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Research Article

Relationships Among Biomass, Carbon, and Microfibril Angle in Young *Shorea* spp. (Dipterocarpaceae) in Indonesia

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ABSTRACT
Indonesia, particularly the island of Java, is dominated by a number of *Shorea* tree species (Dipterocarpaceae). Trees of the genus have been utilized for various practices, and they play a fundamental role in managing the stability of tropical forests. This study was carried out to understand the relationships between biomass and microfibril angle in *Shorea* spp. growing in West Java, where *Shorea* spp., are abundant. A total of 35 young trees belonging to 5 species were studied. The average age of these trees was 9 years, but in general there was a wide variation in tree diameter and total height. On average, biomass was the highest in *S. leprosura* and the lowest in *S. palembanica*. The lowest average microfibril angles (MFAs) were found in *S. leprosura* and *S. mecistopteryx*. The regression relationship between biomass and diameter was strong with an R^2 value of 0.85, while the strength of the relationship between MFA and diameter was weaker (R^2 = 0.195). In general, the MFA degree decreased with increased biomass accumulation *Shorea* species, which affects tree resistance to environmental variables and competitiveness in Indonesian tropical forests.

INTRODUCTION

Management and calculating forest biomass are crucial in addressing the issue of global climate (Mbow et al. 2014). Measuring the carbon stored in tree biomass has been widely applied in order to accurately and inclusively determine the capacity of forests to absorb and store carbon from the atmosphere (Wegiel & Polowy 2020; Rozendaal et al. 2021; Sufrayoga & Mardiatmoko 2022).

Tree biomass can be defined as the mass of organic materials that underpin all physiological and mechanical functions during the life of a tree. As a plant-based material, the biomass contained in trees is important because it contains a myriad of valuable components including carbon dioxide sequestration (Mildrexler et al. 2020; Ameray et al. 2021). Through photosynthesis, energy and other products are then transported to all parts of trees, leading to the accumulation of cellulose, hemicellulose, lignin, and a number of extractive compounds (Ng et al. 2015; Ma et al. 2018) in the wood stem tissue. Cellulose and hemicelluloses are longchain polysaccharide compounds that function as robust structural components in tree woody tissues (Berglund 2018; Donev et al. 2018). Both are involved in the construction of cell walls, help to maintain vertical tree growth, and buffer the effect of extreme environmental conditions alongside lignin compounds (Gibson 2012; Gril et al. 2017; Rongpipi et al. 2019).

Microfibril angle (MFA) is one of the key variables used to evaluate tree growth mechanisms as it describes the orientation of cellulose microfibril in the secondary layer of the cell wall, which significantly influences the mechanical properties of the whole tree (Auty et al. 2017; Xu et al. 2012). However, MFA varies greatly among tree species, locations, and climatic conditions. Even within the same tree, dramatic variation in MFA can be found among the basal, middle, and top parts of the tree (Groover 2016). In general, MFA is high when trees are in the juvenile growing phase, mostly on account of the effects of environmental factors. When trees are growing, the rate of photosynthesis is increased which leads to the accumulation of biomass and carbon sequestration (Kohl et al. 2017; Huang et al. 2021). Consequently, when biomass production is accelerated in young trees, the biomass will be slightly more stable, and this can lessen the impacts of environmental factors such as wind and storms. Craine & Dybzinski (2013), indicated that the frequency of photosynthesis and biomass accumulation is dependent on the surrounding environment, soil nutrients, micro-climate, light availability, and competition.

Shorea is a species-rich tree genus in the Dipterocarpaceae family, which is currently spreading across Southeast Asia. Classified as dense tropical hardwood, the genus has been commercially exploited for construction and housing across Indonesian forests as an economically-important woody product (Gaveau et al. 2013; Widiyanto et al. 2020). Owing to this high rate of usage, species of the genus were also planted and grown in some locations for either merchantable or silvicultural purposes. The decision to undertake this study was based on the wide-ranging benefits of the *Shorea* species in Indonesia. The general objective of this study was to understand the relationships between biomass, carbon sequestration, and MFA angle in some young *Shorea* trees planted in the West Java province of Indonesia. Furthermore, additional analyses were conducted to examine interactions with other variables such as diameter, height, volume, and wood density.

