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ASSESSMENT OF BIOMASS, CARBON STOCK, AND CO_2 SEQUESTRATION IN THE ARBORETUM OF INSTITUT TEKNOLOGI SUMATERA

Kajian Biomassa, Stok Karbon, dan Serapan CO_2 di Arboretum Institut Teknologi Sumatera

Fakhri Muhammad Fikri[1], Nurika Arum Sari[1], Agung Yoga Pangestu[1], Diyanti Isnani Siregar[1], Oktarina Maulidia[1]

[1]*Department of Forestry Engineering, Institut Teknologi Sumatera*

Jl. Terusan Ryacudu, Jati Agung, Lampung Selatan, Lampung, Indonesia 35365

e-mail: nurika.sari@rh.itera.ac.id

ABSTRACT

Global warming driven by rising greenhouse gas emissions has heightened the need to utilize green spaces as carbon sinks, one of which is the arboretum. This study aimed to determine the potential biomass, carbon stock, and CO_2 uptake of the vegetation in the Arboretum of Institut Teknologi Sumatera (Itera). A combination of destructive and non-destructive methods was applied across 12 plots representing three levels of vegetation density: high, medium, and low. The analysis covered biomass, carbon stock, and estimated CO_2 uptake. The results showed an average biomass of 50.51 tons/ha, a carbon stock of 23.74 tons/ha, and CO_2 uptake of 85.82 tons/ha. The highest values were found in the high-density vegetation area, which had a denser tree population. This study provides baseline carbon stock data for a developing campus arboretum in Sumatra, and concludes that, although the carbon stock of the Itera Arboretum remains lower than that of other arboreta, it nonetheless holds potential as a carbon sink that contributes to climate change mitigation. Practically, these results imply that arboretum management must prioritize intensive enrichment planting in low-density zones and establish permanent monitoring plots to optimize long-term carbon sequestration.

Keywords: Arboretum; Biomass; Carbon Stock; Estimation; CO_2 Sequestration

INTRODUCTION

Global warming is one of the most critical environmental issues, triggered by rising concentrations of greenhouse gases—particularly carbon dioxide (CO_2) in the atmosphere. The accumulation of these gases traps heat from solar radiation, thereby driving a significant increase in the average temperature of the air, oceans, and land (Pratama, 2019; Andarini & Sudarti, 2023; Anggraeni et al., 2023). At the same time, deforestation and forest degradation continue to diminish nature's capacity to absorb carbon emissions. In fact, forest ecosystems play a vital role as carbon sinks through sequestration, namely the uptake and storage of carbon in plant biomass (Endriani & Sunarti, 2019).

As an effort to mitigate climate change, enhancing carbon uptake capacity through green open spaces such as arboreta represents an effective solution (Prajapati et al., 2023). An arboretum not only functions as an ex-situ conservation area for preserving biodiversity outside its natural habitat, but also serves as a natural carbon sink because it is planted with a variety of species resembling their original habitats (Napolion et al., 2015). In addition, such an area holds a strategic function as a venue for education and scientific research. Compared to other types of green open space, such as parks, green belts, or ornamental gardens that are typically dominated by a limited number of landscape species, arboreta are deliberately managed and planted to maintain high tree species richness and structural diversity. Such conditions have been shown to enhance aboveground carbon storage through complementary canopy

architecture and functional diversity among species (Mensah et al., 2016). In addition, because arboreta also serve as ex-situ conservation sites for a wide range of tree species, including those of conservation concern, they combine biodiversity protection with climate change mitigation within a single area, a combination rarely found in other types of urban green open space (Arnet et al., 2015). These distinctive characteristics underline the relevance of campus arboreta, rather than green open spaces in general, as a strategic focus for carbon stock and CO_2 sequestration assessment.

One conservation area with substantial potential is the Arboretum of Itera. Situated as part of the Itera Botanical Garden and covering approximately 2.34 hectares, the area is home to more than 1,000 trees comprising 45 species, such as kecapi, matoa, eucalyptus, cinnamon, and damar (Nabilla et al., 2021; Rudi, 2022). As a campus green open space, the Itera Arboretum plays a crucial role in maintaining microecosystem balance and supporting emission reduction. Nevertheless, quantitative data on the capacity of this area to store and absorb carbon emissions still require in-depth investigation.

