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Short Communication: Estimation of aboveground biomass and carbon stock in agroforestry areas of Mergolangu and Karangsambung Villages, Wonosobo, Central Java, Indonesia

ADINDA DEWI LARASATI[1], FAISYA HAQQIN ABRARI[1], MUH. FAQIH MUHAIMIN FATHONI[1], SA'AD ABDUL JABBAR[1], KIRANA NURUL ARIFIANI[1], MUHAMMAD INDRAWAN[1], SUGIYARTO[2,3], AHMAD DWI SETYAWAN[1,3,♥]
[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia
[3]Biodiversity Research Grup, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126. Central Java, Indonesia

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Abstract. *Larasati AD, Abrari FH, Fathoni MFM, Jabbar SA, Arifiani KN, Indrawan M, Sugiyarto, Setyawan AD. 2024. Short Communication: Estimation of aboveground biomass and carbon stock in agroforestry areas of Mergolangu and Karangsambung Villages, Wonosobo, Central Java, Indonesia. Asian J Agric 8: 161-168.* Carbon stock is an essential indicator in assessing ecosystem services that can reduce greenhouse gas emissions in the atmosphere, thereby helping to reduce the negative impacts of global climate change. Vegetation in agroforestry systems is vital in carbon storage and climate change mitigation. As a tropical country, Indonesia is vulnerable to the negative impacts of climate change. Wonosobo, the research location, is a district in Central Java Province, Indonesia. This study aims to estimate aboveground biomass and carbon stock of agroforestry areas in Mergolangu and Karangsambung Villages, Wonosobo, Central Java, Indonesia. The method used is simple random sampling at three research stations, i.e.: Mixed agroforestry (Station I), Agathis-based agroforestry (Station II), and Pine-based agroforestry (Station III). Of the three stations, the most extensive carbon stock was produced by Mixed agroforestry with an Aboveground Biomass (AGB) of 2,169.24 MgB/ha and carbon stock of 1,019.54 MgC/ha, followed by Agathis-based agroforestry with an AGB of 443.20 MgB/ha and carbon stock of 208.30 MgC/ha and Pine-based agroforestry with AGB amount of 359.10 MgB/ha and carbon stock of 158.14 MgC/ha.

Keywords: Allometric equation, biomass, carbon stock, forest, pole and tree

INTRODUCTION

Climate change has been a worldwide concern since prehistoric times (Sudarma and As-syakur 2018). As a tropical country, Indonesia is one of the countries vulnerable to climate change's negative impacts (Legionosuko et al. 2019). Climate change extremes have caused the enhancement of dead trees in all forested continents, and sometimes this damage cannot grow back (Hartmann et al. 2022). Extreme heat waves and droughts can occur simultaneously due to climate change, increasing the frequency of compound occurrences with unclear effects on forests. Numerous trees have experienced catastrophic leaf drop and mortality events as a result of rising summer temperatures and water Vapor Pressure Deficits (VPD) in recent decades. The combination of resilience, natural ecosystem, and adaptation measures used by farmers and holders' interests will determine the overall impact of climate change on human well-being (Gammans et al. 2017). Reducing these risks, which requires consideration of vulnerability and exposure to danger-related climate, can be achieved through adaptation to unavoidable hazards and mitigating climate change through mitigation of greenhouse gas emissions (Stott et al. 2016). It is generally understood that human-caused climate change is causing global warming, but what is less appreciated is the direct impact of heavy rainfall, drought, and storms, which are taking a major toll on society and the environment (Trenberth 2018).

Immediate impact management plan to change climate covers change in Soil Organic Carbon (SOC) stock, and direct emissions of nitrogen oxides (N_2O) and methane (CH_4) from fertilized soil (Krauss et al. 2017). Soil Organic Carbon stock is an indicator important in the evaluation of ecosystem service (Ottoy et al. 2017). Wide-cover forests play an important role in maintaining carbon biomass, increasing carbon sequestration (carbon sinks), and reducing greenhouse gas emissions into the atmosphere (Raihan et al. 2021). Various forest systems can stabilize CO_2 concentrations in the atmosphere (IPCC 2014; Agevi et al. 2017).

