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SPECIES DIVERSITY AND CARBON STORAGE OF UNDERGROWTH AND LITTER IN THE AGROFORESTRY SYSTEM OF NORTH SUMATERA-INDONESIA

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Abstract

The purpose of this research was to look into the diversity of species and carbon storage in agroforestry systems in the Forest for Special Purpose at Aek Nauli, North Sumatera Province, Indonesia. A total of 60 subplots, 1.0x1.0m were used to represent different undergrowth species in the agroforestry system. By identifying constituent species in the agroforestry system, the diversity of undergrowth species was studied, and the potential for biomass and carbon storage of undergrowth and litter was measured and analyzed. Undergrowth species in agroforestry *Toona sureni* and *Coffee Arabica* are significantly richer in plant species (27 species vs. 14 in agroforestry *P. Merkusii* and *C. Arabica*). The results showed that the diversity undergrowth was categorized as moderate, and the evenness indices were low, ranging from 0.33 to 44. In the agroforestry system, the mean biomass of undergrowth was 1.65 tons ha^{-1}, and the carbon storage of undergrowth was 0.43 tons ha^{-1}. Meanwhile, litter biomass was 5.18 tons ha^{-1} on average, with 2.5 tons ha^{-1} of litter carbon storage. Both biomass and carbon storage of undergrowth and litter in agroforestry *T. Sureni, and C. Arabiba vs.* P. *Merkusii and C. Arabica* are significantly different. By applying sustainable agroforestry management in forests for special purposes, this study helps with future climate change adaptation and mitigation.

***Keywords**: Diversity; Biomass; Carbon; Undergrowth; Litter; Agroforestry.*

Introduction

As is the case with many other land use systems, since the Kyoto Protocol, agro-forestry has gotten more attention as a strategy for sequestering carbon (C) and mitigating global climate change. Of all the land uses studied in the IPCC Land Use, Land Use Change, and Forestry reports, agroforestry has been identified as having the greatest potential for C sequestration. Agroforestry has a lot of promise for absorbing carbon and providing biomass for biofuels [1-3].

Research on biomassa and carbon storage in various types of land use has been carried out in Indonesia [3, 4]. However, there hasn't been much talk regarding biomass and carbon storage in forests for special purposes with agroforestry systems that have conservation value and simultaneously have an economic function.

Forest for Special Purpose (KHDTK) Aek Nauli Simalungun Regency in North Sumatera Province has an area of 1900 ha at an altitude of 1.200 meters above sea level, often used as a place for research. Based on its composition, Aek Nauli Forest is divided into two

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types: homogeneous forests with a predominance of pine stands (Pinus merkusii) and heterogeneous natural forests.

Agroforestry practices in the natural forest have been carried out by combining *Toona sureni* and *coffee arabica*, as well as many shrubs growing under tree stands. Increasing carbon stock through forest expansion can help to minimize greenhouse gas emissions. Agroforestry systems are projected to have a lot of carbon storage potential in the form of biomass [5, 6].

For two reasons, agroforestry has the ability to sequester considerable amounts of carbon.To begin with, the current crop and pastoral systems cover a wide region.Second, while carbon storage density is modest in contrast to forest, the woody biomass of the agroforestry system could provide a local fuel source.This fuel would relieve pressure on the area's surviving forests while also acting as a fossil fuel substitute.These consequences are significant since the most effective strategy to use land for atmospheric carbon stabilization is to substitute wood fuel for fossil fuel rather than reforestation [7].

Various institutions are working to reduce CO_2 concentrations through various strategies such as reducing energy use, developing low or no carbon fuel technology, and CO_2 absorption by forestry, agroforestry, and engineering [2, 5]. Among all the techniques, agroforestry is recognized as an important way to reduce CO_2 emissions and increase carbon sequestration. Agroforestry offers a one-of-a-kind chance to integrate climate change adaptation and mitigation goals [9].

Measuring biomass and carbon is critical for determining how much carbon plants can absorb [8].Quantification of vegetation carbon stocks is needed to evaluate the potential for carbon sequestration in ecosystems [5, 9]. In accordance with the set rotation time, sustainable forests would have the potential to trap carbon in increasing amounts and for longer periods of time.

The goal of this research was to (i) investigate the undergrowth species diversity and (ii) estimate biomass and carbon storage in agroforestry *Pinus Merkusii* with *Coffee Arabica* and *Toona Sureni* with *C. Arabica*, expressed in tons ha-1 of oven-dry weight/unit area.

Materials and methods

Study area

Agroforestry research site for special-purpose forest Aek Nauli in Simalungun Regency, North Sumatra, Indonesia. The survey was conducted from April to May 2016. Precipitation in the Aek Nauli region belongs to Type A according to the Smith and Ferguson classification, with an average rainfall of 2199.4 to 2452.0mm and monthly average temperatures of 23 to 24°C. This forest has a temperature range of 2 to 24°C.At 15%, it is divided into flat areas and flat valleys in the hills.

Research material

Agroforestry in Forests for Special Purposes The Aek Nauli-North Sumatera region was established. *Coffee arabica* was planted under *Toona Sureni* Merr and *Pinus Merkusii*. Differences in shade tree species may have an impact on undergrowth and litter species diversity, biomass, and carbon storage.The focus of the research was on species diversity and carbon storage in the agroforestry system's undergrowth and litter. A tally sheet, digital cameras, raffia rope, GPS (Global Positioning Systems), a compass, a wooden cane or bamboo, machetes, and a wooden quadrant were among the tools utilized in this study.

