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Carbon Stock Estimation of Acacia (*Acacia auriculiformis*) and Mahogany (*Swietenia mahagoni* (L.)) in the Unesa Campus Forest Area

Reyna Novita Sari[1]*, Fida Rachmadiarti[2]
Biology Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya
Kampus Unesa 1, Jln. Ketintang, Surabaya 60231, Indonesia
*e-mail: reynanovita.21016@mhs.unesa.ac.id

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Abstract
Global climate change has triggered increased carbon emissions, threatening ecosystem balance. This research supports the campus efforts in implementing the "green campus" concept and contributes to the Sustainable Development Goals (SDGs), particulary goal 13 and 15. This research aims to analyze the relationship between morphological and physiological characteristics and carbon stock in Acacia (*Acacia auriculiformis*) and Mahogany (*Swietenia mahagoni* (L.)) in the Unesa campus forest. The method used in this research is a non-destructive approach with data collection through morphological and physiological measurements and correlation analysis using SPSS. Results showed that Mahogany has superior morphological and physiological characteristics compared to Acacia with Mahogany average height reaching 17 m and chlorophyll content of 29 mg/L. Mahogany carbon is 645 (kg C.tree.$^{-1}$. *year*$^{-1}$), while Acacia is 368,43 (kg C.tree.$^{-1}$. *year*$^{-1}$). There is a strong relationship between morphological and physiological characteristics and carbon stock with very strong correlations (r=0.978 to r=0.985), indicating that chlorophyll content significantly contributes to biomass accumulation and carbon. Mahogany plays an important role in climate change mitigation and should be integrated into sustainable forest management policies

Keywords: Climate Change; Campus Forest; Carbon Stock; Mitigation; Deforestation.

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INTRODUCTION

Climate change is a global challenge characterized by rising temperatures, changing precipitation patterns, and increased frequency of extreme weather (Hausfather and Peters, 2020; Sillmann *et al.*, 2021) Data shows global temperatures have increased by about 1.1°C since the pre-industrial era (IPCC, 2023), with 2023 setting a new record as the hottest year on record (Zhao *et al.*, 2024). This phenomenon poses a major challenge to forest ecosystems and the life that depends on them (Anderegg e*t al.*, 2020; Rocha *et al.*, 2022).

The main cause of climate change is increasing concentrations of greenhouse gases, especially CO_2. Currently the world's largest contributors to CO_2 emissions are China (31%), the US (14%), the European Union (7%), India (8%) and Russia (5%) (Friedlingstein *et al*, 2023). In southeast Asia, Indonesia is the largest contributor to greenhouse gas emissions (40%), followed by Vietnam (18%) and Thailand (16%) (Sarkar *et al*., 2022) In the domestic context, DKI Jakarta is still the province with the highest level of CO_2 emissions in Indonesia (Maulidia *et al*., 2022; Putri *et al*., 2023). One effective climate change mitigation effort is sustainable forest management (Grassi *et al.*, 2021). Mitigation is an action to reduce greenhouse gas emissions and increase carbon storage (IPCC, 2022). This sector has significant potential to implement carbon mitigation measures (Firdaus and Windira, 2022). Mitigation strategies aim to reduce the severity of the impact of disasters through comprehensive risk assessment and effective resource allocation (Seddon *et al.*, 2020). These nature-based solutions not only increase carbon sequestration but also contribute to biodiversity.

Carbon stocks play an important role in maintaining ecosystem balance and mitigating climate change (Pugh *et al*., 2019). Carbon-sequestering plants assist in filtering pollutants from the air and hold back soil erosion (Bastian *et al*., 2020). Trees and plants do photosynthesis and thus can absorb CO_2 from biomass: vegetation acts as a carbon sink holding the carbon available in the atmosphere, therefore low greenhouse gas concentrations (Harris *et al.,* 2021). They help stabilize global climate. Trees are big storage places for carbon; hence they play a role in controlling global temperatures.

