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Carbon Stock Analysis of Waru and Bidara in the Campus Forest of Universitas Negeri Surabaya

An'nur Madani[1]*, Fida Rachmadiarti[1]
Study Program of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya
Kampus Unesa 1, Jln. Ketintang Surabaya 60231 Indonesia
*Corresponding Author, e-mail: annurmadani.21026@mhs.unesa.ac.id

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This study evaluated the carbon stock of *Hibiscus tiliaceus* (Waru) *and Ziziphus mauritiana* (Bidara) in the UNESA Campus Forest, Surabaya, Indonesia. Its main objective is to analyze the morphological and physiological features that influence their capacity for carbon sequestration, in support of urban reforestation efforts. Non-destructive measurements of chest height diameter (DBH), wood density, and allometric equations were used to estimate biomass and carbon stocks, supplemented by physiological assessments including chlorophyll content and leaf surface. The results of the study showed that Waru showed better morphological characteristics, with an average leaf area of 24,003.28 ± 15,212.06 cm², a stem diameter of 20.26 ± 9.49 cm, and a chlorophyll content of 16.77 ± 6.95 mg/L, producing a biomass of 1923.99 ± 367.03 kg per tree and a carbon stock of 885.04 ± 168.83 kg per tree. In contrast, Bidara has smaller leaves (797.56 ± 72.96 cm²), stem diameter (9.20 ± 4.75 cm), and lower chlorophyll (13.09 ± 5.39 mg/L), with a biomass of 305.37 ± 52.58 kg and a carbon stock of 140.47 ± 24.19 kg. Statistical analysis showed a strong positive correlation between rod diameter and biomass ($r = 0.878$, $p < 0.01$) and carbon stock, suggesting that morphological characteristics significantly affect carbon uptake. These findings demonstrate Waru's potential as a strategic urban carbon sink, informing the city's environmental conservation and forestry policies that are aligned with sustainable development goals

Keywords: *Hibiscus tiliaceus*; *Ziziphus mauritiana*; plant morphology; conservation
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INTRODUCTION

Carbon (C) is a naturally occurring chemical element that is essential for life on Earth. These elements can be linked to other elements in a unique way. This is what makes organic compounds, which are the building blocks of almost all living things. Carbon comes in many forms in plants, animals, and humans, showing how important carbon is for survival (Marliza *et al.*, 2023). Carbon dioxide (CO_2) is one of the most common types of carbon in the air. It was created when cells breathe and when humans burn fossil fuels and cut down trees. Too much CO_2 in the air disturbs the balance of the carbon cycle and exacerbates climate change, especially global warming (Kurniawan *et al.*, 2024). Plants that absorb CO_2 through photosynthesis are therefore an important way to help stop climate change. Plants not only absorb CO_2 but also store it in biomass, making it a natural carbon store (Nedhisa and Tjahjaningrum, 2019). Forests and green spaces in cities, such as the UNESA Campus Forest in Surabaya, are important for storing carbon and maintaining ecosystem balance. This 4.64-hectare forest is like the lungs of the city. This helps reduce the amount of carbon in the air and improves the environment. It's important to study the carbon stocks in the area to learn how much carbon urban plants can store and help fight climate change.

A plant's ability to absorb carbon depends on many things, such as the type and age of the plant, its growing conditions, and how well it has photosynthesized. Larger, older plants typically have more biomass, which means they can hold more carbon (Windarni, 2017). The specific weight of plants also affects how much carbon they can store because different species have different types of tissues (Pahrurrozi *et al.*, 2025). So, the allometric method that measures the diameter of a tree trunk at height (DBH) is a good way to find out how much biomass and carbon are present in the forest. Waru and Bidara are two species that are very important for carbon capture in the UNESA Campus Forest. Both trees grow well in cities in the tropical areas and are good for the environment and economy. Bidara is known for its healthy fruit and is used in traditional medicine, while Waru is often used to restore the environment, especially along the coast. Previous research has shown that Waru can absorb large amounts of carbon in mangrove ecosystems, confirming its ability as a carbon-absorbing species (Nahuda *et al.,* 2021).

There are many studies on vegetation carbon stocks, but few have looked at how plant physiological factors such as chlorophyll content and leaf surface affect carbon storage, especially in urban areas such as Waru and Bidara. The chlorophyll content alone is not enough to represent the physiological characteristics of the plant; Thus, additional measurements of physiological parameters are necessary for a comprehensive understanding. The absence of local data in tropical urban environments such as UNESA Campus Forests provides opportunities for additional research on the role of vegetation in carbon capture and climate change mitigation.