MATERIALS AND METHODS

Site

This research was conducted in Gunung Walat educational forest belonging to the Bogor Agricultural University (Institut Pertanian Bogor) in West Java Province, Indonesia, in 2013. The forest was established in 1968 and is primarily used for educational activities, research, endemic tree collection, and recreational purposes. The total area of the forest is 359 hectares, and it is divided into three blocks: an eastern block (Cikatomas) with a total area of 120 hectares, a western block (Cimenyan) of 125 hectares, and a central block (Tangkalak) of 114 hectares. Overall, the forest contains more than 44 tree species, which provide habitats for endemic bird, lizard, and insect species (Kusmana & Susanti 2015).

This forest lies between 460 m – 726 m above sea level. The typical soil is dominated by red-yellow latosols, brown latosols, and some podzols (Wibowo & Alby 2020). The area is relatively humid, with annual precipitation between 1700 mm and 4400 mm, while the temperature ranges from 18 °C to 30 °C (Kusmana & Susanti 2015). The present research was conducted in an *ex situ* conservation plot, which was established in 2004 and was fully planted with *Shorea* spp. The plot measures around 0.6 hectares in area, with the topography relatively even and sloping < 35°.

Biomass & Carbon Estimates

Trees of the following five *Shorea* species planted in 2004 were included in the present study: *Shorea leprosula*, *Shorea mecistopteryx*, *Shorea pinanga*, *Shorea stenoptera*, and *Shorea palembanica*. Seven trees from each species were measured, giving a total of 35 sampled trees. The criteria for tree selection included good physical appearance and distribution within the plot. Then, the non-destructive biomass measurements of circumference at breast height (1.3 m) (DBH) and total height were taken for each tree. The circumference of each stem was measured using a diameter tape measure wrapped around the tree. For the total height measurements, a laser hypsometer was used (clinometer suunto PM–5). The volume was determined using the following allometric equation (Husch et al. 2003):

$$V = \frac{1}{4} (\mu \times d^2 \times t \times a)$$

where: V = tree volume in m^3; d = diameter at breast height (DBH); t = total height of tree sample measurements; a = form factor (0.6) which is a term describing the ratio of tree volume to specified geometric solid volume based trees with similar diameter and height; and μ = phi which is the circumference measurement to diameter.

To obtain carbon accumulation in each sample tree, wood density (g/cm^3) was calculated first, which is the ratio of wood mass to volume under particular moisture conditions for each species. Samples were taken from one side of the trunk at breast height using an increment borer (Haglöf) with a 12 mm core size. In order to obtain more accurate wood density data, the corer was then kept in a green condition (refrigerator). After the cores were collected wood densities were calculated in the laboratory using ASTM standard. The cylindrical core samples were cut from the pith to the outer xylem rings into segments of approximately 1 cm, and these were weighted again until a constant value was achieved (Ricker et al. 2020). This procedure was used to obtain an estimate of average wood density, which was calculated using the following formula:

$$X = \frac{c \cdot \rho}{(b-a)}$$

where: X is the sample density obtained from core measurements, a is the balance obtained when the weighing basket was empty, b is the balance obtained when the weighing basket contained the sample, c is the mass of the dry cores, and ρ is the density of water equal to 1000 kg per cubic meter (Scandinavian Pulp, Paper and Board Testing Committee 1995).

Carbon sequestration measurements were based on the methodology of Krisnawati et al. (2012) because it was assumed this formula was more representative of the specific forest conditions in Indonesia's tropical forest, where the present study had taken place.

$$W = Vt \times BEF \times SG$$

where: W = total tree biomass in kilogram; Vt = total volume of tree in m^3; BEF = biomass expansion factor for tree (0.3; the ratio of the total above ground biomass to the biomass of the merchantable wood)), and SG = wood specific gravity (kg/m^3).

MFA and Fiber Length Measure

The MFA was measured in 35 *Shorea* trees. An increment borer was used to obtain core samples from one side of the tree trunk at a height of 1.3

m. These cores were then stored inside straws to maintain freshness. Visually, the collected cores showed no clear signs of tree ring boundaries. The cores were then sliced into a 1 cm sections to measure MFA and fiber length. Core pieces were first treated using HNO_3, and then KCl was added within minutes until the fibers were separated and the middle lamella portions were dissolved. A total of 30 fibril pieces were taken per sample, and these were placed onto a microscope slide for observations using a microscope interfaced with a digital camera. Images were then taken using the Motic imaging software to obtain fibril length measurements. To observe the fibril orientation angle, thin slices of core samples (± 30 μm) were placed under a microscope with a 100× magnification lens, and 10 images were taken of each sample slide. Three images were selected for further analysis of the microfibril angle, which was measured in degrees in Motic.

