

# Field-Based Estimation of Biomass Carbon and Carbon Dioxide CO<sub>2</sub> Offset from Tree-Integrated Agriculture in Indonesia

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**Abstract:** Agroforestry systems are increasingly recognized as climate-smart land-use strategies that integrate ecological sustainability with socio-economic benefits. This study evaluates the carbon stock and CO<sub>2</sub> sequestration capacity of a mixed-species agroforestry system in Indonesia, specifically focused on Durian tree, Longan tree, Banana tree, and Avocado tree. We used field measurements of basal area and biomass to estimate aboveground carbon stock and CO<sub>2</sub> equivalents. The findings revealed a total above-ground biomass of 47.02 tons ha<sup>-1</sup>, which corresponds to a carbon stock of 22.07 tons C ha<sup>-1</sup> and a CO<sub>2</sub> sequestration potential of 81.02 tCO<sub>2</sub>e ha<sup>-1</sup>. Longan tree and Durian tree contributed the most biomass and carbon storage, while Banana tree and Avocado tree contributed comparatively smaller amounts. Moderate species diversity was indicated by the computed Shannon–Wiener index ( $H' = 1.65$ ), pointing to an agroforestry system that is partially structured but not yet extremely complicated. These findings emphasize the importance of large-diameter, long-lived fruit trees in long-term carbon storage, but fast-growing species like banana improve short-term sequestration. The heterogeneous composition promotes both ecological resilience and continued carbon cycling. Comparisons with recent research show that the sequestration value of this system is within the effective mitigation range of Indonesian agroforestry, making it a potential candidate for inclusion in national climate programs and voluntary carbon markets. Overall, the study emphasizes the potential of agroforestry to considerably reduce greenhouse gas emissions while benefiting rural livelihoods.

**Keywords:** Agroforestry, Biomass, Carbon Stock, CO<sub>2</sub> Sequestration, Plant Diversity.

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## I. INTRODUCTION

Global climate change has emerged as one of the most pressing issues confronting humanity in the twenty-first century. It refers to long-term, persistent alterations in global temperatures and weather patterns that reach from the tropics to the poles [1]. With the acceleration of industrialization, the continual increase in greenhouse gas concentrations has led to an increase in global temperatures, major changes in climatic

patterns, and the frequency of extreme weather occurrences [2]. Land use change, particularly deforestation and the expansion of monoculture farming, remains a significant contributor to global carbon emissions, while simultaneously degrading ecosystem functions and biodiversity, especially in tropical countries where forest conversion to agricultural land is widespread [3]. According to the reference [4], climate-related risks spread throughout several systems, such as ecosystems, biodiversity, agricultural production, water

resources, human health, infrastructure, and the national economy, as global temperatures rise. Indonesia, with one of the world's largest tropical forests, has generated significant carbon fluxes, with annual net emissions from oil palm development alone estimated at 12.41-25.83 t CO<sub>2</sub> ha<sup>-1</sup> per year [5]. These trends have triggered urgent efforts to identify land management options capable of combining agricultural productivity and climate change mitigation.

Sustainable land management approaches are becoming increasingly popular as climate mitigation strategies. Agroforestry, conservation agriculture, and reclaiming degraded land are among strategies that help absorb CO<sub>2</sub> and increase resistance to climatic extremes [6]. Agroforestry, the intentional integration of trees with crops and/or livestock, is a sustainable land-use system that balances environmental conservation with improved rural livelihoods [7]. These systems, which combine agricultural output with permanent woody vegetation, can help smallholder farmers' livelihoods while sequestering carbon in soils and aboveground biomass [8]. Studies of Indonesian home gardens show that traditional agroforestry delivers up to 20 % greater dietary diversity than purely commercial farms, while commercial-oriented systems can generate up to five-fold higher income, thereby improving household resilience to climate shocks [9]. Overall, developing agroforestry in Indonesia's upland and lowland environments provides a viable strategy to combat climate change, maintain biodiversity, and support rural livelihoods.

