570	0.0044	0.0059	0.0070	0.0202

¹⁾ Nirsatmanto *et al.*, (2004)

Remarks: SL : Sub-line

** significant at the level 1 %

^{ns} : not significant

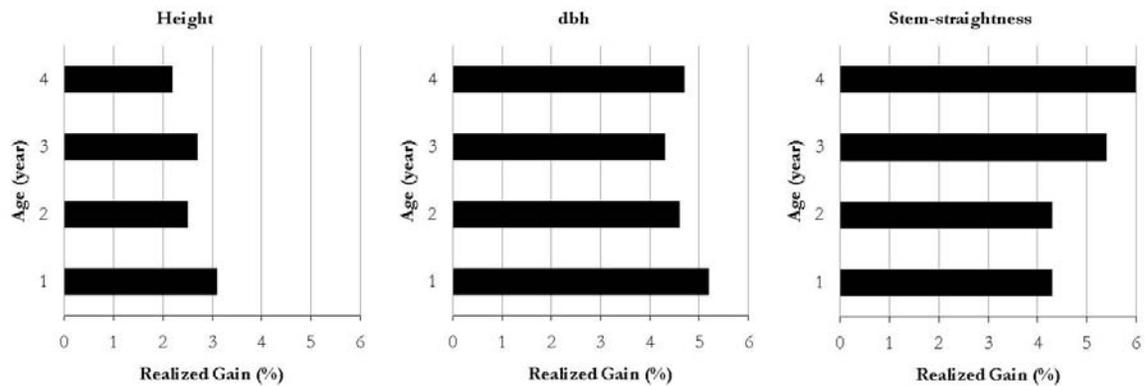


Figure 1. Realized genetic gain across sub-lines up to half of rotation ages

However, it might be controlled genetically as well, because the heritability on this trait was moderately high at around 0.25 - 0.50 (Kurinou *et al.*, 1996; Nirsatmanto and Kurinou, 2002).

The amount of realized genetic gain for tree height in this study was similar to the predicted genetic gain reported in the previous study by Kurinou *et al.* (1996). Whereas for dbh and stem straightness, the realized gain was greater than the predicted one. In the previous study, predictions of total genetic gains calculated as an accumulation gain due to within-plot and family selection were reported averaging at around 2.8% for height, 3.2% for dbh and 2.6% for stem straightness. However, it should be noted that improved population as used in the present study was plus trees selected from the first-generation SSO. Therefore the greater gain to those in the previous study was partly due to the additional selection intensity that had been allocated at the time of plus trees selection. The selection rate for plus trees selection in the first-generation SSO of *A. mangium* was around 3%, while those for final density due to total within and between family selection was around 15% (Nirsatmanto *et al.*, 2004).

Unlike family selection that was done theoretically oriented and straightforward, plus tree selection was done mainly based on superiority of phenotypic performance. Moreover, the unique property of *A. mangium* performance showed that large phenotypic variance was mostly dominated by dbh and stem straightness. These facts lead the plus trees selection practiced in first-generation SSO tended to emphasize on the both dbh and stem straightness traits rather than tree height. In addition, plus trees selection in this study was practiced at almost six years old where the tree height was commonly difficult to be observed as the tree growth progressed and the crown closure. As a result, gain due to plus trees selection was greater for dbh and stem straightness compared to tree height. Similar trend was also observed during within-plot selection which was practiced mainly based on phenotypic performance (Kurinou *et al.* 1996).

The amount of realized genetic gain obtained in this present study could be potentially increased, if the intensity of family selection increases. This is because of the fact that the

actual of pollen parent retained in the first-generation SSO was only 15 %, which was attributed to at least 90% of family selection rate or almost no family selection practiced (Kurinou *et al.* 1998). However, the low selection intensity for family might be better to maintain the genetic variability in the orchards, despite it would bring some reduction in the expecting of genetic gain. Lower selection intensity is also recommended especially in the first generation orchards due to the less reliable result of family ranking caused by the great variation of out crossing rate and neighborhood inbreeding among families (Harwood *et al.*, 1997). A comparison study using microsatellites markers showed that the outcrossing rates of *A. mangium* varied among the original populations, ranging from complete selfing to complete outcrossing, depending on the levels of diversity (Butcher *et al.*, 1999).

Despite the trend of realized genetic gain observed in this study varied dependent on the traits: slightly decreased for growth and increased for stem straightness, outstanding performances of plus trees selected at an older age in the first-generation orchards (around six years) were consistent and well reflected up to the half of rotation ages of their second-generation. This result confirmed that the juvenile-mature correlation for *A. mangium* was strong. The trend of genetic gain also indicated that the effect of G x E interaction between the locations of original plus trees was weak. This is because genetic material collected from the first-generation orchards in South Sumatera (Sub-lines B and D) showed good performance when planted in South Kalimantan. These results provided two good implications for generating future advanced generation breeding strategy of *A. mangium*. Firstly, the strong juvenile-mature correlation will provide high efficiency of early selection practiced in the SSO. Secondly, the weak interaction will provide possibility to combine data from the range of different test locations to be used together in order to conduct more accurate family selection.

IV. CONCLUSION

1. Up to half of rotation ages (four years) observed in three sub-lines of the second-

generation seedling seed orchard of *A. mangium*, performances of improved population produced from the first-generation seedling seed orchard was consistently better than those of unimproved. This result confirmed that selection procedures practiced in the first-generation seedling seed orchard had been done properly.

2. The realized genetic gain across three sub-lines at four year age measurements ranged from 2.2% to 3.1% for height, 4.3% to 5.2% for dbh and 4.3% to 6% for stem straightness.
3. Trend of the realized genetic gains were slightly decreased for dbh and tree height with the increasing of ages, while it was slightly increased for stem straightness.

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