This study seeks to examine the carbon stocks of Waru and Bidara in the UNESA Campus Forest Conservation Area, as well as to evaluate the correlation between plant morphological and physiological parameters and carbon storage capacity. The findings of this study are expected to provide scientific data that support environmental conservation and management initiatives, in addition to supporting policies related to sustainable development and climate change mitigation at both the local and national levels.

MATERIALS AND METHODS

This research was conducted in the UNESA Campus Forest area in Lidah Wetan, Surabaya, East Java (Figure 1), from October to December 2024. The method used was observational by sampling tree biomass using purposive sampling techniques.

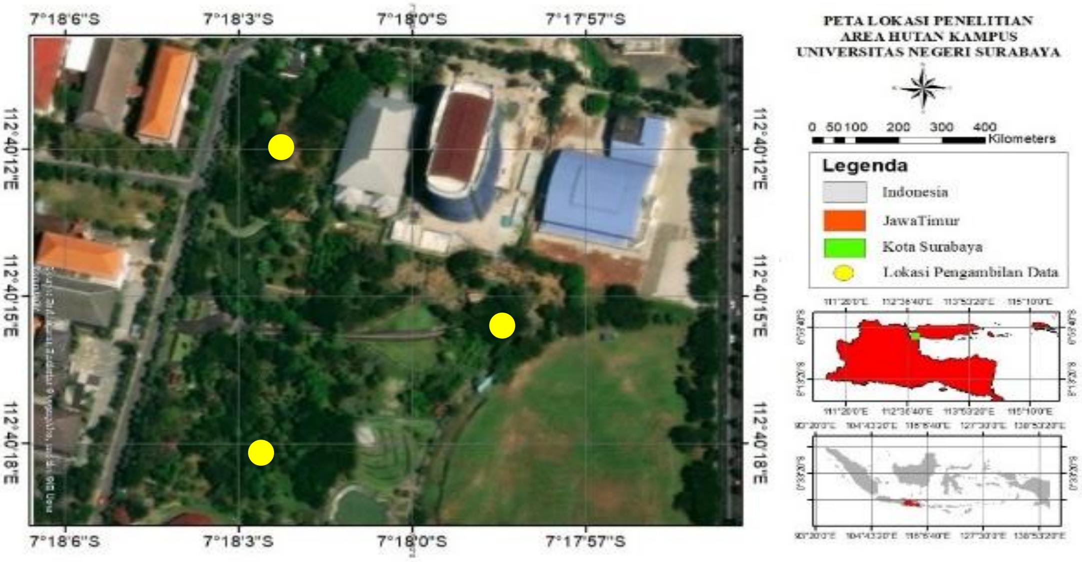

Figure 1. Sampling site in Unesa campus forest, Surabaya

Tree diameter was measured 1.3 meters above ground level, known as Diameter at Breast Height (DBH). A measuring tape was wrapped around the trunk with the tape positioned evenly in all directions to measure circumference of the trunk. Circumference data were converted into diameter using the following equation (Irundu *et al.,* 2020):

$$D = K : \pi$$

Note:
D = tree diameter (in cm),
K = tree trunk circumference (in cm)
π = 3.14

Biomass measurement was performed using a method that does not harm the tree (nondestructive), based on a formula that relates the diameter at 1.3 m height to wood density, as described by Ketterings (2001). The allometric formula for tree biomass measurement is as follows (Renjana *et al.,* 2024):

$$B = 0.11 \times \rho \times D^{2.62}$$

B = Tree biomass (kg/tree)
0.11 = Constant
ρ = Wood density (g/cm³)
D = Diameter at breast height (1.3 m)

To measure tree carbon stocks, tree biomass data must first be obtained, as the carbon content in organic matter is typically around 46% (Windarni, 2017). Therefore, we estimated the amount of carbon using the following equation:

$$\text{Carbon Stock} = \text{Biomass} \times 46\%$$

Chlorophyll content was measured using the Wintermans and De Mots method with a spectrophotometer at 649 and 665 nm, where absorbance values were recorded (A = OD). The absorption results are then converted to mg/L with the following formula (Posumah, 2017):

Chlorophyll a = (13.7 × A665) – (5.76 × A649)
Chlorophyll b = (25.8 × A649) – (7.60 × A665)
Total Chlorophyll = Chlorophyll a + Chlorophyll

Leaf area was measured using a Leaf Area Meter, a device that directly measures the leaf surface area in cm². We selected healthy and intact leaves for measurement, placed them on the device, or took appropriate photos. Information on biomass, carbon stock, chlorophyll content, and leaf surface area was examined to see how these properties relate to carbon stocks, using the Pearson Correlation Test with SPSS version 26.0 for Windows.

