Carbon stock potential at several agarwood-based agroforestry practices in Sragen and Karanganyar, Central Java

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Abstract. Agroforestry practices have a pivotal role to reduce the CO₂ concentration in the atmosphere and they subsequently store the carbon in part of stems, branches, roots, and crowns of the trees composing their vegetation communities. The objective of the research is to determine the carbon stocks in the three agroforestry practices. These are Multilayer Tree Garden (MTG), Taungya (TGY), and Home Garden (HMG). The research was carried out from May 2017 to November 2017 at Sragen and Karanganyar Regency, Central Java. A plot size of 20 m x 100 m for big trees, 5 m x 40 m for small trees, and 1 m x 1 m for understory vegetation was used in the sampling. The carbon stock was measured by Chave's allometric equation. The carbon stock in the multilayer tree garden is the highest (44.47 Mg C/ha) compared with the taungya (38.81 Mg C/ha) and home garden (31.41 Mg C/ha). Meanwhile, the above-ground carbon stock in the home garden practice is the biggest (14.97 Mg C/ha or 48%) among the multilayer tree garden (9.67 Mg C/ha or 23%) and taungya (6.11 Mg C/ha or 16%). A 14-year-old G. versteegii in the taungya practice has the biggest carbon stocks (2.46 Mg C/ha) compared to the multilayer tree garden (1.73 Mg C/ha) and home garden (0.56 Mg C/ha).

Keywords: G.versteegii, multilayer tree garden, taungya, home garden, carbon stocks

1. Introduction
In the last 50 years since 1750, atmospheric CO₂ concentration increased by 30%. According to the Intergovernmental Panel on Climate Change (IPCC), the increase of atmospheric concentration in that time was higher than those in the pre-industrial level [1]. In the mid-end of the 21st century, the CO₂ concentration is estimated to increase 0.5% per year or 3.6 G ton per hectare [2][3]. The carbon stock of a terrestrial (plants and soil) ecosystem estimate achieved 2000±500 Pg. or 25% of global carbon stock [4].

The carbon accumulation in the atmosphere is proportionally caused by a fuel fossil burning, conversion of tropical forest area to an agricultural area, and forest burning [1][5]. Tropical forest deforestation and forest degradation caused 17.4% Greenhouse Gas (GHG) emissions [5]; the fire used...
in agricultural practice in the tropic can also increase the climate change. Anthropogenically, agricultural practices affected the one-fourth of the global warming increase [2]. The increasing of CO$_2$ concentration in the atmosphere is the main cause of ensuring global warming. Temperature strongly increased in achieving 1.5°C until 4.5°C [2][3]. Although the increase of CO$_2$ concentration has a positive effect on increasing the plant productivity, it has more negative effects such as climate change, the increase of air temperature, drought, and flood. Moreover, an area conversion to the agricultural ecosystem area can also increase the soil temperature that decrease the humidity of the root zone [1].

Land use practices such as afforestation, reforestation, forest natural regeneration, silvicultural system, and agroforestry can reduce the CO$_2$ concentration in the atmosphere [5]; the type of land use practices for reducing the CO$_2$ concentration and GHG emission are different from one another. Peichl et al. [2] reported that the agroforestry system, including agrisilviculture which integrates agricultural plants and trees in one area, is strongly considered as a good carbon sequestration because it is stored in vegetation. The agroforestry system is not only as an alternative technology for reducing forest degradation and deforestation, but also offering the services of various products for rural communities. It has a pivotal role in integrating the food material needs and environmental services [5].

Carbon stocks stored in the agroforestry system in the tropical region is 21-240 Mg C/ha [2]. Those according to Soto-Pinto et al. (2010) [5] is 12-228 Mg C/ha whereas the carbon stocks in the sub-tropical region are 10-280 Mg C/ha [2]. The total of carbon sequestration in the agroforestry system area is depended on the type of plant species [2], structure and function of each component composing the agroforestry system [5], species diversity, soil properties, climate, and geographical characteristic [6]. The amount of carbon stock in the agroforestry system is significantly affected by the type of agroforestry practices applied in the region [2][6][7][8][9].

Gaharu (Gyrinops versteegii) is one of the non-timber forest products which has a high economic value because it has many functions in perfumery, oil, cosmetics, accessories, and medicine [10]. The benefits of gaharu and its derivative products have been developing due to the fast-technological pharmacy development in the world. The countries such as Saudi Arabia, United Arab Emirates, Kuwait, Japan, United States of America, Singapore, and China are the importer of gaharu and its derivative products. The Arabian communities traditionally use the gaharu for a familial perfumery while China and Japan utilize it for medicine and ritual materials [11].