Information regarding carbon stock and CO_2 sequestration capacity of campus arboreta in Indonesia remains limited. Previous studies on campus carbon stocks in Indonesia have predominantly focused on mature green open spaces or older campus forests with stable, high-density vegetation, such as those at Universitas Indonesia or Universitas Gadjah Mada. Previous studies on carbon stock and sequestration in campus green open spaces have generally addressed general vegetation cover rather than arboreta with their distinctive species composition and planting density. Consequently, there is a profound lack of empirical data regarding how expanding, newly established, and developing campus arboreta accumulate carbon across different spatial variations of initial planting densities. This gap underscores a critical limitation in current ecological modeling: the baseline carbon dynamics of young, transition-state urban conservation forests remain poorly understood compared to well-established old-growth campus forests. This gap underscores the need for a site-specific quantitative assessment of carbon stock and sequestration capacity in campus arboreta such as the Itera Arboretum.

Studying the Itera Arboretum provides a highly compelling and distinct scientific justification compared to other older arboreta in Indonesia. First, the Itera Arboretum represents a unique, fast-evolving conservation landscape in the southern gateway of Sumatra, a region heavily impacted by rapid land-use conversion. Second, unlike older established arboreta that possess uniform and mature canopy structures, the Itera Arboretum exhibits highly heterogeneous spatial structures due to its phased development. This provides a rare, real-time ecological laboratory to evaluate carbon storage variations across distinct localized density zones within a developing urban ecosystem.

Therefore, this study aimed to estimate the biomass potential, calculate the magnitude of carbon stock, and analyze the contribution of the Itera Arboretum to absorbing CO_2 emissions. This study was based on the premise that vegetation structure strongly influences carbon storage capacity as stand density and basal area have been shown to be positively correlated with biomass and carbon stock in tropical forest ecosystems (Wassihun et al., 2019). Based on these ecological mechanisms, this study hypothesized that: (1) there is a significant variation in biomass, carbon stock, and CO_2 uptake across high, medium, and low vegetation density zones within the developing arboretum; and (2) the high-density vegetation area, characterized by a denser tree population and overlapping canopy layers, will exhibit a exponentially higher capacity to store biomass and capture CO_2 than the medium and low-density zones.

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Data collection in this study was limited to two principal approaches, namely the non-destructive method for tree stands through measurement of diameter at breast height, and the destructive method for understory plants and litter in order to obtain the dry weight of biomass. The findings of this study are expected to enrich the scientific literature in the field of climate change mitigation while serving as a practical basis for managers in formulating sustainable conservation strategies for campus green open spaces.

RESEARCH METHODS

Time and Location of the Study

This study was conducted from May to July 2025 at the Arboretum of Institut Teknologi Sumatera (Itera). Primary data collection was carried out directly in the arboretum area, while the processing of destructive samples—comprising oven-drying and dry-mass weighing—was performed at the Forestry Engineering Laboratory of Itera.

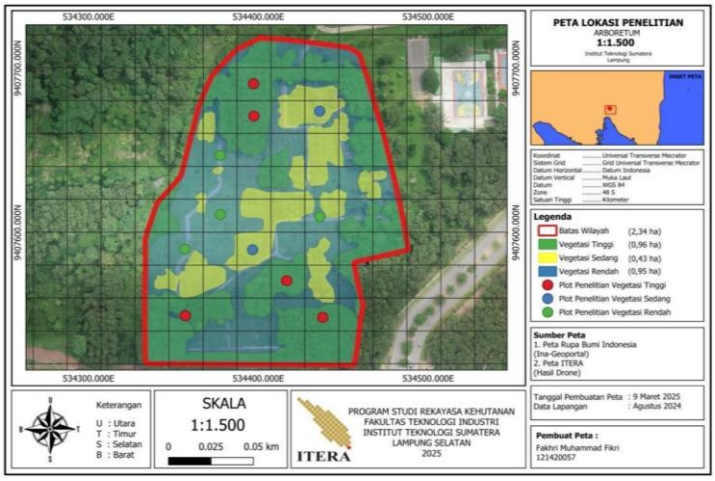


Figure 1. Distribution of research plot points

Research Tools and Materials

The research tools employed included instruments for measuring tree and environmental dimensions (haga meter, 100 m and 1.5 m measuring tapes, thermo-hygrometer), navigation equipment (GPS), laboratory analysis equipment (digital scales, oven), and supporting equipment (camera, machete, and stationery). The materials used comprised marker stakes, raffia string, tally sheets, plastic bags, brown envelopes, and label paper for documentation purposes as well as for handling biomass samples (litter and understory plants).