The carbon sequestration potential of Indonesian agroforestry varies significantly depending on system and management approaches. The results of a study led in Indonesia has showed a biomass estimation of 3011.79 tons ha<sup>-1</sup> and a carbon stock estimated to 94.30 tons ha<sup>-1</sup> [10]. Regardless of age, mixed tree agroforestry systems in Indonesia's Bengkulu province store about 95.2 tons ha<sup>-1</sup> [11]. Depending on the soil bulk density, carbon stock storage in agroforestry systems that combine oil palm and agar wood ranges from 78.28 to 79.13 Mg C ha<sup>-1</sup> [12]. These findings underscore the critical importance of mature, native tree retention for maximizing carbon storage without compromising agricultural yields.

Evaluating carbon stocks and CO<sub>2</sub> sequestration potential in Indonesian agroforestry systems is crucial for understanding their ecological value and providing scientific evidence to support sustainable agriculture, climate mitigation strategies, and rural development policies. The purpose of this study is to quantify carbon storage and assess the sequestration capability of agroforestry systems in Indonesia, thereby helping to climate change mitigation and sustainable land-use planning.

## II. MATERIEL AND METHODS

### A. Study Area

This research was situated in Wonosalam district, Jombang Regency East Java based on the slopes of Mount

Anjasmoro and geographically at 112° 21' 05" to 112° 23' 22" East Longitude and 07° 44' 59" to 07° 40' 01" South Latitude. Wonosalam is the most distant and highest sub-district in Jombang Regency with geography in the form of green hills. It is dominated by forest areas and plantations with the main commodities such as konjac (*Amorphophallus muelleri*), coffee (*Coffea arabica*), cloves (*Syzygium aromaticum*), djenkol beans (*Archidendron pauciflorum*) and the most famous is durian (*Durio zibethinus*). This site was delimited over an area of 10 \* 20 m<sup>2</sup> = 200 m<sup>2</sup>.

### B. Material and Tools

The tools required for this research include is the administrative map of Wonosalam District, GPS, measuring tapes, wooden sticks, tree height measuring devices, plastic ropes, observation blanks, digital cameras, a clinometer and writing instruments.

### C. Data Analysis

The data of biomass, carbon stock and carbon dioxide was calculated, analyzed and interpreted in the laboratory of the Faculty of Agriculture at Universitas Pembangunan Nasional "Veteran" Jawa Timur.

#### ➤ Calculation of the Basal Area (BA)

Basal Area (BA) is the cross-sectional area of a tree trunk measured at breast height (usually 1.3 meters above the ground). When scaled up, it represents how much of a hectare is actually "covered" by tree stems. To determine the Basal area, we used the following formula:

$$BA (m^2) = 3.142 \times (DBH/200)^2$$

Where:

BA = Basal area (m<sup>2</sup>)

DBH = diameter at breast height (1.3 m from ground level)

#### ➤ Calculation of Above-Ground Biomass (AGB)

All trees in the sampling plot had their diameter at breast height (DBH, cm) measured at 1.3 m above ground level, as well as their overall height. Above-ground biomass (AGB) was evaluated using a conventional tropical allometric equation (Chave model).

$$AGB = 0.11 \rho D^{2.62}$$

Where:

AGB = above-ground biomass (kg tree<sup>-1</sup>)

$\rho$  = wood density (g cm<sup>-3</sup>)

D = diameter at breast height (cm)

To get the above-ground biomass for Banana trees, we need to use an allometric equation:  $AGB = 0.281 D^{2.06}$

#### ➤ Calculation of the Carbon Stock (C)

Carbon reserves in trees are the result of multiplying tree biomass (kg/tree) by the fixed value of the total Carbon content in plant tissue, which is 0.47% [13].