Materials used in this research were *T. Sureni, P. Merkusii, and Coffee Arabica*. T. sureni and T. merkusii are 3.0x2.0m apart, while *C. Arabica* and *P. Merkusii* are 3.0x3.0m apart. While *T. Sureni* is 14 years old, *C. Arabica* is 4-5 years old, and *P. Merkusii* is 12–14 years old.

Techniques of data collection

According to the agroforestry system's plant species, a total of 6 plots measuring 20x100m were installed. Placements of plots were conducted by systematic random sampling. Ten 1.0x1.0m subplots were employed for each sample plot to quantify species diversity, biomass, and carbon storage of undergrowth species and litter. The arrangement and size of sample plots and subplots are depicted in figure 1.

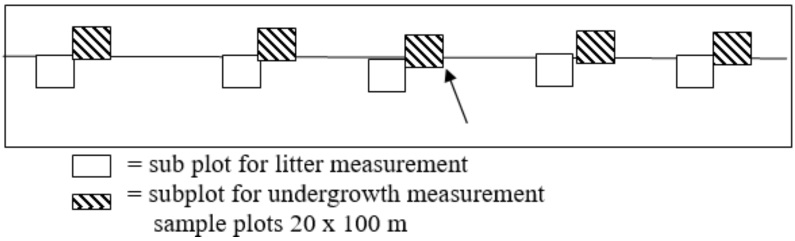


Fig. 1. The size and shape of the plots and subplots

Data Analysis

The Importance Value Index (IVI). The Importance Value Index is used to determine the species composition and dominating species in agroforestry undergrowth [10-12]:

$$IVI = RD + RF \qquad (1)$$

where: *RD* stands for Relative Density, and *RF* is for Relative Frequency.

As detailed in [10] and [12], we examined the regeneration status of all species of undergrowth and recorded density, frequency, relative density, relative frequency, and value of importance (IV).

*Indices of Diversity and Evenness***.** The Shannon-Wiener Diversity Index (H') was used to assess species diversity [10-14]:

$$H' = -\sum_{i=1}^{n} {}^{s}\, pi \ln pi \qquad (2)$$

where: *H'* represents the Shannon-Wiener Diversity Index, *S* represents the number of species, pi represents the fraction of individual species, and ln is the log base n.

When *H'* denotes a lack of diversity, *H'* > 1 and 3 indicate moderate diversity, and *H'* > 3 denotes a high level of variety. The species evenness index determines the level of undergrowth species evenness in agroforestry [10, 14]:

$$E' = \underline{H}`\ln (S) \qquad (3)$$

where: *E'* is the species evenness index, *H* denotes the Shannon-Wiener Diversity Index, and *S* denotes the total number of species. When *E'* is 0.5–1.0, the species evenness index is high, and when *E'* is 0.0-0.5, the species evenness index is low.

Consequently, the larger the value of E', the more uniformly the species is dispersed in the community.

Measurement of biomass and carbon storage

The direct and indirect approaches [2, 15, 16] are the two most often used approaches for estimating biomass.The direct or destructive method entails harvesting or retrieving the entire litter and undergrowth vegetation and directly weighing each component to determine its biomass. To estimate biomass in this study, a destructive sample method (or harvesting approach) was applied. Harvesting all of the components allowed the biomass of understory vegetation and litter to be measured [17].

The destructive sampling method is more accurate than using an allometric equation to estimate undergrowth vegetation and litter biomass. Because all of the generated allometric equations are fitted (derived) using the destructive sampling method [18], all of the developed allometric equations are derived from biomass data. The undergrowth littter biomas and carbon storage were calculated using equations as follows:

The following formula was used to compute the percentage of water content (WC) [3].

$$WC\ (\%) = 100x(FW\text{-}ODW)/ODW, \quad (4)$$

where: *WC* (%) denotes the percentage of water content, *ODW* denotes the oven dry weight of the test sample (g), and *FW* is the fresh weight of the test sample (g).

The following equation is used to calculate biomass based on water content data [3]:

$$ODW = FW\ x\ [\ 1 + (WC)/100], \quad (5)$$

where: *ODW* denotes the test sample's oven dry weight (g); *FW* denotes the sample's fresh weight (g), and % *WC* = water content percentage.

Levels of volatile were calculated based on the following equations:

$$Volatile\ substances\ (\%) = 100x(A - B)/A, \quad (6)$$

where: A = the dry weight of the furnace at 105°C, B = the weight of the sample used in the test.

The following formula is used to determine the amount of ash in a product:

$$Ash\ content\ (\%) = ash\ weight\ x\ 100 \quad (7)$$

Determination of carbon content bound (fixed carbon) was calculated with the following formula:

$$Fixed\ carbon\ content\ (\%C) = 100 - Volatile\ substances\ (\%) - Ash\ content\ (\%) \quad (8)$$

The following formula is used to calculate carbon from biomass [3]:

$$Cb = B\ x\ \%C \quad (9)$$

where: Cb = carbon storage (tons/ha), B = Total biomass (tons/ha), %C = Fixed carbon content (laboratory measurements).

Independent Sample t test

The Independent Sample t test examines the meanings of the two independent groups to see if statistical evidence exists that the related population means are significantly different. The Independent Samples t Test's null hypothesis (H_0) and alternative hypothesis (H_1) can be presented in two different but comparable ways [19]:

H_0: *1 = 2* ("the two population means are the same") and H_1: $\mu_1 \neq \mu_2$ ("the two population means are not equal").

