

The effect of planting technique on the growth of two *Shorea* species in Gunung Dahu, Bogor, Indonesia

HENTI H. RACHMAT^{1,✉}, PRIJANTO PAMOENGKAS², LUSIANA SHOLIHAH², RIZKI ARY FAMBAYUN¹, ARIDA SUSILOWATI^{3,✉}

¹Forest Research and Development Center. Jl. Gunung Batu No 5, Bogor 16118, West Java, Indonesia. Tel./fax. +62-251-8334314, ✉email: hendalastuti@yahoo.co.uk

²Department of Silviculture, Faculty of Forestry, Institut Pertanian Bogor. Jl. Lingkar Akademik, Dramaga, Bogor 16680, West Java, Indonesia

³Faculty of Forestry, Universitas Sumatera Utara. Jl. Tri Dharma Ujung No.1, Kampus USU, Medan 20155, North Sumatra, Indonesia
Tel./fax.: +62-61-8201920, ✉email: arida_iswanto@yahoo.co.id

Manuscript received: 3 August 2020. Revision accepted: 14 August 2020.

Abstract. Rachmat HH, Pamoengkas P, Sholihah L, Fambayun RA, Susilowati A. 2020. The effect of planting technique on the growth of two *Shorea* species in Gunung Dahu, Bogor, Indonesia. *Biodiversitas* 21: 4131-4138. Forest rehabilitation is the counterforce of deforestation and forest degradation. One of the promising strategies for rehabilitating degraded forest land is through replanting of native tree species. Nonetheless, investigation in which planting technique is more effective in supporting plant growth is required in various regional contexts. This study aimed to analyze the growth performance in terms of diameter and height of *Shorea leprosula* and *S. selanica* planted in Gunung Dahu Research Forest (GDRF), Bogor, Indonesia treated with total planting and line planting techniques. Diameter and height, as well as environmental factors such as soil texture, average litter thickness, slope, the average thickness of topsoil, and canopy density were observed. Data analysis was performed using ANOVA and followed by Duncan's test. The result showed that line planting was better in accelerating the diameter growth of *S. leprosula* and *S. selanica* than total planting. However, planting techniques had no effect on the height growth of both species. The highest growth rate was found in *S. selanica* treated with line planting with the average diameter and height increment was 1.13 cm/year and 0.78 cm/year, respectively. Line planting also produced higher basal area and stand volume with 0.06 m² and 0.64 m³ per year, respectively for *S. leprosula* and 0.06 m² and 0.66 m³ per year, respectively for *S. selanica*.

Keywords: Dipterocarp, line planting, *Shorea leprosula*, *Shorea selanica*, total planting

INTRODUCTION

Indonesia's tropical forests play a significant role in the economic, ecological, social, and cultural aspects. However, tropical forests in Indonesia experience one of the world's highest deforestation rates, second place after Brazil (Hansen, 2009) both in terms of quantity and quality. In Indonesia, in particular, over 6 Mha of primary forests were lost from 2000 to 2012 (Margono et al., 2014). There are many causes of forest loss in the country, including the development of oil palm plantation and timber plantation, mining, high population growth, urbanization and expansion of urban areas, illegal timber extraction, land encroachment and occupation in forest areas, governance problem, and forest fires (Tsumura et al. 2011; van Lierop 2015; Austin et al. 2018; Susanto et al. 2018).

Forest rehabilitation is considered as the counterforce of deforestation and forest degradation. One of the promising strategies for rehabilitating degraded forest land is through replanting of native tree species. Native tree species from the family of Dipterocarpaceae are frequently advocated for forest rehabilitation in Indonesia instead of introduced species, such as *Acacia mangium*. Dipterocarp species that have been promoted as potential trees for forest rehabilitation including those from red meranti group

(Kobayashi et al. 2001). The trees from the group of red meranti are known as relatively slow-growing species (Hidayat et al. 2017) with stem structure that is naturally straight and cylindrical (Wistara et al. 2016).

Two species from the red meranti group potentials to be replanted in degraded forest land are *Shorea leprosula* and *Shorea selanica*. These two species have been widely known in various Southeast Asian countries (Appanah and Turnbull 1998) as major commercial timber species. Kenzo et al. (2011) stated that sunlight exposures enhanced the growth performance of Dipterocarp species under suitable planting conditions. Furthermore, Lestari et al. (2019) stated that soil pH and sloping terrain could increase the growth performance of planted species in post-coal mining reclamation area in East Kalimantan. In this study, *Shorea balangeran* became one of the most suitable plant species to be planted in this area, especially in sloping terrain.

Considering the various condition of rehabilitation areas in Indonesia, there are two common methods in forest rehabilitation, namely line planting and total/intensive planting. Line planting involves growing targeted species in a lane, where in a specific terrain will be found planted lanes and unplanted lanes (gap lanes). Line planting method has been used widely, such as in Bukit Kinta Forest, Peninsular Malaysia (Abdu et al. 2008), and lowland forests in South Kalimantan (Adjers et al. 1995).

