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Full Length Research Article

Assessment of Growth and Carbon Stock of 6-Year-Old *Dryobalanops lanceolata*

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ABSTRACT

Dipterocarp species are the mainstay of forest products in the form of woodworking. *Dryobalanops lanceolata* is one of the dipterocarp species. The study aimed to analyze the effect of canopy cover on the growth and carbon storage of 6-year-old *D. lanceolata*. Data were collected by measuring diameter, height, canopy cover, soil samples, and carbon storage. The research method was carried out by regression between canopy cover and tree diameter and height growth, analyzing soil fertility and carbon content. The 6-year-old *D. lanceolata* has grown well with a canopy cover of less than 34% (canopy openness of more than 66%) and could grow on clay soil with acidic pH. *D. lanceolata* at the age of 6 years has been able to improve the nutrient content in the soil. Under 6-year-old *D. lanceolata* stands, it has provided significant changes to increase the availability of soil nutrients for C-organic, total N, and K-available content. Carbon storage in *D. lanceolata* has increased in 1 year by 41.91%.

1. Introduction

The potential of natural forests in Indonesia tends to decline regarding timber production and biodiversity. In order to increase the production of forest products, especially timber from these forests, efficiency in timber harvesting is needed. Efforts to increase timber production have been made since 2005 when the Ministry of Forestry introduced the intensive selective cutting and planting or *Tebang Pilih Tanam Indonesia Intensif* (TPTII) silviculture system. These resource-use techniques can increase forest productivity and timber harvesting efficiency in natural forests (Dulsalam et al. 2018).

This system applies selective logging and enrichment planting with strip planting using the intensive silviculture (SILIN) technique. This method is carried out by opening a three-meter-wide planting strip (cutting down plants with a strip system for planting activities) with a planting distance within the strip for selective cutting and line planting or *Tebang Pilih Tanam Jalur* (TPTJ) and TPTII/TPTJ with SILIN of 5 m and 2.5 m, respectively, and the distance between lanes for TPTJ and TPTII/TPTJ with SILIN of 25 m and 20 m, respectively (Widiyatno et al. 2014).

The results of Hadiansyah et al. (2016) showed that the potential growth rate of meranti in the path system in the TPTJ with SILIN area for diameter increments of around 1.2 cm/year and height increments of around 1.42 m/year, higher than general growth in natural forests which is only around 0.5 cm/year. Permata et al. (2023) stated that the removal of forest covers causes sunlight to enter the stands, thereby affecting the growth rate of seedlings. This suggests that canopy clearing, fertilization, planting superior seeds, and environmental manipulation in the SILIN technique influence growth rates in both diameter and height. The SILIN technique's growth rate is relatively high so that log production can increase. Timber harvesting activities are essential in increasing timber production, considering that timber harvesting productivity varies according to the silviculture system applied (Widiyatmo et al. 2014; Tirkaamiana 2020).

Dipterocarp species in Indonesia account for 62% (238 species) of Malesia's total number of species (386 species). This shows Indonesia is a dipterocarp habitat, especially in Western Indonesia (Purwaningsih 2004; Husch et al. 2003). Ecologically, dipterocarp species have several limiting factors for their growth and distribution. The most critical factors are soil, climate, and altitude. Generally, dipterocarp species grow on yellow-red podzolic soil with altitudes below 1,300 m above sea level and rainfall > 1,000 mm per year (Whitmore 1975).

One of the dipterocarp species with potential to increase forest productivity and carbon storage is horned lime (*Dryobalanops lanceolata* Burck.). *D. lanceolata* is endemic to Borneo and grows widely in the northern and eastern parts of Borneo Island. It is widespread on fertile clay soils and abundant on undulating soils at elevations up to 700 m above sea level. South Kalimantan is one of the potential distribution areas of this species, especially areas bordering East Kalimantan and Central Kalimantan. This species can grow well in wet climates with rainfall of more than 1,000 mm/year (Dodo and Hidayat 2018; Philips et al. 2002). In addition, *D. lanceolata* is a fast-growing species (Dodo 2016) and can grow in unproductive forests (Mardhatillah et al. 2019). *D. lanceolata* has the potential to be used in rehabilitating unproductive natural forests. Therefore, research related to the growth and carbon storage of *D. lanceolata* needs to be conducted. The objectives of the study were (1) to analyze the effect of canopy cover on the growth of *D. lanceolata*, (2) to analyze soil conditions in *D. lanceolata* stands, and (3) to determine the carbon storage of the stand at the age of 6 years.

