The effect of slope aspect on growth attributes of *Shorea leprosula* Miq. in a rehabilitated hilly landscape

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Abstract. *Shorea leprosula* Miq. is one of Indonesia’s native red meranti species with a higher growth increment than other meranti species. Gunung Dahu Research Forest is a rehabilitated hilly landscape planted with various species of Dipterocarpaceae. This study aims to analyze the growth performance of 24 years old of *S. leprosula* stands in various slope classes of line planting technique at Gunung Dahu Research Forest. Growth analysis of *S. leprosula* was carried out by measuring the stem diameter, total tree height, basal area, diameter increment, height increment, and Leaf Area Index (LAI). Slopes were divided into three classes: mild/gentle (15-25%), steep (>25-45%) and very steep (>45%). The results showed that slope class significantly affected height growth and the canopy cover of *S. leprosula*, but it did not affect the diameter growth. A very steep slope provided the best growth to diameter (average diameter 30.07 cm; MAI 1.25 cm/year) and height (average height 23.7 m; MAI 0.99 m year⁻¹). Furthermore, a linear relationship was formed between the crown cover and slope class in which denser crowns were established in response to a steeper slope (LAI 3.4). Thus, planting *S. leprosula* as a rehabilitation effort in steep slope landscape delivers beneficial as they showed better growth performance.

1. Introduction

*Shorea leprosula* was planted with line planting methods at Gunung Dahu Research Forest (GDRF) in 1997, and currently, it reached 24 years old stands [1]. This line planting method is able to produce plants with a larger diameter compared to total planting techniques [1]. The distance between lines was 10 m, which provided space for the species to grow optimally due to sufficient sunlight. The genus *Shorea* is known as semi-tolerant trees. They need shade when juvenile and require space to get full sunlight when mature so that they will generally occupy the top canopy strata in the climax natural forest. Environmental factors influence plant growth and have a significant role in determining the success of planting activities. The slope is one of the environmental factors that indirectly affect plant growth through the process of erosion of the soil surface, which impacts the degradation of soil function as a medium for plant growth [2]. Therefore, sloping areas should be conserved through planting trees [3, 4], such as *S. leprosula*.

*S. leprosula* is the target species for enrichment planting in the TPTI-SILIN system due to its characteristics as one of the fastest-growing meranti species [1]. Research related to site characteristics is necessary to conduct to determine the supporting and limiting factors for *S. leprosula* growth and increase the success of planting activity. Several locations in GDRF have hilly terrain with rough slopes
and are fragile to soil disturbances. At the steep slope, the rainwater that falls above the ground will flow faster and bring the soil particles to the bottom of the slope by the stream known as surface run-off [5]. The stream will get heavier at the long slope and make the soil prone to erosion [6]. The line planting method was considered a proper technique for rehabilitation efforts in hilly terrain that aimed to increase land productivity while supporting species and soil conservation. Plants' growth generally varies due to competition for nutrients and the adaptability of each individual to environmental factors where they grow. A previous study confirmed that planted trees showed different growth attributes due to specific sites' characteristics [1, 7], including slope conditions [7]. Uneven topographical conditions can affect plant growth from the soil vulnerability due to erosion factors [8]. The steep slope makes it difficult for the soil to store water, which later affects plant growth [9] and is prone to landslides. A study on how slope can shape the growth attributes of *S. leprosula* planted in GDRF through line planting technique is necessary to determine the species' adaptability at various slope classes. Thus the result may become important advice or recommendations for practical application on a broader scale.

2. Materials and Methods

2.1. Study sites and materials

Field data collection was conducted on March 2021 at Plot 8 of Gunung Dahu Research Forest (GDRF), Leuwiliang, Bogor District, Indonesia. The GDRF lies at an altitude ranging from 550-800 m above sea level [1]. It receives rainfall of 2500-2700 mm year\(^{-1}\) with soil type of reddish brown latosol [1]. The plot is 24 years-old *Shorea leprosula* stand planted with line planting technique. The plot was divided into three planting lines with 10 m widths, and each planting line consisted of five rows of planted trees at spacing 2 x 2 m. Spacing between planting lines was set at 15 m (Figure 1). The topography of this area is grouped into three slope classes (mild/gentle (15-25%), steep (>25-45%) and very steep (>45%), the steep slope class was dominated. Soil is identified as latosol reddish-brown with a clay texture. A previous study [1] showed that the thickness of the topsoil was 4 cm and litter thickness was about 9 cm.