Total planting is a planting technique where all areas or plots are completely planted at certain planting distance. The conservation plot in Haurbentes Research Forest is also applied total planting technique (Kosasih and Mindawati 2011).

Considering the importance of selecting planting techniques of dipterocarp species, an assessment is required to investigate which method, either total planting or line planting, is more effective to support plant growth. This study aimed to analyze the growth performance in terms of diameter and height of *S. leprosula* and *S. selanica* in Gunung Dahu Research Forest (GDRF), Bogor, Indonesia treated with total planting and line planting. GDRF is an excellent case study as in the area has been established research and practice of forest rehabilitation in the form of a mixed meranti forest. The hilly environmental conditions and diverse slopes in GDRF make the rehabilitation activities adopted several planting techniques, including line planting and total planting.

MATERIALS AND METHODS

Study area

The research was conducted in Gunung Dahu Research Forest (GDRF), Bogor, West Java, Indonesia. Geographically GDRF area lies at 06°36'30"-06°37'00" S and 106°34'00"-106°35'30" E. It has climate type B with annual rainfall of 2,500-2,700 mm. The soil is grouped into reddish-brown latosol. The topography varies from flat to hilly and steep, with altitude ranging from 550 to 800 m

above sea level. Research plots for the growth measurement of *S. leprosula* were in plots 1 and plot 8, while for *S. selanica* were in plots 10 and 17. Plots 1 and 10 represented total planting technique, while plots 8 and 17 represented line planting (Figure 1).

Experimental plot

The seedlings planted in GDRF were from cutting propagation using KOFFCO method, a cutting technology developed by the Forestry Research and Development Agency, Bogor, Indonesia in collaboration with the Research Center, Komatsu Ltd. It can be simply interpreted as a vegetative propagation technique of shoot cutting with fogging treatment. This technique was developed to propagate meranti dipterocarp species in particular and other local species in general by controlling and maintaining three important elements, namely temperature, humidity, and light intensity (Rachmat et al. 2018).

The planting techniques applied at the selected plots in GDRF were line planting and total planting. For line planting technique, lines were made in 10 m wide, with 15 m distance between the centers of adjacent lines. Undesired vegetation was removed in the lines before planting, for example, ground cover, bushes, small pioneer trees, and climbers. For total planting technique, land preparation through clearing was carried out to create open space for 2 x 2 m planting distance. The initial planting density for line planting and total planting was 750 individuals/ha and 2,500 individuals/ha, respectively. The planting layout was described in Figure 2.

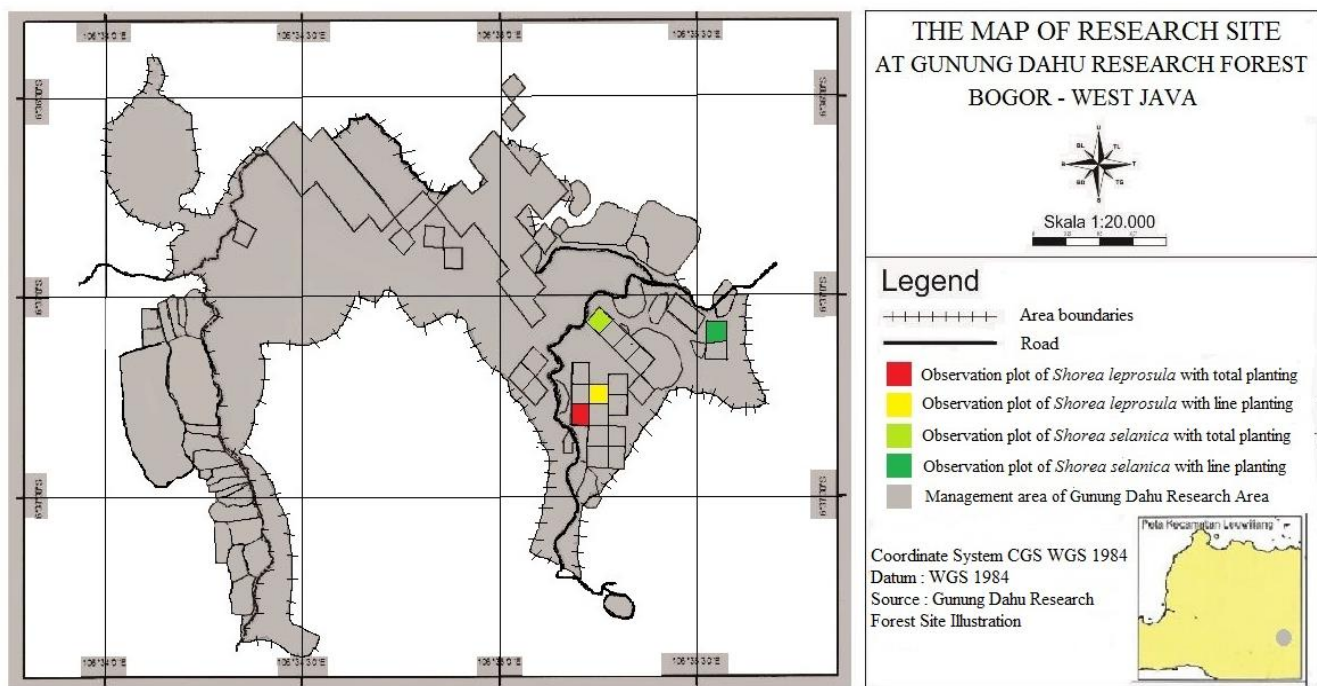


Figure 1. Research plot at Gunung Dahu Research Forest (GDRF), Bogor, West Java, Indonesia