Research Stages

This study began with a literature review to determine the most relevant formulas and data-collection methods. Once the methodological framework had been established, instruments and supporting materials were prepared for field observation at the Itera Arboretum. Data collection focused on measuring biomass parameters comprising tree stands, understory plants, and litter. All data obtained were then processed using Microsoft Excel, in which tree biomass was estimated through allometric equations, whereas the biomass of understory plants and litter was determined from the dry weight after oven-drying. In the final stage, the accumulated biomass data were converted to estimate the total carbon stock as well as the CO_2 uptake capacity, in accordance with the Indonesian National Standard (SNI) 7724:2019.

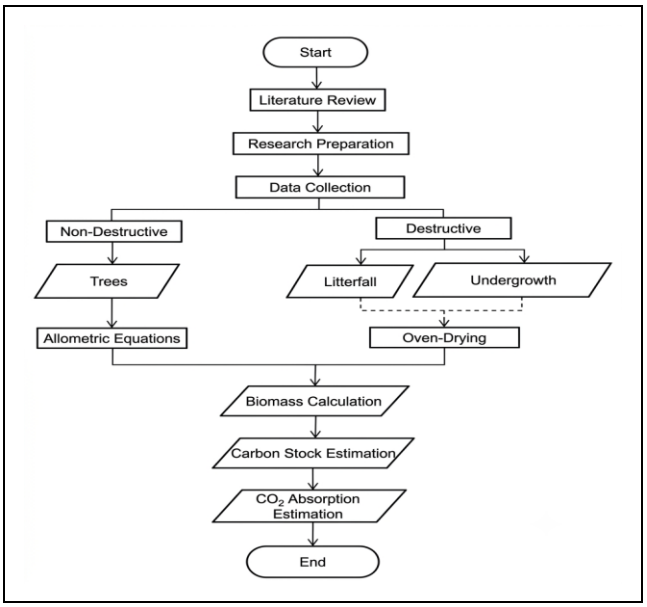


Figure 2. Research stages

Data Collection Method

The determination of research plots employed the purposive sampling method, namely a sampling technique conducted deliberately based on certain considerations, in which the selected samples are deemed most suitable for representing the population or answering the research question. The shape and size of the sampling plots were established as follows (BSN, 2019):

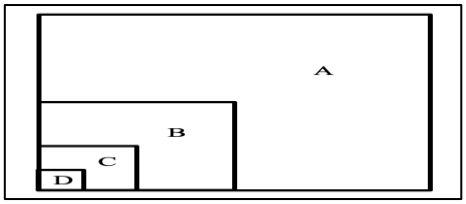


Figure 3. Research plots

a. Plot of 20 m × 20 m: tree data collection
b. Plot of 10 m × 10 m: pole data collection
c. Plot of 5 m × 5 m: sapling data collection
d. Plot of 2 m × 2 m: understory plant and litter data collection

The number of sample plots was determined by considering the area of the Itera Arboretum, which covers 2.34 ha. If the research subjects number fewer than 100 individuals, it is advisable to take all of them, making the study a population study; however, if the number of subjects is large, approximately 10 to 15% or more may be sampled (Bakti et al., 2018). Considering the total area of the Itera Arboretum (2,34 ha), the sampling intensity used was 20%. Based on the basic formula for sampling intensity from the forest inventory textbook of the Ministry of Education and Culture (2013), the number of plots was calculated as follows:

Number of plots created: n = (A x f)/a

= (2.34 x 20%) / 0.04 = 12 plots

Notes: n = Number of research plots; A = Research area (ha); f = Sampling intensity (%); a = Area of research plot (ha)

The vegetation density classification was determined using a stratified approach based on direct field observation, drone-based aerial photographs, and quantitative stand-density calculation. Each density class was not determined solely by visual interpretation, but was supported by the

number of woody individuals recorded in the sample plots and converted into individual density per hectare. The high-density vegetation class was characterized by a high number of woody individuals, denser canopy cover, and the dominance of tree-stage vegetation. In this class, 68 individuals were recorded from five 20 m × 20 m plots, corresponding to a density of 340 individuals/ha, with a mean DBH of 22.91 cm. The medium-density vegetation class was characterized by a more open canopy and the dominance of poles and saplings, with 9 individuals recorded from two 20 m × 20 m plots, corresponding to 112.5 individuals/ha and a mean DBH of 7.30 cm.