![Figure 1](image_url). The layout of planting line method of *S. leprosula* Miq. on plot 8.

2.2. Measured parameters

Measurement of growth attributes was determined by total height, diameters at breast height (DBH) based on [10], and leaf area index (LAI) by taking canopy pictures of each *S. leprosula* tree at each slope class based on [11]. A total of 244 trees were inventoried and measured. The mean annual increment was calculated by dividing the average DBH and total tree height with the stand age (24 years old)
formula [1]. Basal area was calculated based on [12] per slope class to get information about the density of each slope class.

2.3. Data analysis
Canopy pictures were performed using Hemiview to get the LAI value from each slope class. All data were analyzed using ANOVA and Duncan’s Multiple Range Test to determine the effect of slope classes on each growth parameter.

3. Results and Discussion
3.1. Characteristics of Shorea leprosula stand
At the beginning of the planting, 250 trees were planted at each planting line with a spacing of 2 x 2 m totaling 750 trees per hectare. However, at the time of the study, only 244 trees were found in the studied plot, covering 83 trees grow at a mild slope, 110 trees at a steep slope, and 51 trees at a very steep slope. The highest trees mortality was found on line 3 which the survival rate was only 20.80%, followed by line 2 of 33.60%, and line 1 of 43.20%. The low survival rate of *S. leprosula* at the studied plot was due to the extreme topographic conditions. Research conducted by [13] showed that the slope significantly affects the mortality rate of *Parashorea macrophylla* species. Very steep slopes affect the root, and they are prone to landslides, causing the death of the above vegetation [14]. Similar results were also shown by [15], in which pine species were planted on hilly land in Jiuzhaigou Country. The environment requirements for Dipterocarpaceae family growing are mostly in wet climates with high humidity. Their main natural habitat types range from 0-300 m asl (low-undulating dipterocarp forest), 300-750 m asl (hill dipterocarp forest), and 750-1200 m asl (upper dipterocarp forest) [16] with rainfall above 2000 mm year⁻¹ and a short dry season on various types of soil [17]. *S. leprosula* species are naturally found in low-undulating dipterocarp forests. They can grow well in opened land and are mostly grown on latosol soil, a yellow podzolic, and a wider range of soil physical and chemical characteristics [18]. Thus, the GDRF is suitable for *S. leprosula* to grow in terms of climate but relatively marginal in altitude.

Latosol soil is a general type of soil found in the tropical rain forest which has experienced further leaching [20]. It has high clay content with high aggregate stability, so the higher the binding force between soil particles, the more difficult it is for the soil to be affected by the destructive force. According to [21], latosol soil affects plant growth in root growth and plant height, which is very good on latosol soils. Thick litter was found in the research plots due to the pruning ability of the dipterocarps family [22] and ferns which were found in abundance at the research site. According to [23], *S. leprosula* is able to associate with mycorrhizae, and the trees generate litter that can provide sufficient nutrients for their growth. The slope has an indirect effect on plant growth through soil properties. In general, soil properties that are affected by slope are the soil's physical properties, such as soil moisture content. Steep slopes will affect groundwater runoff. Rainwater that falls on the ground flows directly on the soil surface before entering the soil pores [9]. This can affect the soil water content and plant growth.