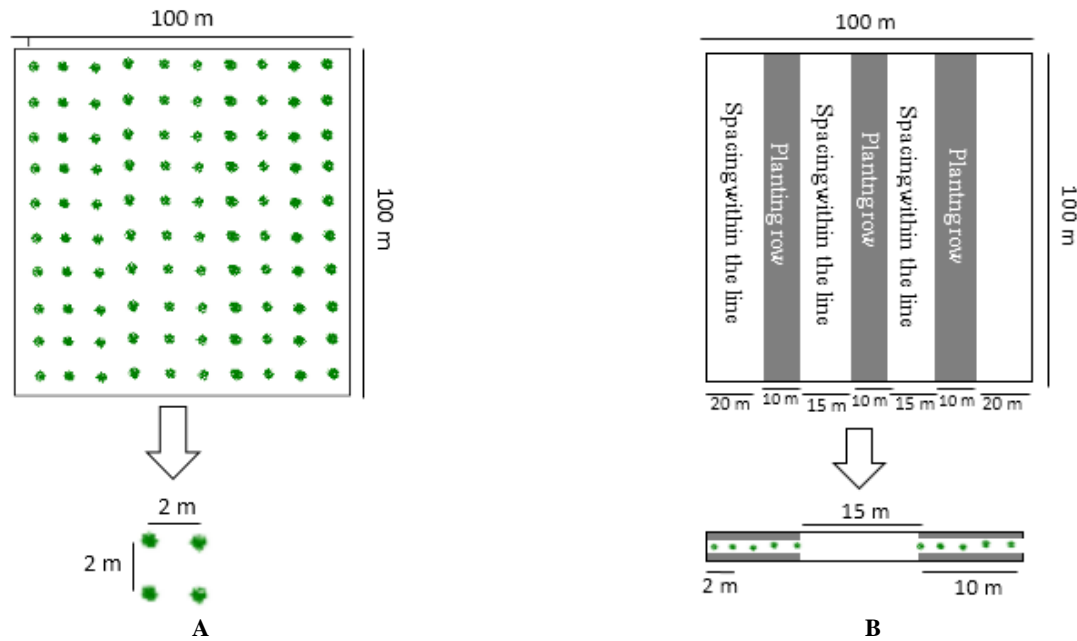


Figure 2. The planting layout: A. Total planting technique, B. Line planting technique

Table 1. The information and environmental conditions of *Shorea leprosula* and *S. selanica* stands at the research plot in Gunung Dahu Research Forest (GDRF) Bogor, West Java, Indonesia

Species	Planting technique	Plot number	Elevation (m asl.)	Initial stand density (ind/ha)	Stand density at measurement time (ind/ha)	Average litter thickness (cm)	Slope (%)	LAI
<i>S. leprosula</i>	Total planting	1	713	2,500	1,137	4.94	>45	1.58
	Line planting	8	713	750	241	9.60	>70	1.32
<i>S. selanica</i>	Total planting	10	785	2,500	682	2.66	>35	1.66
	Line planting	17	744	750	161	5.94	>70	1.85

Note: Each plot has the total area of 1 ha. All plots were planted in 1997 and the soil texture in this area was clay

Based on the results of the preliminary survey, information and environmental conditions related to the observation plots are presented in Table 1. All observation plots have similarity in the area extent and year of planting, which was in 1997. Hence, all observed trees in each plot were about 22 years old. The elevation of each plot ranged from 713 to 785 m asl, with the highest point was located in plot 10 and the lowest location was in plots 1 and 8. Purwaningsih (2004) stated that in Indonesia, Dipterocarp species could grow naturally at elevation up to 1,500 m asl. Soil texture in all observation plots site was clay.

Stand density in GDRF has experienced a reduction since at the beginning of the planting. This reduction was due to many factors, for example, the community's high disturbance as the planting began and the absence of intensive maintenance such as replanting (due to limited planting stock) and weeding, resulting in high competition between individuals and weeds. Most dipterocarps are shade tolerant species (Appanah and Turnbull 1998). It required shade at a young age up to the age of two years or a height of 1.5 m or more so that a relatively open field

condition during the initial planting caused high mortality of seedlings or small plants.

Data collection

The following parameters representing growth performance were observed.