Acacia (*A. auriculiformis*) is a fast growth tree, and it is adaptive to almost all environmental conditions. Acacia fixes nitrogen from the air improves soil fertility and vegetation growth (Jusoh *et al.*, 2021). Because of its fast growth and huge adaptability, Acacia has great potential in increasing carbon stocks (Napitupulu *et al.,* 2022). Meanwhile, Mahogany has stable growth and lives longer, thus stores carbon for long periods. Mahogany (*S. mahogani*) has large trunk with high-quality wood and excellent adaptability, thus has potential for carbon stocks (Thant *et al*., 2020).

This study tries to look at the link between shape and body traits and the ability to hold carbon stock of acacia (*A. auriculiformis*) and mahogany (*S. mahogani*) species campus tries in putting into practice the idea of a "green campus." It helps in reaching Sustainable Development Goals (SDGs), mainly goals 13 and 15 wich are about action on climate change and the care of land ecosystems (Indana and Pahlevi, 2023). The results of this study are expected to be used as a consideration toward the management and development of green space within campus areas.

MATERIALS AND METHODS

This research was an observational study conducted in the Campus Forest area of Surabaya State University. This study was conducted in September-October 2024. There were seven stages of procedures, including initial observation, station determination, purposive sampling, identification, measurement of environmental factors, chlorophyll testing, and biomass calculation. Initial observations aimed to determine research stations that contained acacia and mahogany. Determine stations consisting of 3 station points for each species. This study used a purposive sampling technique by making a transect line along 20 m x 20 m and then measuring the height, circumference, and diameter of the tree. PlanNet application was used to identify tree species (Figure 1).

Measurement of environmental factors were performed based on physicochemical parameters for soil, such as pH, moisture, and temperature using a soil thermometer. As for air quality, such as light intensity, temperature, humidity, and CO_2 were measured.

Chlorophyll content testing on leaf samples was tested from leaf samples. Leaves were pureed and dissolved with 96% alcohol. Extract was measured using a spectrophotometer (UV-VIS V1100D) to measure the absorbance of the extract at a wavelength of 665 nm for chlorophyll a and 649 nm for chlorophyll b. Calculation of chlorophyll content was carried out using the formula developed by Arnon (1949) in Rajalakshmi and Banu (2021), which was specifically used for calculations with alcohol solvents.

$$\text{Chlorophyll a} = 25.8 \times A665 - 7.6 \times A649$$
$$\text{Chlorophyll b} = 25.8 \times A649 - 7.7 \times A665$$
$$\text{Total chlorophyll} = 20 \times A649 + 6.1 \times A665$$

Note:
Chlorophyll a = Chlorophyll responsible for the photosynthesis process
Chlorophyll b = Chlorophyll that helps the absorption of photosynthetic
light Total chlorophyll = Total amount of chlorophyll in types a and b
A649 = Absorbance 649 nm
A665 = Absorbance 665 nm

Calculation of tree biomass used allometric equations appropriate for acacia and mahogany based on Diameter at Breast Height (DBH*)* and tree height data in the following the allometric equation (Ketterings *et al.*, 2001).

$$B = 0.11 \times \rho \times DBH^{2.62} \quad (1)$$

Note:
B = Above ground biomass (kg/ton)
0.11 = Coefficient from empirical analysis
P (rho) = Wood density (g/cm³)
DBH = Diameter of the trunk
2,62 = Non-linear relationship exponent