RESULTS

The measurement results show that the value of environmental conditions varies at each station. The air temperature at Station 1 is highest at 35°C, which is higher than 32°C at Station 2. We think the difference in air temperature values at each station is due to the amount of light and the amount of vegetation. The air humidity at Station 1 was also lower (45%) than at the other two stations (63%). This means that Stations 2 and 3 have more shady and humid areas. From Station 1 to Station 3, the CO_2 level rises. This may be due to differences in biological activity. Station 3 has the most light (489 lux), which means it is a more open area. Soil moisture levels remain low (10%) at all stations, which means dry soil. The pH of the soil changes, with Stations 1 and 2 being alkaline (pH 8) and Station 3 being neutral (pH 7). The soil temperature is between 30 and 32°C, which is warm enough to affect the way microbes work in the soil.

Table 1. Environmental conditions at three different station

Environmental Factors	Station 1	Station 2	Station 3
Air Physicochemical parameters			
Temperature (°C)	35 ± 0	32 ± 0.57	32 ± 0.57
Humidity (%)	45 ± 0.58	63 ± 10.97	63 ± 1
CO_2 (ppm)	457 ± 3.21	474 ± 3.06	487 ± 13.51
Light intensity (lux)	384 ± 122.55	405 ± 83.34	489 ± 58.03
Soil Physicochemical parameters			
Humidity (%)	10 ± 0	10 ± 0	10 ± 0.57
pH	8 ± 0.57	8	7
Temperature (°C)	31 ± 1.15	30 ± 1	32 ± 3.06

This study evaluated 28 *H. tilaceus* and 27 *Z. mauritiana* trees. The measured morphological characteristics included tree height, stem circumference, diameter at breast height (1.3 m), and leaf area (Table 2). Physiological aspects were assessed based on the chlorophyll content. The parts of the Waru and Bidara plants are shown in Figure 2 and 3, respectively. The results showed that *H. tilaceus* plants had larger morphological sizes than *Z. mauritiana* plants.

Table 2. Morphological characteristics of *H. tilaceus* and *Z. mauritiana* plants

Plant Species	Leaf Area (cm²)	Circumference (cm)	Diameter (cm)	Height (cm)
H. tiliaceus	24,003.28 ± 15,212.06	64.29 ± 29.83	20.26 ± 9.49	623.93 ± 116.79
Z. mauritiana	797.56 ± 72.96	25.56 ± 14.91	9.20 ± 4.75	288.70 ± 155.87