Agroforestry is a system of management land that integrates trees with crop plants or livestock in one unit of land (Nair et al. 2021). Agroforestry plays an important role in maintaining carbon biomass, increasing carbon sequestration, and reducing greenhouse gas emissions into the atmosphere, which helps mitigate the negative impacts of global climate change (Raihan et al. 2021). In addition, forest plants can support downstream ecosystem services that are important to the land (Lorenz and Lal 2015). In agroforestry, plants have an important role in creating the continuity of the system (Dissanayaka et al. 2023). Agroforestry has an important role in the storage of carbon and climate change mitigation. In this context, agroforestry contributes in a way significant to maintaining stock carbon in various ecosystem components, as well as reducing emissions of greenhouse gases (Baliton et al. 2017). The trees planted in the agroforestry system provide carbon in the form of their biomass and help increase carbon levels in the soil and surrounding vegetation (Chaturvedi et al. 2016).

Wonosobo is a district in Central Java Province, Indonesia. In 2020, Wonosobo had rainfall for 207 days. The area is 948.68 km^2, between 7011'-7036' S and 109043' -110004' E. It is a mountainous area with an altitude range of between 275 to 2,250 m asl., characterized by its unique geographical features (BPS Wonosobo 2020). Even though it has risks of disaster land high landslides, Wonosobo successfully utilizes potency agriculture and forests as a source of income for most of the population. Some types of plants found in the area are pine trees (*Pinus merkusii* Jungh. & de Vriese), *damar* (*Agathis dammara* (Lamb.) Rich. and A. Rich.), *sengon* (*Albizia chinensis* (Osbeck) Merr.), and mahogany (*Swietenia mahagoni* (L.) Jacq.)(Lazuardi et al. 2021). Trees planted in agroforestry systems provide carbon in the form of biomass and help increase carbon levels in the soil and surrounding vegetation (Chaturvedi et al. 2016). Carbon stocks and tree diversity in an ecosystem, both in natural forests and agroecosystems are dynamic over time and still need to be studied.

This study aims to estimate aboveground biomass and carbon stocks in three agroforestry areas in Mergolangu and Karangsambung Villages, Wonosobo, Central Java, Indonesia, i.e. Mixed agroforestry, Agathis-based agroforestry, and Pine-based agroforestry.

MATERIALS AND METHODS

Study area

This research was located in the agroforestry complex in Karangsambung and Mergolangu Villages, of the Kalibawang Sub-district, Wonosobo District, Central Java, Indonesia (Figures 1 and 2), i.e. the Mixed agroforestry of Karangsambung Village (Station I), the Agathis-based agroforestry (*Agathis dammara*) in Karangsambung Village (Station II), and the Pine-based agroforestry (*Pinus merkusii*) of Margolangu Village (Station III), which were determined using the random sampling method.

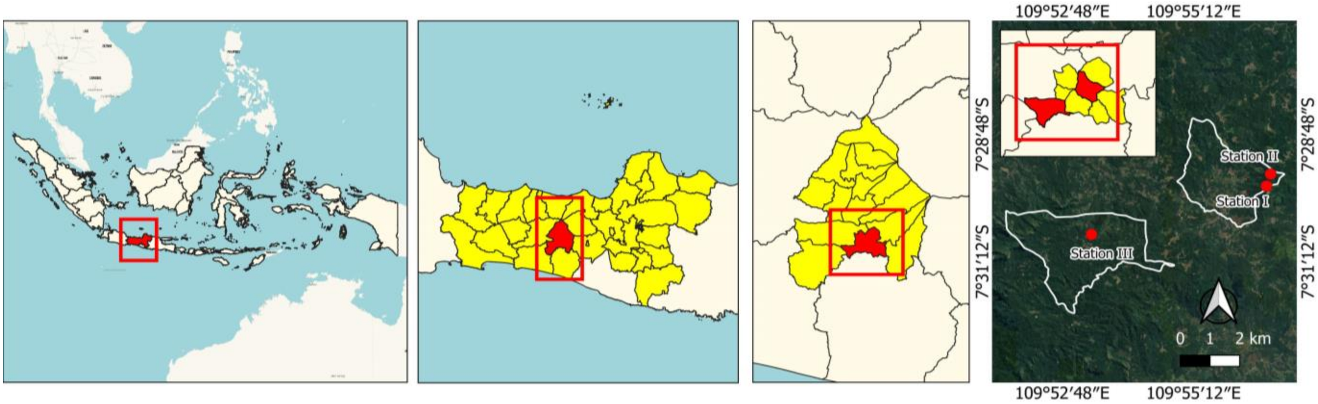

Figure 1. Location of agroforestry research in Kalibawang Sub-district, Wonosobo District, Central Java Province, Indonesia. Station I: Mixed agroforestry, Station II: Agathis-based agroforestry, Station III: Pine-based agroforestry