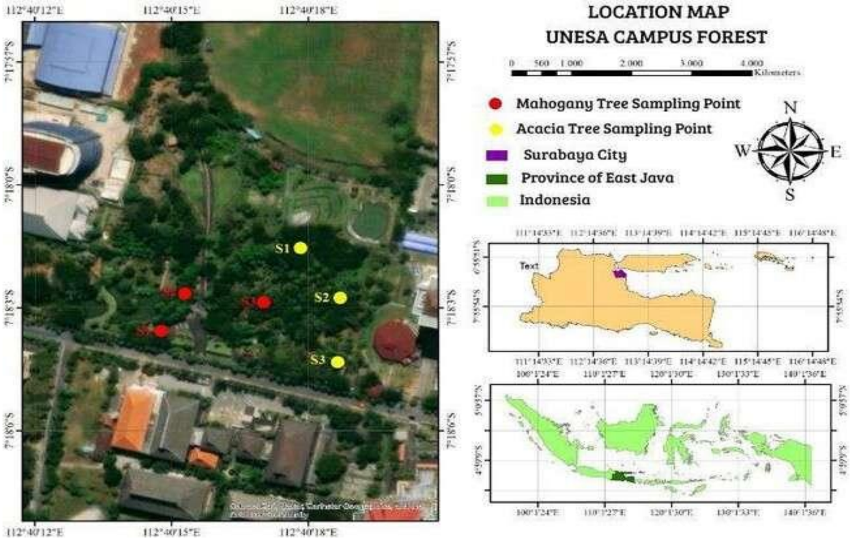

Figure 1. Sampling site

Carbon stocks were analyzed based on the allometric equation (Ketterings *et al*., 2001) as follows:

$$CS= W \times 0.46 \quad (2)$$

Note:
CS = Carbon stock
W = Biomass
0,46 = Stored carbon 46% of tree biomass

The research data obtained was analyzed using the *Pearson correlation* tes ton *Statistical Product and Service Solution* (SPSS) 26.0 for Windows to determine rhe level of linear relationship between variables.

RESULTS

Research conducted in the Unesa Campus Forest Area revealed a total of 150 individual trees, comprising two dominant species: acacia (*Acacia auriculiformis*) with 62 individuals and the rest mahogany. The results indicate that mahogany (*Swietenia mahogani* (L.)) was more abundant than acacia in this area. Acacia has a mean tree height of 12 m with mean circumference of 81 cm^2, diameter 26 cm^2, and leaf area of 686 mm^2 (Table 1). The mahogany species has a mean tree height of 17 cm^2 with mean circumference of 110 cm^2, diameter of 35 cm^2, and leaf area of 957 mm^2.

Acacia (*Acacia auriculiformis*) (Figure 2) exhibits distinctive morphological characteristics throughout its various parts. The pods are flat and curved, often spiraling into a shape, turning blackish-brown when fully ripe. The phyllodes, which are modified petioles, are also curved, resembling a sickle. The stem has a gray to grayish-brown color and features a rough, grooved texture. This tree typically grows to a height of 20 to 30 meters, boasting a lush and spreading crown.

Mahogany (*Swietenia mahogani* (L.)) (Figure 3) has distinctive morphological characteristics on its body parts. The leaves are compound (paripinnate) and arranged spirally with oval to lanceolate leaflets with pointed tips and shiny dark green upper surfaces and light green lower surfaces; hard woody stems with grayish brown skin; and a stature that can reach 30-40 meters and has an umbrella-shaped leafy crown.

The were variations in the concentrations of chlorophyll a, chlorophyll b, and total chlorophyll in acacia and mahogany (Table 2). In acacia, chlorophyll a concentration measured 10.29 (mg/L), chlorophyll b measured 7.3 (mg/L), and total chlorophyll measured 23.29 (mg/L). In contrast, Mahogany plants exhibited chlorophyll a level of 13.55 (mg/L), chlorophyll b levels of 1146 (mg/L), and total chlorophyll levels of 29.22 (mg/L). Overall, mahogany has the highest chlorophyll concentration among the two plants.

Table 1. Morphological characteristics of acacia and mahogany in Unesa Campus Forest

Description	*Accacia auriculiformis*	*Swietenia mahagoni* L.
Hight (m)	12±6.25	17±6.42
Centimeter (*cm*²)	81±58.53	110±54.91
Diameter (*cm*²)	26±18.64	35±17.13
Leaf Area (*mm*²)	686±426.03	957±468.32

Notes: The data shown is the average of the replication ± standard deviation.

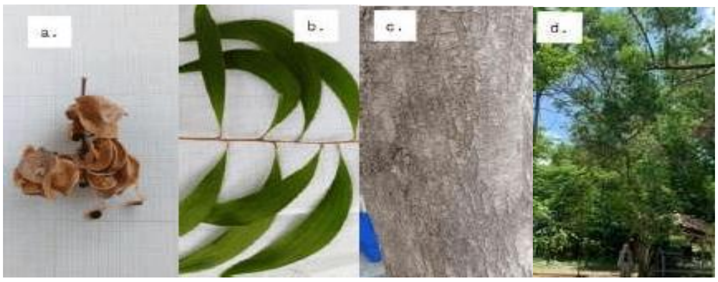

Figure 2. Morphological characteristics of Acacia. a. Pods, b. Leaf *phyllodes*, c. Stems, d. Stature