If the p-value of the t test is greater than the 0.05 significance level, no significant difference between the two population means exists. On the other hand, there is a significant difference between the two population means if the p-value of the t test is less than 0.05.

Results and Discussion

Important Value Index (IVI)

An *IVI*, in general, is a quantitative parameter used to express the level of dominance of a species in a plant community. The sum of relative frequency and relative density was used to calculate the *importance value index (IVI)* of understorey species. Each of these numbers is a percentage that ranges from 0 to 100.The larger a species' INP value, the greater its dominance over the community, and vice versa.

Regarding species in this study area, the number of undergrowth vegetation at Agroforestry *T. Sureni* with *C. Arabica* is 27 species. While the number of undergrowth vegetation species at Agroforestry *P. Merkusii* and *C. Arabica* is 14 species, *Ageratum conyzoides* has the highest number of individus (1121 individus), while *Crassocepalum crepidioides*, *Emilia sonchifolia*, *Chromolaena odorata,* and *Colopogonium mucunoides* have the lowest number of individus at Agroforestry *T. sureni* and *C. arabic*. The results showed that *Paspalum conyugatum* has the highest number of individus (807), as undergrowth vegetation at Agroforestry *P.merkusii* with *C. Arabica*, while *Mimosa diplotica* and *Centella asiatica* have the lowest number of individus (3 individus).

The quantitative structure depicted by the *Importance Value Index (IVI)* is distinct in each plot viewed, according to formula 1. *Ageratum conyzoides*, *Bidens chinensis, and Borreria latifolia are the dominant undergrowth species in agroforestry T. sureni and C. Arabica.* The IVI of these species was 28.7; 21.3; and 17.55, respectively. While the lower IVI was dominated by Colopogonium mucunoides and Crassocepalum crepidioides (2.16), followed by Drymaria hirsuta and Chromolaena odorata (2.18) (Fig. 2).

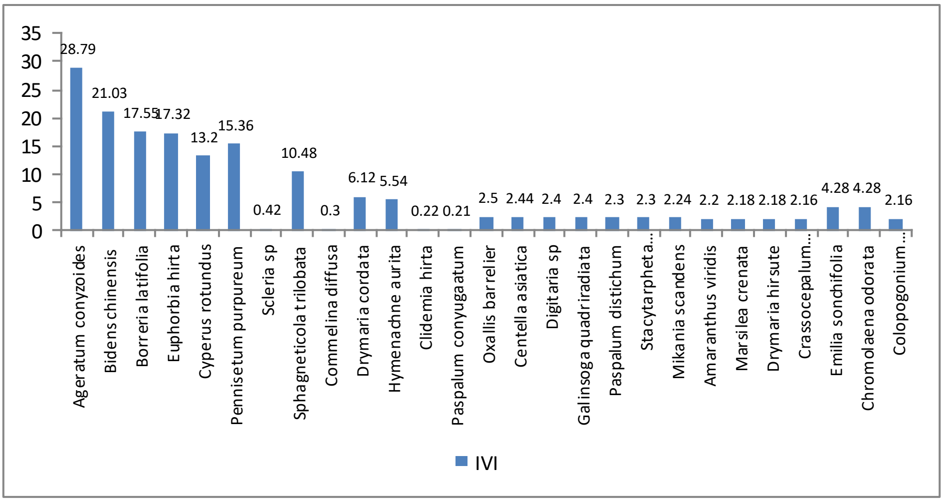


Fig. 2. The important value Index (IVI) of undergrowth species at Agroforestry *T. Sureni and C. Arabica*

Whereas the *important value index (IVI)* of undergrowth species at Agroforestry *P. Merkusii* and *C. Arabica* were dominated by several undergrowth species, including *Paspalum conyugatum* (56.59%), followed by *Elephantopus scaber* (30.6%), while the lower IVI was dominated by *Centella asiatica* (3.72%) (Fig. 3).

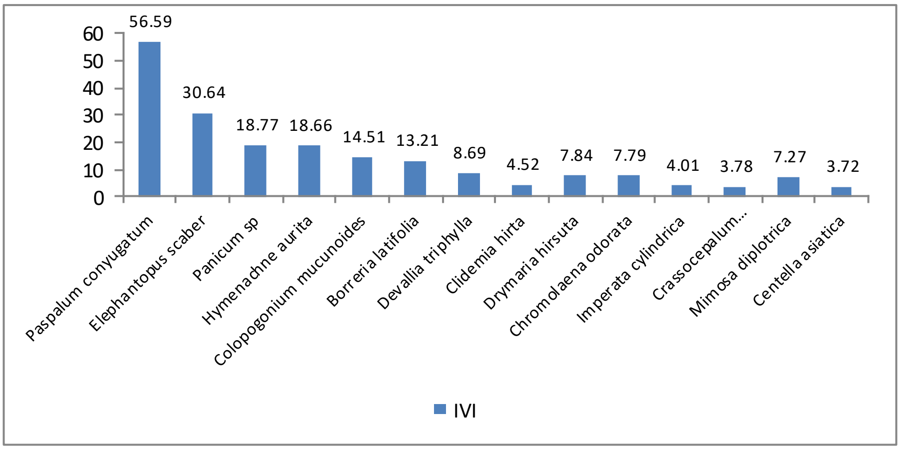


Fig. 3. The results of the calculation of the important value index (IVI) of understorey species in *P. Merkusii* and *C. Arabica* Agroforestry

Diversity and evenness indices

Undergrowth diversity was categorized as moderate using Formula 2 and 3, with a value of 2.29 in agroforestry *C. Arabica* and *T. Sureni* and 1.62 in agroforestry *C. Arabica* and P. *Merkusii*. All of the research plots had low evenness indices, with values ranging from 0.33-0.44. As a result, the higher the H value, the more diversified the area's species [11, 14].