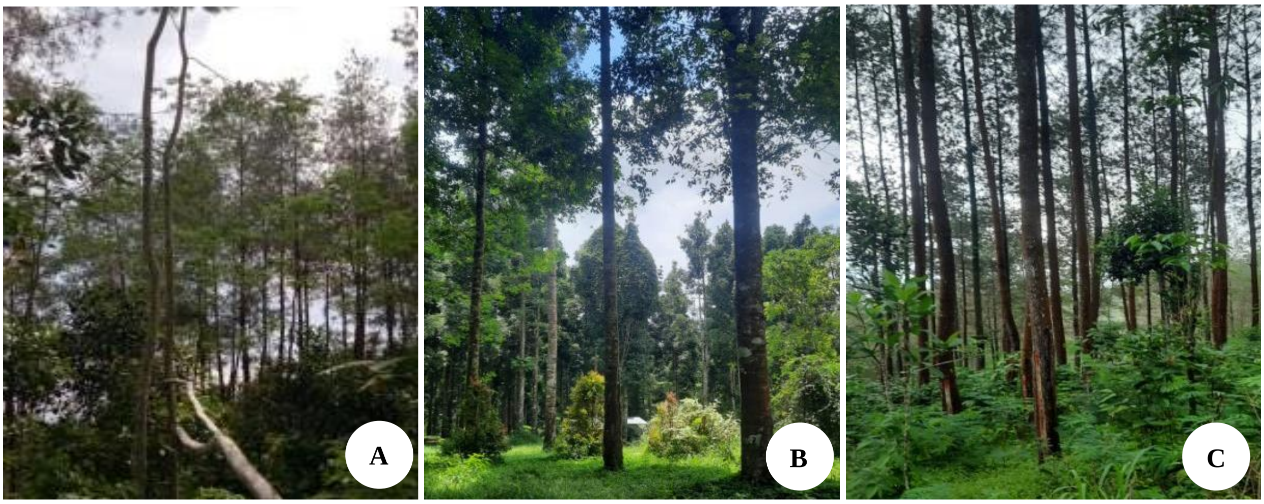

Figure 2. Research locations in the Kalibawang Sub-district, Wonosobo District, Central Java, Indonesia: A. Mixed agroforestry in Karangsambung Village, B. Agathis-based agroforestry in Karangsambung Village, C. Pine-based agroforestry in Margolangu Village

Table 1. Species-specific allometric equations in aboveground biomass calculations

Species	Equation	References
Acacia mangium Willd.	$0.0000478 * D^{2.76}$	Hairiah et al. (2001)
Albizia chinensis (Osbeck) Merr.	$0.027 * D^{2.23}$	Hairiah et al. (2001)
Artocarpus heterophyllus Lam.	$0.1792 * D^{2.25112}$	Kumar et al. (1998)
Branched tree	$0.11 * p * D^{2.62}$	Ketterings et al. (2001)
Coffea sp.	$0.281 * H * D^{2.06}$	Arifin (2001)
Pinus merkusii Jungh. & de Vriese	$0.0936 * D^{2.4323}$	Siregar (2007)
Swietenia mahagoni (L.) Jacq.	$0.048 * D^{2.3}$	Hairiah et al. (2001)
Unbranched tree	$3.14 * p * H * D^{2\cdot}/40$	Hairiah et al. (2001)

Note: D: Diameter; P: Rho/wood density

Study area

Preparation

Research was prepared by conducting a literature study by reviewing books, notes, and literature on carbon stocks in forests. In the primary research, the tools and materials used were stationary, road boards, and tally sheets containing columns for species name, local name, circumference (cm), category of tree or pole, which station it was found in, and which plot. Secondary data tools and materials used are the website https://www.gbif.org/user/profile to detect types or names of plant species that are rarely found.

Data collection and analysis

Vegetation samples were focused on two levels of vegetation, namely trees and poles. Each station has a different level of dominance in the vegetation growth category, so it is necessary to adjust the research variables to the growth category in the three forest types. Vegetation categories are measured based on the Diameter at Breast Height (DBH). Young trees with a DBH of 10-20 cm are considered poles, and woody plants with a DBH of >20 cm are classified as tree stage. Plots representing the species at each station were created by random sampling and used to collect vegetation data. The plot area used was 20×20 m^2 for tree stands and 10×10 m^2 for pole stands. The total number of plots at all stations was 30 plots.