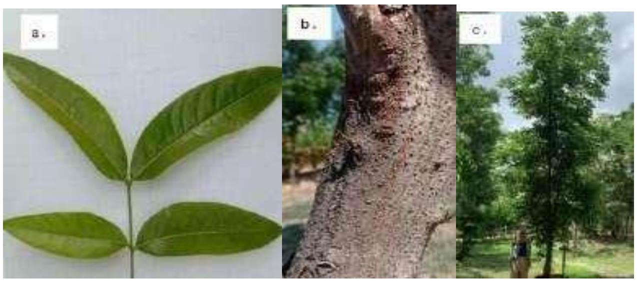

Figure 3. Morphological Characteristics of Mahogany. a. Leaf, b. Stem, c. Stature

Table 2. Physiological characteristics of acacia and mahogany in the Unesa campus forest.

Species	Chlorophyll a (mg/l)	Chlorophyll b (mg/l)	Total Chlorophyll (mg/l)
Acacia auriculiformis	10.29±1232	7.30±2.86	23.29±5.28
Swietenia mahagoni (L.)	13.55±14.44	11.46±7.23	29.22±13.96

Notes: The data shown is the average of the replication ± standard deviation.

The environmental conditions were relatively consistent, and there were no differences between the three stations (Table 3). Air physicochemical parameters on temperature only ranged from 33-34°C, with the highest mean of 34°C at station 3 and the lowest mean of 33 at stations 1 and 2. Humidity ranged from 50-56% with the highest mean of 56% at station 3 and the lowest mean of 50% at station 1. CO_2 levels ranged from 440-461 ppm with the highest mean of 461 ppm at station 3 and the lowest mean of 440 ppm at station 2. Light intensity ranged from 440-564 with the highest of 564 at station 2 and the lowest of 440 at station 3.

Soil physicochemical parameters on moisture only ranged from 20-30% with the highest average of 23% at station 3 and the lowest average of 20% at stations 1 and 2. pH only ranged from 7-8 with highest average of 8 at stations 1 and 2 and the lowest average of 7 at station 3. Temperature only ranged from 31-35°C with the highest average of 35°C at station 1 and 2, while the lowest average of 31°C at station 3. Uniform environmental parameters indicate relatively stable ecosystem.

Table 3. Environmental factors in Acacia and Mahogany in the Unesa Campus Forest.

Parameters	Station 1	Station 2	Station 3
Air			
Temperature (°C)	33±1	33±058	34±1.73
Humidity (%)	50±0.58	54±1.15	56±9.24
CO_2 (ppm)	453±11.02	440±608	461±9.24
Light Intensity (Lux)	456±98.55	564±21.3	440±49.81
Land			
Humidity (%)	20±1.53	20±4.04	23±6.43
pH	8±0	8±0.58	7±0.58
Temperature (°C)	35±3.79	35±4.36	31±1

Notes: The data shown is the average of the replication ± standard deviation.

The results of biomass and carbon stock evaluation are presented in (Table 4) shows that Acacia (*Acacia auriculiformis*) has a mean biomass of 800.93 (kg.tree.$^{-1}$. $year^{-1}$) with a carbon stock of 368.43 (kg C.tree.$^{-1}$. $year^{-1}$), which falls into the medium category. Mahogany exhibits a higher biomass of 1403 (kg.tree.$^{-1}$. $year^{-1}$) and a carbon stock of 645 (kg C.tree.$^{-1}$. $year^{-1}$), categorized as high. Among the two species, Mahogany (*Swietenia mahagoni* (L.)) has the greatest potential to store and offset carbon emissions.

Table 4. Carbon emission storage potential of Acacia and Mahogany

Species	Biomass (kg.tree.$^{-1}$. $year^{-1}$)	Carbon Stock (kg C.tree.$^{-1}$. $year^{-1}$)
Acacia auriculiformis	800.93±1516.21	368.43± 697.46
Swietenia mahagoni (L.)	1403±1778,52	645± 818.12

Notes: The data shown is the average of the replication ± standard deviation.