$C = \text{Biomass} * 0.47$

Where: C= carbon stock (t C ha<sup>-1</sup>)

Table 1. Wood Density for Avocado, Durian and Longan Trees

Trees	Wood Density	Source
Avocado	0.54	[14]
Longan	0.51	[15]
Durian	0.80	[16]

Table 2. Structural Characteristics of the Trees in the Observation Area

Vegetation Type	Quantity (n)	Circumference (cm)	Diameter (cm)	Basal Area (m <sup>2</sup> )
Avocado	1	6	1.91	0.0003
Durian	5	55.60	17.69	0.0263
Longan	6	36.33	11.56	0.0130
Bananas	12	44.08	14.03	0.0160

➤ *Calculation of the Carbon Dioxide Equivalent (CO<sub>2</sub>e)*

To determine the quantity of atmospheric carbon dioxide stored in the environment, carbon stock measurements were converted to CO<sub>2</sub> equivalent using the molecular weight ratio between CO<sub>2</sub> and carbon (44/12 = 3.67).

$CO_{2e} = C * 3.67$

Where: CO<sub>2e</sub> = Carbon dioxide equivalent (t CO<sub>2</sub> ha<sup>-1</sup>)

➤ *Plant Diversity Measurement*

To measure the diversity in our plot area, we used the Shannon-Weaver Index (often called the Shannon Diversity Index or Shannon-Wiener Index) which is a mathematical formula used to measure biodiversity or the complexity of a community.

$H = - \sum_{i=1}^s pi \ln(pi)$

Where:

- S: The total number of species in the community (richness).
- pi: The proportion of individuals belonging to the i<sup>th</sup> species (number of individuals of species i divided by the total number of individuals in the sample).
- ln: The natural logarithm.
- : The negative sign at the front is used to make the final value positive (since the log of a fraction is always negative).

**III. RESULTS AND DISCUSSION**

*A. Trees Characteristics*

The four main permanent crop species found in the agroforestry system were banana, durian, avocado, and longan. The structural characteristics of these trees are presented in Table 2.

From these results, the measured vegetation stands avocado, durian, longan, and banana show distinct structural differences. Banana showed the highest population density (12 individuals), followed by longan (6 individuals), durian (5 individuals), and avocado (1 individual). Durian trees had the largest diameter (17.69 cm) and highest basal area (0.0263 m<sup>2</sup>) exhibited the most substantial contribution to stand structure despite having fewer individuals (n=5) than either longan or banana whereas avocado had the lowest basal area (0.0003 m<sup>2</sup>). This finding supports the explanation of [17], which said that Durian trees are reported to reach very large stem diameters at breast height (DBH) of about 450 cm and mean DBH values around 20 cm. Durian has a higher basal area, which suggests more woody biomass accumulation because

basal area is directly proportional to tree volume and above-ground biomass [18].

*B. Estimation of tree biomass*

The estimation of aboveground biomass for the four vegetation types—avocado, durian, longan, and banana calculated from a formula with the diameter at breast height and the wood density are shown in the table 3.

Table 3. Estimated Above-Ground Biomass

Vegetation Type	Biomass (kg/tree)	Biomass (tons/ha)
Avocado	0.32	0.02
Durian	104.40	26.10
Longan	53.04	15.91
Bananas	8.32	4.99
Total	166.08	47.02

The assessment of aboveground biomass for the four vegetation types such as avocado, durian, longan, and banana show significant variance in biomass contribution among species. The total stand biomass reached 47.02 tons ha<sup>-1</sup>, with a cumulative trunk biomass of 166.08 kg tree<sup>-1</sup> across species. Durian tree produced the largest biomass, accounting for 104.40 kg tree<sup>-1</sup> and 26.10 tons ha<sup>-1</sup>, with more than 55% of the overall stand biomass followed by Longan tree with 53.04 kg per tree, 15.91 tons ha<sup>-1</sup> (31.9% of total). This major contribution is due to its bigger stem diameter and woody structure, which considerably increase above-ground biomass accumulation [19]. This finding coincides with data from home gardens in Bogor Regency, where Durian tree was identified as one of the major fruit tree species with significant aboveground biomass increase [20]. In contrast, banana tree contributed 8.32 kg tree<sup>-1</sup> and 4.99 tons ha<sup>-1</sup>, while Avocado tree showed the lowest biomass value at 0.32 kg tree<sup>-1</sup> and 0.02 tons ha<sup>-1</sup>. Despite having a higher plant density, banana contributed less biomass due to its herbaceous pseudostem form and lower wood density [21]. According to [22], low biomass accumulation in avocado trees is usually driven by environmental stressors, particularly in clay soils that inhibit root growth and water intake, or under saltwater circumstances. Based on these findings, biomass buildup in agroforestry systems is largely determined by species traits rather than just plant number. Woody perennials with lignified tissues, larger stem diameters, and longer lifespans, like durian and longan, store significantly more biomass [23].