Data analysis was performed using descriptive quantitative field data obtained and calculated from equality allometrics. The content biomass on the plot (pole and trees) is converted to biomass per hectare using the following formula, following National Standardization Agency (2011) standards:

$$Cn = \frac{Cx}{1.000} \, x \, \frac{10.000}{lsub{-}plot}$$

Where: Cn is carbon stock; Cx is the total carbons for each transect/sub-plot (kg); and the lsub-plot is the total area of the lsub-plot in m^2. Allometric calculations were performed using each species' DBH, wood density, and height (Purwiyanto and Agustriani 2017). Some species have special allometric values for calculating biomass on the ground surface as in Table 1.

RESULTS AND DISCUSSION

Result of the study, there are 31 species in three station research (Tables 2 and 3). Pine (*P. merkusii*) is the most species of tree category found in stations I and III. The dominance of pine in the forests at Station III is due to its status as one of the main species in the ecosystem, playing an important role in the sustainable rehabilitation of land (Nur et al. 2024). On a pine tree, resin channels can produce secondary metabolites, allelopathic. Compound the toxic with plants or insects so that pine can prevent nor hinder other plants from growing too close and stop them from taking space and availability of nutrients. These conditions affect pine dominance in the forest (Sila et al. 2022). Pine forests contribute to environmental services by absorbing one of the significant greenhouse gases, viz carbon dioxide (CO_2) (Polosakan et al. 2014). At Station II, the most dominant is agathis (*A. dammara*). Mixed agroforestry has a high biomass content because it absorbs much more carbon than plants similar or homogeneous (Paembonan et al. 2019). The larger diameter of the tree causes the low mark biomass pole with a probability tree in comparison pole. Under these conditions, then increase in diameter along with enhanced tree biomass.

The height of plants can also influence the difference between biomass in trees and poles (Hartoyo et al. 2022). The higher it is the plant, the greater its biomass. The amount of biomass is also influenced by factors of physiology tree, especially photosynthesis, which is a process major in manufacturing food from inorganic materials to become organic. Maintaining a natural, whole forest and increasing the density of the population of trees in the forest are the ways to control global warming. Photosynthesis converts charcoal gas (CO_2) from the air into carbohydrates that plants absorb (Daud et al. 2019). These carbohydrates then spread throughout the body of plants and are finally stored in the body of plants from leaves, stems, flowers, and fruit. Measuring the amount of carbon stored in the body of plant life (biomass) in a location shows how much plants from the atmosphere absorb a lot of CO_2 (Abobsesa et al. 2018). Biomass measurement considers each species' stem diameter and height (Ulak et al. 2022). Maintaining the wholeness of forest nature and increasing the population density of the trees in the forest are ways to control global warming (Kushawaha et al. 2021).

A total of 31 species were found in the tree category (Table 2). *P. merkusii* became the species with the largest

Abovegroud Biomass (AGB) and carbon stock values at Stations I and III. At Station I, pine had an AGB value of 788.9 MgB/ha and an equivalent carbon stock of 370.8 MgC/ha. Then at Station III, *P. merkusii* obtained the largest AGB and carbon stock, which was 276 MgB/ha AGB equivalent to 129.73 MgC/ha carbon stock. While at Station II, the largest AGB and carbon stock were contributed by *A. dammara* with an AGB of 260.8 MgB/ha and an equivalent of 122.5 MgC/ha. Based on Table 3, stands poles found 13 species. Most species are found in Station I, with 18 species. At Station I, *Coffea* sp. holds the highest AGB and carbon stock in the category pole, with an equivalent carbon stock of 39.78 MgC/ha and an AGB of 84.64 MgB/ha. *Cocos nucifera* L. follows with an AGB of 20.34 MgB/ha and an equivalent carbon stock of 9.56 MgC/ha. At Station II, the species that has the largest AGB and carbon stock is *Artocarpus heterophyllus* Lam., with an AGB of 14.77 MgB/ha and equivalent with Carbon stock as big as 6.94 MgC/ha, followed by species *Aglaia palembanica* Miq. with an AGB amount of 8.78 MgB/ha and equivalent stock carbon of 4.12 MgC/ha. At the Station III species, whose own amount of AGB and carbon stock is *Coffea* sp. with an AGB amount of 22.62 MgB/ha and an equivalent carbon stock of 10.63 MgC/ha.