Meanwhile, the low-density vegetation class was characterized by sparse woody vegetation, wider open areas, and the dominance of understory plants, with 13 individuals recorded from five 20 m × 20 m plots, corresponding to 65 individuals/ha and a mean DBH of 7.39 cm. Therefore, the three vegetation density classes were quantitatively distinguished as follows: high-density vegetation ≥300 individuals/ha, medium-density vegetation 100–299 individuals/ha, and low-density vegetation <100 individuals/ha. Based on the classification results, the area of each vegetation stratum was 0.96 ha for high-density vegetation, 0.43 ha for medium-density vegetation, and 0.95 ha for low-density vegetation. The plot allocation was then determined proportionally, resulting in five plots in the high-density vegetation stratum, two plots in the medium-density vegetation stratum, and five plots in the low-density vegetation stratum.

Microclimate Conditions and Rainfall

Temperature and relative humidity were measured three times a day (morning at 07:00 WIB, midday at 12:00 WIB, and afternoon at 17:00 WIB) using a thermo-hygrometer placed across the three variations of vegetation density in the research plots (high, medium, and low), since this instrument fundamentally functions to measure temperature and humidity (Rohman et al., 2021). Meanwhile, rainfall data were obtained through a research-facility collaboration with the Itera Meteorology, Climatology, and Geophysics Station (Itera - BMKG), which were subsequently processed using Microsoft Office Excel to be presented in tabular form.

Sampling of Tree, Understory Plant, and Litter Biomass

The estimation of biomass and carbon stock can be carried out through destructive and non-destructive methods. The destructive method (destructive sampling) is difficult to apply on a large scale because it is resource-intensive and may damage forest stands; therefore, estimation is generally conducted indirectly using a statistical allometric-model approach based on tree diameter and height parameters (Zaenal et al., 2020). Conversely, the non-destructive method is conducted without damaging the trees, through measurement of the diameter at breast height (Diameter at Breast Height/DBH) at a height of 1.3 meters as well as tree height, which are then calculated using allometric equations (Saputra et al., 2018). Accordingly, this study applied the non-destructive method for the sake of efficiency and vegetation conservation, with a tree plot size of 20 m × 20 m in accordance with the SNI 7724:2019 standard.

For the understory plant and litter components, samples were taken using plots measuring 2 m × 2 m based on the SNI 7724:2019 standard. The measurement applied the destructive method (destructive sampling) by cutting all understory plants above the ground surface and collecting all litter within the plot to weigh their wet weight. Dry-weight measurement was carried out by taking a subsample of approximately ±300 g, which was then dried in a laboratory electric oven at 80°C for 48 hours until a constant weight was reached (Ariani et al., 2014).

Data Analysis

The biomass of trees, poles, and saplings can be estimated using allometric

equations. Allometric equations differ for each species; the selection of an allometric equation is determined by the tree species, ecosystem type, and the distribution range of that species. Sixteen tree species were found in the research plots within the Itera Arboretum. The following are the allometric equations used to calculate biomass in this study.

Table 1. Allometric equations used in the study

No	Species Name	Allometric Equation	Source
1	Acacia	$BBA = 0{,}070 \times D^{2{,}58}$	(Krisnawati et al., 2012)
2	Cempaka	$BBA = 0{,}064 \times D^{2{,}71}$	(Appi' et al., 2019)
3	Damar (Agathis)	$BBA = 0{,}4725 \times D^{2{,}0112}$	(Uthbah et al., 2017)
4	Gmelina	$BBA = 0{,}06 \times (D^2 \times H)^{0{,}88}$	(Krisnawati et al., 2012)
5	Guava	$BBA = 0{,}11 \times \rho \times D^{2{,}62}$	(Dewi et al., 2019)
6	Mahogany	$BBA = 0{,}903 \times (D^2 \times H)^{0{,}684}$	(Krisnawati et al., 2012)
7	Sengon	$BBA = 0{,}020 \times (D^2 \times H)^{0{,}93}$	(Ristiara et al., 2017)
8	Other trees	$BBA = 0{,}0673 \times (\rho \times D^2 \times H)^{0{,}976}$	(Chave et al., 2014)

Notes: BBA = Stand biomass (kg); D = Diameter at breast height (cm); H = Total plant height (cm); ρ = Wood density (g/cm^3)