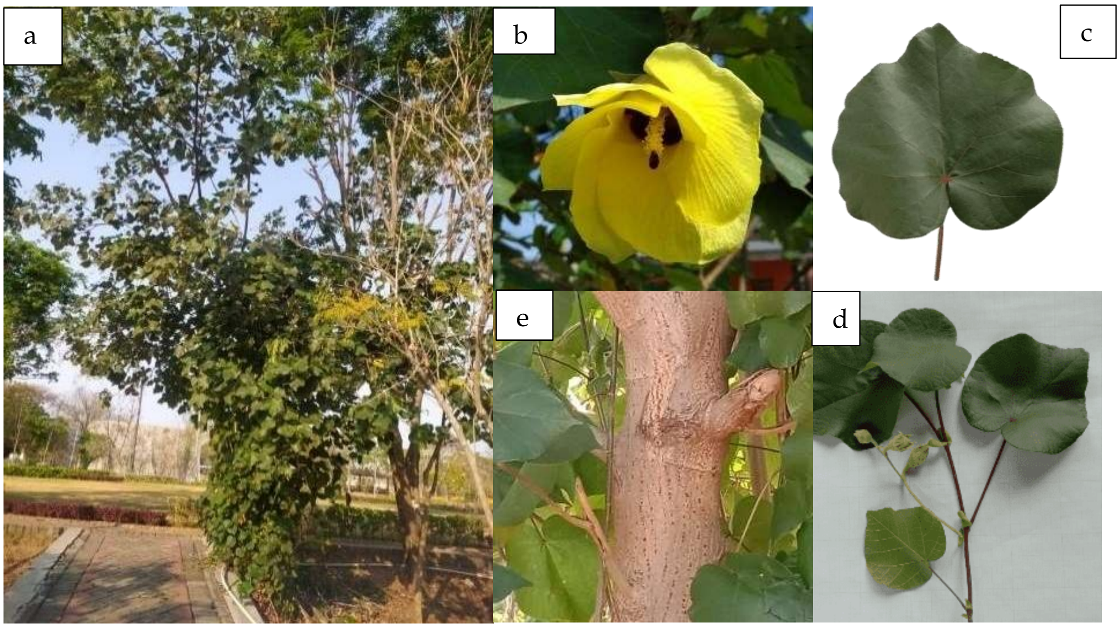

Figure 2. The morphology of the *H. Tiliaceus* plant, including: a. habits, b. flower, c. leaf, d. leaf branching, e. bark texture.

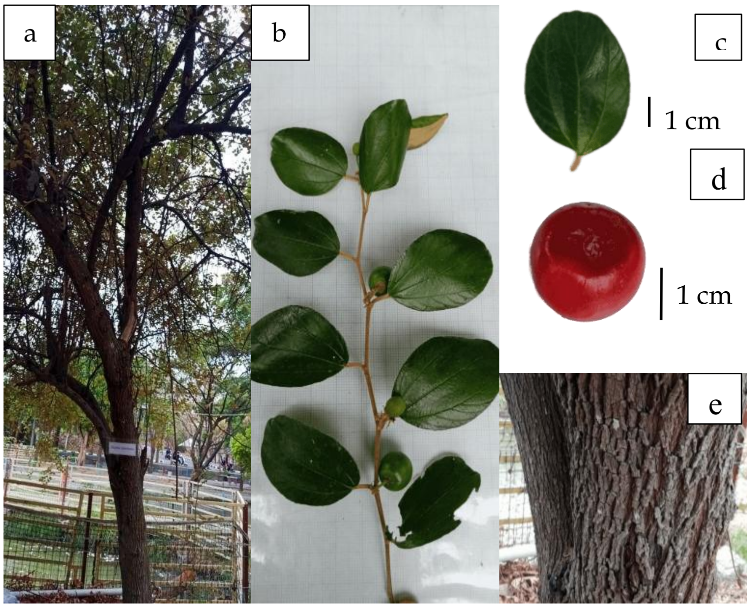

Figure 3. The morphology of *Z. mauritiana* plant, including: a. habits, b. leaf branching, c. leaf, d. fruit, e. bark texture.

Table 3 shows that the highest chlorophyll content in *H. tilaceus* was recorded from Station 2 at 20.87 ± 3.24 mg/L, while the lowest at Station 1 at 8.93 ± 0.59 mg/L. The average overall chlorophyll content of *H. tilaceus* was 16.77 ± 6.95 mg/L. In *Z. mauritiana*, the highest chlorophyll content was found at Station 3 at 15.25 ± 8.12 mg/L, and the lowest at Station 1 at 10.59 ± 3.03 mg/L, with an overall average of 13.09 ± 5.39 mg/L. In general, *H. tilaceus* had a higher chlorophyll content than Bidara.

Table 3. Chlorophyll content in *H. tiliaceus* and *Z. mauritiana* leaves

Plant Species	Station 1 (mg/L)	Station 2 (mg/L)	Station 3 (mg/L)	Mean (mg/L)
H. tiliaceus	8.93 ± 0.59	20.87 ± 3.24	20.52 ± 6.61	16.77 ± 6.95
Z. mauritiana	10.59 ± 3.03	13.42 ± 4.92	15.25 ± 8.12	13.09 ± 5.39

Table 4 shows that *H. tiliaceus* has a biomass of 1923.99 ± 367.03 kg/tree/year, producing a carbon stock of 885.04 ± 168.83 kg/tree/year, which is categorized as very high. Meanwhile, although *Z. mauritiana* has higher wood density (0.76 g/cm³), its biomass wass lower at 305.37 ± 52.58 kg/tree/year, with a carbon stock of 140.47 ± 24.19 kg/tree/year, which falls into the medium category. This difference indicates that stem diameter significantly influenced the biomass and carbon stock. In the study location, the larger stem diameter of *H. tiliaceus* trees compared to *Z. mauritiana* trees resulted in significantly higher biomass and carbon accumulation, despite the lower wood density of *H. tiliaceus*.