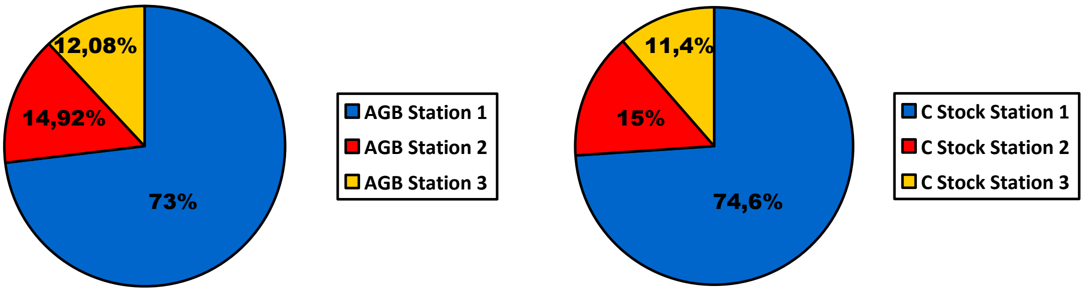

Figure 3. A. Amount AGB every station, B. Amount C stock every station

Table 2. Aboveground biomass and carbon stocks of tree categories

Station	Family	Local name	Scientific name	AGB (MgB/ha)	Carbon stock (MgC/ha)
Station I (Mixed agroforestry in Karangsambung Village)	Moraceae	*Beringin*	*Ficus benjamina* L.	390.38	183.48
	Pinaceae	*Pinus*	*Pinus merkusii* Jungh. & de Vriese	788.90	370.80
	Meliaceae	*Sapen*	*Aglaia palembanica* Miq.	187.47	88.11
	Araucariaceae	*Damar*	*Agathis dammara* (Lamb.) Rich. & A. Rich .	163.80	77.01
	Lauraceae	*Ulin*	*Eusideroxylon zwageri* Teijsm. & Binn.	110.90	52.14
	Malvaceae	*Waru*	*Hibiscus tiliaceus* L.	83.31	39.16
	Calophyllaceae	*Rakas*	*Calophyllum acidus* Kosterm.	57.47	27.16
	Arecaceae	*Kelapa*	*Cocos nucifera* L.	32.37	15.21
	Arecaceae	*Aren*	*Arenga pinnata* (Wurmb) Merr.	25.51	11.99
	Salicaceae	*Rukem*	*Flacourtia rukam* Zoll. & Moritzi.	24.67	11.60
	Elaeocarpaceae	*Jenitri*	*Elaeocarpus ganitrus* F. Muell.	19.64	9.23
	Moraceae	*Nangka*	*Acacia heterophyllus* Lam.	17.13	8.05
	Altingiceae	*Rasamala*	*Altingia excelsa* Noronha	14.04	6.60
	Moraceae	*Wilodo*	*Ficus fistulosa* Reinw. ex Blume.	10.79	5.07
	Rubiaceae	*Jabon*	*Neolamarcki cadamba* (Roxb.) Bosser	10.36	4.86
	Meliaceae	*Suren*	*Toona sureni* (Blume) Merr.	6.90	3.24
	Malvaceae	*Durian*	*Durio zibethinus* Murray	3.91	1.83
	Meliaceae	*Mahoni*	*Swietenia mahagony* (L.) Jacq.	3.52	1.65
	Fabaceae	*Sengon laut*	*Falcataria falcata* (L.) Greuter & R. Rankin	1.88	0.88
	Fabaceae	*Sengon*	*Albizia chinensis* (Osbeck) Merr.	1.35	0.63
	Fabaceae	*Akasia*	*Acacia mangium* Willd.	0.06	0.029
Station II (Agathis-based agroforestry in Karangsambung Village)	Araucariaceae	*Damar*	*Agathis dammara* (Lamb.) Rich. & A. Rich.	260.80	122.58
	Moraceae	*Beringin*	*Ficus benjamina* L.	46.00	21.62
	Rubiaceae	*Kopi*	*Coffea* sp.	37.72	17.73
	Meliaceae	*Mahoni*	*Swietenia mahagony* (L.) Jacq.	29.80	14.00
	Sapindaceae	*Matoa*	*Pometia pinnata* J. R. Forst. & G. Forst.	24.51	11.52
	Combretaceae	*Ketapang*	*Terminalia catappa* L.	5.83	2.74
	Moraceae	*Nangka*	*Artocarphus heterophyllus* Lam.	1.84	0.86
Station III (Pine-based agroforestry in Margolangu Village)	Pinaceae	*Pinus*	*Pinus merkusii* Jungh. & de Vriese	276.02	129.73
	Moraceae	*Nangka*	*Artocarphus heterophyllus* Lam.	23.09	10.85
	Fabaceae	*Sengon*	*Albizia chinensis* (Osbeck) Merr.	2.80	1.31