Calculation of Understory Plant and Litter Biomass

Based on SNI 7724:2019, the estimation of understory plant and litter biomass can be obtained by calculating the total dry weight as follows:

$$Botb = (Bks \times Bbt) / Bbs$$

Notes: Botb = Organic Matter Weight (kg); Bks = Dry Weight of Sample (kg); Bbt = Total Wet Weight (kg); Bbs = Wet Weight of Sample (kg)

Calculation of Carbon Stock of Trees, Poles, and Saplings

Based on SNI 7724:2019, the calculation of carbon from vegetation biomass uses the following formula:

$$Cv = Bov \times \%\ C\ organic$$

Notes: Cv = Carbon content of vegetation biomass (kg); Bov = Total vegetation biomass (kg); % C organic = Percentage value of carbon content, equal to 0.47 or using the carbon percentage value obtained from laboratory analysis.

Calculation of Carbon Stock of Understory Plants and Litter

Based on SNI 7724:2019, the calculation of carbon from understory plants and litter can be computed using the following formula.

$$Ctb = Botb \times \%\ C\ organic$$

Notes: Ctb = Carbon content of understory-plant organic matter (kg); Botb = Total understory-plant biomass/organic matter (kg); % C organic = Percentage value of carbon content, equal to 0.47 or using the carbon percentage value obtained from laboratory analysis.

Calculation of CO_2 Uptake

The estimated CO_2 uptake value can be obtained by multiplying the carbon content by the conversion factor from the element C to CO_2. The CO_2 uptake value can be determined based on the following equation (Panjaitan et al., 2024).

$$WCO_2 = Cn \times 3.67$$

Notes: Cn = Carbon content; WCO_2 = CO_2 uptake capacity; 3.67=Equivalent or conversion factor from the element C to CO_2 (atomic mass C = 12, O = 16, CO_2 = (1×12) + (2×16) = 44; the conversion is (44:12) = 3.67).

RESULTS AND DISCUSSION

Biomass Potential, Carbon Stock, and CO_2 Uptake of Trees

Biomass, carbon stock, and CO_2 uptake of trees were calculated using allometric equations based on diameter (DBH) and tree height values. The results are presented in Table 2.

Table 2. Biomass, carbon stock, and CO_2 uptake of trees

Vegetation Density	Area (ha)	Mean DBH (cm)	Number of Trees	Biomass (tons/ha)	Carbon Stock (tons/ha)	CO_2 Uptake (tons/ha)
High Density	0.96	22.91	68	98.72	46.40	170.29
Medium Density	0.43	7.30	9	13.53	6.36	23.34
Low Density	0.95	7.39	13	8.78	4.13	15.15
Average				**46.55**	**21.88**	**80.30**

Based on Table 2. the average tree biomass across the three vegetation density levels was 46.55 tons/ha, carbon stock was 21.88 tons/ha, and CO_2 uptake was 80.30 tons/ha. The highest values were recorded in the high-density vegetation plot, with biomass of 98.72 tons/ha, carbon stock of 46.40 tons/ha, and CO_2 uptake of 170.29 tons/ha. These high values were influenced by the greater number of trees compared to the medium and low density plots, as well as the dominance of Acacia mangium (22 individuals), which grows optimally under the climatic conditions of the ITERA Arboretum (mean temperature 28.1°C, relative humidity 80.1%, annual rainfall 2,294.4 mm/year). The denser the vegetation in an area, the greater the biomass accumulation due to an increasing number of individuals and total recorded diameter and tree height (Witno et al., 2018).

The lowest values were found in the low-density vegetation plot, with biomass of 8.78 tons/ha, carbon stock of 4.13 tons/ha, and CO_2 uptake of 15.15 tons/ha, dominated by soursop (Annona muricata) with 4 individuals. Differences in values across density levels are generally influenced by the number and species of trees, DBH values, and local ecological conditions (Siswanto et al., 2024). DBH directly affects the amount of biomass produced, as a larger DBH corresponds to greater tree biomass.

Potential Biomass, Carbon Stock, and CO_2 Uptake of the Itera Arboretum

The measurement results showed that the values of biomass, carbon stock, and CO_2 uptake in the Arboretum of Itera differed significantly across vegetation density levels. These differences were primarily determined by the number of individual trees, the diameter at breast height, stand height, and the dominance of constituent species in each density class. In areas with high vegetation, the stand structure was denser and the number of trees greater, so that biomass accumulation reached its highest value. Conversely, in low vegetation, tree stands were still sparse and there were many open spaces dominated by understory plants, so that the biomass and carbon stock values were smaller.