Table 4. Biomass and carbon stock evaluation of *H. tiliaceus* and *Z. mauritiana*

Plant Species	Wood Density (g/cm³)	Biomass (kg/tree/year)	Carbon Stock (kg/tree/year)	Category*
H. tiliaceus	0.57	1923.99 ± 367.03	885.04 ± 168.83	Very High
Z. mauritiana	0.76	305.37 ± 52.58	140.47 ± 24.19	Medium

*Note: Carbon stock categories based on Dahlan (2008); 1000 = Extra High; 500–1000 = Very High; 150–499 = High; 50–149 = Medium; 10–49 = Low; <10 = Very Low

Table 5 shows the results of the correlation analysis between morphological variables and carbon stocks. The findings showed that the diameter of the rod had the most significant correlation with biomass (r = 0.878**) and carbon stock (r = 0.878**), achieving a high level of statistical significance (p = 0.000). This strong positive correlation implies that the increase in trunk diameter is closely related to increased biomass accumulation and increased carbon storage. The importance of this relationship suggests that the diameter of the stem is an important factor in knowing how much carbon is stored in the plant. This variable accurately reflects total vegetative growth, which directly affects the production of biomass and, consequently, the carbon content in plant tissues.

Table 5. Pearson correlation test results between morphological variables and carbon stock

Variable	Biomass (r)	Biomass (Sig.)	Carbon Stock (r)	Carbon Stock (Sig.)
Stem Diameter	0.878*	0.000	0.878*	0.000
Plant Height	0.453*	0.001	0.453*	0.001
Leaf Area	0.301	0.024	0.301	0.024
Chlorophyll	0.125	0.317	0.125	0.317

Note: * = significant at the 0.01 level (2-tailed)

Although lower than the diameter of the stem, plant height is significantly correlated with carbon stock (r = 0.453**, p = 0.001). Leaf area showed a significant but moderate relationship (r = 0.301, p = 0.024), suggesting that the contribution of photosynthesis to biomass increased, although not as strongly as the diameter and height of the stem. Meanwhile, chlorophyll showed a low and negligible correlation with biomass and carbon stocks (r = 0.125, p = 0.317). The correlation value between chlorophyll and biomass suggests that while chlorophyll is essential in photosynthesis, this parameter does not directly reflect long-term biomass accumulation.

DISCUSSION

This study documented a total of 28 Waru individuals and 27 Bidara individuals in the research area. Both species can grow in the same type of environment, but they have very different physical characteristics. Plant morphology, such as leaf size, plant height, and stem diameter, is an important factor in how well plants can absorb and store carbon.

Waru has a wooden trunk structure with many branches and heart-shaped leaves, according to what people see. The waru tree usually grows between 5 and 15 m tall, and its trunk is about 20.26 ± 9.49 cm in diameter. The average leaf area is 24,003.28 ± 15,212.06 cm², which means that the plant has a large surface area for photosynthesis. The average chlorophyll content of Waru leaves is also 16.77 ± 6.95 mg/L, indicating that they have a lot of photosynthesis potential. Taiz and Zeiger (2015) say that the amount of chlorophyll in a plant is closely related to how well it can photosynthesize, which in turn affects how much biomass it can produce and how much carbon it can store.

The bidara tree is very adaptable to soil that is not very good. This species can grow up to about 15 m tall and has spiny stems and twigs, drooping branches, and unique dimorphic structures on stems and branches. The average amount of chlorophyll in Bidara leaves was found at 13.09 ± 5.39 mg/L. This value is slightly lower than that seen in Waru leaves, but still high enough to support good photosynthesis. The amount of chlorophyll in Bidara changes depending on the environment, such as how bright the light is, how hot it is, and how humid it is (Zakkiyah *et al.*, 2018). When the environment is right, higher levels of chlorophyll make plants better at absorbing light, which in turn helps to grow and build biomass (Misra *et al.,* 2022; Kumar *et al.,* 2021). The age of the leaves also affects the amount of chlorophyll in them. Younger leaves typically have more chlorophyll than older leaves (Zakkiyah *et al.*, 2028).