The correlation pattern between the morphological characteristics of both species is presented in (Figure 4). Acacia shows correlation coefficients ranging from 0.956 to 0.962, with the strongest relationship occurring between circumference and diameter at 0.962, followed by height at 0.959 and leaf area at 0.956. Mahogany exhibits higher coefficients, ranging from 0.978 to 0.985, with the strongest correlation at 0.985. The association between plant characteristics and carbon stock is further illustrated in (Figure 5). Acacia demonstrates a very strong correlation between chlorophyll content and carbon stock at 0.942, while Mahogany shows an even stronger correlation of 0.951. Although both species have perfect significance levels (<0.01), Mahogany consistently displays superior correlation strength across both figures.

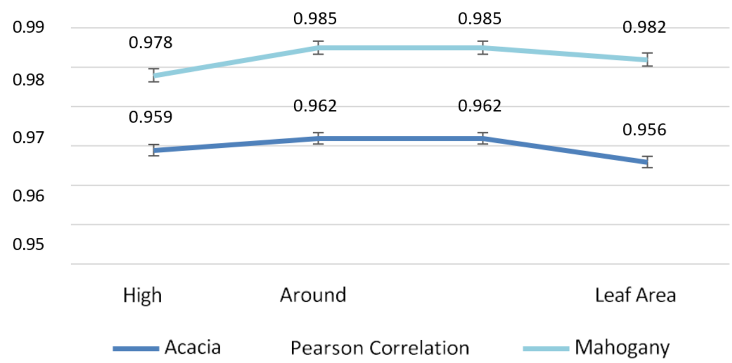

Figure 4. Correlation of morphology coefficient to carbon stock

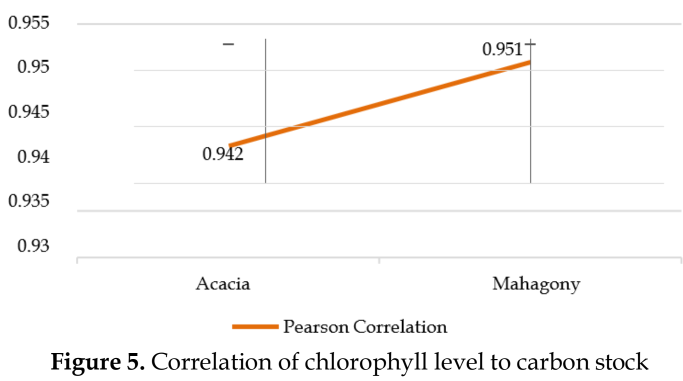

Figure 5. Correlation of chlorophyll level to carbon stock

DISCUSSION

Based on the results of the analysis that has been carried out on various characteristics with a focus on the two dominant species of Acacia (*Acacia auriculiformis*) and Mahogany (*Swietenia mahagoni* (L.)) in the Unesa Campus Forest Area, it can be seen the differences in morphology and physiology of the two species. Mahogany has a higher number of individuals which is 85 individuals, while Acacia has a total of 65 individuals. The distribution pattern of trees that tend to be random and not in groups indicates that the environment in the area is relatively uniform and able to adapt to local environmental conditions (Najih *et al.,* 2021).

Morphological characteristics between Acacia (*Acacia auriculiformis*) and Mahogany (*Swietenia mahagoni* (L.)) in the Unesa Campus Forest Area show specific adaptations of each species to environmental conditions. Of the two, Mahogany exhibited more vigorous growth, with better morphological characteristics in all measured parameters, reflecting better adaptability to local ecosystem conditions (Saputra and Sulistyawati, 2021). This difference in morphological characteristics is in line with the research of Fawzi *et al.* (2020), which states that tree morphology reflects species specific adaptations to their habitat. The pattern of distribution of these two species tends to be random, indicates relatively uniform environmental conditions and good adaptability. Mahogany with its umbrella-shaped leafy crown structure and hardwood trunk (Budiaman and Rahmat, 2022), has an advantage in biomass accumulation whereas Acacia with modified phyllode leaves and grey trunk, shows particular adaptation to tropical environment (Ismanto *et al.*, 2023).