Table 3. Potential biomass, carbon stock, and CO_2 uptake in the Itera Arboretum

Density Level	Area (ha)	Biomass (tons/ha)	Carbon Stock (tons/ha)	CO_2 Uptake (tons/ha)
High Vegetation	0,96	103,18	48,50	175,61
Medium Vegetation	0,43	17,98	8,45	29,41
Low Vegetation	0,95	11,99	5,64	20,62
Arboretum Average	-	**50,51**	**23,74**	**85,82**

Based on Table 3. high vegetation had a biomass of 103.18 tons/ha, a carbon stock of 48.50 tons/ha, and CO_2 uptake of 175.61 tons/ha. These values were far higher than those of the medium and low vegetation. Medium vegetation had only 17.98 tons/ha of biomass, 8.45 tons/ha of carbon stock, and 29.41 tons/ha of CO_2 uptake, whereas low vegetation had 11.99 tons/ha of biomass, 5.64 tons/ha of carbon stock, and 20.62 tons/ha of CO_2 uptake. The overall average for the Itera Arboretum was 50.51 tons/ha of biomass, 23.74 tons/ha of carbon stock, and 85.82 tons/ha of CO_2 uptake. When multiplied by

the area of each density level, the total absolute accumulation in the Itera Arboretum reached 118.18 tons of biomass, 55.55 tons of carbon, and 200.82 tons of CO_2.

This pattern indicates that biomass and carbon in the Itera Arboretum are still strongly governed by stand structure. Tree biomass increases as tree diameter and height grow, because the stem, branches, and crown undergo an increase in wood volume. Consequently, plots with high density produced the largest carbon stock. This finding is consistent with Chave et al., (2014), who identified stem diameter, tree height, and wood specific gravity as the principal variables in estimating tropical tree biomass. In the context of the Itera Arboretum, the average diameter in the high vegetation was greater than in the medium and low vegetation, so that its carbon contribution was also greater.

Influence of Species Composition and Stand Density on Carbon Stock

The tree composition in the Itera Arboretum was dominated by acacia (*Acacia mangium*), with 22 individuals out of a total of 90 trees. The dominance of acacia influences biomass formation because this species is known as a fast-growing species capable of adapting to various site conditions. In young stands, fast-growing species can accelerate initial biomass formation, particularly on open land or in areas undergoing vegetation enrichment. However, the magnitude of acacia's contribution to carbon is determined not only by the number of individuals, but also by diameter size, tree height, and stand age. Thus, the dominance of acacia serves as an important indicator that the Itera Arboretum has the potential for increased carbon in the future, although its current carbon accumulation is not yet as high as that of arboreta dominated by large-diameter, old-aged trees.

This condition explains why high vegetation became the class with the most dominant biomass value. In that class, the number of trees was greater and the canopy cover denser. Tree density causes the vertical growing space to be more filled with woody biomass, whereas the medium and low vegetation classes still exhibited stand structures that had not developed optimally. The findings of Banjarnahor et al., (2018) at the Arboretum of the University of Lampung likewise showed that carbon storage is strongly influenced by tree dominance, with carbon in the tree component reaching 223.03 tons/ha, or 98.36% of the total carbon stored above ground. This comparison underscores that the tree component is the principal contributor of carbon in arboretum ecosystems, whereas understory plants and litter make a smaller contribution.

The Role of Microclimate and Rainfall in Biomass Productivity

The environmental conditions in the Itera Arboretum support the process of vegetation growth. The average temperature in high vegetation was 27.6°C with a relative humidity of 84.0%, in medium vegetation 28.1°C with a relative humidity of 78.8%, and in low vegetation 28.7°C with a relative humidity of 77.5%. This pattern shows that the denser the tree canopy, the lower the temperature beneath the stand and the higher the humidity. The tree canopy functions to block direct solar radiation, reduce heating of the soil surface, and maintain air humidity beneath the stand. Such microclimatic conditions are important for growth because plant photosynthesis, respiration, and transpiration are strongly influenced by the balance of temperature, light, and water availability.