Leaf area index

The amount of sunlight accepted by the canopy stand was calculated by measuring the amount of leaf area index (LAI). The leaf area index (LAI) is defined as half the total all-sided leaf area per unit ground surface area (Chen and Black 1992), which is used as a quantitative measurement of canopy foliar area (De Kauwe et al. 2011)

The measurement of LAI at plots 1 and 10 was conducted at five points on each plot. While LAI measurement in plots 8 and 17 was conducted on each planting line and spacing between lines. Canopy cover was measured using a camera with a fisheye lens and further analyzed using HemiView software package. The results

obtained by averaging LAI value using the following formula:

$$\text{Average LAI} = \frac{\text{The total LAI}}{\text{The Number of take points}}$$

Total diameter and height

Measurement of total diameter and height were carried out on each plot using census method. Tree diameter was measured at breast height (1.3 m) using a phi band, while total height measurement using hypsometer. The average diameter and height were calculated based on the formula:

$$\text{Average diameter} = \frac{\text{The total diameter of the tree observed (cm)}}{\text{The number of individual trees observed}}$$

$$\text{Average height} = \frac{\text{The total height of the tree observed (m)}}{\text{The number of individual trees observed}}$$

Mean Annual Increment (MAI)

MAI is a rate of plant growth that can be measured by counting individual trees, number of stands per unit of time, or accumulating dimensional increase such as diameter and height for each year. The MAI value is perpendicular to the average value. Calculation of the MAI of height and diameter were based on the formula developed by Pordan (1968):

$$I_{hi} = \frac{h_i}{t_i} \quad I_{di} = \frac{d_i}{t_i}$$

Where:

- I_{di} : average diameter in the i year (cm/year)
- I_{hi} : average height in the i year (m/year)
- D_i : average diameter in the i planting year (cm)
- h_i : average height in the i planting year (m)
- t_i : the age of the plant in the i year (year)

Stand volume

The stand volume was calculated based on the formula:

$$V = \text{LBD} \times T \times f$$

Where:

- V : Volume (m^3/ha)
- LBD : Basal area (m^2)
- T : Height (m)
- f : Form factor (0.6)
- $\text{LBD} : \frac{1}{4} \pi d^2$

Where:

- π : Constanta (3.14)
- d : Diameter (m)

Data analysis

The data were analyzed using ANOVA (Analysis of Variance) and then followed by Duncan's test at 5% confidence level. The box plot diagram was used to

describe data distribution. All statistical analyses were conducted using SPSS 25.

RESULTS AND DISCUSSION

General description of *S. leprosula* and *S. selanica* stands

Originally, *S. leprosula* grows naturally in mineral soil in Kalimantan and Sumatra, while *S. selanica* grows naturally in mineral soil in Maluku. Based on the field observation, the highest average litter thickness was found in plot 8 with the line planting technique, and the lowest one was found in plot 10 with the total planting technique. Factors affecting the fallen litters are forest type, environment climate, degrees of latitude, soil fertility and moisture, silvicultural treatments, the influence of tree density and basal area, thinning, litter collection, seasonal variation, and age of stands (Bray and Gorham 1964). Appanah and Weinland (1996) stated that all species of Dipterocarpaceae generally have self-mechanism of natural pruning in their life. The lowest branch of Dipterocarp species will fall off by their own mechanism regardless of the competition.

At the line planting plot, fern *Gleichenia linearis* grew in the space between the lanes, while bamboo (*Bambusa* sp.) colonized the space around the observation plot, creating more diverse and thicker litter composition in the area (Figure 3). The thick litter is likely caused by the time of observation which took place at the end of the dry season in which the ferns dried out and fell, and similar conditions happened to bamboo leaves. Increased fallen litter during the dry season was related to the condition of lack of water that triggered plant to decrease their evapotranspiration (Welder and Wright 1995).

The elevation in plots 1, 8, 10, and 17 were 713, 713, 785, and 744 m asl, respectively. Plot 10, which was planted with *S. selanica* using total planting technique, had the lowest slope with >35% of slope. Whereas the highest slope was in plots 17 and 8 with >70% of slope, both plots were applied line planting techniques. Total planting was applied in the area with mild steepness, while line planting was applied in areas with a high level of steepness.

According to Mohamad Jaffar (2018), Dipterocarp trees under 30% relative light intensity were better in height and diameter increment as well as leaf number increment than those under full sunlight. LAI is often used as an indicator of plant growth as light plays an important role in plant energy intake through photosynthesis by direct photon absorption facilitated by pigment molecules such as chlorophyll. The amount of light is expressed by LAI value.

The highest LAI was recorded at plot 17 with 1.85, followed by plots 10, 1, and 8 with LAI of 1.66, 1.58, and 1.32, respectively. Higher LAI value resulted in the greater radiation intensity absorbed by plants. The level of shade illustrates the condition of canopy cover in each plot. The shade levels on these plots tend to bring similar environmental conditions in terms of temperature and moisture.