In their physiological characteristics, it is the difference in chlorophyll that Acacia and Mahogany have different photosynthetic efficiencies. The higher chlorophyll levels in Mahogany allow for more optimal photosynthetic capacity. Photosynthetic directly equates to carbon sequestration capability (Handoko *et al.*, 2021). This is also in line with research done by Nguyen *et al.* (2020), where it was confirmed that the content of chlorophyll has a positive correlation with the rate of photosynthetic and light use efficiency. Differences in chlorophyll between those two species may be the differences in leaf size which affects the efficiency of absorption of light energy, as well as adaptation to other stresses from the environment, explained by Chen *et al.* (2022). Chlorophyll content has high levels means that this species (Mahogany) can better adapt to environmental conditions in Unesa Campus Forest Area, otherwise vegetation growth parameters here are described as optimal by Azahra *et al.* (2023).

The same potential to optimally store carbon stocks, but Mahogany has a high amount of carbon stocks while Acacia is in the medium category (Widiyanto *et al.*, 2022). The variation in the carbon stocks owed to better morphological and physiological characteristics (Prayitno *et al.*, 2021). This indicates that Mahogany can play a big role in mitigating climate change by storing carbon (Sari *et al.*, 2020). Growth in Mahogany is very good as the morphological and physiological parameters are higher (Adinugroho *et al.*, 2021). Generally, species with good growth and bigger size normally have higher carbon storage capacity (Tiryana *et al.*, 2023). Based on the environmental factors, Mahogany seems to be more adaptive to conditions at the Campus Forest Area Unesa. Physicochemical parameters support good growth and the ability of the tree to adapt (Wijaya et al., 2023). This contributes to better photosynthetic efficiency, thus increasing chlorophyll production and carbon sequestration capacity (Chen *et al.*, 2022). The combination of biomass, morphological, and physiological characteristics favors Mahogany as a more effective species for carbon emission storage (Rahman and Shaque, 2021).

Physical environmental parameters in the Unesa Campus Forest show relatively stable conditions, although some parameters are at the optimal threshold. Air temperature 33-34°C, slightly exceeds the optimal limit for tree growth 25-32°C, but this difference is not significant, so it does not have a major impact on vegetation. Air humidity 50-56% is in line with Indonesia's tropical climate standard of 50-60%, according to Pratama *et al.* (2021). CO_2 levels 440-461 ppm are categorized as good for health because they are in the range of 400-750 ppm (Hasanah *et al.*, 2020). Light intensity 440-564 lux, varied between stations, with station 2 in the high category >500 lux, and stations 1 and 3 in the medium category 200-500 lux, which is still ideal for plant growth according to Haryanto *et al.* (2023). For soil parameters, soil moisture 20-23% is classified as medium 20-40% due to measurements taken during the dry season, which reduces water supply, in line with the opinion of Pradiko *et al.* (2020) that soil moisture is influenced by rainfall and radiation intensity. Soil pH 7-8 varies, with station 3 still in the optimal category pH 7 and stations 1 and 2 less optimal pH 8 (Wijayanti *et al.*, 2022). Azahra *et al.* (2023) explained that rainfall conditions with high temperatures. Soil temperature 3-35°C is still within the optimal range 20-35°C according to Meilianto *et al.* (2022), supporting vegetation growth in the area.