Note: AGB: Abovegroud Biomass

Table 3. Aboveground biomass and carbon stocks of pole categories

Station	Family	Local name	Scientific name	AGB (MgB/ha)	Carbon stock (MgC /ha)
Station I (Mixed agroforestry in Karangsambung Village)	Rubiaceae	*Kopi*	*Coffea* sp.	84.64	39.78
	Arecaceae	*Kelapa*	*Cocos nucifera* L.	20.34	9.56
	Rubiaceae	*Jabon*	*Neolamarckia cadamba* (Roxb.) Bosser	16.38	7.70
	Lauraceae	*Kemrunggi*	*Eusideroxylon zwageri* Teijsm. and Binn.	14.61	6.87
	Moraceae	*Nangka*	*Artocarphus heterophyllus* Lam.	11.40	5.36
	Moraceae	*Wilodo*	*Ficus fistulosa* Reinw. ex Blume	11.39	5.35
	Malvaceae	*Waru*	*Hibiscus tiliaceus* L.	9.37	4.40
	Araucariaceae	*Damar*	*Agathis dammara* (Lamb.) Rich. & A. Rich.	8.81	4.14
	Malvaceae	*Durian*	*Durio zibethinus* Murray	7.91	3.72
	Meliaceae	*Mahoni*	*Swietenia mahagony* (L.) Jacq.	6.34	2.98
	Fabaceae	*Sengon*	*Albizia. chinensis* (Osbeck) Merr.	6.04	2.84
	Moraceae	*Kluweh*	*Artocarpus camansi* Blanco	4.49	2.11
	Styracaceae	*Kemenyan*	*Styrax sumatranus* JJSm.	3.68	1.73
	Elaeocarpaceae	*Jenitri*	*Elaeocarpus ganitrus* F. Muell.	3.30	1.55
	Fabaceae	*Trembesi*	*Albizia saman* (Jacq.) Merr.	2.22	1.04
	Gnetaceae	*Melinjo*	*Gnetum gnemon* L.	1.31	0.61
	Urticaceae	*Kemadu*	*Laportea sinuata* (Blume) Miq.	1.24	0.59
	Anacardiaceae	*Rengas*	*Gluta renghas* L.	0.28	0.39
Station II (Agathis-based agroforestry in Karangsambung Village)	Moraceae	*Nangka*	*Artocarphus heterophyllus* Lam.	14.77	6.94
	Meliaceae	*Sapen*	*Aglaia palembanica* Miq.	8.78	4.12
	Araucariaceae	*Damar*	*Agathis dammara* (Lamb.) Rich. & A. Rich.	8.08	3.80
	Meliaceae	*Mahoni*	*Swietenia mahagony* (L.) Jacq.	4.88	2.29
	Cycadaceae	*Pakis*	*Cyathea pseudo-muelleri* Holttum	0.11	0.05
Station III (Pine-based agroforestry in Margolangu Village)	Rubiaceae	*Kopi*	*Coffea* sp.	22.62	10.63
	Moraceae	*Wilodo*	*Ficus fistulosa* Reinw. ex Blume	7.91	3.72
	Moraceae	*Nangka*	*Artocarphus heterophyllus* Lam.	7.67	3.60
	Malvaceae	*Waru*	*Hibiscus tiliaceus* L.	6.50	3.06
	Pinaceae	*Pinus*	*Pinus merkusii* Jungh. & de Vriese	6.05	2.84
	Rubiaceae	*Jabon*	*Neolamarckia cadamba* (Roxb.) Bosser	4.52	2.13
	Fabaceae	*Sengon*	*Albizia chinensis* (Osbeck) Merr.	1.88	0.88