2. Materials and Methods

2.1. Study Site Description

This research was conducted at Forest Area with Special Purpose (KHDTK) Haurbentes, Jasinga District, Bogor Regency, West Java, from February to April 2023. The study was conducted on *D. lanceolata* stands planted in August 2016 with a spacing of 2.5 m × 2.5 m. The location of KHDTK Haurbentes is geographically located at 6°32'–6°33' N and 106°26' E, while the *D. lanceolata* in Haurbentes KHDTK is located at 6°32'42.8"–6°33'23.6" N and 106°43'47.1'–106°26'5' E.

Based on climatic data from the Haurbentes Research Forest Climatology Station, the highest average temperature was 28°C in September, and the lowest was 23°C in February. The rainfall type of the Haurbentes KHDTK area based on the Schmidt and Ferguson classification is type A and is included in the wet climate category with an average rainfall of 4,267 mm/year. The highest rainfall (475 mm) falls in April and the lowest (199 mm) in August (Puslitbanghut 2015).

Haurbentes KHDTK is at an altitude of ± 250 m above sea level (masl), and the elevation of the research location is 266–278 masl (Puslitbanghut 2015). Soil types in Haurbentes KHDTK consist of three soil types: red-yellow podsolic soil, regosol, and brown forest soil. The general properties and characteristics of the three soil types are slow permeability and drainage from obstructed to good. The top-to-bottom soil layers are acidic (pH 4.6) with low organic matter, nitrogen, P_2O_5, and K_2O, and the C/N ratio decreases from the top to the bottom layers (Puslitbanghut 2015).

2.2. Work Procedures

The data obtained are primary data and secondary data. Primary data were obtained by measuring and observing the growth of *D. lanceolata,* including the diameter at breast height, tree height, plant spacing, and soil physical and chemical properties. Secondary data in the form of initial growth data when *D. lanceolata* was newly planted and the general condition of the research site. Data was collected on a trial plot of planting *D. lanceolata* under a stand of sengon (*Paraserianthes falcataria*), pulai (*Alstonia scholaris*), and other Dipterocarp species. *D. lanceolata* stands are homogeneous but surrounded by other species such as sengon, pulai, and Dipterocarp species. All *D. lanceolata* plants in the plot were observed for parameters such as diameter at breast height, total height, and percentage of canopy cover.

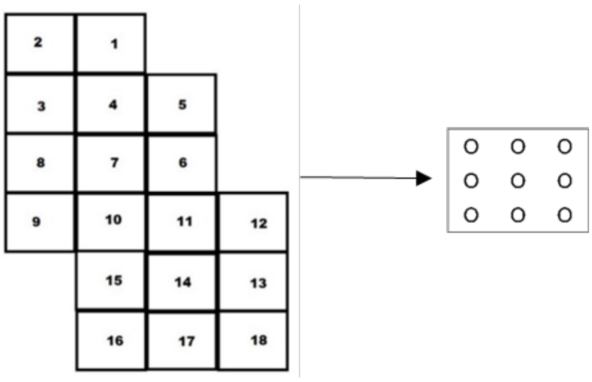

Fig. 1. Research plot shape and cropping pattern *D. lanceolata*.

2.3. Measurement of Height, Tree Diameter, and Canopy Cover

Measurement of *D. lanceolata* tree height was carried out using a haga hypsometer. Measurement of trunk diameter at chest height was carried out using a meter. Canopy cover measurement was done by placing a spherical densiometer at arm height 30–40 cm from the body. In each observation plot, there were nine plants with a spacing of 4 m × 4 m per plant. Spherical densiometer readings were taken in four cardinal directions: North, South, East, and West. Each box on the tool was calculated as the percentage of canopy opening.

The spherical densiometer consists of twenty-four ¼-inch squares engraved onto a concave mirror. Each grid square must be subdivided mentally into four smaller squares and represented by an imaginary dot in the center of each of the smaller squares. A total of 96 dots can be counted within the grid. Densiometer readings can range from 0 (no canopy cover) to 96 (maximum canopy cover) (Dharmawan 2020). The measurement results were then calculated using the formula presented in the data analysis.

2.4. Soil Sample Collection

Soil samples taken are intact soil samples and non-intact soil samples. Sampling of non-intact soil is taken as many as 3 points on each plot with random sampling, then the soil is put together or composite and then put into a plastic bag (Salam 2020). Whole soil samples were taken using a sampling ring with a depth of (0–30 cm) from the top soil layer (Delsiyanti et al. 2016). Intact soil sampling points were located on plots 4, 10, and 17.