Gyrinops versteegii, one of the trees producing a good gaharu, has begun to be domesticated in Java Island by stakeholders such as local communities and local government since 2000 [12]. This species was planted by the agroforestry system in the home garden, plantation, and rice field areas; the latter has changed the ecosystem from an agricultural ecosystem to an agroforestry system that grows the G.versteegii tree in the area. Conversion of the traditional agricultural practices to agroforestry practices affected the change in global landscape that serve as a good environment such as carbon sequestration in permanent storage and reducing CO$_2$ concentration. According to the IPCC, afforestation is one of the recommended strategies to mitigate climate change and CO$_2$ emission in the atmosphere [2]. The research regarding carbon stock in the agroforestry system area especially in Java Island is relatively few. Moreover, the research regarding G.versteegii tree carbon stock planted in several agroforestry practices especially in Java Island is not conducted yet. The objective of the research is to determine the carbon stock potential in the multilayer tree garden, taungya, and home garden practice.

2. Materials and Methods
The research was carried out from May 2017 to November 2017 at Sragen and Karanganyar Regency, Central Java. Geographically, the site in Sragen is located at 7°28'31.18"–7°28'40.95" and 111°2'55.55"E–111°3'8.50"E with 116 m above sea level. The site slope is 2–3%, grumusol soil type with rainfall of 2.123 mm/year, and the number of 119 rainy days. Furthermore, there are two sites namely Ngépos and Tawang hamlet in Karanganyar. The former is geographically located at 7°37'2.17"S–7°37'3.71"S and 111°0'49.46"E–111°0'50.26"E with 313 m above sea level while the latter is geographically located at 7°36'55.70"S—7°36'57.61"S and 111° 0'40.70"E–111° 0'42.56"E with 309
m above sea level. Both Ngepos and Tawang hamlet have the average of 9 wet months and 3 dry months with the average of rainfall between 2.094 mm/year until 3.424 mm/year, and the climate type is C [13].

In all sites, the G. versteegii tree was simultaneously planted with agroforestry system in 2004. Based on Nair [14], the agroforestry classification in the research area is classified into agrisilvicultural system grouped in three agroforestry practices i.e. Multilayer Tree Garden (MTG) applied at Sragen, Taungya (TGY) applied at Ngepos, and Home Garden (HMG) applied at Tawang, Karanganyar.

The randomized nested plot method was used for the sampling. A plot size of 20 m x 100 m was used to record the big trees with more than 30 cm diameter (DBH 1.3m above the soil surface) more than 30 cm as well as necromass for big trees; a 5 m x 40 m plot for small trees (5<DBH<30 cm) as well as necromass for small trees; a plot size with 1 m x1 m for understory vegetation; and 0.5 m x 0.5 m plot for litter [15]. The layout of the sampling is shown in Figure 1. Soil samples were collected by digging 0-15 cm depth. Walkley-Black method was used to analyze the soil organic carbon and it was conducted by STIPER Agriculture Institute, Yogyakarta. Soil bulk density sample was taken by hammering an iron cylinder (with the size of 6.8 cm inner diameter, outer diameter of 7 cm, and its 4 cm height) onto 10 cm depth. Bulk density was measured after drying it at the oven with 100°C for 24 hours. The carbon stock measurement was based on the manual measuring carbon stocks across the land-use system by [15]. The un-destructive method was selected for measuring carbon stocks. The allometric equation for measuring above-ground biomass was based on [16] with rainfall between 1500 mm/year until 4000 mm/year. The formula follows:

\[(AGB)_{est} = \exp (-2.977 + \ln(\rho D^2 H)) \equiv 0.0509 \times \rho D^2 H \]  

Where: AGB=above-ground biomass; \(\rho\)=wood specific gravity; \(D\)=diameter at breast height (cm); \(H\)=tree height (m).