Data Analysis

A non-linear model was derived to analyze the relationships between biomass, carbon sequestration, and MFA orientation as well as the correlations among diameter, height, volume, and density in young *Shorea* trees. Fang and Bailey (1998) indicated that non-linear models are more adaptable when studying dense tropical forests. Given that certain uncontrollable factors affected this study, the power non-linear function for two parameters was used as a regression analysis tool. In addition, a pre-analysis was carried out using some existing models, and this revealed that the non-linear power model was the best fit for the measured variables. Nonlinear models can be used to make biological interpretations and are less sensitive to individual data points, making them better and more reliable for data extrapolation (Archontoulis & Miguez 2015). This model has also been widely used to understand tree allometric relationships, and particularly to model height-diameter relationships (Scaranello et al. 2012). The power model had the following form (Fang & Bailey 1998):

$$Y = aX^b$$

where, a is the scaling coefficient (constant), and b is the scaling exponent derived from the regression fit to the empirical data. The variables included diameter, MFA (°), height (m), volume (m^3), total biomass (kg), total carbon (kg), and wood density (gr/cm^3). The chi square test was used to estimate the significance of differences among parameters (biomass accumulation, carbon accumulation, MFA, diameter, and height). In addition to nonlinear power models, statistical analysis of parameters was also undertaken. All statistical analyses were performed using SPSS version 23.0 for Windows (SPSS Inc., Chicago, IL, USA).

RESULTS

Biomass & MFA Variation

Biomass accumulation varied across the five measured *Shorea* species, with *S. leprosura* (15.728 kg) producing the greatest biomass, and *S. palembanica* (1.842 kg) producing the lowest biomass. Such variation within the genus is due to the number of tree species and size, particularly tree diameter and height. On the other hand, MFA only differed slightly among the *Shorea* species, with the highest average degree found in *S. mecistopteryx* (41.67°) and the lowest average degree observed in *S. leprosura* (35.94°).

Biomass accumulation differed significantly among species, while MFA did not differ significantly among species (Figure 1). The chi-square analysis showed significantly different biomass accumulation in both *S. leprosura* and *S. stenoptera* with P values of 0.038 and 0.014, re-

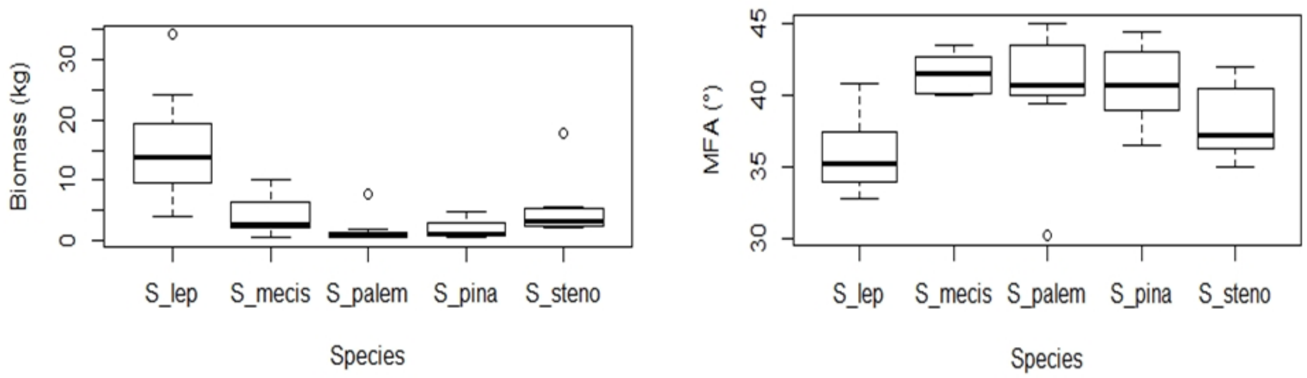

Figure 1. (A) Boxplots show the total number of biomass accumulation among five *Shorea* species with a significant difference as indicated by p-value of 0.00034 (< 0.05 of significance level); **(B)** Boxplot shows the average of MFA value from five species of Shorea with the significant difference as indicated by p-value of 0.017 (< 0.05 of significance level) in Gunung Walat. *Asterisk* (*) and *null* (○) information in both figures indicated the statistical significance among each measured species.

spectively.