2.5. Data Analysis

2.5.1. Percentage of canopy cover

The percentage of canopy cover was obtained using a spherical densiometer tool, which was then calculated using the following formula (Dharmawan 2020).

$$\%Ti = \left(\left(\frac{Score\ weight}{2{,}500}\right) \times 100\%\right) \times 1.04 \tag{1}$$

Equation 1 was used to estimate the percent cover at one point, after obtaining 4 points of percent cover, then averaged using Equation 2 and 3.

$$\%Ti = \frac{N + E + S + W}{4} \tag{2}$$

$$\%TI = 100\% - Ti \tag{3}$$

where *Ti* is canopy openness, *TI* is canopy cover, and *N, E, S, and W* are the percentages of canopy openness in North, East, South, and West.

2.5.2. Relationship between percentage of canopy cover and growth D. lanceolata

Estimating the relationship between the growth of *D. lanceolata* saplings and the percentage of canopy cover requires some regression model testing. The regression model used is linear regression (Equation 4), quadratic non-linear regression (Equation 5), and cubic non-linear regression (Equation 6) (Ghozali 2016).

$$y = a + bx \tag{4}$$

$$y = a + bx + cx^2 \tag{5}$$

$$y = a + bx + cx^2 + dx^3 \tag{6}$$

where *y* is the height (cm) or diameter (cm), *a* is the intercept, *b* is the regression coefficient, and *x* is the canopy cover percentage.

The linear regression direction coefficient is expressed by the letter *b,* which states the average change in variable *Y* for each variable *X* by one unit. If the *b* value is positive, the *Y* variable will increase. Conversely, if the value of *b* is negative, the *Y* variable will decrease. Selection of the best equation model is obtained by conducting statistical tests. The best equation model is the model that has the most significant coefficient of determination (R^2) with the smallest Standard Error (SE). The closer R^2 is to 100%, the better the data fits the model (Paiman 2022).

2.5.3. Soil analysis

Soil analysis was conducted at the Indonesian Center for Biodiversity and Biotechnology (ICBB) laboratory. The parameters analyzed include soil texture, porosity, bulk density, total N, available P, K, organic C, and pH. Soil texture analysis uses a texture triangle divided into 12 classes, which are then equalized with the soil analysis data obtained from the ICBB laboratory.

The analysis of the assessment of soil chemical properties was then determined using the technical guidelines for land fertility evaluation made by Batu et al. (2019).

2.5.4. Estimation of stand biomass and carbon

Estimation of biomass in *D. lanceolata* stands using the biomass formula for mixed dipterocarp species in East Kalimantan according to (Krisnawati et al. 2012), using Equation 7.

$$B = 0.19999 \times D^{2.14} \tag{7}$$

where B is tree biomass (kg/tree), and D is diameter (cm).

According to (BSN 2011), the carbon percentage in wood, litter, and dead wood is 47%, so the tree carbon was calculated using Equation 8.

$$C = 0.47 \times B \tag{8}$$

where C is tree carbon (kg/ha), and B is tree biomass (kg/tree).

3. Results and Discussion

3.1. D. lanceolata Growth and Percentage of Canopy Cover

Plant growth is the event of increasing plant size in diameter and height. The increase in the plant body size as a whole results from an increase in the number and size of cells. Plant development can be seen from the shape changes of the stem, root, and leaf organs, flowers' appearance, and fruit formation (Budi 2022). The distribution of the diameter results at breast height (DBH), height, and percentage of canopy cover measurements in *D. lanceolata* can be seen in **Fig. 2**.

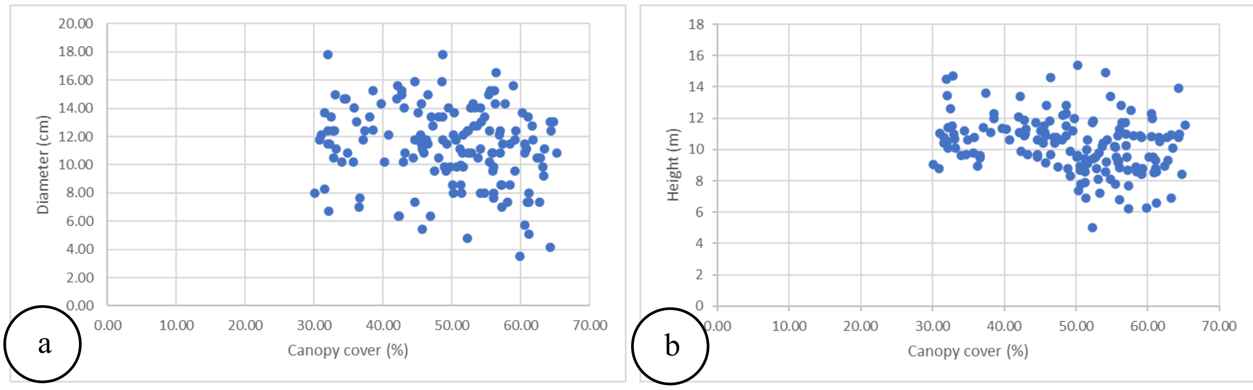

Fig. 2. Growth distribution of (a) diameter and (b) total height of *D. lanceolata* with canopy cover.