Among the species present in both agroforestry systems, *P.merkusii* with *C. arabica* and T. *sureni* with *C. arabica*, are *Colopogonium mucunoides, Barreria latifolia, Drymaria hirsute, Crassocepalum crepidioides, Chromolaena odorata, Clidemia hirta, Centella asiatica,* and *Paspalum conyugatum*. Species found in these two locations tend to have a wide tolerance range for light intensity and allelopathic substances, which are considered very important factors that affect the growth of undergrowth. Elephantopus scaber, Devallia triphylla, Panicum sp, Imperata cylindrica, and Mimosa diplotica were exclusively found in agroforestry *P. merkusii* with *C. Arabica*.

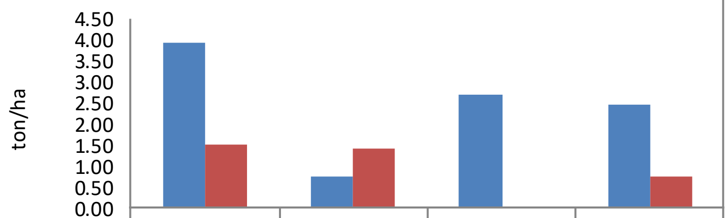
This is presumably because these types are tolerant of allelopathic substances which can inhibit growth [20, 21]. Plants use allelopathy as a chemical mechanism to prevent other plants from growing too close to them. Some pine trees are allelopathic. When their needles fall to the ground, they allelopathically inhibit the growth and development of other plants, reducing their productivity [21].Allelopathy has positive and negative effects from one plant on another through the environment, although most studies seem to focus on its negative effects. It plays a key role in natural and managed ecosystems [21, 22].

According to [11], enrichment planting has been used successfully in the tropics to recover degraded forests.The number of species and families in the regeneration location through enrichment planting shows that the silvicultural approach to recovering soil nutrients as a means of sustainable forest management has the greatest influence on tree species diversity. Biodiversity indices are used to compare the quantity and diversity of species in various ecosystems, and the higher the value, the greater the species richness [22 23].

Biomass and carbon of undergrowth species in agroforestry system

Above-ground biomass and below-ground biomass are the two types of biomass that can be found [5, 6]. We don't include estimates of belowground biomass in this situation.The information in this study was used to calculate the biomass and carbon storage of undergrowth and litter vegetation in agroforestry systems with various tree crops.The amount of organic matter generated by an organism per unit area at a given period is referred to as biomass potency [24, 25].

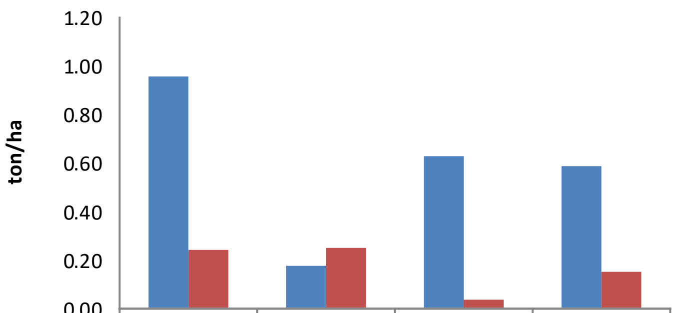
The undergrowth includes shrubs with stem diameters of 5 cm, creepers, weeds, or weeds. Estimates of undergrowth biomass are carried out by taking parts of plants or by being destructive [24]. Total biomass undergrowth varied greatly between plots, ranging from 0.2 to 6.78 tons ha^{-1}, as shown in figure 4. The average biomass undergrowth for all plots in both types of agroforestry was 1.65 tons ha^{-1}. The average biomass undergrowth in agroforestry T. *Sureni* and *C. Arabica* is greater than in agroforestry P. *Merkusii* and *Arabica*. We can reject the null hypothesis since the p-value (0.03) is smaller than the 0.05 significance level, indicating that the biomass undergrowth in agroforestry *T. Sureni* and *C. Arabica* vs. P. *Merkusii* and *C. Arabica* is significantly different.



	Plot 1	Plot 2	Plot 3	average-plots 123
Agroforestry C. arabica & T. sureni	3.91	0.77	2.70	2.46
Agroforestry C. arabica & P. merkusii	1.52	1.44	0.00	0.78

Fig. 4. Average biomass of undergrowth in the observed plots

As presented in Figure 5, total carbon storage in undergrowth varies greatly between plots, ranging from 0.04 to 1.62 tons ha^{-1}.