*C. Potential Carbon Stock*

The carbon stock which refers to the total amount of carbon stored in various global carbon pools, including the

atmosphere, and terrestrial ecosystems calculated for the four species through the biomass accumulation is presented in Table 4.

Table 4. Estimated Carbon Stock

Vegetation Type	Trunk Carbon Reserves (kg/Tree)	Trunk Carbon Reserves (tons/ha)
Avocado	0.15	0.009
Durian	49.07	12.26
Longan	24.93	7.47
Bananas	3.91	2.34
Total	78.06	22.07

The carbon stock estimation revealed distinct patterns of carbon storage among the four vegetation types present in the agroforestry system. Among the vegetation components, Durian tree contributed the largest share of carbon storage, with 49.07 kg C tree<sup>-1</sup> and 12.26 tons C ha<sup>-1</sup>, representing 62.9% of the total per-tree carbon reserves. Longan tree ranked second with 24.93 kg C tree<sup>-1</sup> and 7.47 tons C ha<sup>-1</sup>. This finding aligns with research from [24] about durian (traditional fruit gardens) in East Kalimantan, where old-growth durian-based agroforestry systems achieved carbon stocks of 53.62 tons C ha<sup>-1</sup> in aboveground biomass. Trees with dense wood and big stem diameter can store carbon for a long time because carbon is fixed by photosynthesis and absorbed into lignin and cellulose tissues [25]. Large-diameter trees continuously gather carbon as they develop; a 180-year-old oak in a temperate forest was found to hold ≈ 120 Mg C and Trees with diameters > 100 cm can retain up to half of a stand's total

above-ground carbon [26]. Banana's tree stored 3.91 kg C tree<sup>-1</sup> or 2.34 tons C ha<sup>-1</sup>, while avocado tree contributed only 0.15 kg C tree<sup>-1</sup> and 0.009 tons C ha<sup>-1</sup>. Reference [27] stated that Banana plants have low long-term carbon storage capacity because they are fast-growing herbaceous perennials with soft, water-rich pseudostems and short, rapid harvest cycles. For Avocado trees, they have a lower aboveground carbon storage capacity than natural pine-oak forests because of their lower wood density [28].

*D. Estimation of Carbon Dioxide CO<sub>2</sub> Equivalent*

The carbon stocks estimated from aboveground biomass were converted to carbon dioxide equivalent (CO<sub>2</sub>e) to quantify the climate change mitigation potential of the agroforestry system. Table 5 presents the carbon dioxide values derived from the carbon stock estimates for each vegetation type.

Table 5. Carbon Dioxide Equivalent (CO<sub>2</sub>e) Estimates by Vegetation Type

Vegetation Type	Carbon dioxide equivalent (tCO <sub>2</sub> e/ ha)
Avocado	0.03
Durian	44.99
Longan	27.41
Bananas	8.59
Total	81.02