Fig. 2 shows the growth distribution of *D. lanceolata* growing in the shade of pulai stands and other dipterocarp species with a range of canopy cover percentages from the smallest to the largest of 30.07%–65.24%. The most significant tree diameter growth was 17.83 cm, growing under a shade of 31.38%, while the smallest diameter was 3.5 cm, growing under a shade of 59.86%. The highest tree height growth was 15.4 m, growing under a shade of 50.24%, while the lowest tree height was 5 m, growing under a shade of 52.25%. According to Susilawati et al. (2016), light is meaningful for plants because of its role in physiological activities such as photosynthesis, respiration, growth and flowering, opening and closing of stomata, germination, and plant growth.

The range of canopy cover is divided into three parts: canopy cover below 45%, canopy cover between 45%–50%, and canopy cover above 50%, which is then used to determine soil sampling. Canopy cover below 45% is found in plot numbers 6–12, with an average growth diameter of 11.48 cm and a height of 7.59 m. Canopy cover of 45%–50% is found in plots 1–5, with an average diameter growth of 12.24 cm and a height of 7.76 m. Canopy cover above 50% is found in plots 13–18, with an average diameter growth of 10.27 cm and a height of 7.96 m.

3.2. Relationship Between Canopy Cover Percentage and Growth of D. lanceolata

The relationship between the percentage of canopy cover and the growth of *D. lanceolata* can be seen with the regression model with the highest coefficient of determination (R^2) among the three existing regression models. Regression analysis using equation models produces different R^2. The greater the R^2 value, the more the model can explain the behavior of variable Y (plant diameter and height).

Table 1. Regression equation model between diameter growth and percent canopy cover

Model	Equation	R^2	S	P
Linear regression	$y = 14.00 - 0.0549x$	3.57%	2.75	0.019*
Quadratic regression	$y = 6.697 + 0.266x - 0.003x^2$	4.79%	2.73	0.025*
Cubic regression	$y = -2.45 + 0.874x - 0.016x^2 + 0.00009x^3$	4.85%	2.75	0.058

Note: * = significant.

Table 1 shows the equation data and the percentage coefficient of determination of the relationship between the percentage of canopy cover and diameter growth. The cubic regression equation has the highest coefficient of determination of 4.85% compared to the other equations. This shows that the cubic regression equation can better explain the relationship between variables than other regression equations. Based on the coefficient of determination obtained, it can be said that diameter growth is only 4.85% influenced by canopy cover, while other factors influence 95.15%. According to Ghozali (2016), a small coefficient of determination means that the ability of the independent variables to explain the dependent variable is minimal. Otherwise, if the coefficient of determination is close to 100% and away from 0%, the independent variables can provide all the information needed to predict the dependent variable.

Fig. 3 shows the data distribution on the relationship between the percentage of canopy cover and diameter growth, which spreads randomly on the scatter diagram, illustrating the absence of linearity. **Fig. 3** shows the distribution of data that forms an inverted U (**Fig. 3b**), indicating that the higher the level of canopy cover, the more diameter growth decreases. Optimal diameter growth is found in the 40% canopy cover percentage range, located at the curved line's peak that forms an inverted U.

Table 2 shows the equation data and the percentage coefficient of determination of the relationship between the percentage of canopy cover and height growth. The cubic regression equation had the highest coefficient of determination of 11.27% compared to the other equations. This shows that the cubic regression equation can better explain the relationship between variables than the other regression equations. Based on the coefficient of determination obtained, it can be said that the canopy influenced 11.27% of the tree's height, while other factors influenced 88.73%. According to Ghozali (2016), the regression model is suitable if the coefficient of determination is more than 0.5, while the regression model is considered unsuitable if the coefficient of determination is below 0.5.