	Plot 1	Plot 2	Plot 3	average - plots 123
Agroforestry C. arabica & T. sureni	0.96	0.18	0.63	0.59
Agroforestry C. arabica & P. merkusii	0.24	0.25	0.04	0.15

Fig. 5. Average carbon storage of undergrowth in the observed plots

The mean carbon storage of undergrowth for all plots in both types of agroforestry was 0.43 tons ha^{-1}. Agroforestry *T. Sureni* and *C. Arabica* has a higher average carbon storage undergrowth than agroforestry *P. Merkusii* and *C. Arabica*. We may reject the null hypothesis since the p-value (0.006) is smaller than the 0.05 significance level, indicating that the carbon storage of undergrowth in agroforestry *T. Sureni* and C. *Arabica* vs. *P. Merkusii* and *C. Arabica* is significantly different. This is influenced by the presence of more biomass undergrowth in agroforestry *T. Sureni* and *C. Arabica* than in agroforestry *P. Merkusii* and *C. Arabica*. In addition, the amount of undergrowth at agroforestry *T. Sureni* and *Arabica* is greater than at agroforestry P. *Merkusii and C. Arabica*. Our findings reveal a complex and varied link between biomass and species diversity in the agroforestry system of North Sumatra, Indonesia. Some plots with limited diversity had a lot of biomasses, whereas others with a lot of diversity had a lot of biomasses [2, 24-26].

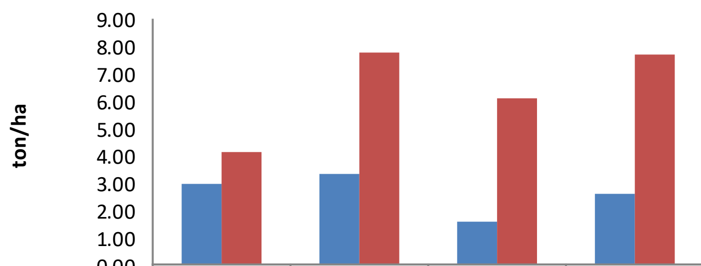
The amount of litter found in pine stands, such as leaves, which also contain allelopathic substances, can inhibit the growth of the understorey. This makes the amount of undergrowth in pine stands less than undergrowth in agroforestry (*C. Arabica* and *T. Sureni)*. Some types of plants, such as red pine (*Pinus densiflora* Sieb, et Zucc), contain allelopathic compounds that affect the diversity of undergrowth that inhibit the growth of other individual plants. Allelopathic chemical interaction determines the formation of the forest floor [27].

Changes in ground vegetation biomass are usually connected to competition with overstory trees for light, soil water, or nutrients, according to another study [28, 29]. Light blocking by tree canopies has been found to be the most important environmental element in most northern forest ecosystems [30]. All of these writers agree that in an agroforestry system, a more open canopy (less shadow) leads to higher ground vegetation biomass as well as diversified undergrowth and litter carbon storage [7, 10, 31, 32]. In forests, herbaceous strata contribute to primary production, nutrient supply, carbon stock, and species diversity, as well as providing food and habitat for other forest organisms [31].

Biomass and carbon of litter in agroforestry system

Litter is a layer that consists of parts of plants that have died, such as falling leaves, twigs and branches of flowers, fruit, flowers, bark, and other parts that spread on the surface under the forest floor before the material decomposes [27].

Figure 6 shows how the total biomass of litter varied greatly between plots, ranging from 0.49 to 14.14 tons ha^{-1}.



	Plot 1	Plot 2	Plot 3	average - plots 123
Agroforestry C. arabica & T. sureni	2.99	3.38	1.62	2.66
Agroforestry C. arabica & P. merkusii	4.14	7.78	6.13	7.7

Fig. 6. Average biomass of litter in the observed plots

The average litter biomass from all sample plots in both types of agroforestry was 5.18 tons ha^{-1}. According to Figure 6, the average litter found in agroforestry *C. Arabica and P. Merkusii* was 7.70 tons ha^{-1}. It was greater than Agroforestry *C. Arabica* and *T. Sureni* (2.66 tons ha^{-1}). The difference in the total value of biomass of litter in both stands is 5.04 tons ha$^{-1.}$ The difference in litter biomass in the two stands is due to the greater amount of litter found in the *P. Merkusii* stands. We can reject the null hypothesis since the p-value (0.00006) is lower than the 0.05 significance level, indicating that the biomass of litter in agroforestry *T. Sureni* and *C. Arabica* and *P. Merkusii* and *C. Arabica* is significantly different.

Figure 7 shows how total carbon storage in litter varies greatly between plots, ranging from 0.22 to 7.18 tons ha-1. The average amount of litter carbon from all sample plots in both types of agroforestry was 2.5 tons ha^{-1}. Litter carbon storage in the agroforestry system of *P. Merkusii* and *C. Arabica* is greater than in the agroforestry system of *T. Sureni* and *C. Arabica*.We may reject the null hypothesis because the p-value (0.00002) is lower than the 0.05 significance level, and we can conclude that the carbon storage of litter in agroforestry T. sureni and *C. Arabica* and *P. Merkusii* and *C. Arabica* is significantly different. The difference in the amount of carbon storage is influenced by the dry mass of litter in agroforestry by *P. Merkusii and C. Arabica*. This difference is also influenced by the ability of forest ecosystems to store and absorb carbon based on the type of vegetation, vegetation composition, topography, and growing place [11, 24, 31] .