3.2. Distribution of growth parameters on the slope classes
Figure 2 shows that the DBH data of *S. leprosula* usually are spread at the very steep slope, as shown from the median value right in the middle of the box. This symmetrical box plot represented a normal data distribution that resembled even age plantation, forming a bell-shaped histogram [26]. However, the DBH data for the mild and steep slope showed that they did not spread normally; there was an outlier of diameter. Outliers indicated the existence of individual trees with diameters exceeding their average, which may be caused by some individuals’ high adaptability or superior growth. The total height data for the steep slope has a normal data distribution. Overall, the whole boxes have longer top whiskers. This shows that there are larger plants than the middle value in the observed growth parameters, both in terms of diameter and total plant height. Different plant responses due to their habitat or environment may yield different growth performances. The existence of some larger trees will reduce the growth of smaller trees around them due to the competition of sunlight by the crown cover [27, 28].
Figure 2. Distribution of growth parameters of *S. leprosula* on each slope class: (a) DBH, (b) Total Tree Height.

Growth performance is the interaction between genetic and environmental factors where the plants grow. Growth is also conceived as an increasing number and size of plant cells that are irreversible [24]. With this, plant growth can be determined by measuring plant height and diameter [25]. Growth parameters observed on the studied plot were diameter at breast height, total height, basal area, and leaf area index (LAI) to determine the crown cover classes.

3.3. Diameter, total height and basal area of trees

Basal area results from diameter growth, indicating stand density and its ability to occupy space horizontally [12]. Table 1 shows that the highest basal area is on the steep slope class due to its highest number of survived trees compared to other slope classes. Stands with a denser density (high BA value) tend to produce lower diameters due to horizontal competition for space [29]. Therefore, it can be seen in Table 1 that even though it has the largest BA value (620.99 m² ha⁻¹), it stands on the steep slope have the lowest diameter growth performance (25.57 cm). Plant growth is strongly influenced by stand density [30]. A dense stand with many individuals will increase competition in terms of space, sunlight, and nutrition [31]. A very steep slope has the least number of individuals compared to other slope classes. This enables the trees to get a larger space than other individual trees growing on slope classes with higher density, and thus caused the highest diameter growth of trees growing in the very steep slope class.
Table 1. Growth attributes of *Shorea leprosula* on each slope class.

| Slope Classes           | Average Basal Area (m² ha⁻¹) | Average DBH (cm) | MAI of DBH (cm year⁻¹) | Average Total Tree Height (m) | MAI of Tree Height (m year⁻¹) |
|-------------------------|-------------------------------|------------------|------------------------|-----------------------------|-------------------------------|
| Mild (15-25)%           | 389.98 ns                     | 26.95 ns         | 1.12 ns                | 18.70 b                     | 0.78 b                        |
| Steep (>25-45)%         | 620.99 ns                     | 25.57 ns         | 1.07 ns                | 23.60 a                     | 0.98 a                        |
| Very Steep (>45%)       | 184.59 ns                     | 30.07 ns         | 1.25 ns                | 23.69 a                     | 0.99 a                        |

Remark: The numbers in the same column followed by different letters are significantly different at the 5% test level (Duncan's multiple range test), ns=not significantly different at the alfa level of 5%.

The very steep slope supports the growth attributes for *S. leprosula* as indicated by the maximum value for each observed growth parameter. The diameter increment is considered a reasonably accurate parameter to describe plant growth as it can show the speed of tree growth. In general, the diameter growth of *S. leprosula* in line planting techniques with various slope classes was included in the standard (0.79-1.19 increment) to fast (1.19-1.40 increment) category according to the growth rate classification by [32]. The diameter increment of *S. leprosula* growing in a very steep slope (MAI 1.25) was classified as fast, followed by the mild slope (MAI 1.12) and steep slope (MAI 1.07), which are classified as normal. However, this result has a lower value when compared to a study by [33], where *S. leprosula* planted in the pathway of the TPTJ system. It was able to achieve a very fast diameter increment of 2.81 cm year⁻¹ in logged-over natural forests. The current diameter MAI is also slightly lower than the study by [34] in PT. Sari Bumi Kusuma and research by [26], on the forests of PT. Sarpatim in Central Kalimantan, where the diameter increment of *S. leprosula* can reach an average of 1.30-1.40 cm year⁻¹. The lower value of diameter increment in this study could be caused by the habitat characteristic where Kalimantan is known as a natural habitat for this species [16] while Gunung Dahu is known as an introduced habitat with a higher altitude than the species' natural distribution range. In addition, the above forest concessions have been known for their active involvement in Silviculture Intensive program, which requires the company to do a breeding program and practice clonal propagation for the superior individuals [34]. The best plant height increment in this study was found on very steep slopes of 0.99 m year⁻¹. However, the value was still lower compared to research by [35] at PT. Suka Jaya Makmur Nanga Tayap in the TPTJ system, which is 1.75 m year⁻¹.