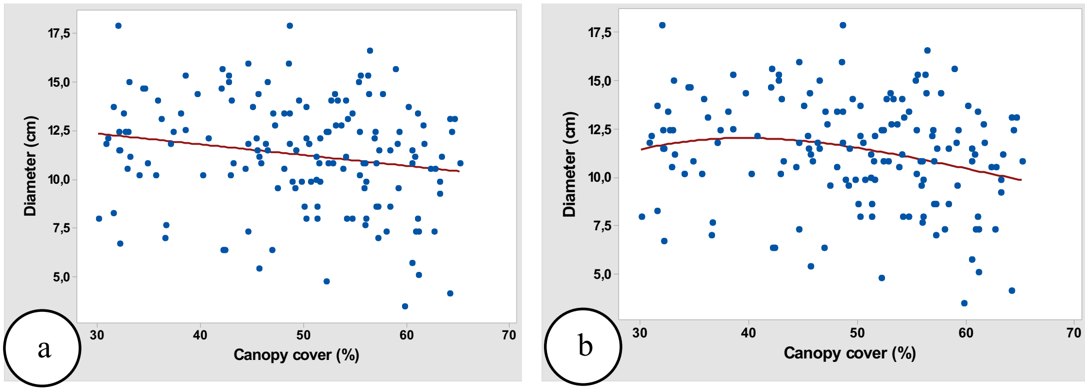

Fig. 3. Relationship between percent canopy cover and diameter growth using (a) simple linear and (b) cubic regression models.

Table 2. Regression equation model between height growth and percent canopy cover

Model	Equation	R^2	S	P
Linear regression	$y = 12.86 – 0.051x$	7.68%	1.72	0.001*
Quadratic regression	$y = 13.78 - 0.092x + 0.0004x^2$	7.72%	1.72	0.002*
Cubic regression	$y = -30.85 + 2.876x – 0.063x^2 + 0.0004x^3$	11.27%	1.70	0.0004*

Note: * = significant.

Fig. 4 shows the data distribution of the relationship between the percentage of canopy cover and diameter growth, which spreads randomly on the scatter diagram, illustrating the absence of linearity. **Fig. 4** shows a decreasing (**Fig. 4a**) and S-shaped (**Fig. 4b**) distribution of data, indicating that height growth is optimal at a percentage of canopy cover of 35%–40%, which is located at the peak of the inverted U-shaped curved line, while height growth slows down at a percentage of canopy cover of 55%–60% which is located in the valley of the U-shaped curved line.

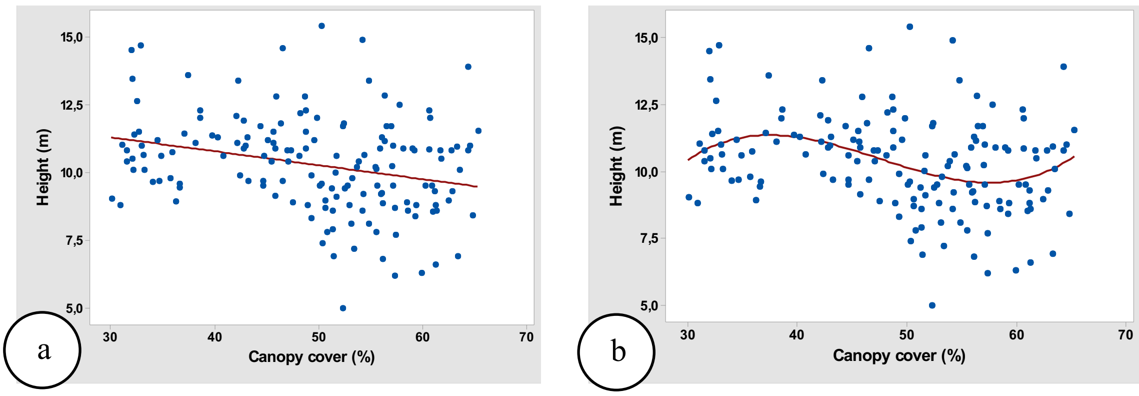

Fig. 4. Relationship between percent canopy cover and height growth using (a) simple linear and (b) cubic regression models.

The regression analysis results showed a low coefficient of determination. Therefore, the percent canopy cover was grouped into four groups, namely (1) canopy cover of more than 54%, (2) canopy cover between 45–54%, (3) canopy cover between 35–44%, and (4) canopy cover between less than 34%. The T-test results showed that the average diameter was not significantly different between the four groupings of canopy cover. This indicates that diameter growth can develop well in the range of canopy cover less than 34–54% or canopy openness between 46–66%. However, total height growth grew well at a canopy cover of less than 54% (**Table 3**). Thus, *D. lanceolata* will grow well at a canopy cover of less than 34% (canopy openness of more than 66%).

The bigger the *D. lanceolata tree*, the more sunlight it needs. This is due to the increasing need for light in photosynthesis.