Figure 3. Condition of undergrowth: A. Total planting, B. Line planting

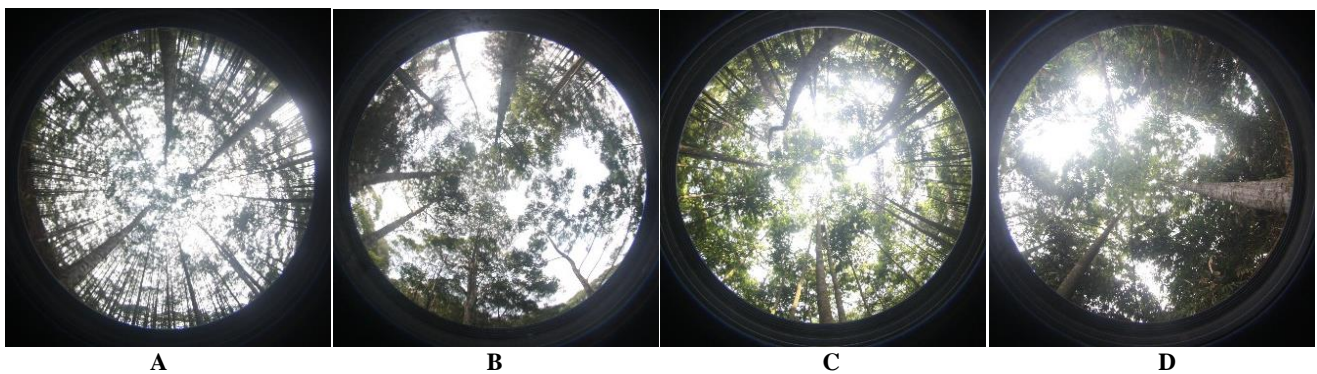


Figure 4. Canopy closure in each observation plot. A. Plot 1 (LAI value = 1.58), B. Plot 8 (LAI value = 1.32), C. Plot 10 (LAI value = 1.32), D. Plot 17 (LAI value = 1.85)

Overall effect of planting technique on the growth of the stands

Planting technique is intended to regulate the intensity of light received by tree stand. Appropriate planting techniques give more growing space and reduce individual resource competition, maximizing growth. The ANOVA results show that overall, there was a significant effect of planting technique on the diameter of the stands planted on DGRF (F-value <0.05), but this did not apply on the height (F-value >0.05) (Table 2). There was also interaction effect between planting technique and species studied on the diameter (Table 2). Our finding implies that diameter was the only parameter influenced by planting technique and species chosen, and it could be a choice when forest manager plan to increase the production of a forest stand.

Effect of planting technique on diameter growth

Table 3 shows that planting techniques significantly affected diameter growth and increment of the two species studied. The best results were observed in line planting technique plots, suggesting that line planting technique is a better choice to produce plants with large diameters. Adjers et al. (1995) stated that line planting technique is best applied in secondary forests with relatively homogeneous

canopy structures or in a former area of shifting cultivation with underdeveloped stratification of canopy layer. Such statement is in accordance with the condition in GDRF, which was previously a cultivation land with shrubs and pine trees grew on the land.

Duncan's test results of the effect of planting technique on the diameter growth and Mean Annual Increment (MAI) of *S. leprosula* and *S. selanica* can be seen in Table 4. Based on Duncan's test results, the largest average diameter was observed in *S. selanica* treated with line planting (24.74 cm) and the MAI of 1.13 cm/year. While the lowest value was recorded in *S. selanica* treated with total planting (16.40 cm) and the MAI of 0.75 cm/year.

The MAI of diameter of the total planting in this study is lower than that of *S. leprosula* at 11 years of age planted in Jasinga, Bogor with 1.99 cm/year (Arim 1995). Jasinga is located at an elevation of 233–358 m asl, which is considered suitable for the growth of red meranti. *S. leprosula* is commonly found on well-drained or swampy sites on clay soils with the elevation less than 700 m asl (Kochummen et al. 1994). This is different from the condition of GDRF since the elevation of this area is > 700 m asl.

Age, competition, and environmental variables, especially elevations and light, are considered to be the cause of lower growth of diameter in DGRF. The decrease in MAI as plant age increase is likely due to higher energy requirement for metabolic processes as plant increase in size. This means more energy is needed from photosynthesis to support metabolic processes result in less energy available for plant growth. However, the result of this research shows that *S. leprosula* and *S. selanica* could grow relatively good in a quite high elevation and it can be an alternative species to be planted in other areas with the elevation up to 800 m asl in the eastern part of Java.

Diameter MAI of the two species treated with line planting is far higher than that of red meranti planted in Bukit Kinta Forest, Malaysia, with diameter MAI ranging from 0.46-0.96 cm/yr (Abdu et al. 2008). This is apparently due to environmental differences and spacing between planting lanes. The space between planting lanes applied in our study was 20 m, while the space between the lines in Bukit Kinta was 10 m. Wider lane spacing provides better exposure to sunlight. The success of planting Dipterocarp in field trials can be perceived from the selection of species, planting techniques, and light availability (Adjers et al. 1996; Bebbler et al. 2002).