The conversion of carbon stock to CO<sub>2</sub>e revealed that the agroforestry system has a total sequestration capability of 81.02 tCO<sub>2</sub>e ha<sup>-1</sup>. The figure was calculated using the usual conversion factor (1 ton C = 3.67 tons CO<sub>2</sub>), as recommended by the Intergovernmental Panel on Climate Change (IPCC). The Durian tree had the highest CO<sub>2</sub> sequestration potential of 44.99 tCO<sub>2</sub>e ha<sup>-1</sup>, accounting for more than 55% of the total CO<sub>2</sub> equivalent. The Longan tree had 27.41 tCO<sub>2</sub>e ha<sup>-1</sup>, while the Banana tree had 8.59 tCO<sub>2</sub>e ha<sup>-1</sup>. Meanwhile, avocado trees contributed 0.03 tCO<sub>2</sub>e ha<sup>-1</sup>.

tCO<sub>2</sub>e ha<sup>-1</sup> are deemed robust enough to contribute meaningfully to national climate targets and voluntary carbon markets [30]. This level of sequestration shows that the system can offset a significant portion of emissions from land-use change and small-scale agriculture. It aligns with Indonesia's commitments under the Paris Agreement, where agroforestry is promoted as a climate-smart land-use strategy [31]. In fact, according to [32], Agroforestry in Indonesia is an important climate-smart method to meet Paris Agreement obligations, aiming to reduce net-sink emissions in the Forestry and Other Land Use (FOLU) sector by 2030 and by including trees with crops, it contributes to Indonesia's Enhanced NDC to cut emissions by 31.89-43.20% encourages sustainable land management, biodiversity, and carbon sequestration.

Durian and longan have larger diameters and denser wood, which directly increase biomass and carbon storage and they excel in CO<sub>2</sub> sequestration due to their enormous aboveground biomass, particularly big trunks and canopy. This study's total sequestration value of 81.02 tCO<sub>2</sub>e ha<sup>-1</sup> is within the range reported for tropical smallholder agroforestry systems. The results are consistent with usual findings for tropical smallholder agroforestry systems, which range from 12 to 228 Mg ha<sup>-1</sup> [29]. Sequestration values exceeding 75

*E. Plant Diversity Index*

The vegetation analysis recorded 24 individual plants belonging to four species: Avocado Durian, longan and banana. The results are shown in Table 6.

Table 6. Plant Diversity Index in the Observation Area

Species	Total of each species	Pi (ni/N)	Ln(pi)	Pi * Ln(pi)
Avocado	1	0.04	-3.21	-0.13
Durian	5	0.20	-1.60	-0.32

Longan	6	0.25	-1.38	-0.35
Bananas	12	0.5	-1.69	-0.85
Total of species (N)	24			
Richness diversity	4			
Diversity index (H')	1.65			

The Shannon–Wiener diversity index (H') calculated from the relative abundance (Pi) of each species was  $H' = 1.65$ . According to [33], the H' value is an indicator of the level of species variation in an area. If  $H' < 1$ , that is the case of Low diversity; H' between 1 – 3, Moderate diversity;  $H' > 3$  High diversity (natural forest).

According to the results, a H' score between 1 and 3 shows moderate diversity, implying that the agroforestry system is neither species-poor nor very complicated. Richness was acceptable in this trial, but because bananas predominated, evenness was low. Similar circumstances have been seen in Southeast Asian smallholder tropical agroforestry systems, where farmers give priority to commercially significant species, resulting in an uneven distribution of species [34]. The moderate diversity value ( $H' = 1.65$ ) indicates that the analysed agroforestry system still has room for ecological development. Increasing the number of woody perennial species will promote canopy stratification and carbon storage. Moreover, through the integration of various tree species, crops, and animals, agroforestry systems establish resilient ecosystems that promote and profit from enhanced biodiversity. By storing carbon, these systems simultaneously slow down climate change and help to adapt to and gain from increased biodiversity [35].