Table 3. Mean diameter height of 6-year-old *D. lanceolata* under various canopy covers

No.	Canopy cover	Number of trees	Diameter (cm)		Total height (m)	
			Mean	Standard deviation	Mean	Standard deviation
1	> 54%	57	10.80 a	2.82	9.9 b	1.9
2	45–54%	54	11.45 a	2.56	10.1 ab	1.9
3	35–44%	26	12.02 a	2.86	10.9 ab	1.2
4	< 34%	16	11.78 a	2.70	11.3 a	1.7

3.3. Soil Conditions in D. lanceolata Stands

Soil texture is one of the soil properties that significantly determines the ability of soil to support soil growth. According to Salam (2020), soil properties that support the soil are the percentage of dust, sand, clay, organic matter, pH, structure, content weight in the tillage and subsoil layers, surface slope conditions, pore space filled with air, the influence of plant residues, soil particle aggregation, parent material, clay type and the interaction of these factors. The condition of canopy cover is used to determine soil sampling: (a) canopy cover above 50% is found in plots 6, 7, 8, 9, 10, 11, and 12; (b) canopy cover between 45%–50% is found in plots 1, 2, 3, 4, and 5; (c) canopy cover below 45% is found in plots 13, 14, 15, 16, 17, and 18. The results of the soil analysis are presented in **Table 4**.

Table 4. Results of soil analysis at the growing site *D. lanceolata*

No.	Parameters	Canopy cover		
		< 45%	45–50%	> 50%
1	Sand (%)	9	13	8
2	Dust (%)	24	21	25
3	Clay (%)	67	66	67
4	Soil texture	Clay	Clay	Clay
5	Bulk density (g/cm^3)	0.87	0.71	0.97
6	Porosity (%)	67.17	73.21	63.39
7	Soil pH (H_2O)	4.5^{M}	4.4^{SM}	4.4^{SM}

Notes: SM = very acidic, and M = acidic.

Soil texture will affect the ability of soil to store and deliver water and provide plant nutrients. The texture analysis results of the three fractions show that the soil texture in *D. lanceolata* stands is clay texture in all three canopy cover classifications. This happens because the composition of clay has a high percentage, above 60%, compared to the percentage of sand and dust.

According to Isra et al. (2019), Sand-textured soil is soil with sand content > 70%, low porosity (< 40%), some pore spaces are large so that the aeration is good, the water conductivity is fast, but the ability to store nutrients is low. If the clay is > 35%, the ability to store water and plant nutrients is high in clay-textured soil. Existing water is absorbed with high energy, so the clay is difficult to release, mainly when dry, making it less available to plants.

Bulk density is a parameter that can be used to assess soil density. The smaller the weight of the soil content, the looser the soil. Conversely, the greater the weight of the content, the denser the soil (Hartanto et al. 2022). The observation of bulk density shows that the percentage of coverage is 45–50%, and the lowest bulk density value is 0.71 g/cc. The highest bulk density value is found in the percentage of crown cover above 50% at 0.97 g/cc. According to Hartanto et al. (2022), the value of good soil bulk density for plant growth is 1.00 g/cc. If it exceeds this value, the soil will be dense, impacting the difficulty of plant roots penetrating the soil surface to find water and nutrient sources.

Margolang et al. (2015) stated that the higher the soil bulk density, the lower the total porosity, and vice versa. The lowest bulk density value obtained resulted in a high soil porosity value of 73.21% at a canopy cover percentage of 45–50%. According to Margolang et al. (2015), the lower the bulk density and the higher the total porous space can be caused by the high soil organic matter in the stand. The critical threshold of soil damage for porosity is if it is higher than 70% or less than 30%. Soils with less than 30% porosity values are dense soils usually dominated by micropores that hold water very firmly, making it difficult for roots to absorb water. Conversely, if the porosity is more than 70%, the soil pores are dominated by macro pores, which are easy to pass water due to gravity, so that the soil can lose much water in the tillage layer (Hartanto et al. 2022).

Soil pH value can be used as an indicator of soil fertility because it can reflect the availability of nutrients in the soil (Salam 2020). Plants can absorb nutrients at a neutral pH (Merani et al. 2015). Soil pH in *D. lanceolata* stands at a value of 4.4 in canopy cover was above 45%, while pH 4.5 was found in the percentage of canopy cover of < 45%. According to (Batu et al. 2019), pH values below 4.5 are very acidic soils, while pH values between 4.5–5 are acidic. Based on the results of measurements in the field, obtained macro-nutrients based on laboratory tests are shown in **Table 5**.