High vegetation not only had a greater number of trees but also formed a more stable sub-canopy environment. Higher humidity can reduce the pressure of water loss through excessive transpiration, while a temperature that is not too high helps maintain the physiological activity of plants. This explains why the high vegetation class had greater biomass and CO_2 uptake. Even so, a high canopy density can limit light intensity on the forest floor, so that understory plant growth becomes lower than in medium vegetation. In this study, the highest understory plant

biomass was in fact found in the medium vegetation, namely 3.52 tons/ha, because the moderate canopy opening still provided sufficient light without causing conditions that were too hot and dry.

In terms of rainfall, the total rainfall in the Itera region from July 2024 to June 2025 reached 2,294.4 mm/year, with an average of 191.2 mm/month. This value falls within the moderate rainfall category according to the BMKG classification and lies within a range that supports tropical vegetation growth. Taylor et al., (2017), explained that temperature and rainfall interact in controlling the carbon cycle in tropical forests. Adequate rainfall maintains soil-water availability, so that photosynthesis and biomass formation can proceed more stably. Therefore, the rainfall conditions of the Itera Arboretum constitute a supporting ecological factor for increasing carbon stock, particularly if vegetation management is directed toward increasing density and maintaining the stands.

The Role of Understory Plants and Litter in the Arboretum Carbon Cycle

In addition to trees, understory plants and litter also contribute to carbon stock, although in smaller proportions. The average biomass of understory plants in the Itera Arboretum reached 3.20 tons/ha, with a carbon stock of 1.50 tons/ha and CO_2 uptake of 5.52 tons/ha. Understory plants still possess living tissue and chlorophyll, enabling them to carry out photosynthesis and absorb CO_2. This role is important in the medium and low vegetation areas because the presence of understory plants helps cover the soil surface, maintain humidity, and add organic-matter input.

Unlike understory plants, litter functions only as a temporary carbon store. The average litter biomass in the Itera Arboretum was 0.75 tons/ha, with a carbon stock of 0.35 tons/ha. Litter is not counted as a CO_2 uptake component because it is dead organic matter that no longer performs active photosynthesis. The carbon within litter is stored temporarily before undergoing decomposition. During decomposition, some carbon may return to the atmosphere in the form of CO_2, while another portion enters the soil as organic matter. Therefore, in this discussion litter is positioned as part of the carbon cycle and as a temporary carbon store, rather than as an active CO_2 sink.

These results can be compared with the study by Nofrianto et al., (2018), at the Arboretum of Universitas Lancang Kuning. That study showed that litter carbon reached 7.12 tons/ha, whereas understory plant carbon was only 0.28 tons/ha. The litter value at the Arboretum of Universitas Lancang Kuning was far higher than that of the Itera Arboretum, which was only 0.35 tons/ha. This difference indicates that litter production in an arboretum is strongly influenced by canopy density, stand age, number of trees, and the accumulation of organic matter on the forest floor. Arboreta with older stands and denser canopies produce more falling leaves and twigs, so that litter carbon increases. Conversely, the Itera Arboretum, which is still dominated by young stands and partly composed of low-vegetation areas, has a relatively small litter accumulation.

Comparison of the Itera Arboretum Carbon Stock with Other Locations

The carbon stock value of the Itera Arboretum, at 23.74 tons/ha, remains lower than that reported by several studies on other arboreta and green open spaces. This comparison is important for placing the research findings within a broader ecological context. The Arboretum of the University of Lampung was reported to have an above-ground carbon storage of 226.75 tons/ha, whereas the Bamboo Arboretum of IPB Darmaga Campus had a total carbon storage of 87.93 tons/ha and CO_2 uptake of 324.65 tons/ha. Maluku Park in Bandung City had a total carbon stock of approximately 183.052 tons and carbon uptake of 731.422 tons. These differences in value indicate that the uptake and storage capacity of carbon in green spaces depend strongly on site area, vegetation structure, species composition,

stand age, and the diameter of the constituent trees.