The information in Table 4 shows *H. tiliaceus* and *Z. mauritiana* in the Unesa campus forest has striking difference in their carbon storage capacity. *H. tiliaceus* had a wood density of 0.57 g/cm³, produces a total biomass of 1923,989 ± 367,024 kg/tree/year, and stores carbon stocks of 885,035 ± 168,831 kg/tree/year. In contrast, although *Z. mauritiana* had a higher wood density of 0.76 g/cm³, it only produces biomass of 305,368 ± 52,577 kg/tree/year with a carbon stock of 140,469 ± 24,185 kg/tree/year. This confirms that while wood density is an important indicator of carbon storage, the size and diameter of tree trunks, as seen in *H. tiliaceus*, have a greater influence on biomass and carbon accumulation. This conclusion is consistent with the fndings of Sari et al. (2021), which showed a strong positive correlation between trunk diameter and tree biomass, suggesting that trees with larger diameters typically absorb larger amounts of carbon. In addition, diferences in carbon storage capacity between species are infuenced by other factors, such as the age of trees, the amount of moisture in the soil, the type of soil, and the amount of nutrients available (Amin *et al.,* 2021).

Waru is known for its high carbon storage capacity, as evidenced by its above-average biomass value and carbon stock. With a wood density of 0.57 g/cm³, Waru is among medium to high density trees, ideal for absorbing atmospheric carbon dioxide. Waru's annual biomass reaches almost two tons per tree and its carbon stock exceeds 880 kg/tree/year, which places this species in the category of very high carbon stocks according to IPCC standards and some studies such as Fatima et al. (2020). This value reflects Waru's important contribution to climate change mitigation, particularly in tropical and coastal ecosystems. Even in a study by Kauffman & Donato (2012), the carbon stock of Waru in coastal tropical ecosystems can reach 10-30 tons/ha, which is considered moderate according to IPCC guidelines (2006). Although considered moderate on a broader scale (per hectare), this value remains significant, especially when Waru is planted in large numbers in strategic areas such as campus forests or conservation areas. Therefore, Waru has strong potential for use in vegetation restoration and carbon-based conservation programs.

Bidara also plays an important ecological role, although its biomass value and carbon stock are categorized as moderate. Its high wood density (0.76 g/cm³) reflects a dense wood structure, but due to the smaller tree size compared to Waru, the amount of biomass and carbon stored is lower. Its annual biomass is 305.37 ± 52.58 kg/tree, and its carbon stock is 140.47 ± 24.19 kg/tree, which puts it in the category of moderate carbon storage. However, its high potential for adaptation to dry and degraded soils makes Bidara well-suited for reforestation and soil rehabilitation programs. Studies such as Sammi *et al.,* (2021) and Sugiatmo *et al.,* (2023) report that carbon stocks in Bidara can reach 200–500 kg/tree/year, depending on environmental conditions and tree age. Therefore, even though Waru's contribution is less significant, Bidara continues to increase the capacity for carbon storage on a landscape scale, especially in tropical and subtropical areas. Based on their ecological properties and carbon sequestration capacity, we can strategically use both species in environmental management and climate change mitigation.

The results of the Pearson correlation test showed a significant relationship between several variables. Biomass and carbon stocks showed a strong correlation (1,000, $p<0.01$), meaning that the higher the biomass of the tree, the more carbon is stored. The correlation between biomass and carbon stocks supports Ibrahim's (2020) idea that trees absorb carbon from aie and store it in their parts, roots, and soil as biomass. A strong correlation was also found between biomass and tree diameter (0.878, $p<0.01$), suggesting that larger diameter was associated with higher biomass. Thus, the diameter of the tree affects the amount of carbon stored. The strong correlation between biomass and tree diameter is also consistent with the theorem of Brown (1997), where the diameter of the tree trunk is a key indicator in the calculation of biomass and carbon stock using allometric equations. The relationship between tree diameter and carbon content is exponential, which means that an increase in tree diameter significantly increases biomass, and thus carbon stocks. According to Chave et al. (2014), tree trunk diameter, wood density, and tree height are key variables in allometric models to estimate carbon stocks in trees in tropical ecosystems. Smaller-diameter trees contribute less carbon stock than larger trees because their total biomass is lower.