Table 5. Macronutrient content of the growing site *D. lanceolata*

No.	Nutrients	Canopy cover				
		< 45%	**45%–50%**	**> 50%**	**30%***	**70%***
1	C-organic (%)	4.97^{T}	5.1^{ST}	4.52^{T}	2.14^{R}	1.87^{R}
2	N-total (%)	0.34^{S}	0.37^{S}	0.31^{S}	0.2^{R}	0.18^{R}
3	P_2O_5 available (mg/Kg)	10.7^{R}	10.1^{R}	13.2^{R}	9.4^{SR}	7.3^{SR}
4	K_2O available (mg/Kg)	6.1^{SR}	4.3^{SR}	6^{SR}	0.17^{SR}	0.76^{SR}

Notes: ST = very high, T = high, S = moderate, R = low, and SR = very low. *based on the results of Mardhatilla et al. (2019).

Based on the analysis of nutrient content in the three canopy cover classes, we have results that are not much different. C-organic content in 45%–50% canopy cover (5.1%) has a higher value than in < 45% cover (4.97%) and > 50% cover (4.52%). According to (Batu et al. 2019), C-organic content above 5.00% can be categorized as very high, while a value of 3.01–5.00 is classified as high. This shows an increase in organic matter compared to the results of Mardhatillah et al. (2019), showing organic matter content in 30% of the canopy cover at 2.14% and 70% of the canopy cover at 1.87%. The increase in C-organic value after 6 years of planting occurred due to the increasing litter of leaves and twigs that fell from *D. lanceolata*. As the amount of litter increases, decomposing microorganisms also increase. The litter is then decomposed by microorganisms so that the C-organic in the soil increases (Budi 2022). Soil organic matter usually makes up about 5% of the total weight of the soil. Although only a little, it is essential in determining soil fertility (Salam 2020). According to Bakri et al. (2016), the high value of C-organic in the forest land use type is due to the presence of weathered plant litter, thus affecting the high content of organic matter in the soil of this land use type.

Nitrogen is the primary macronutrient that is essential for plant growth. The value of N-total content in 45%–50% canopy cover (0.37%) has the highest value compared to < 45% (0.34%) and > 50% (0.31%). According to (Batu et al. 2019), the value of N-total is categorized as moderate if it has a value of 0.21%–0.5%. The N-total content increased compared to the results of Mardhatillah et al. (2019), showing the N-total content in 30% of the canopy cover at 0.2% and 70% of the canopy cover at 0.18%. The increase in N-total value after 6 years of planting is influenced by the availability of organic matter in the soil. If the C-organic value is high, the N-total value is high, and vice versa. The higher the C-organic value in the soil, the more microorganisms live in the soil, one of which makes N elements that are initially unavailable to plants become available through nitrogen fixation (Budi 2022).

Phosphor is a nutrient that plays a role in stem and root formation (Azizzadeh et al. 2016). Available P content in > 50% canopy cover (13.2 mg/Kg) has the highest value compared to 45%–50% cover (10.1 mg/Kg) and < 45% (10.7 mg/Kg). The value of available P content is categorized as low if it has a value of 10–20 mg/Kg (Batu et al. 2019). The available P content increased compared to the results of Mardhatillah et al. (2019), showing the available P content in 30% of the canopy cover at 9.4% and 70% of the canopy cover at 7.3%. Due to the high soil pH acidity, the low P element in *D. lanceolata* stands after 6 years of planting. Acidic soil pH prevents phosphorus from dissolving because it will be fixed with iron (Fe +) and aluminum (Al +) ions, which plants cannot use. It also makes P elements prone to leaching by rainwater, so the soil will lose the amount of P elements (Budi 2022).

Budi (2022) stated that the availability of phosphorus in plants depends on (1) the amount of soil acidity and the influence of the solubility of iron, aluminum, and manganese where the insoluble form produces land with high acidity, (2) the availability of lime that can react to reduce solubility on acidic land, and (3) the activity of microorganisms that control the level and number of decay organisms.

The value of available K content in canopy cover < 45% (6.1 mg/kg) has the highest value compared to canopy cover 45%–50% (4.3 mg/kg) and > 50% (6 mg/kg). According to (Batu et al. (2019), this value is categorized as very low if it has a value of < 10 mg/kg. The K-available content increased compared to the results of Mardhatillah et al. (2019), showing the K-available content in 30% of the canopy cover at 0.17% and 70% of the canopy cover at 0.76%. The acidic soil pH influences the low K content in *D. lanceolata* stands. Acidic soil pH will fix the K element with aluminum ions (Al +) and will be prone to leaching by rainwater so that the soil will lose the amount of K element (Budi 2022). Potassium is absorbed in the form of K+ ions. Its availability in the soil varies widely and is small. The total K in the soil in the tropics is low. This is due to naturally low K levels, rapid weathering, and high leaching of bases. In addition, the element potassium has a relatively large hydrated form size, so it is not strong in colloidal surface charge and is easily leached from the soil (Bakri et al. 2016).