#### IV. CONCLUSION

The study on carbon stock and CO<sub>2</sub> sequestration capability in agroforestry systems emphasizes the importance of species composition, tree size, and planting density in influencing overall climate mitigation capacity. Durian and longan appear as the primary contributors due to their vast basal area and dense wood, whereas bananas contribute significant short-term sequestration due to their quick growth and high density. Avocado, while less significant in this case, shows the diversity of species contributions in a mixed system. The existing carbon stock of 81.02 tons CO<sub>2</sub> ha<sup>-1</sup> only covers a part of the system's sequestration capacity. Carbon stocks in mature homegarden systems can reach 123 Mg C ha<sup>-1</sup> with proper growth and management, including retention of mature trees, enrichment planting with additional native or fruit tree species, and species diversity maintenance. With a total sequestration value of 81.02 tCO<sub>2</sub>e ha<sup>-1</sup>, the system demonstrates a moderately high potential for greenhouse gas mitigation, placing it within the effective range of tropical agroforestry systems in Indonesia. The Shannon-Wiener diversity index ( $H' = 1.65$ ) showed a modest level of species diversity. This shows that the agroforestry system already serves ecological purposes, although it is still dominated by a single species. These findings highlight the relevance of agroforestry as a climate-smart land-use plan that can help Indonesia meet its Paris Agreement goals while also providing prospects for carbon monetization through voluntary markets. Agroforestry systems like this one stand out as long-term solutions for balancing rural development and climate security

because they combine ecological advantages with livelihood assistance.

#### REFERENCES

- [1]. Usman, S., Jayeoba, J. O., & Kundiari, A. M. (2024). Climate change at a global concept: Impacts and adaptation measures. *International Journal of Environment and Climate Change*, 14(6), 445–459. ArticleIJECC.117988. <https://doi.org/10.9734/ajee/2024/v14i64242>
- [2]. Adom, P. K., & Amoani, S. (2021). The role of climate adaptation readiness in economic growth and climate change relationship: An analysis of the output/income and productivity/institution channels. *Journal of Environmental Management*, 293, 112923. <https://doi.org/10.1016/j.jenvman.2021.112923>
- [3]. Adam, M. K., Karuniasa, M., & Wardhana, Y. M. A. (2025). Empirical data-based carbon stock projection in agroforestry for climate change mitigation. *Jurnal Ilmu Kehutanan*, 19(2), 193–203. <https://doi.org/10.22146/jik.v19i2.20118>
- [4]. World Health Organization. (2023, October 12). Climate change and health. World Health Organization. <https://www.who.int/news-room/factsheets/detail/climate-change-and-health>
- [5]. Rahmani, T. A., Nurrochmat, D. R., Park, M. S., Boer, R., & Ekayani, M. (2024). The potential ecological impact of oil palm agroforestry as term of improvement for restoring Harapan Rainforest. *Jurnal Manajemen Hutan Tropika*, 30(3), 376–389. <https://doi.org/10.7226/jtfm.30.3.376>
- [6]. Eekhout, J. P. C., & de Vente, J. (2019). Assessing the effectiveness of sustainable land management for large-scale climate change adaptation. *Science of the Total Environment*, 654, 85–93. <https://doi.org/10.1016/j.scitotenv.2018.10.350>
- [7]. Kumar, R., Veeraragavan, M., Baral, K., Saikanth, D. R. K., Singh, V., Upadhyay, L., & Raj, S. (2023). Agroforestry and its potential for sustainable land management and climate action: A review. *International Journal of Environment and Climate Change*, 13(12), 620–629.
- [8]. Alexander, L., Manson, S., Jain, V., Setiawan, I. M., Sadnyana, M. D., Syirazi, M., Wibowo, Z. A., Sukmadewi, D. K. T., & Campera, M. (2025). The interplay between carbon storage, productivity, and native tree density of agroforestry systems. *Land*, 14(2), 344. <https://doi.org/10.3390/land14020344>
- [9]. Duffy, C., Toth, G. G., Hagan, R. P. O., McKeown, P. C., Rahman, S. A., Widyaningsih, Y., Sunderland, T. C. H., & Spillane, C. (2021). Agroforestry contributions to smallholder farmer food security in Indonesia. *Agroforestry Systems*, 95, 1109–1124. <https://doi.org/10.1007/s10457-021-00632-8>

