JURNAL ILMU LINGKUNGAN
Volume 22 Issue 1 (2024) :93- 99 ISSN 1829-8907

# The Composition, Structure, and Standing Carbon Stock of Teak Based Agroforestry Systems in Gundih, Grobogan Regency, Central Java

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**ABSTRAK**

Sistem agroforestri berbasis jati di Gundih, Kabupaten Grobogan, Provinsi Jawa Tengah berpotensi setara dengan hutan sekunder, berdasarkan keanekaragaman hayati, cadangan karbon, dan kegunaannya. Terbatasnya penelitian mengenai analisis vegetasi pohon pada sistem agroforestri berbasis jati mendorong dilakukannya penelitian ini. Penelitian ini bertujuan untuk mengetahui komposisi dan struktur vegetasi komunitas pohon pada sistem agroforestri di Kawasan Gundih. Metode penelitian menggunakan petak (kuadrat) dengan ukuran 20 x 20 m$^2$, dan luas pencuplikan sebesar 1 ha serta peletakan petak dengan metode *Purposive Sampling*. Hasil penelitian menunjukan terdapat 12 jenis pohon dari 9 famili dengan jumlah total individu yaitu 341 individu/ha. Dua jenis pohon dengan Indeks Nilai Penting tertinggi adalah *Tectona grandis* L.f (93,48) dan *Swietenia mahagoni* (L.) Jacq (66,78). Indeks Keanekeragaman menunjukan bahwa komunitas tumbuhan pada sistem agroforestri di Kawasan Gundih tergolong sedang dengan nilai H’1,81. Simpanan karbon tegakan pohon pada pada sistem agroforestri di Kawasan Gundih adalah sebesar 64,43 MgC/ha. Dapat disimpulkan bahwa agroforestri berbasis jati berpotensi dijadikan opsi untuk konservasi lingkungan.

***Kata kunci***: Agroforestri, Jati, Stok Karbon, Keanekaragaman, Pohon

**ABSTRACT**

The teak-based agroforestry system in Gundih, Grobogan Regency, Central Java Province is potentially equivalent to a secondary forest, based on the biodiversity, carbon stock, and utility. This study is prompted by the lack of research on tree vegetation analysis in teak-based agroforestry systems. The aim of this study is to determine the composition and structure of tree vegetation in agroforestry systems within the Gundih area. The research method used plots measuring 20 x 20 m$^2$, in a sampling area of 1 ha and with plot placement using the Purposive Sampling method. The results show that there are 12 tree species from 9 families with a total population of 341 trees/ha. The two tree species with the highest Important Value (IV) are *Tectona grandis* L.f (93,48) and *Swietenia mahagoni* (L.) Jacq (66,78). The tree diversity of teak-based agroforestry systems is classified as moderate with an H’ value of 1,81. The carbon stock of tree stands in the agroforestry system is 64,43 MgC/ha. It can be concluded that teak-based agroforestry has the potential to be an option for environmental conservation.

***Keywords***: Agroforestry, Teak, Carbon stock, Diversity, Tree

***Citation**:* Santhyami., Isnaini, A. K. (2024). The composition, structure, and standing carbon stock of teak based agroforestry systems in Gundih, Grobogan Regency, Central Java. Jurnal Ilmu Lingkungan, 22(1), 93-99, doi:10.14710/jil.22.1.93-99

## 1. Introduction

Agroforestry is a system of land utilization that includes the planting and maintenance of perennial woody plants alongside crops or animals. The various different components of this system are thus designed to interact and provide both ecological as well as economic benefits (ICRAF, 1993). There two most prevalent types of agroforestry systems found in Indonesia are as follows: 1) simple agroforestry, where perennial woody plants considered beneficial are planted either randomly or other various patterns and used: as: planted fences, shade plants, or windbreaks; 2) complex agroforestry where several types of trees are planted concurrently often times mimicking natural forest ecosystems (Hairiah et al., 2015; Utomo, 2020). Tree coverage must be at least ten percent of total area of cultivated land to be considered as an agroforestry system, with average tree coverage of >30% common to southeast Asia (ICRAF, 1993).

The spread of trees inherent to agroforestry systems mimic the effect of natural forests and can provide various benefits. The ecological benefits include: 1) controlling the damage from both wind and water-based erosion, 2) providing natural compost from the organic waste produced by agroforestry activities, 3) providing habitat for fauna, 4) absorbing carbon dioxide and other heavy pollutants form the air (Yulliana & Syafrudin, 2021), 5) cooling local temperatures and maintaining humidity (Candra et al., 2019; Aprilia et al., 2021). Aside from the pivotal ecological role trees serve, there are non-ecological benefits such as both natural and agroforestry provide community recreational and educational facilities (Saroh & Krisdianto, 2020).