Generally, there was a direct relationship between the diameter and the dependent variables (biomass, carbon, volume, and tree height) in the five *Shorea* species (Table 2). Biomass and carbon had a tendency to increase with increasing diameter (kg $year^{-1}$). Figure 2a and 2b indicate these relationships within the five *Shorea* species, with an R^2 of 0.85 and mean ± standard deviation of 5.54 for the relationship between biomass and diameter and an R^2 of 0.85 and mean ± standard deviation of 5.47 for the relationship between carbon and diameter. Other positive relationships were observed between volume and diameter as well as between height and diameter (Figure 2c and d). At 0.88, the greatest R^2 was observed for volume and diameter, while the least strong positive relationship was observed between height and diameter relationship, with an R^2 of 0.77.

S. leprosura produced the greatest biomass accumulation and carbon content of the five species, with average annual accumulations of 1747 kg and 0.803 respectively (Table 1). Moreover, *S. leprosura* also shows produced the greatest tree volume, with an average annual increase of 0.0101 g/cm^3. The lowest of biomass, carbon, and volume accumulations were observed in *S. palembanica* with average annual increases of 0.2047 kg, 0.0941 kg, and 0.0014 g/cm^3, respectively. With regard to tree height, *S. leprosura* had the greatest average annual growth of the *Shorea* species, with an average annual growth of 1.4746 m $year^{-1}$. On the contrary, *S. palembanica* had an annual primary growth of just 0.6063 m $year^{-1}$, which was the lowest of the *Shorea* species.

Table 1. Growth of Wood Characteristic of the Five *Shorea* Tree Species.

Species	Age (year)	Density (g/cm^3)	MFA (°)	Volume (m^3)	Biomass (kg)	Carbon (kg)	Annual biomass accumulation (Kg $year^{-1}$)	Annual carbon accumulation (Kg $year^{-1}$)
S. leprosura	9	0.575	35.94	0.0912	15.728	7.235	1.747	0.803
S. mecistopteryx	9	0.476	41.67	0.0297	4.266	1.962	0.474	0.218
S. pinanga	9	0.53	40.82	0.0123	1.959	0.901	0.217	0.100
S. stenoptera	9	0.491	38.24	0.0376	5.534	2.546	0.614	0.282
S. palembanica	9	0.478	40.41	0.0129	1.842	847	0.204	0.094

Table 2. Statistical Parameters for the Non-linear Regression Equations based on the Power Model for Five *Shorea* Species.

Species	Dependent variable	Independent variable	Parameter a coefficient	Parameter a SE	Parameter b coefficient	Parameter b SE	Model R^2	Model SE	Mean ± Standard Deviation	Model P Value
S. leprosura	Biomass	Diameter	-25.6185	10.2770	4.2563	1.0366	0.725	5.4290	9.9387	0.0093
	Carbon	Diameter	-11.78396	4.7275	1.9578	0.4768	0.725	2.4974	3.7676	0.0093
	MFA	Biomass	37.9519	2.1024	-0.1277	0.1141	0.040	2.8965	23.0575	0.3138
	MFA	Carbon	37.9519	2.1024	-0.2776	0.2480	0.040	2.8965	29.3582	0.3138
S. mecistopteryx	Biomass	Diameter	-5.7778	2.1948	1.2122	0.2546	0.783	1.5990	4.2699	0.0050
	Carbon	Diameter	-2.6577	1.0096	0.5576	0.1171	0.783	0.7355	6.4396	0.0050
	MFA	Biomass	42.3062	0.9363	-0.1822	0.1759	0.011	1.4800	37.4717	0.3477
	MFA	Carbon	42.3062	0.9363	-0.3962	0.3825	0.011	1.4800	39.6382	0.3477
S. palembanica	Biomass	Diameter	-4.9656	0.8709	1.1005	0.1330	0.918	0.7554	4.3956	0.0004
	Carbon	Diameter	-2.2841	0.4006	0.5062	0.0611	0.918	0.3474	5.4504	0.0004
	MFA	Biomass	40.8541	2.5404	-0.2395	0.8294	0.000	5.3699	38.9552	0.7842
	MFA	Carbon	40.8542	2.5404	-0.5208	1.8031	0.000	5.3699	39.8617	0.7842
S. pinata	Biomass	Diameter	-2.6323	0.4311	0.7616	0.0678	0.954	0.3593	4.1081	0.0000
	Carbon	Diameter	-1.2108	0.1983	0.3503	0.0312	0.954	0.1653	5.2912	0.0000
	MFA	Biomass	43.1069	1.3825	-1.1663	0.5527	0.365	2.2730	39.0547	0.0886
	MFA	Carbon	43.1069	1.3825	-2.5356	1.2017	0.365	2.273	40.0461	0.088
S. stenoptera	Biomass	Diameter	-21.6231	4.9624	3.0662	0.5518	0.832	2.2658	4.9986	0.0025
	Carbon	Diameter	-9.9466	2.2827	1.4104	0.2538	0.832	1.0422	6.4041	0.0025
	MFA	Biomass	39.6830	1.4395	-0.2602	0.1907	0.125	2.5887	33.4124	0.2307
	MFA	Carbon	39.6830	1.4394	-0.5656	0.4147	0.125	2.5887	35.9541	0.2307