- [10]. Febrianti, W. N., Budianto, S., Laela, F., & Evitasari, D. (2023). Carbon stocks from the use of agroforestry cultivation systems in Wonosalam District, Jombang. *Jurnal Envirotek*, 15(2), 141–148.
- [11]. Wiryono, W.; Puteri, V.N.U.; Senoaji, G. The diversity of plant species, the types of plant uses and the estimate of carbon stock in agroforestry system in Harapan Makmur Village, Bengkulu, Indonesia. *Biodivers. J. Biol. Divers.* 2016, 17
- [12]. Besar, N.A.; Suardi, H.; Phua, M.-H.; James, D.; Mokhtar, M.B.; Ahmed, M.F. Carbon Stock and Sequestration Potential of an Agroforestry System in Sabah, Malaysia. *Forests* 2020, 11.
- [13]. IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). Hayama, Japan: Institute for Global Environmental Strategies (IGES).
- [14]. Fuentes-Talavera, F. J., Silva-Guzmán, J. A., Rodríguez-Anda, R., Lomelí-Ramírez, M. G., Sanjuán-Dueñas, R., & Richter, H. G. (2011). Strength properties and natural durability of avocado (*Persea americana* Mill.) branch wood. *Madera y Bosques*, 17(3), 23–36.
- [15]. Herawati, E., Hartono, R., & Sinaga, H. M. M. (2021). Physical and mechanical properties of four wood species from community forests in Binjai Regency, North Sumatra. *IOP Conference Series: Earth and Environmental Science*, 912(1), 012024.
- [16]. Nowak, D. J., Greenfield, E. J., & Pasek, M. A. (2023). Understanding i-Tree: Appendix 11 – Wood density values 2023. General Technical Report NRS-200-2023. USDA Forest Service, Northern Research Station.
- [17]. Ekasari, I., & Kurnia, R. (2023). Relationship between tree height–diameter at breast height (DBH) and crown diameter–DBH of fruit trees in Bogor Botanical Gardens. *BIO Web of Conferences*, 80, 03015. <https://doi.org/10.1051/bioconf/20238003015>
- [18]. Seiwa, K., Sasaki, T., & Masaka, K. (2023). Important role of a few large-diameter tree species in basal area and its increase in an old-growth deciduous broadleaf forest in Japan. *Trees, Forests and People*, 13, 100421. <https://doi.org/10.1016/j.tfp.2023.100421>
- [19]. Biah, I., Azihou, A. F., Guendehou, S., & Sinsin, B. (2025). Aboveground biomass variation in relation to woody species dominance in West Africa. *Discover Forests*, 1, 18. <https://doi.org/10.1007/s44415-025-00022-3>
- [20]. Adijaya, S. D., Kartawinata, K., & Nisyawat. (2021). Carbon potentials in biomass of fruit trees in home gardens in the Bogor Regency, West Java. *Journal of Tropical Ethnobiology*.
- [21]. Yamaguchi, J., & Araki, S. (2004). Biomass production of banana plants in the indigenous farming system of the East African Highland: A case study on the Kamachumu Plateau in northwest Tanzania. *Agriculture, Ecosystems & Environment*, 102(1), 93–111. [https://doi.org/10.1016/S0167-8809\(03\)00230-5](https://doi.org/10.1016/S0167-8809(03)00230-5)
- [22]. Bonomelli, C., Gil, P. M., & Schaffer, B. (2019). Effect of soil type on calcium absorption and partitioning in young avocado (*Persea americana* Mill.) trees. *Agronomy*, 9(12), 837. <https://doi.org/10.3390/agronomy9120837>
- [23]. World Agroforestry (ICRAF). (2020). Guidelines for measuring carbon stocks in agroforestry systems
- [24]. Hartati, W., Suhardiman, A., Sudarmadji, T., & Sulistiyo, E. A. (2021). Estimation of carbon stocks in understory plants and litter in the Educational and Research Forest of the Faculty of Forestry, Mulawarman University, Samarinda. *ULIN: Journal of Tropical Forestry*, 5(2), 55–64