Table 4. Comparison of the Itera Arboretum carbon stock with several other study locations

Study location	Area type	Main carbon/CO_2 value	Source
Itera Arboretum	Campus arboretum	Carbon 23.74 tons/ha; CO_2 uptake 85.82 tons/ha	Study data
Arboretum of the University of Lampung	Arboretum kampus	Above-ground carbon 226.75 tons/ha	Banjarnahor et al., (2018)
Bamboo Arboretum of IPB Darmaga Campus	Arboretum kampus	Carbon 87.93 tons/ha; CO_2 uptake 324.65 tons/ha	Bagaskara et al. (2024)
Arboretum of Universitas Lancang Kuning	Arboretum kampus	Litter carbon 7.12 tons/ha; understory plant carbon 0.28 tons/ha	Nofrianto et al., (2018)
Maluku Park, Bandung City	Urban green open space	Total carbon stock 183.052 tons; carbon uptake 731.422 tons	Darlina et al., (2023)

The comparison in Table 4. shows that the position of the Itera Arboretum is still at a relatively early phase of carbon accumulation. The Arboretum of the University of Lampung had a far higher carbon value because the area possesses high tree density and species richness. Banjarnahor et al., (2018), reported that the carbon storage of the Arboretum of the University of Lampung increased from 141.97 tons/ha in 2010 to 226.75 tons/ha in 2016. This increase was attributed to a rise in the number of trees through planting and natural regeneration. This condition serves as an important benchmark for the Itera Arboretum, as it demonstrates that an increase in the number of trees and the development of stand structure over time can raise carbon stock significantly.

The comparison with the Bamboo Arboretum of IPB Darmaga Campus also provides a relevant illustration. Bagaskara et al. (2024) reported a total carbon storage of 87.93 tons/ha and CO_2 uptake of 324.65 tons/ha. These values were higher than those of the Itera Arboretum. One reason is the stand structure of the IPB Bamboo Arboretum, which encompasses several vegetation zones with larger-diameter trees, as well as contributions from above-ground biomass, below-ground biomass, and necromass. In this study, the Itera Arboretum accounted only for the above-ground carbon components comprising trees, understory plants, and litter, so that the total carbon value does not yet reflect all of the ecosystem's carbon pools.

The low carbon value of the Itera Arboretum can also be explained by stand-age conditions. Most of the vegetation in the Itera Arboretum is still young and has a relatively small stem diameter. In young stands, the growth rate can proceed rapidly, but the volume of woody biomass stored is not yet as large as in mature stands. Arboreta with old, large-diameter trees have a much greater accumulation of stem and branch biomass. This is consistent with the allometric principle that an increase in diameter raises biomass non-linearly. In other words, a small increase in diameter in larger trees can yield a greater addition of biomass and carbon than in small trees.

Although the carbon stock value of the Itera Arboretum is lower than that of the comparison locations, the area nonetheless holds a strategic function as a local campus carbon sink. The value of 23.74 tons/ha indicates that the existing vegetation has contributed to storing carbon and absorbing CO_2. Furthermore, the total CO_2 uptake of 200.82 tons across the area shows that the

arboretum makes a tangible ecological contribution to climate change mitigation at the campus scale. This potential can be enhanced through species enrichment, maintenance of young trees, planting in low-vegetation areas, and the arrangement of species compositions that exhibit good growth and high biomass values.

Accordingly, the findings of this study not only show the magnitude of the current biomass and carbon stock, but also provide a management basis for improving the quality of the Itera Arboretum. The low vegetation class, with an area of 0.95 ha, should become a priority for enrichment because its area is almost the same as that of the high vegetation, yet its carbon value is far smaller. If the low-vegetation area is managed through the planting of woody trees, an increase in canopy cover, and intensive maintenance, the difference in carbon stock among density classes can be reduced. In the long term, an increase in stand age and tree diameter will enlarge carbon storage, so that the Itera Arboretum can function more optimally as a living laboratory, a conservation space, and a carbon sink within the campus environment.

CONCLUSION

Itera Arboretum serves as a vital transition-state carbon sink, with its biomass allocation, carbon stock, and CO_2 sequestration capacity heavily dictated by localized planting density and canopy architecture. The primary finding reveals that high-density zones dominated by fast-growing, adaptive species like Acacia mangium optimize carbon capture efficiency under local microclimatic conditions. Although its current carbon storage remains lower than older, well-established campus arboreta due to the predominantly young age and small stem diameters of its stands, the area exhibits high ecological elasticity and significant growth potential.

Mechanistically, the practical implication for management shifts from basic conservation to targeted spatial optimization. To elevate the arboretum's carbon sink capacity, future development must prioritize aggressive enrichment planting using dense-canopy, fast-growing local species specifically within the identified low- and medium-density zones. Furthermore, establishing these research plots as permanent monitoring stations will allow campus managers to track real-time carbon dynamics, integrating empirical ecological data directly into the university's green campus policy and climate mitigation strategies.

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