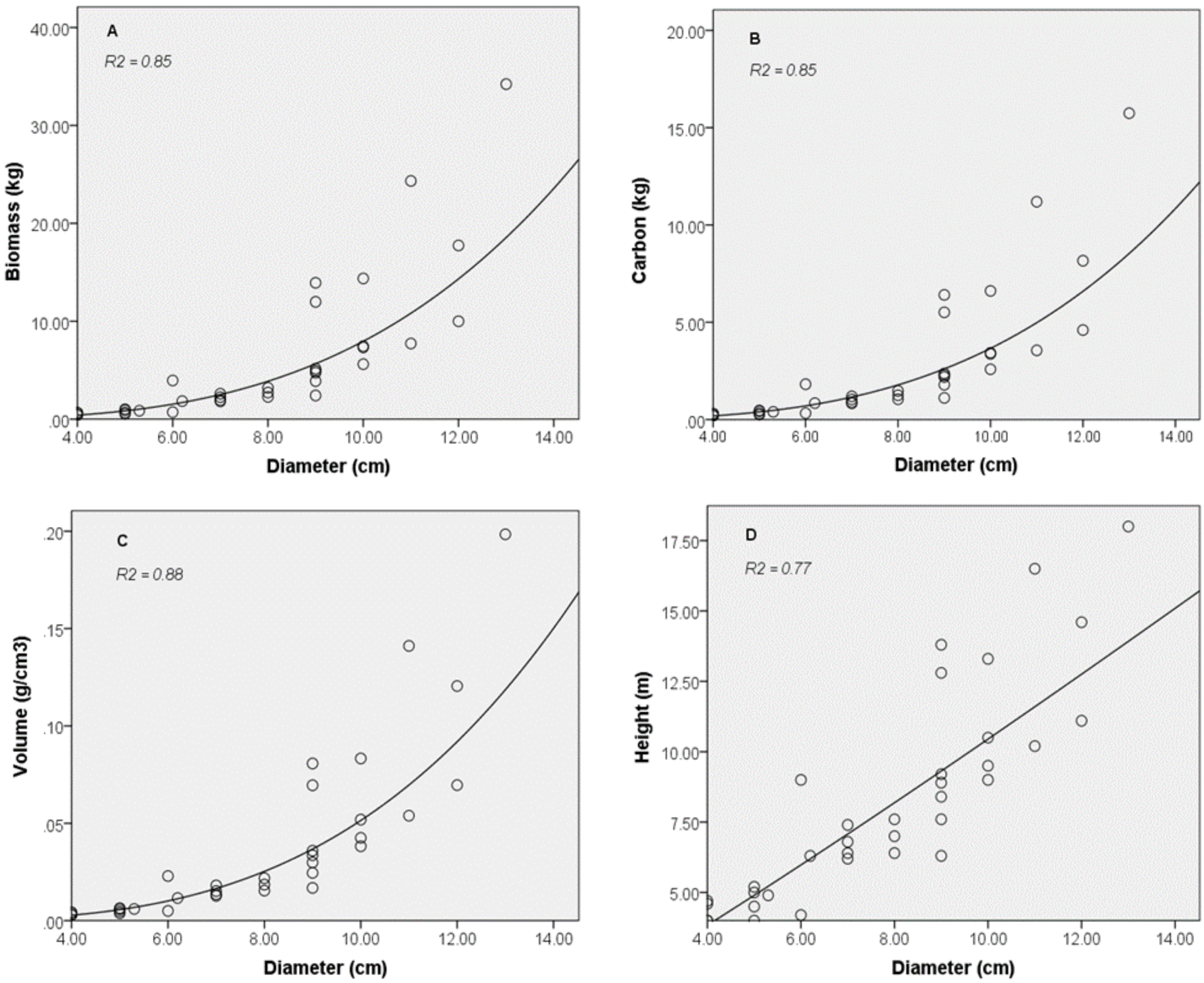

Figure 2. **(A)** The relationship between diameter (cm) as an independent variable and biomass (kg) as in the dependent variable; **(B)** The relationship between diameter (cm) as a dependent variable and carbon (kg) as an independent variable; **(C)** The relationship between diameter (cm) as a dependent variable and tree volume (g/cm^3) as an independent variable; and **(D)** is the relationship between diameter (cm) as a dependent variable and height (m) as an independent variable.