Analysis of variance (ANOVA) test was carried out to determine the effect of different slope classes on growth parameters. The results showed that slope affects total tree height (significant value 0.009 <0.05) but not for diameter at breast height. Research by [7] to *S. leprosula* showed the same results where differences in slope class did not affect diameter growth.

Duncan Multiple Range Test (MRT) was carried out to determine the effect of different slope classes on growth parameters, resulting in significant differences. Table 1 shows that steep and very steep slope classes have no significant difference in total height growth and plant height MAI, but they differ significantly from mild slope for both growth parameters. The very steep slopes yield the best height growth, while the lowest average is in the mild slope class.

3.4. Leaf area index (LAI)

The LAI value is used to determine the canopy cover class of a stand which is classified into three classes, namely not shady, shady, and very shady [11]. All slope classes have a significant effect on the addition of LAI values (Table 2). The effect of slope class on LAI is almost linear; increasing slope class will increase LAI as it increases the canopy cover.
Table 2. Leaf area index (LAI) of *Shorea leprosula* on each slope class.

| Slope Class       | LAI            | Canopy cover class |
|-------------------|----------------|-------------------|
| Mild (15-25)%     | 1.408 ± 0.102c| Not shady         |
| Steep (>25-45)%   | 2.235 ± 0.107b| Shady             |
| Very Steep (>45%) | 3.371 ± 0.107a| Very Shady        |

Remark: The numbers in the same column followed by different letters are significantly different at the 5% test level (Duncan's multiple range test).

Figure 3. Crown photos of *Shorea leprosula* trees on various slope classes: (a) mild, (b) steep, (c) very steep.

Figure 3 showed the differences in canopy cover for various slope classes as not shady in mild slope class (a), shady in the steep slope (b), and very shady in very steep slope (c).

Figure 4. Crown cover of *Shorea leprosula* trees in a spacing area between planting lines.

Figure 4 shows that tree crowns have intercrossed with tree crowns from the adjacent planting line. The canopy conditions of *S. leprosula* on the very steep slope were very tight, categorized as very shady (Figure 3c). On the other hand, low tree density on a very steep slope (51 trees) caused a larger tree canopy as a form of tree adaptation in occupying space to absorb light as much as possible [31]. In line with this statement, [36] stated that *S. leprosula* requires 74-100% light at the sapling to tree stages. This also occurred in the spacing line between line 1 and line 2, where the outer trees from each planting line form a canopy that almost covered the spacing line (Figure 4). The tighter canopy cover supports higher
growth due to the photosynthesis process that takes place in the canopy. So that, at the sapling to tree stages, *S. leprosula* requires sufficient space to get maximum sunlight for its growth.

Overall, the growth of *S. leprosula* on very steep slopes was better than steep slopes and mild slopes. This contradicts the opinion of [37], where steep land generally contains little nutrients and groundwater so that it is less likely to support optimum growth. In line with this statement, according to [8], it was stated that sloping land can be more easily disturbed or damaged and has a tendency for higher erosion and sedimentation. However, this opposite research result could have happened because the studied plot was located at the bottom of the slope next to the valley. This position will benefit plants with the accumulation of soil so that the plant obtained accumulated nutrients transported from the top of the slope from erosion [38, 39].

4. Conclusion
The height growth and canopy cover of *S. leprosula* were affected by the slope significantly. Very steep slope class (>45%) on the bottom of the hills with the lowest trees density produced the best growth in all observed growth parameters, diameter (increment 1.25 cm year⁻¹), total tree height (increment 0.99 m year⁻¹) and canopy cover (LAI 3.37). Slope class has no significant effect on diameter growth.

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