The most common form of agroforestry in Indonesia is intercropping, locally known as *Tumpangsari* whereby both grain and non-grain crops are grown in the alleys and corridors between trees. In the Wonogiri Regency, rhizome plants such as turmeric (*Curcuma longa* L.) and temulawak (*Curcuma zanthorrhiza* Roxb.) (Ratri et al., 2015) are most prevalent; while in Gundih, Grobogan Regency, the primary crops are grain. A unique form of *tumpangsari* specific for the industrial production of teak (*Tectona grandis* L.f) is known as *Taungya* (Widiyanto, 2016).

Several studies on agroforestry have made comparisons between agroforestry systems and secondary forests. The Diversity Index measured in various agroforestry systems is variably between low to moderate range. This is comparable to secondary forest, as is demonstrated by the following studies: 1) secondary forests in Labanan, east Kalimantan have a diversity index of 2.99 (Karmilasanti & Fajri, 2020), 2) secondary forests in Powela, Central Sulawesi have a diversity index of 2.0 (Naharuddin, 2020). In addition to maintaining biodiversity, agroforestry also sequester carbon on par with secondary forests as demonstrated by Santhyami et al (2018,2021) comparing cocoa-rubber based agroforestry systems (61,89 MgC/ha) and cocoa-coconut based agroforestry systems (103,42 MgC/ha) with secondary forest (190,62 MgC/ha).

Thus far there has been a lack of studies measuring the vegetation diversity, specifically for teak-based agroforestry systems. Therefore, the purpose of this study is to determine the composition, tree community structure, and standing carbon stock of agroforestry systems in Gundih, Grobogan district, Central Java province. The findings of the study may not completely account for the total carbon stock. This analysis only records carbon stock information for tree stands, excluding carbon pools from understory plants and litter.

## 2. Methods

This research was conducted from February to July 2022 in the agroforestry system located in Gundih, Grobogan district, Central Java province. Grobogan Regency is located in Central Java Province, which is geographically located at $110^0 15'$ E – $111^0 25'$ E and $7^0$ S - $7^0 30'$ S. Soil conditions are generally calcareous areas in the area of limestone with substantial hills and mountains towards middle region of the regency. The regional boundaries of Grobogan Regency are as follows: 1) Western part: Semarang Regency, 2) Northern Part: Kudus, Pati and Blora Regencies, 3) Eastern Part: Blora Regency, 4) Southern Part: Ngawi, Sragen, Boyolali, and Semarang Regencies. Grobogan Regency has a total area of 1975,86 $km^2$ and is the second largest regency in Central Java Province, after Cilacap Regency. Administratively, Grobogan Regency is subdivided into 7 districts, 19 sub-districts, and 273 villages. The largest district is Gayer, which is the widest district with an area of 196,19 $km^2$. A map of the research locations in Figure 1.

This study used an exploratory sampling approach with the plot method (squared). The plot size was 20 x 20 $m^2$ with a total plot area of 1 ha (ForestWorks ISC, 2014). Laying of plots used purposive sampling method. The identification of tree species was carried out at the Biology Laboratory of the Faculty of Teacher Training and Education, University of Muhammadiyah Surakarta.

The following analysis were used: IV (Importance Value), Relative Density (RD), Relative Frequency (FR), Relative Dominance (RDo), and Index of Species Diversity (H') (Shannon and Weiner 1963; Mueller-Dombois & Ellenberg; 1974; Price et al., 1997). Tree standing carbon stock was expressed in MgC/ha and estimated by using an allometric approach based on diameter at breast height (dbh) by Ketterings et al. (2001).

## 3. Result and discussions

### 3.1. Composition and structure of teak-based agroforestry

Based on field data obtained in Gundih with a target area of 1 ha, there are 12 tree species from 9 families with a total of tree individuals is 341. The species are acacia (*Acacia auriculiformis* A. Cunn. ex Benth.), awar-awar (*Ficus septica* Burm.F), buni (*Antidesma bunius* (L.) Spreng), teak (*Tectona grandis* Lf), johar (*Senna siamea* (Lam.) Irwin & Barneby), kapuk (*Ceiba pentandra* (L.) Gaertn.), ketapang (*Terminalia catappa* L.), mahoni (*Swietenia mahagoni* (L.) Jacq.), mimba (*Azadirachta indica* A. Juss.), rambutan (*Nephelium lappaceum* L.), sengon (*Albizia chinensis* (Osbeck) Merr.), sonokeling (*Dalbergia latifolia* Roxb) (See Table 1).