Based on the diameter MAI, the growth of both species with the line planting is categorized as normal. While the growth of *S. selanica* with total planting is categorized as moderately slow (Meijer in Mindawati and Tryana 2002). The result illustrates that line planting techniques perform better than total planting. The higher diameter growth and MAI in line planting are likely related to environmental factors, especially the average litter thickness (Table 1). The leaf litter types and interactions between litter diversity and macrofauna are considered to be important in influencing decomposition rates (Slade and Riutta 2012).

Table 2. Results of ANOVA to test the effect of planting technique on the growth of the stands in DGRF.

Factor	Diameter	Height
Planting technique	0.000*	0.260
Species x planting techniques	0.004*	0.805

Note: The numbers shown in the table are significant values. * = treatment significantly affected the 95% confidence interval with a significant value (F-value) <0.05 (α).

Table 3. Effect of planting technique on the diameter growth and MAI of the stands in DGRF

Planting technique	Average diameter	MAI diameter
Total planting	17.98±8.54b	0.82±0.39b
Line planting	24.48±11.41a	1.12±0.52a

Note: Numbers followed by different letters show significantly different treatments at 95% confidence intervals

Furthermore, the decomposition of leaf litter is closely related to soil nutrient cycling (Ristok et al. 2019).

Effect of planting technique on height growth

Differs with the effect on diameter growth, the results of Duncan's test showed that planting technique has no significant effect on the height growth and MAI (Table 5). Similar results are shown in several studies, such as the study of spacing distance by Kosasih and Mindawati (2011) in the Haurbentes Research Forest, Bogor and research by Abdu et al. (2008) on the selection of line planting and gap planting techniques in Bukit Kinta, Peninsular Malaysia.

Duncan's test results of the effect of planting technique on the height growth and MAI of *S. leprosula* and *S. selanica* can be seen in Table 6. Average height growth and MAI of *S. leprosula* and *S. selanica* showed no significant difference. Kosasih and Mindawati (2011) explained that another factor strongly influences the vertical growth and MAI of height of *S. leprosula* and *S. selanica*. Equal response of the plants to grow vertically across all plots is believed to be the cause of this indifferent result.

Effect of planting technique on basal area and stand volume

Planting techniques significantly affected basal area and stand volumes (Table 7). Line planting produced the highest basal area and stand volumes with 0.06 m² and 0.64 m³ per year, respectively for *S. leprosula*, and 0.06 m² and 0.66 m³ per year, respectively for *S. selanica*. The lowest result was *S. selanica* treated with total planting with the basal area of 0.02 m² and stand volumes of 0.28 m³ per year.

Table 4. Effect of planting technique on the diameter growth and MAI of *Shorea leprosula* and *S. selanica*

Species	Planting technique	Average diameter	MAI diameter
<i>S. leprosula</i>	Total planting	18.94±9.29b	0.86±0.42b
	Line planting	24.31±11.50a	1.11±0.52a
<i>S. selanica</i>	Total planting	16.40±6.83c	0.75±0.31c
	Line planting	24.74±11.32a	1.13±0.52a

Note: Numbers followed by different letters show significantly different treatments at 95% confidence intervals

Table 5. Effect of planting technique on the height growth and MAI of the stands in DGRF

Planting technique	Average height	MAI height
Total planting	16.63±5.14a	0.82±0.39a
Line planting	16.97±4.99a	1.12±0.52a

Note: Numbers followed by the same letters indicate that the treatment is not significantly different at 95% confidence intervals

Table 6. Effect of planting technique on the diameter growth and MAI of *Shorea leprosula* and *S. selanica*

Type of plant	Planting technique	Average height	MAI height
<i>S. leprosula</i>	Total planting	16.52±5.23a	0.75±0.24a
	Line planting	16.91±4.95a	0.77±0.23a
<i>S. selanica</i>	Total planting	16.81±4.99a	0.76±0.23a
	Line planting	17.06±5.06a	0.78±0.23a

Note: Numbers followed by the same letters indicate that the treatment is not significantly different at 95% confidence intervals

In general, the result showed that basal area and stand volume in line planting are higher than those in total planting. The dense population and the high number of individuals in total planting technique (Table 1) increased the competition among individuals and limit the nutrients absorption, light, and water availability for each individual (Subiakto et al. 2016).

Novak et al. (2010) suggested that growth is largely influenced by growth factors, one of which is stand density. Higher stand density in total planting techniques likely caused higher competition among individual trees. Overcrowded stand inhibits individual growth due to fierce competition to get growth factors, such as sunlight, water, and mineral nutrients, that eventually led to lower growth and MAI (Phitaloka et al. 2015). Lipiec et al. (2013) stated that water stress has a great influence in the plants' mineral nutrition as most of the nutrients are provided with water. Plants need water for carbohydrate production in leaves, maintaining protoplasm hydration, and transporting and translocating food and mineral elements to other plant body parts.