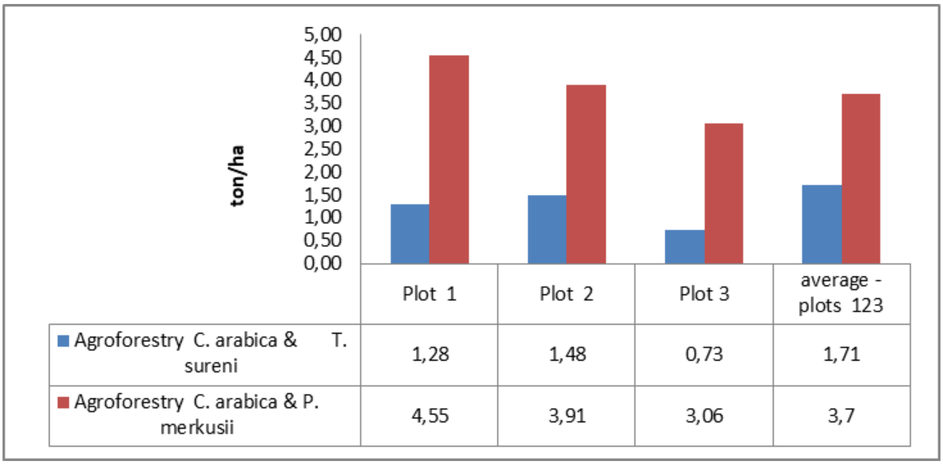


Fig. 7. Average carbon of litter in the observed plots

The amount of litter in the two types of agroforestry is different. This is due to the fact that the canopy covers in the two stands are different.The canopy of *P. Merkusii* stands closed is thicker than the canopy cover of *T. Sureni*, so that the amount of dry mass produced in the form of leaves, twigs, and branches of dead trees is greater in *P. Merkusii* stands. According to [31], thin canopy stands produce less litter than thick canopy stands, and vice versa.

Another researcher mentioned that the amount of carbon in herb and moss layers in different forest stands is very diversified [18, 32]. The amount of biomass and carbon stock in terms of trees and shrubs, as well as medicinal plants and mosses, differs from each species [34]. Because the forest is affected by a wide range of physical, climate, and other natural disturbances, geostatistics is increasingly being employed in forest ecology, including forest biomass estimation [31].Carbon storage models in forest ecosystems must take this variability into account [36].Temporal changes in the structure and composition of forest communities must be considered on an ongoing basis [35].

It is vital to estimate vegetative carbon storage in order to assess the ecosystem's potential for carbon sequestration. formalized [5, 30, 37, 38] Formalized paraphraseformalized paraphrase The ecological function of forests in absorbing carbon has the potential to play a significant role in resolving global environmental issues such as atmospheric GHG accumulation and climate change. The positive association between biomass and species diversity has substantial policy implications, and it should back up assertions that REDD schemes can provide large biodiversity conservation co-benefits [9, 14, 22]. Maintaining intact forest ecosystems, including genetic diversity and understorey species, is essential [5, 14, 38, 39] .

This is owing to the importance of forests, particularly agroforestry, in a variety of ecosystem services, such as the global carbon cycle, their enormous carbon stock, and their contribution to adaptation, all of which are critical for human well-being. Agroforestry offers a unique potential to boost C supplies in the terrestrial biosphere, according to research findings from around the world [10, 24, 31].

Conclusions

This study showed that undergrowth species in Agroforestry *T. Sureni* and *C. Arabica in Aek Nauli-North Sumatera* have a more diverse population compared to undergrowth species in Agroforestry *P. Merkusii* and *C. Arabica* in the same locality. Agroforestry T. Sureni and C. Arabica has a somewhat higher biomass and carbon storage capacity than agroforestry P. Merkusii and C. Arabica. While the biomass and carbon content of litter are marginally higher in P. Merkusii and C. Arabica agroforestry than in T. Sureni and C. Arabica agroforestry.In an agroforestry system, the kind of stand has a considerable impact on the amount of undergrowth and litter biomass.The global carbon cycle relies heavily on biomass and carbon storage in forest ecosystems. Agroforestry has the potential to reduce CO2 levels in the atmosphere by storing carbon in the undergrowth and trash.

The research findings offered in this study, we feel, will be valuable in addressing the protection of undergrowth and litter species diversity, as well as providing a foundation for studying ecology in agroforestry systems. More research is needed, however, to consider the potential of agroforestry for biodiversity conservation, as well as timber and non-timber production, in order to support sustainable forest management and important ecosystem services.

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References

[1] S. Jose, M.A. Gold, H.E. Garrett, *Agroforestry: The Future of Global Land Use,* (Editors: P.K.R. Nair and D. Garrity), **Springer, The Netherlands,** 2012. pp. 217–246.

[2] Latifah, Siti, Muhdi, A. Purwoko, E. Tanjung, *Estimation of aboveground tree biomass Toona sureni and Coffea arabica in the agroforestry system of Simalungun, North Sumatra, Indonesia*, **Juornal of Biodiversitas**, **19**(2), 2018, pp. 670-675.

[3] K. Hairiah, S. Dewi, F. Agus, S. Velarde, A. Ekadinata, S. Rahayu, M. Noordwijk, **Measuring Carbon Stocks Across Land Use Systems: A Manual,** Bogor, Indonesia. World Agroforestry Centre (ICRAF), SEA Regional Office, 2011, 154p.

[4] D. Murdiyarso, U. Rosalina, K. Hairiah, L/ Muslihat, I.N.N. Suryadiputra, A. Jaya, *A Field Guide: Estimation of Carbon of Peatland,* **Wetlands International-Indonesia Programme and Wildlife Habitat Canada**, Bogor, Indonesia, 2004, p. 42.