Important Value (IV) is a parameter used to express the dominance level of species in a plant community, so that the plant species that have the highest index are the most dominant species. It was observed that species with the highest IV are teak (*T. grandis*) and mahogany (*S. mahagoni*), with values of 93,48 % and 66,78 %, respectively. Thus, these two species are the most dominant species and have the most prominent role for the surrounding ecosystem.

As the dominating species, teak and mahogany trees in Gundih can also be utilized to produce natural dyes, made from the leaves and stems, used in the production of traditional batik cloth (Hariyanto, Fajar, & Suryani, 2017). Timber obtained from *T. grandis, S. mahagoni, A. auriculiformis,* and *D. latifolia*, is highly sought after for construction and fine furniture (Purusottama et al., 2022). *F. septica, T. catappa, S. siamea,* and *A. indica*, can be used as medicine for poisonous snake bites, skin diseases and malaria (Baderan & Utina, 2021; Hidayat & Napitupulu, 2015; Nomleni et al., 2020). *C. pentandra, N. lappaceum,* and *A. bunius*, the fruit of which is used for the textile industry and can be consumed (Gunawan et al., 2019; Subagia et al., 2021). It can be concluded that the agroforestry system in the Gundih area is filled with highly beneficial trees, which can be utilized in various means.

The results also show that in one ha of the research area there is a diverse range of tree diameter sizes, which is presented in Figure 2.

Specific ranges on each species observed in Gundih, are as follows: 1) teak with a diameter of 20-25 cm, while mahogany species (*S. mahagoni*) with an average diameter of 25-37 cm, indicating ~10-15 years. Field data recovered indicated that there is only one species with a diameter of 56-61 cm, that being acacia (*A. auriculiformis*). It is different from the teak and mahogany, *A. auriculiformis* only takes 5-7 years to reach a diameter of 30 cm (Mansur, 2015), so it can be concluded that the tree vegetation in the agroforestry system in the Gundih area has an average tree age of more than 5 years. This finding is supported by information from interviews with local farmers.

Table 2 demonstrates that previous research into agroforestry had been conducted several times. The research on agroforestry shows different results on the density value, thus showing each research area is unique. Such discrepancies can be caused by the spacing and age of the tree (Djajapertjunda & Djamhuri, 2013; Prijono, 2021). Diversity Index (H') of teak-based agroforestry are often more consistent, regularly achieving moderate diversity. This corroborates other studies measuring the biodiversity of other types of agroforestry systems, such as: cocoa-coconut agroforestry in Pariaman, West Sumatra, the value of H' 1,02 (Santhyami et al., 2020); and other similarly complex cocoa-based agroforestry systems in Pasaman, West Sumatra H' 1,93 (Sumilia et al., 2019). However, these values are lower than the diversity of trees in botanical gardens, one of which is the Jompie Botanical Garden in Soreang, Pare-Pare, South Sulawesi, with H' of 2,31. This is due to the fact that Botanical Garden have historically served as ex situ areas of plant conservation in an effort to reduce the rate of deforestation and forest degradation (Muhammad, 2021).

The diversity of agroforestry systems in the Gundih area has the potential for diversity close to that of secondary forest. This can be seen from the H' value of secondary forest which has a medium-high diversity range. While the agroforestry system in the Gundih area has moderate diversity, it can be concluded that the agroforestry system in the Gundih area has a diversity close to that of secondary forest.