In the total planting plots, the growth of *S. leprosula* was higher compared to *S. selanica*. *S. leprosula* is known for the faster growth compared to other species of *Shorea*, especially in diameter growth. This has been tested by Kosasih and Mindawati (2011) that the diameter growth in *S. leprosula* was superior with an average diameter of 26.30 cm, significantly higher from *S. selanica* with an average diameter of 20.76 cm and *S. mecistopteryx* with an average diameter of 20.76 cm at the age of 13 years.

Assessing the success of rehabilitation project by selecting the best planting technique will optimize the growth of Dipterocarps species. The results of our study suggest that line planting is better in accelerating the diameter growth, basal area, and stand volume than total planting of *S. leprosula* and *S. selanica* planted in Gunung Dahu Research Forest. However, planting technique has no effect on the height growth of both species. Our findings imply that planting Dipterocarp species could be an option for rehabilitation activities in other areas which have similar characteristic with GDRF.

ACKNOWLEDGEMENTS

The authors would like to thank project collaboration between FOERDIA-KOMATSU for providing funding

Table 7. Effect of planting technique on the basal area and stand volume of *Shorea leprosula* and *S. selanica*

Species	Planting techniques	Basal area (m ²)	Stand volume (m ³ /year)
<i>S. leprosula</i>	Total planting	0.03±0.03b	0.41±0.53b
	Line planting	0.06±0.05a	0.64±0.66a
<i>S. selanica</i>	Total planting	0.02±0.02c	0.28±0.29c
	Line planting	0.06±0.05a	0.66±0.68a

Note: Numbers followed by different letters show significantly different treatments at 95% confidence intervals

during the experiment. The authors would also like to thank KOMATSU- FOERDIA team for total support in the field and thank Forest Research and Development Center for allowing and facilitating this research. HHR and PP designed, developed, and monitored the experiments, analyzed and interpreted the data, wrote and edited the manuscripts. LS, RAF, and AS performed experiments, collected data, and analyzed the data, wrote and edited the manuscripts. All authors approved final manuscript for publications

REFERENCES

- Abdu A, Tanaka S, Jusop S, Majid NM, Ibrahim Z, Wasli ME, Sakurai K. 2008. Assessment on soil fertility status and growth performance of planted dipterocarp species in Perak, Peninsular Malaysia. *J Appl Sci* 8 (21): 3795-3805.
- Adjers G, Hadengganan, Kuusipalo, Nuryanto K, Vesa L. 1995. Enrichment planting of dipterocarps in logged-over secondary forests: effect of width, direction and maintenance method of planting line on selected *Shorea* species. *For Ecol Manag* 73: 259-270.
- Adjers G, Kuusipalo, Hadengganan S, Nuryanto K, Vesa L. 1996. Performance of ten dipterocarp species in restocking logged-over forest areas subjected to shifting cultivator. *J Trop For Sci* 9: 151-160.
- Appanah, S., Turnbull, J.W. 1998. A review of dipterocarps: taxonomy, ecology and silviculture. CIFOR, Bogor
- Appanah S, Weinland G. 1996. Experience with planting Dipterocarps in Peninsular Malaysia. In: Schulte A, Schone D (eds.). *Dipterocarp Forest Ecosystem: Towards Sustainable Management*. World Scientific Publishing, Singapore.
- Arim HD. 1995. Studi Pertumbuhan Tanaman Meranti (*Shorea* spp.) di BKPH Jasinga, KPH Bogor. [Skripsi]. IPB University, Bogor. [Indonesian]
- Austin KG, Schwantes A, Gu Y, Kasibhatla PS. 2019. What causes deforestation in Indonesia?. *Environmental Research Letters* 14(2): 024007.
- Bebber D, Brown N, Speight M, Moura-Costa P, Wai YS. 2002. Spatial structure of light and dipterocarp seedling growth in a tropical secondary forest. *For Ecol Manag* 157 (1-3): 65-75.
- Bray JR, Gorham. 1964. Litter Production in Forest of The World. In: Cragg JB (ed) *Advances in Ecological Research*. Academic Press, London-New.
- Chen JM, Cihlar J. 1996. Retrieving leaf area index of boreal conifer forests using Landsat TM images. *Remote Sens Environ* 55(2): 153-162.
- De Kauwe MG, Disney MI, Quaife T, Lewis P, Williams M. (2011). An assessment of the MODIS collection 5 leaf area index product for a region of mixed coniferous forest. *Remote Sensing of Environment*. 115(2): 767-780.
- Hansen MC, Stehman SV, Potapov PV, Pittman KW, Margono AB, Stolle F. 2009. Quantifying changes in the rates of forest clearing in Indonesia from 1990 to 2005 using remotely sensed data sets. *Environmental Research Letter* 4(3): 1-12.
- Hidayat, W., Kim, Y., Jeon, W., Lee, J., Kim, A., Park, S., ... Kim, N. 2017. Qualitative and quantitative anatomical characteristics of four