Significant relationships between morphological and physiological characteristics in both species and carbon storage ability. The graph of the correlation pattern of morphology and physiology with the carbon stock of the two species shows a positive relationship between the characteristics and carbon stock. The positive correlation is shown by the upward trend line with a relatively high R^2 value and unidirectional. Sig (2-tailed) values on morphological characteristics with carbon stocks showed a level of 0,01 or >0,05. There is consistency in the distribution of the data. Mahogany was observed to have a higher correlation than Acacia. Thus mahogany shows a perfect correlation the pattern is also seen in Acacia which has a slightly lower correlation but is still in the perfect correlation category. Diameter and circumference have a strong allometric relationship with biomass because they reflect the accumulation of photosynthetic products during tree growth. This approach is in line with the study of Asante *et al.* (2022), which emphasized the importance of appropriate species selection for optimizing carbon sequestration in tropical forests. The difference in carbon storage capacity between Mahogany and Acacia can also be explained through photosynthetic efficiency, which is influenced by chlorophyll levels. As shown by Rahman *et al.* (2020), photosynthetic efficiency is positively correlated with carbon sequestration capacity. A strong relationship between morphological and physiological characteristics and carbon stocks can be seen in that larger tree size (height, diameter, and trunk circumference) indicates a greater capacity for biomass accumulation through photosynthesis. An increased leaf area enhances the total photosynthetic rate (Ahmed *et al.,* 2021). Greater biomass accumulates for a given light energy when there is a higher chlorophyll content. The presence of strong relationships may be applicable in forest stewardship and carbon stock assessment, allowing them to find appropriate trees for afforestation. Morphological parameters, especially stem diameter and circumference, can be used as a benchmark for estimating carbon stocks in trees using nondestructive methods. From a tree's physiological parameters, measuring chlorophyll levels provides an early indication of a tree's carbon sequestration potential (Hasanah *et al*., 2020).

Even though Acacia (*Acacia auriculiformis)* doesn't store as much carbon, it has special features that help it adjust to its environment. It can take nitrogen from the air and turn it into a from that plants can use, thanks to a partnership with *Rhizobium* bacteria. This helps make the soil better, as described by Napitupulu *et al.* (2022). Acacia grows fairly quickly and can live in different places, even poor-quality land. This helps it compete with other plants to take over new areas. While it doesn't store a huge amount of carbon, it grows steadily. This means it helps store carbon over a long time.

Mahogany (*Swietenia mahagoni* (L.)) showed superiority in all aspects studied, with a more dominant morphological structure and higher carbon storage capability. The characteristics of umbrella- shaped leafy crowns, hard-woody stems, and compound leaves with glossy upper surfaces provide an adaptive advantage in capturing light for photosynthesis. This results in increase in chlorophyll concentration which has a direct effect on the efficiency of photosynthetis and the accumulation of biomass. As Zhao *et al.* (2024) noted, high efficiency in photosynthesis serves as a critical factor in effective carbon sequestration. Owing to the greater carbon stock, mahogany is more suitable than other species for forest ecosystems based on climate change mitigation strategies.

The interaction between morphological and physiological features of an organism and its capacity for carbon storage suggests an intricate system. Numerous researches have already supported the fact that morphological features like stem diameter and circumference give accurate estimates for carbon stock estimation. This research also shows that the very high correlation between physiological features and carbon stocks of both species suggests that the two are integrated together with the carbon storage capacity (Zhao *et al*., 2024). An equilibrated integration of tree architecture with its biological functions and its ecological role in carbon sequestration (Malhi *et al.,* 2021). A planting strategy that accounts for adequate species composition focuesd on prioritizing. Mahogany for carbon sequestration maximization and integrating Acacia to improve soil quality can result in a sustainable campus forest ecosystem and contribute significantly to local and global climate change mitigation efforts as outlined in Sustainable Development Goals (SDGs) goals 13 and 15 (Indana and Pahlevi, 2023).

CONCLUSION

Based on the results of research and data analysis, it can be concluded that Mahogany (*Swietenia mahagoni* (L.)) shows morphological and physiological characteristics that are superior to *Acacia* (*Acacia auriculiformis*) in the Campus Forest Area, Unesa. Mahogany has an average tree height of 17 m and a higher chlorophyll concentration of 29 mg/L, supported by optimal environmental conditions with a temperature of 33-34°C, air humidity of 50-60%, and light intensity of 440-140% lux. The carbon stock storage potential of Mahogany was also higher, reaching 645 (kg.tree.$^{-1}$. year^{-1}) (high category), compared to Acacia which only reached 368.43 (kg.tree.$^{-1}$. year^{-1}) (medium category). There was a very strong relationship between the morphological and physiological characteristics of trees and carbon stocks in both plant species, as evidenced by the very strong morphological correlation values (r=0.978- 0.985). Chlorophyll concentration was shown to contribute significantly to biomass accumulation and carbon storage. The results of this study confirm the important role of species selection in efforts to optimize carbon sequestration in campus areas as part of climate change mitigation.

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CONFLICT OF INTEREST

There is no conflict of interest.

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