In general, MFA declined with increasing biomass, carbon, diameter, and wood density across the five *Shorea* species (Figure 3a and b). The relationships between MFA and diameter and between MFA and tree density (Figure 3c and d) were slightly positive, with R^2 value of 0.95 and 0.78, respectively.

DISCUSSION

Biomass accumulation varied among the five *Shorea* species (Figure 1a), and there are numerous factors that could have been an effective catalyst for such variations. It is likely that ecological variables, such as water and soil nutrient distribution, light availability, CO_2 availability, competition among trees, slope of the growing area, rate of photosynthesis, as well as intrinsic properties of the wood, significantly contributed to the huge disparity among species (Raich et al. 2014). A number of hypotheses (Brancalion et al. 2019; Phan et al. 2019) have suggested that increases in tree biomass accumulation make trees more robust to various environmental factors that affect growth, automatically reducing tree microfibril orientation angle.

The relationships between MFA and diameter as well as between MFA and density were not found to be significant in the present study. However, in reality, these variables are impactful during the tree grow-

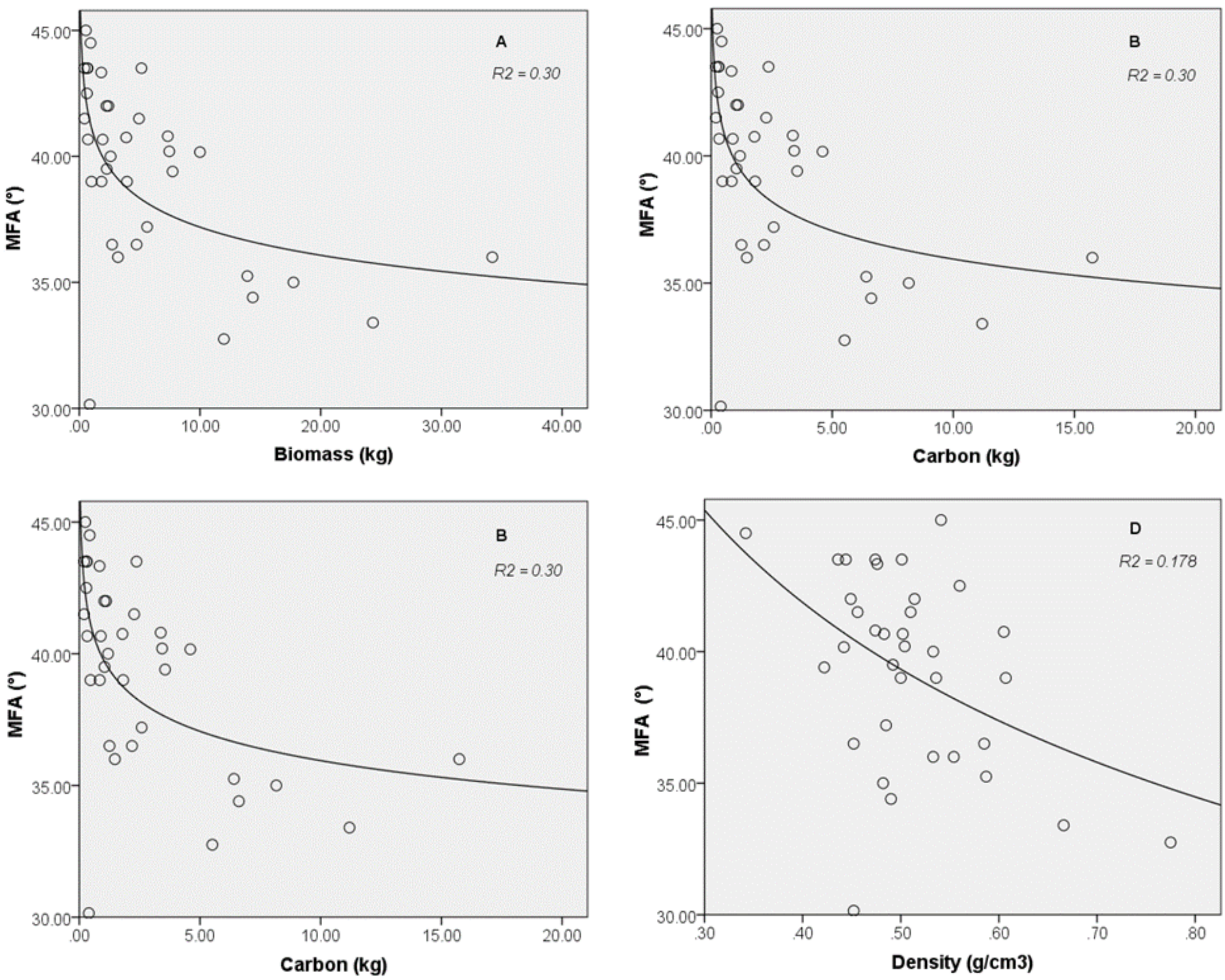

Figure 3. (A) The relationship between MFA (°) as an independent variable and biomass (kg) as in the dependent variable; **(B)** The relationship between MFA (°) as a dependent variable and carbon (kg) as an independent variable; **(C)** The relationship between MFA (°) as a dependent variable and tree diameter (cm) as an independent variable; and **(D)** is the relationship between MFA (°) as a dependent variable and wood density (g/cm^3) as an independent variable.

ing process. The increasing tree diameter (cm year^{-1}) is a key element in forest dynamics which also determines competitiveness among young trees of various species. Tree density is also an important indicator in measuring tree existence. It is also one of the upholding mechanical characteristics which keeps trees growing correctly. Higher wood density provides essential resistance and causes trees to be more robust toward other environmental disturbances.

Overall, the MFA degrees measured in this study are considered high when compared to other tropical tree genera. This is likely due to the fact that all measured trees were still young (< 10 years old) and were therefore very susceptible to a wide range of environmental factors such as wind, slope of the growing area, and anthropogenic activities (Minamino & Taneko 2014).