In addition, there was a moderate correlation between biomass and tree height (0.453, $p<0.01$), suggesting that taller trees tend to have greater biomass. According to Chave et al. (2014), tree height is often used in conjunction with tree diameter to estimate tree biomass through allometric equations.

Taller trees typically have more branches, leaves, and deeper roots, which collectively increase the tree's ability to store carbon. Thus, taller trees tended to have larger carbon stores.

Another morphological relationship is between leaf area and biomass and carbon stock. Based on the results of the correlation test, the ratio of leaf area to biomass showed a significant correlation with an r-value of 0.370 and a significance of 0.026, meaning that there was a relatively strong positive relationship between the two. The correlation value between leaf area and biomass shows that the larger the leaf area, the higher the plant biomass production. In addition, the relationship between leaf surface area and carbon stock is strong, with an r-value of 0.391 and a significance of 0.018, meaning that plants with larger leaves typically have more carbon stored because they can absorb and retain more carbon in their tissues. Plants with wider leaves have a greater photosynthesis capacity, which increases biomass production and carbon buildup, which explains this significant correlation. The surface area of the leaves plays an important role in photosynthesis because the larger the leaf surface, the more sunlight it can absorb, supporting the production of plant biomass (Maisura & Jamidi, 2020). The biomass produced by photosynthesis helps increase the carbon stored in plants because the carbon absorbed during photosynthesis is stored as biomass, mostly in parts such as leaves, stems, and roots (Nuranisa, *et al.*, 2020). However, this relationship is also influenced by other factors such as plant species, environmental conditions, and resource availability, which affect how effectively plants use their leaf surface to absorb carbon.

Indeed, the chlorophyll content of leaves is one of the physiological traits that plays a role in photosynthesis and could theoretically affect biomass and plant carbon stocks. However, based on the results of Pearson's correlation test in this study, chlorophyll content did not show a significant correlation with biomass or carbon stocks. The Pearson correlation value between chlorophyll and biomass was -0.053 with a p value of 0.834, and the same value was also found between chlorophyll and carbon stocks, indicating the absence of a statistically significant relationship. This statement is consistent with the results shown in Table 5, where chlorophyll content has a low and negligible correlation with biomass and carbon stocks ($r = 0.125$, $p = 0.317$). This suggests that the chlorophyll content alone cannot represent the overall physiological characteristics of the plant in relation to carbon storage. Other factors such as plant size (trunk diameter and tree height), plant species, and environmental conditions have a more dominant influence on biomass and carbon stocks. Stem diameter, for example, has shown a very strong correlation with biomass and carbon stock ($r = 0.878$, $p = 0.000$), confirming that morphological aspects play a larger role in determining a plant's carbon storage capacity than just chlorophyll content. Thus, although chlorophyll is important in the process of photosynthesis as a key pigment that absorbs light to produce energy, the variation in the measured chlorophyll content does not directly reflect the accumulation of biomass and carbon stocks of plants. Other factors such as leaf age, species, and environmental conditions influence the ratio, so the correlation between chlorophyll and carbon stocks is not significant in the data used in this study.

CONCLUSION

Hibiscus tiliaceus and *Ziziphus mauritiana* are classified under different taxonomic groups in Kingdom Plantae. Morphologically and ecologically, *H. tiliaceus* is more suitable as carbon absorber than the *Z. mauritiana*. *H. tiliaceus* has more prominent morphological characteristics, such as a larger leaf area (19,447.722 cm^2 vs. 797.556 cm^2), larger trunk diameter (20.26 cm vs. 9.20 cm), and higher chlorophyll content (16.772 mg/L vs. 13.086 mg/L) compared to *Z. mauritiana*. The carbon stock of *H. tiliaceus* in Unesa campus forest was much higher, at 885.035 kg/tree/year, compared to *Z. mauritiana*, at 140.469 kg/tree/year. Although *Z. mauritiana* had denser wood, *H. tiliaceus* excelled because of its larger trunk diameter. The main factors affecting the carbon stock were trunk diameter and tree height, followed by leaf surface area. Meanwhile, chlorophyll content did not significantly affect the amount of carbon stored.

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CONFLICT OF INTEREST

The author states that there is no conflict of interest between the author and any entity, whether personal, institutional, or financial, in the implementation and preparation of this research. All data, analysis, and results presented in this report have been independently and objectively prepared based on field findings, without any pressure or influence from external parties that could affect the integrity of the research results.

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