Notes: AGB: Aboveground Biomass

Table 4. Comparisonof AGB and carbon stock between tree and pole

Station	Biomass and carbon stock				Total	
	Tree		Pole			
	AGB (MgB/ha)	Carbon stock (MgC/ha)	AGB (MgB/ha)	Carbon stock (MgC/ha)	AGB (MgB/ha)	Carbon stock (MgC/ha)
I (Mixed agroforestry in Karangsambung Village)	1,954.86	918.78	214.39	100.76	2,169.24	1,019.54
II (Agathis-based agroforestry in Karangsambung Village)	406.55	191.08	36.65	17.23	443.20	208.30
III (Pine-based agroforestry in Margolangu Village)	301.92	141.9	57.18	16.24	359.10	158.14
Total	2,663.33	1,251.76	308.22	134.23	2,971.54	1,385.98

Note: AGB: Aboveground Biomass

Discussion

Young trees known as poles have a diameter of 10 to 20 cm and are thought to be carbon sinks because of their high rate of photosynthesis. As explained by Pebriandi et al. (2023), poles can contribute to carbon stock storage; however, because the diameter of the trunk is smaller than that of the tree, the amount of biomass produced by the pole is less than that of trees with a larger diameter than the pole. The average AGB across all stations researched is 990.5 MgB/ha or equivalent, with a carbon stock of 462 MgC/ha (Table 4). The allometric equation states that the important biomass and carbon stock of each species vary generally and are influenced by ability sequestration. This conclusion may be drawn from the diameter, value density, and height of the trees (Ariani et al. 2016). Through photosynthesis, plants take up CO_2 from the atmosphere and convert it into useful organic compounds (Handoyo et al. 2020). Other parts of Indonesia have varying total carbon stocks. The average carbon mangrove land stock in North Sulawesi is 456.86 MgC/ha (Kepel et al. 2019).

According to Alongi et al. (2016), the average carbon savings in a number of Indonesian locales are 191.23 MgC/ha in biomass above, 21.13 MgC/ha in biomass below, and 761.38 MgC/ha in sediment (Alongi et al. 2016).

With an AGB of 2,169.2 MgB/ha (73%), or 1,019.5 MgC/ha (74,6%), Station I (Mixed agroforestry) has the highest total carbon stock and AGB of the three stations. Station II (Agathis-based agroforestry) is next, with an AGB of 443.1 MgB/ha (14,92%) or 208.3 MgC/ha (15%). Station III (Pine-based agroforestry) has the lowest amount of AGB, which is 359 MgB/ha (12,08%) or 158.1 MgC/ha (11,6%) (Table 4, Figure 3). Differences in DBH values, dimensions/heights and wood density can cause discrepancies in AGB/biomass values. DBH and/or wood density of each species are needed in calculating species biomass using the allometric formula. Purwanto et al. (2021) explained that plant dimensions, namely DBH, will affect the total biomass and carbon stored; the carbon stored in tree stands will be greater than in pole stands. If the area is planted with high-density and large-diameter trees, the biomass produced will be greater than land planted with low-density and small diameters, such as poles. Variation of AGB in successional gradients is known to be significantly influenced by woody species (Ketterings et al. 2001). Differences in AGB and biomass stored at each station can also cause differences in density among plants at each location.

The study concluded that the total carbon stock in Station I (Mixed agroforestry) in Karangsambung Village, Station II (Agathis-based agroforestry) in Karangsambung Village, and Station III (Pine-based agroforestry) in Margolangu Village were 1,019.54 Mg C/ha, 208.30 Mg C/ha, 158.14 Mg C/ha, respectively. The total carbon stock of the third station was 1,385.98 Mg C/ha. The largest carbon stock (tree category) from the third station was produced by *P. merkusii* (Station I), with a carbon stock of 370.8 MgC/ha. While, *Coffea* sp. produced the largest carbon stock (pole category) from the third station with a value of 39.78 MgC/ha. The results of this study confirm that trees' crucial role as sources of carbon stocks has consequences for preventing climate change and maintaining global environmental balance. Through photosynthesis, trees and plants in forests can absorb carbon dioxide (CO_2) from the atmosphere and store it in biomass and then soil. Thus, it is critical to protect agroforestry as one of the most efficient means of lowering carbon emissions, which are the primary drivers of global warming.

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