The soil in the study area consisted of red-yellow latosols, brown latosols, and some podzols. However, because the study area was not large (< 1 hectare), this factor is unlikely to be a key driving factor of biomass distribution. In fact, the study site was primarily composed of latosol soils (> 75%) but podzols were found in some areas, which contain huge concentrations of soil nutrients from tropical forest decomposition. Based on the obtained biomass accumulation results, it is likely that *S. leprosura* has higher total N, P, and K contents than other *Shorea* species.

Lira-Martins et al. (2019) noted positive correlation between tree trunk growth and the accumulation of N, P, K, and Ca in young tropical trees of tropical tree species in Amazonia and Australia. Jiang et al. (2018) showed that the amount of nitrogen in the trunk has a significant effect on total biomass and other biomass components in young tree. In addition, *S. leprosura* is more productive in terms of nutrient-use efficiency. Zhang et al. (2021) observed that some tropical trees could have different nutrient use efficiencies even among similar growing areas. Water availability likely had no significant influence on biomass accumulation because the location experienced similar precipitation levels throughout, and it can be assumed that each of the *Shorea* trees in the location received sufficient water to support their life. With the annual precipitation from 1700 mm to 4400 mm, water availability was high enough for trees using a variety of ecophysiological mechanisms.

Competition among young *Shorea* trees was also an important factor in this study. In general, *Shorea* species, classified as a shade tolerant, need enough shade during growing phase (Pamoengkas & Prasetia 2014; Hussein 2015). In this study, most of the young *Shorea* species were shaded by the bigger *Agathis* trees, which possibly lessened the amount of sunlight reaching the ground that could be used in photosynthesis. Lack of light at early life stages has a negative impact on the growth rates of young trees (Tripathi et al. 2020; Bianchi et al. 2021). In the present study, there was variation in the locations of trees growing simultaneously. In fact, the study site had slopes (between 10° to 45°) that may have affected the ability of young trees to absorb light during the middle of the day (Lekitoo et al. 2017). Various mechanisms are employed by trees to obtain enough sunlight which effectively contributes to their productivity (Darko et al. 2014; Li et al. 2020).