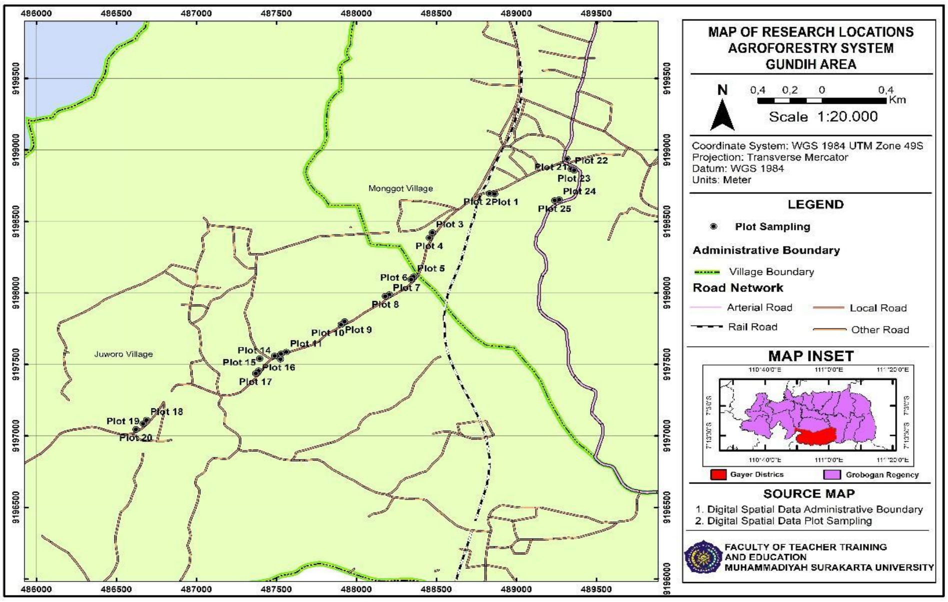

**Figure 1.** Research locations on agroforestry systems in the Gundih area

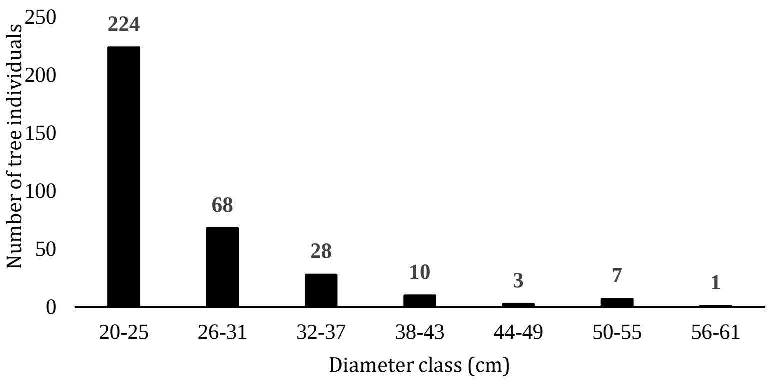


**Figure 2**. Number of trees individual based on diameter class

**Table 1.** Tree vegetation diversity in agroforestry systems in the Gundih area

| No | Local name | Scientific name | RD (%) | RF (%) | RDo (%) | IV | H' |
|---|---|---|---|---|---|---|---|
| 1 | Akasia | *Acacia auriculiformis* | 8,21 | 7,14 | 9,87 | 25,23 | 0,21 |
| 2 | Awar-awar | *Ficus septica* | 0,59 | 1,19 | 0,44 | 2,22 | 0,03 |
| 3 | Buni | *Antidesma bunius* | 0,59 | 1,19 | 0,37 | 2,15 | 0,03 |
| 4 | Jati | *Tectona grandis* | 37,83 | 22,62 | 33,03 | 93,48 | 0,37 |
| 5 | Johar | *Senna siamea* | 2,64 | 5,95 | 3,36 | 11,96 | 0,10 |
| 6 | Kapuk | *Caiba pentandra* | 3,81 | 5,95 | 2,9 | 12,66 | 0,12 |
| 7 | Ketapang | *Terminalia catappa* | 2,35 | 5,95 | 1,81 | 10,11 | 0,09 |
| 8 | Mahoni | *Swietenia mahagoni* | 21,7 | 22,62 | 22,46 | 66,78 | 0,33 |
| 9 | Mimba | *Azadirachta indica* | 1,17 | 1,19 | 1,13 | 3,5 | 0,05 |
| 10 | Rambutan | *Nephelium lappaceum* | 2,93 | 7,14 | 2,98 | 13,06 | 0,10 |
| 11 | Sengon | *Albizia chinensis* | 2,64 | 3,57 | 3,09 | 9,3 | 0,10 |
| 12 | Sonokeling | *Dalbergia latifolia* | 15,54 | 15,48 | 18,55 | 49,57 | 0,29 |
| **Amount** | | | **100** | **100** | **100** | **300** | **1,81** |

Note: RD = Relative Density; RF = Relative Frequency; RDo = Relative Dominance; IV = Important Value; H' = Diversity Index.