[5] B.M. Kumar, P.K.R. Nair, **Carbon Sequestration Potential of Agroforestry Systems: Opportunities and Challenges**, Springer, Netherlands, 2011, p. 307.

[6] P.K.R. Nair, V.D. Nair, B.M. Kumar, J.M. Showalter, *Carbon sequestration in agroforestry systems.* **Advanced in Agronomy, 108**, 2010**,** pp. 237–307, https://doi.org/10.1016/S0065-2113(10)08005-3.

[7] S.K. Dhyani, A. Ram, I. Dev, *Potential of agroforestry systems in carbon sequestration in India*, **Indian Journal of Agricultural Sciences, 86**(9), 2016, pp. 1103-1112.

[8] J.Q. Yuen, T. Fung, A.D. Ziegler, Review *of allometric equations for major land covers in SE Asia: uncertainty and implications for above-and below-ground carbon estimates*, **Forest Ecology and Management, 360**, 2016, pp. 323-340.

[9] I.M. Becknell, A.R. Desai, M.C. Dietze, C.A. Schultz, G. Starr, P.A. Duffy, J.F. Franklin, A. Pourmokhtarian, J. Hall, P.C. Stoy, M.W. Binford, L.R. Boring, C.L. Staudhammer, *Assessing Interactions Between Changing Climate, Management, and Disturbance in Forests*: A *Macrosystem Approach*, **BioScience, 65**(3), 2015, pp. 263–274, https://doi.org/10.1093/biosci/biu234.

[10] S.A. Paembonan, S, Millang, A Umar, *Species diversity and carbon storage in agroforestry system of Toraja highland Indonesia*, **IOP Conf, Series: Earth and Environmental Science, 343**(1), 2019, Article Number: 012048.

[11] A, Lawal, V.A.J. Adekunle, *A silvicultural approach to volume yield, biodiversity and soilfertility restoration of degraded natural forest in South-West Nigeria*, **International Journal of Biodiversity Science, Ecosystem Services & Management, 9**(3), 2013. pp. 201-214, https://doi.org/10.1080/21513732.2013.823464.

[12] Md.H, Rahman, Md.A.S.A. Khan, B. Roy, M.J. Fardusi, *Assessment of natural regeneration status and diversity of tree species in the biodiversity conservation areas of Northeastern Bangladesh*, **Journal of Forest Research Ecosystem management, 22**(4), 2011, pp. 551-559.

[13] A.D. Agbelade, B.H. Ojop, *Species Diversity, Volume Determination and Structure of Protected Forests for In-Situ Biodiversity Conservation*, **International Journal of Conservation Science, 11**(1), 2020, pp. 133-144.

[14] M. Day, C. Baldauf, E. Rutishauser, T.C.H. Sunderland, *Relationships between tree species diversity and above-ground biomass in Central African rainforests: Implications for REDD*. **Environmental Conservation**, **41**(1), 2014, pp. 64-72.

[15] Vahedi, A, A, Mataji, A, Hodjati, S, M, Djomo. *A, Allometric equations for predicting aboveground biomass of beech hornbeam stands in the Hyrcanian forests of Iran,* **Journal of Forest Science**, **60**(6), 2016, pp. 236–24.

[16] A. Lima, R. Suwa, G.H. Pires de Mello Ribeiro, T. Kajimoto, J. Dos Santos, R. Pereira da Silva, C.A. Sampaio de Souza, P. Castro de Barros, H. Noguchi, M. Ishizuka, N. Higuchi, *Allometric models for estimating above-and below-groundbiomass in Amazonian forests at Sao Gabriel da Cachoeira in the upper Rio Negro, Brazil,* **Forest Ecology and Management, 277**, 2012, pp. 163–172.

[17] V.T. Nam, M. Van Kuijk, N.P.R. Anten, *Allometric equations for aboveground and belowground biomass estimations in an evergreen forest in Vietnam,* **PloS One, 11**(6), 2016, Article Number: e0156827, DOI: 10.1371/journal.pone.0156827.

[18] X. Gao, Z.H. Jiang, Q.R. Guo, Zhang Y, Yin H, He F, Qi LH, Shi L, *Allometry and biomass production of Phyllostachys edulis across the whole lifespan,* **Polish Journal of Environ-mental Studies, 24**(9), 2015, pp. 511–517.

[19] E.M. Mutiara, **Computer Based Statistics for Non Statistical People**, Elex Media Komputindo, Gramedia Publising, Jakarta Indonesia, 2015, p. 367.

[20**]** M. Sato, *Allelopathy of pine litter: Delivery of allelopathic substances into the forest floor*, **Journal of Plant Biology, 58**(1), 2015, p. 61–67.

[21] A.A.P.M. Azania, C.A.M. Azania, P.L.C.A. R. Palaniraj, H.S. Canadian,S.C. Sati, L.S. Ravat, D.S. Dahiya, S.S. Narwal, *Allelopathic Plants, Sunflower (Helianthus annuus L)*, **Allelopathy Journal, 11**(1), 2003, pp. 1-20.

[22] P. Anderson, I. Santoso, B. Steni, A. Mahaningtyas, E. Mansur, M. Ahmad, D. Elson, *Tenure, governance, and climate change,* **Tropical Forest**, **20**(4), 2011, pp. 17–18.