However, the variation in biomass accumulation may come from leaf differentiation and leaf numbers in each young tree in the context of impacting upon ecophysiological effectiveness. It was observed that young *S. leprosura* tree generally had good overall health compared to other species. Visual observation revealed that the species looked greener with many regular leaves, longer branches, and a healthy trunk. In contrast, around a third of *S. palembanica* leaves were unhealthy due to disease and insect pests. Lelana et al. (2022) specified several leaf predators such as *Mucanum* spp., *Pteroma plagiophelps*, *Valanga nigricornis*, and *Pestalotia* spp., which have been found to effectively cause reduced leaf quality in *Shorea* species in Indonesia. Leaf size, shape, and canopy arrangement can influence photosynthesis rate and total biomass production in many tree species (Falster et al. 2018; West 2020). Given that these factors are important for young trees, and based on visual observation of each young tree, it can be assumed that *S. leprosura* retains higher biomass through a higher rate of photosynthesis compared with other species.

Measuring MFA can provide important insight into various tree mechanisms and how they contribute toward tree productivity (Xu et al. 2012; Auty et al. 2013). Here, MFA varied among *Shorea* tree species, and there was a negative relationship between biomass content and MFA (Figure 3). These results indicate that there is a tendency for MFA to decline when both biomass accumulation and carbon content increase. Negative relationships were also present between MFA, wood density, and tree diameter (table 2). Microfibril angle has been reported to be high when trees are in the growing phases (seedling and sapling periods), and it continues to decline gradually when trees grow in both vertical and lateral directions. Since most of the trees in this study were considered juvenile, they were not really composed of solid wood structures and mainly comprised young cell walls, which in turn caused the negative relationships with the mechanical functions of wood properties (Xi 2018; Rocha et al. 2019; Eder et al. 2020).

The present study found that the MFA was high among the 35 young trees, with the average ranging from 35.94° to 41.67°. This wide range of MFAs is likely due to vulnerability to various environmental disturbances. It is likely that external factors, such as regular gales and the slope of the growing area (between 10° to 45°), have contributed to high MFA variation in these young trees. With a regular windy period during the rainy and dry seasons, wind is a key factor in determining MFA orientation in most young trees in Indonesia (Ishigura et al. 2012; Alteyrac 2015). In addition, the slope in the study area has forced the young trees to retain their growing orientation over a period of time since they were planted. Hein et al. (2015) indicated that the effects of slope and wind are positively associated with MFA orientation in young trees. Variation in MFA was also found among *Shorea* species (table 1), which indicates differences in wood stiffness and durability against various environmental disturbances such as wind, rain, and flood. In many cases, MFA is negatively correlated with wood stiffness, meaning that when MFA decreases, wood stiffness increases as a consequence of biomass accumulation and wood productivity over a growing period. Although several studies have failed to find a positive correlation between wood density and MFA, a positive tendency between these was noted in the present study (Figure 3d). Overall, MFA declined when wood density increased. In conclusion, *S. leprosura* seems to have a stiffer trunk than other species. Tree wood tends to be denser when the rate of photosynthesis is higher which leads to biomass accumulation throughout the year. In contrast, *S. palembanica* showed the lowest rate of biomass accumulation and the lowest wood density and tended to be unhealthy. This may be because the species has not fully adapted to the existing growing area, as it normally grows along riverbanks, in swampy forests, and in low-lands with Inundated areas (Erizilina et al. 2019).

CONCLUSIONS

The relationship among carbon, biomass, and MFA for the five young-tree species of *Shorea* were tested through quantitative data analysis. A total of 35 tree species were considered with good physical appearances and distributing along the observed plot. Non-destructive biomass measurement was carried out using diameter tape and a laser hypsometer to determine allometric equation. Carbon accumulation was estimated through laboratory analysis of wood core sample with the ASTM standard. MFA was measured using core samples that were sliced every centimeter then combined with HNO_3 and KCl to separate fibers. Fiber angle orientation was observed under a microscope with 100 time magnification lens Motic Image Software. In order to identify the best fit correlation between carbon, biomass and MFA, non-linear Power models were performed. *S. leprosura* turned out to be the highest biomass and carbon accumulation, volume and annual increase, while *S. palembanica* was the lowest among the five young *Shorea* species. It is obvious that MFA was declining with the increase in biomass, carbon, diameter, and wood density among the five *Shorea* species. The relationship between biomass and diameter was strong with an R^2 value of 0.85, while the strength of the relationship between MFA and diameter was weaker with R^2 value of 0.195. MFA degree decreased with increased biomass accumulation in in *Shorea* species.

AUTHOR CONTRIBUTION

R.L.C., D.W., D.A.J. and S.C. have equal contributions to this work as the main contributor. R.L.C., and D.W. designed the project and collected the data. R.L.C. & S.C. performed the analyses. R.L.C., D.W., D.A.J., and S.C. wrote, revised, and approved the manuscript

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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