**Table 2.** Comparison of teak-based agroforestry

| No | Location | Density (Ind/ha) | H' | Source |
|---|---|---|---|---|
| **Agroforestry** | | | | |
| 1 | Gundih, Central Java | 341 | 1,81 | This research |
| 2 | Soreang, South Sulawesi | 121 | 2,31 | Muhammad, 2021 |
| 3 | Semarang, Central Java | 1155 | 1,54 | Gustiani et al., 2019 |
| **Secondary Forest** | | | | |
| 1 | Kamal, Maluku | 192 | 1,44 | Komul & Hitipeuw, 2022 |
| 2 | Powelua, Central Sulawesi | 564 | 2.0 | Naharuddin, 2020 |
| 3 | Pasaman, West Sumatra | 446 | 3,13 | Santhyami et al., 2021 |

**Table 3.** Carbon stock in agroforestry and secondary forest comparison

| No | Location | Carbon stock (MgC/ha) | Source |
|---|---|---|---|
| **Teak Based Agroforestry** | | | |
| 1 | Gundih, Grobogan | 64,43 | This research |
| 2 | Simo, Boyolali | 47,41 | Suyana et al., 2021 |
| 3 | Dungus, Madiun | 46,61 | Rohmatinah & Martin, 2015 |
| **Cocoa Based Agroforestry** | | | |
| 1 | Bandar Lampung, Lampung | 60,26 | Safe'i et al., 2021 |
| 2 | Pariaman, West Sumatra | 61,89 | Santhyami et al., 2018 |
| **Secondary Forest** | | | |
| 1 | Banyuasin, South Sumatra | 90,79 | Heriyanto et al., 2020 |
| 2 | Pasaman, West Sumatra | 190,62 | Santhyami et al., 2021 |

### 3.2. Standing carbon stock of teak-based agroforestry

The carbon stock potential of the agroforestry systems in the Gundih is substantial (see Table 3); albeit, the total carbon value found in agroforestry systems is lower than in secondary forests. The difference in carbon value is due to the higher density and diversity found in secondary forests (Banuwa, 2013). Due to human intervention, agroforestry systems manage and maintain only those species which are considered beneficial, leading to less dense and diverse ecosystems; meanwhile, secondary forest is not affected by human activities in its management so in secondary forest areas there is interspecific competition (Kantun, 2020).

The teak-based agroforestry in Gundih area has a total carbon stock of 64,43 MgC/ha (see table 3), higher than cocoa-based agroforestry systems; however, other teak-based agroforestry systems show lower total carbon values than cocoa systems. Differences between the various teak-based agroforestry are due to the unique types and arrangement of intercropping vegetation that is a natural response to the unique environment where the system is established. While the location of the cocoa-based agroforestry system in Bandar Lampung, Lampung Province has 20 types of intercrops and the cocoa-based agroforestry system in Pariaman, West Sumatra has 7 types of intercrops.

Another major contributor to the varying values of biomass and standing carbon stock is caused prevalence and the lack thereof of large-diameter trees. The larger the diameter of a tree, the higher the biomass contained (Rohmatinah & Martin, 2015). Ariyanti (2018) has also demonstrated that the opposite is also true, showing that smaller plants have a lower carbon value, due to the smaller capacity of the stem to store the excess production of organic compounds from photosynthesis. Carbon stock is also affected by the various wood densities of different species of trees, with higher-density wood having higher carbon stock values.

## 4. Conclusion

In one hectare of plot in teak-based agroforestry in Gundih, Grobogan Regency, Central Java, we recorded a total population 341 trees, representing 12 tree species from 9 families with diameter ranges from 20 – 60 cm. Teak and mahogany were two most dominant species with Important Value (IV) of 93,48 and 66,78 respectively. The tree diversity of teak-based agroforestry systems is classified as moderate with an H' value of 1,81. The standing carbon stock of tree is 64,43 MgC/ha. The number is substantial compared to other types of agroforestry, though the total carbon value found is lower than in secondary forests. It can thus be concluded that teak-based agroforestry could be considered as an option for environmental conservation.

Based on the above stated conclusions of this paper, the authors would suggest the following strategies to optimize the benefits of the Gundih agroforestry system. The further diversification of the tree species, especially by large-diameter trees would increase standing carbon stocks on agricultural land. It is also necessary to ensure the spread and density of long-lived trees with dense woods to ensure the long-term sequestering of carbon. The timber harvested and its subsequent product could provide both short term as well as long term benefits as described above. Furthermore, it is suggested to do further research in the interactions of the various tree species upon local fauna as well as the environment in general.

**Acknowledgement**

This study was not funded by a grant and is wholly self-funded by the authors. The author would like to thank the head and staff of the Indonesian forestry service, specifically those in Gundih who assisted. The author also acknowledges the Muhammadiyah University of Surakarta whose staff and facilities have been essential in the writing of this paper.

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