[23] S.M. Shirley, Z. Yang, R.A. Hutchinson, J.D. Alexander, K. McGarigal, M.G. Betts, *Species distribution modelling for people: unclassified landsat TM imagery predicts bird occurrence at fine resolutions,* **Diversity and Distributions**, **19**(7), 2013, pp. 855-866. DOI:

[24] S. Latifah, Y. Afifuddin, S. Widya, *Analysis of Community Income on Suren (Toona sureni (Blume) Merr,) and Cacao Crops Theobroma cacao L,) in Simalungun, North Sumatera-Indonesia,* **IOP Conference Series: Earth and Environmental Science**, **122**(1), 2018, Article Number: 012140.

[25] K. Haruni, C.A. Wahyu, R. Imanuddin, **Allometric Models for Tree Biomass Estimation on Different Types of Forest Ecosystems in Indonesia,** Publisher: Research and

Development Center for Conservation and Rehabilitation, Forestry Research and Development Agency, Bogor, Indonesia, 2012.
[26] L. Jost, *Diversity the Relation between Evenness and Diversity*, **Diversity, 2**(2), 2010, pp. 207-232.
[27] F. Kimura, M. Sato, H. Kato-Noguchi, *Allelopathy of pine litter: Delivery of allelopathic substances into forest floor,* **Journal of Plant Biology, 58**(1), 2015, pp. 61–67, DOI: 10.1007/s12374-014-0322-8.
[28] Y. Zhang, X.H. Yue, L.H. Qi, Z.H. Jiang, L. Shi, *Estimation of Phyllostachys edulis forest biomass in southern Wuyishan Mountain using allometric equation and geostatistical technique*, **Chinese Journal of Ecology, 359**(1), 2016, pp. 1957–1962.
[29] J. Zhao, F. Kang, L. Wang, X. Yu, W. Zhao, X. Song, Y. Zhang, F. Chen, Y. Sun, T. He, H. Han, *Patterns of biomass and carbon distribution across a chronosequence of Chinese pine (Pinus tabulaeformis) forests*, **PLoS One, 9**(4), 2014, Article Number: e94966.
[30] A. Ali, D. Dai, K. Akhtar, M.J. Teng, Z. Yan, N. Urbina-Cardona, J. Mullerova, Z.X. Zhou, *Response of understory vegetation, tree regeneration, and soil quality to manipulated stand density in a Pinus massoniana plantation*, **Global Ecology and Conservation, 20**, 2019, Article Number: e00775. https://doi, org/10,1016/j, gecco,2019, e00775
[31] D. Thom, W. Rammer, R. Seidl, *The impact of future forest dynamics on climate: Interactive effects of changing vegetation and disturbance regimes*, **Ecological Monographs, 87**(4), 2017, p. 665–684.
[32] R. Baishya, S.K. Barik, *Estimation of tree biomass, carbon pool, and net primary production of an old-growth Pinus kesiya Royle ex, Gordon forest in north-eastern India*, **Annals of Forest Science**, **68**, 2011, pp. 727–736.
[32] A. Ahmad, Q. Liu, S.M. Nizami, A. Mannan, S. Saeed, *Carbon emission from deforestation, forest degradation and wood harvest in the temperate region of Hindukush Himalaya, Pakistan between 1994 and 2016*, **Land Use Policy, 78,** 2018, pp. 781-790.
[33] H.J. Kim, J.B. Jung, Y.L. Jang, J.H. Sung, P.S. Park, *Effects of experimental early canopy closure on the growth and reproduction of spring ephemeral Erythronium japonicum in a montane deciduous forest,* **Journal of Plant Biology, 58**(3), 2015, pp. 164–174.
[34] A. Parzych, Z. Sobisz, *Biomasa i produkcja pierwotna netto roślin runa w wybranych zespołach leśnych Słowińskiego Parku Narodowego, [Biomass and net primary production of herbaceous plants in chosen forest associations in the Słowiński National Park*], **Ochrona środowiska i Zasobów Naturalnych, 42,** 2010, pp. 72–83. [in Polish].
[35] B. Woziwoda, A. Parzych, D. Kopeć, *Species diversity, biomass accumulation and carbon sequestration in the understorey of post-agricultural Scots pine forests,* **Silva Fennica, 48**(4), 2014, Article Number: 1119, DOI: 10.14214/sf.1119.
[36] S. Latifah, N. Sulistiyono, *Carbon Sequestration Potential in Aboveground Biomass of Hybrid Eucalyptus Plantation Forest*, **Journal of Tropical Forest Management**, **19**(1), 2013, pp. 54-62.
[37] L. Banin, T.R. Feldpausch, O.L. Phillips, T.R. Baker, J. Lloyd, K.M. Affum-Baffoe, E.J.M.M. Arets, N.J. Berry, M. Bradford, R.J.W. Brienen, S. Davies, M. Drescher, N. Higuchi, D. Hilbert, *Testing environmental, structural and floristic drivers*, **Global Ecology and Biogeography**, **21**(12), 2012, pp. 1179–1190.
[38] B.O. Adetola, E.E. Ofuya, *Evaluating the mitigation measures to biodiversity Threats in cross river national park, Nigeria,* **International Journal of Conservation Science, 12**(1), 2021, pp. 237-246.
[39] M.H. Ismail, M.F.A. Fuad, P.H. Zaki, N.J. Naim Emali, *Analysis of importance value index of unlogged and logged peat swamp forest in Nenasi Forest Reserve, Peninsular Malaysia*, **Bonorowo Wetland, 7**(2), 2017, pp. 74-78.

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