- [25]. Mo, L., Crowther, T. W., Maynard, D. S., van den Hoogen, J., Ma, H., Bialic-Murphy, L., Liang, J., de-Miguel, S., Nabuurs, G., Reich, P. B., Phillips, O. L., Abegg, M., Adou Yao, Y. C., Alberti, G., Almeyda Zambrano, A. M., Alvarado, B. V., Alvarez-Dávila, E., Alvarez-Loayza, P., Alves, L. F., ... Werner, G. D. A. (2024). The global distribution and drivers of wood density and their impact on forest carbon stocks. *Nature Ecology & Evolution*, 8(12), 2195–2212.
- [26]. Norby, R. J., Loader, N. J., Mayoral, C., Ullah, S., Curioni, G., Smith, A. R., Reay, M. K., Wijngaarden, K., Amjad, M. S., Brettle, D., Crockatt, M. E., Denny, G., Grzesik, R. T., Hamilton, R. L., Hart, K. M., Hartley, I. P., Jones, A. G., Kourmouli, A., Larsen, J. R., Shi, Z., Thomas, R. M., & MacKenzie, A. R. (2024). Enhanced woody biomass production in a mature temperate forest under elevated CO<sub>2</sub>. *Nature Climate Change*, 14(9), 983–988
- [27]. Zhao, M. Q., Li, M., & Shi, Y. F. (2014). Carbon storage and carbon dioxide sequestration of banana plants at different growth stages. *Advanced Materials Research*, 1010–1012, 662–665
- [28]. Denvir, A., García-Oliva, F., Arima, E. Y., Latorre-Cárdenas, M. C., González-Rodríguez, A., Young, K. R., & Lara de la Cruz, L. I. (2024). Sustainability implications of carbon dynamics on the avocado frontier. *Agriculture, Ecosystems & Environment*, 359, 108746.
- [29]. Albrecht, A., & Kandji, S. T. (2003). Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems & Environment*, 99(1–3), 15–27. [https://doi.org/10.1016/S0167-8809\(03\)00138-5](https://doi.org/10.1016/S0167-8809(03)00138-5)
- [30]. Siagian, K., Karuniasa, M., & Mizuno, K. (2024). The estimation of economic valuation on carbon sequestration of agroforestry land system. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan*, 14(2), 231–242. <http://dx.doi.org/10.29244/jpsl.14.2.231>
- [31]. Broadsheet Asia. 2025. “Indonesia’s Climate Commitment Under Scrutiny Amid Paris Agreement Debate.” February 11, 2025. <https://broadsheet.asia/2025/02/11/indonesias-climate-commitment-under-scrutiny-amid-paris-agreement-debate/>.
- [32]. Ministry of Environment and Forestry of the Republic of Indonesia. (2023). Photo Book: FOLU Net Sink — Indonesia’s Climate Actions Towards 2030. Jakarta, Indonesia: Ministry of Environment and Forestry of the Republic of Indonesia. ISBN: 978-623-440-021-2.
- [33]. Baderan, D. W. K., Rahim S., Angio, M., Ilham, A. (2021). Diversity, evenness, and species richness of plants from the potential geosite of Otanaha Fortress as a

- pilot for the development of a geopark in Gorontalo Province. *Journal of Biology*, 14(2), 264-274.
- [34]. Siarudin, M., et al. (2021). Carbon sequestration potential of agroforestry systems in Indonesia. *Forests*, 12(6), 714.
- [35]. Sridhar, R., Longkumer, L. T., Pilla, A., Bharteey, P. K., Jatav, H. S., Hareesh, D., Vilakar, K., Singh, A. P., Srikar, K., Aruna, K., & Reddy, M. S. P. (2025). Diverse fields for stronger yields: Crop diversification strategies for sustainable agriculture and climate-resilient ecosystems. *Frontiers in Agronomy*, 7, 1746895. <https://doi.org/10.3389/fagro.2025.1746895>