- tropical wood species from Moluccas, Indonesia. *Journal of the Korean Wood Science and Technology*, 45(4): 369-381.
- Kenzo T, Yoneda R, Matsumoto Y, Azani AM, Majid MN. (2011). Growth and photosynthetic response of four Malaysian indigenous tree species under different light conditions. *Journal of Tropical Forest Science* 271-281.
- Kobayashi S, Turnbull J W, Cossalter C. 2001. In S Kobayashi, JW Turnbull, T Toma, T Mori, NMNA Majid (Eds.). *Rehabilitation of degraded tropical forest ecosystems*. CIFOR, Bogor.
- Kochummen KM, Wong WC, Sudo S, Frietema FT, Sosef MSM. 1994. *Shorea leprosula*. In: Soerianegara, Lemmens RHMJ (eds) *Plant Resources of South East Asia No 5 (1). Timber Trees: Major Commercial Timbers*. Prosea Foundation, Bogor.
- Kosasih AS, Mindawati N. 2011. Pengaruh jarak tanam pada pertumbuhan tiga jenis meranti di Hutan Penelitian Haurbentes. *Jurnal Dipterokarpa* 5: 1-10. [Indonesian]
- Lestari DA, Fiqa AP, Fauziah, Budiharta S. 2019. Growth evaluation of native tree species planted on post-coal mining reclamation site in East Kalimantan, Indonesia. *Biodiversitas* 20 (1): 134-143.
- Lipiec J, Doussan C, Nosalewicz A, Kondracka K. 2013. Effect of drought and heat stresses on plant growth and yield: a review. *International Agrophysics* 27(4).
- Margono BA, Potapov PV, Turubanova S, Stolle F, Hansen MC. 2014. Primary forest cover loss in Indonesia over 2000–2012. *Nature climate change* 4(8): 730-735.
- Mindawati N, Triyana T. 2002. Pertumbuhan pohon *Khaya anthotecha* di Jawa Barat. *Buletin Penelitian Hutan* 632: 47-58. [Indonesian]
- Mohamad Jaffar, A. N. N., Wasli, M. E., Perumal, M., Lat, J., & Sani, H. 2018. Effects of soil compaction and relative light intensity on survival and growth performance of planted *Shorea macrophylla* (de Vriese) in riparian forest along Kayan Ulu River, Sarawak, Malaysia. *International Journal of Forestry Research*. <https://doi.org/10.1155/2018/6329295>
- Novak J, Slodivack M, Kacalek D, Dusek D. 2010. The effect of different stand density on diameter growth response in Scots pine stands in relation to climate situations. *J For Sci* 56 (10): 461-473.
- Phitaloka SA, Sunyoto, Kamal M, Hidayat KF. 2015. Pengaruh kerapatan tanaman terhadap pertumbuhan dan hasil beberapa varietas sorgum (*Sorghum bicolor* (L.) Moench). *J Agrotek Tropika* 3 (1): 56-63. [Indonesian]
- Pordan M. 1968. *Forest Biometrics*. Pergamon Press, Oxford.
- Purwaningsih. 2004. Ecological distribution of Dipterocarpaceae species in Indonesia. *Biodiversitas* 5 (2): 89-95.
- Rachmat HH, Subiakto A, Susilowati A. 2018. Mass vegetative propagation of rare and endangered tree species of Indonesia by shoot cuttings by KOFFCO method and effect of container type on nursery storage of rooted cuttings. *Biodiversitas* 19 (6): 2353-2358.
- Ristok C, Leppert KN, Scherer-Lorenzen M, Niklaus PA, Bruelheide H. 2019. Soil macrofauna and leaf functional traits drive the decomposition of secondary metabolites in leaf litter. *Soil Biology and Biochemistry* 13: 429-437.
- Slade EM, Riutta T. 2012. Interacting effects of leaf litter species and macrofauna on decomposition in different litter environments. *Basic and Applied Ecology* 13(5): 423-431.
- Subiakto A, Rachmat HH, Sakai C. 2016. Choosing native tree species for establishing man-made forest: A new perspective for sustainable forest management in changing world. *Biodiversitas* 17 (2): 620-625.
- Susanto E, Lestari N, Hapsari M, Krisdiyatmiko K. 2018. Driving factors of Deforestation in Indonesia: A case of Central Kalimantan. *Jurnal Studi Pemerintahan* 9(4): 511-532.
- Tsumura Y, Kado T, Yoshida K, Abe H, Ohtani M, Taguchi Y, ... Kamiya K. 2011. Molecular database for classifying *Shorea* species (Dipterocarpaceae) and techniques for checking the legitimacy of timber and wood products. *Journal of plant research* 124(1): 35-48.
- Van Lierop P, Lindquist E, Sathyapala S, Franceschini G. 2015. Global forest area disturbance from fire, insect pests, diseases and severe weather events. *Forest Ecology and Management* 35: 78-88.
- Welder RK, Wright SJ. 1995. Tropical forest litter dynamics and dry season irrigation on Barro Colorado Island, Panama. *Ecology* 76: 1971-1979.
- Wistara NJ, Sukowati M, Pamoengkas P. 2016. The properties of red meranti wood (*Shorea leprosula* Miq) from stand with thinning and shade free gap treatments. *J Indian Acad Wood Sci* 13 (1): 21-32.