Planting *D. lanceolata* species significantly changes the macro-nutrients present, especially for the content of C-organic, total N, and K available (**Table 5**). This means *D. lanceolata* species can be used to improve unproductive forest land. The T-test results show that macro-nutrients in *D. lanceolata* stands of 0.5-year and 6-year-old plants had significant differences in C-organic nutrients, N-total, and K available (**Table 6**). At the same time, the available P element does not show a substantial difference between 0.5-year and 6-year-old plants. This shows that *D. lanceolata* can improve the nutrient content of the soil.

Table 6. Comparison of macronutrient content at 0.5-year and 6-year-old plants

No.	Macronutrient	6-year-old plants			0.5-year-old plants*		
		Mean		Standard deviation	Mean		Standard deviation
1	C-organic (%)	4.86	a	0.30	2.01	b	0.19
2	N-total (%)	0.34	a	0.03	0.19	b	0.01
3	P_2O_5 available (mg/kg)	11.33	a	4.64	8.35	a	1.48
4	K_2O available (mg/kg)	5.47	a	1.01	0.47	b	0.42

Notes: The letter in the row indicates no significant difference at a 95% confidence level. *based on the results of Mardhatilla et al. (2019).

3.4. Biomass and Carbon Reserves of D. lanceolata Stands

Climate change in the form of global warming is caused by increasing concentrations of greenhouse gases (GHG) in the atmosphere, namely CO_2, CH_4, N_2O, HFC, PFC, and SF_6. The increase in GHGs that cause the greenhouse effect is produced by activities sourced from the industrial sector, transportation, power generation, waste, agriculture, and land change (Ibrahim and Lukman 2022). CO_2 is the most significant GHG, including the primary GHG produced from the forestry sector and natural changes. Efforts to reduce GHG concentrations in the atmosphere (emission) are to reduce the release of CO_2 into the air. The amount of CO_2 in the air must be controlled by increasing the amount of CO_2 uptake by plants as much as possible and suppressing the release of GHGs as low as possible. One way to increase the amount of CO_2 uptake is by planting trees (Ibrahim and Lukman 2022).

Carbon calculations can be made using the results of biomass calculations. BSN (2011) states that carbon is 47% of the tree's biomass. Biomass is the total living material above the surface of the tree, which can be determined by diameter, height, specific gravity of wood, and stand density (Ibrahim and Lukman 2022).

Table 7 shows that the total carbon storage in 5-year-old stands was 19.60 tons of carbon/ha and increased to 27.81 tons of carbon/ha in 6-year-old stands. *D. lanceolata* has an increase in total carbon of 41.91% for 1 year. This occurred because, in 1 year, the *D. lanceolata* stand experienced an average increase in diameter of 19.34%. The carbon storage value of 5-year-old *D. lanceolata* is lower than the 5-year-old *Tectona grandis* plantation in the Mustikaningrum and Rosida (2023), which is 43.4 tons of carbon/ha. The carbon storage value of 5-year-old *D. lanceolata* is lower than the 5-year-old *Swietenia macrophylla* plantation in the study Mustikaningrum and Rosida (2023), which amounted to 18.8 tons of carbon/ha. This result can approximate the carbon obtained when planting in the forest using the *D. lanceolata* species.

Table 7. Potential standing carbon mass of *D. lanceolata*

Stand age (years)	Average diameter (cm)	Total biomass (tons/ha)	Total carbon (tons/ha)
5	9.46	16.09	7.56
6	11.29	22.83	10.73

4. Conclusions

The relationship between the percentage of crown cover and the diameter and height of *D. lanceolata* stands in KHDTK Haurbentes is significantly correlated but has a low coefficient of determination. The 6-year-old *D. lanceolata* has grown well with a canopy cover of less than 34% (canopy openness of more than 66%) and can grow on clay soil with acidic pH. The 6-year-old *D.*

lanceolata could also improve the nutrient content in the soil. The nutrient content where *D. lanceolata* grows has a very high C-organic value, medium N-total, low phosphorus, and very low K-available. The 6-year-old *D. lanceolata* could significantly change existing macronutrients, especially the content of C-organic, total N, and K-available content. Therefore, *D. lanceolata* can be used to rehabilitate unproductive forests. Carbon storage in *D. lanceolata* has increased 1 year by 41.91%.

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