The carbon stock is calculated by multiplying the carbon content conversion factor (use the default value of 0.46) by the tree biomass. Wood specific gravity (ws) was categorized into four classes i.e. light wood (ws<0.6 g.cm\(^{-3}\)), medium wood (ws 0.6 to 0.75 g.cm\(^{-3}\)), heavy wood (ws 0.75 to 0.9 g.cm\(^{-3}\)), and very heavy wood (ws>0.9 g.cm\(^{-3}\)) [6]

![Figure 1. A plot scheme to observe the carbon stocks in five carbon pools](image)

3. Results and Discussion

3.1. Vegetation Composition

There were eight species composing the multilayer tree garden i.e. Gyrinops versteegii, Eugenia aquea, Tectona grandis, Dimocarpus longan, Aleurites moluccana, Mangifera indica, Manilkara zapota, and Paraserianthes falcataria. All the species belong into the eight families of Thymelaeaceae, Myrtaceae, Verbenaceae, Sapindaceae, Euphorbiaceae, Anacardiaceae, Sapotaceae and Fabaceae. Meanwhile, the home garden was composed by five species i.e. Gyrinops versteegii, Eugenia aquea,
Spondias dulcis, Swietenia macrophylla, and Mimusops elengi. All the species belong into a family of Thymelaeaceae, Myrtaceae, Anacardiaceae, Meliaceae, and Sapotaceae. In the taungya, it was composed by Gyrinops versteegii and Tectona grandis with the family of Thymelaeaceae and Verbenaceae respectively (see Table 1).

| Common Name | Scientific Name | Family Name |
|-------------|-----------------|-------------|
| Multilayer Tree Garden | | |
| Gaharu | Gyrinops versteegii | Thymelaeaceae |
| Jambu | Eugenia aquea | Myrtaceae |
| Jati | Tectona grandis | Verbenaceae |
| Kelengkeng | Dimocarpus longan | Sapindaceae |
| Kemiri | Aleurites moluccana | Euphorbiaceae |
| Mangga | Mangifera indica | Anacardiaceae |
| Sawo | Manilkara zapota | Sapotaceae |
| Sengon | Paraserianthes falcatoria | Fabaceae |
| Home Garden | | |
| Gaharu | Gyrinops versteegii | Thymelaeaceae |
| Jambu | Eugenia aquea | Myrtaceae |
| Kedondong | Spondias dulcis | Anacardiaceae |
| Mahoni | Swietenia macrophylla | Meliaceae |
| Tanjung | Mimusops elengi | Sapotaceae |
| Taungya | | |
| Gaharu | Gyrinops versteegii | Thymelaeaceae |
| Jati | Tectona grandis | Verbenaceae |

The conducted research by Labata et al. (2012) [7] reported that the tree species composing the mixed multistory species are 24 species; six species in the falcate-coffee multistory system; and two woody species in taungya. It was the same number of tree species we found in the taungya. The number of species composing the multilayer tree garden of this research has more species than Labata's research at the falcate-coffee multistory system, but it has fewer species than Labata's research at the mixed multistory system.

The big trees composing the multilayer tree garden were dominated by trees that have the very heavy wood specific gravity such as M. zapota tree and E. aquea. Both species were occupying 54.44% out of all species composing the agroforestry practice. Meanwhile, the big trees composing the taungya practice were dominated by the tree which entirely has the wood specific gravity categorized as a light group namely G. versteegii. Based on Figure 2a, the tree composing the agroforestry practice of home garden was dominated by the tree with the wood specific gravity categorized as a heavy group occupying 80.01% of the entire species. According to Figure 2b, both the multilayer tree garden and taungya were mainly composed of the tree which has a wood specific gravity categorized as a light group namely 92.46%, and 84.37% respectively. The home garden practice was composed of the tree which has a wood specific gravity categorized as a medium group of 63.07%.
Figure 2. The proportion of tree number (%) based on wood specific gravity (ws) classes a. tree with the DBH>30 cm, b. tree with the DBH<30 cm. Note: MTG=multilayer tree garden; TGY=taungya; HMG=home garden.

3.2. Carbon Stock of the Agroforestry Practices

Carbon stock in the multilayer tree garden was the largest with 44.47 Mg C ha⁻¹ between the taungya (38.81 Mg C/ha) and home garden (31.41 Mg C/ha) (See Table 2). Based on Figure 3a, the carbon stock above the ground in the home garden was the highest (14.97 Mg C/ha), followed by the multilayer tree garden (9.67 Mg C/ha) and the taungya practice (6.11 Mg C/ha). The carbon stock percentage above the ground in the home garden, multilayer tree garden, and taungya practice was 48%, 23%, and 16% respectively. Hierarchically, carbon stock stored below the ground was the multilayer tree garden 34.8 Mg C/ha >taungya 32.7 Mg C/ha >home garden 16.44 Mg C/ha. Based on Figure 3b, the percentage of carbon stock stored below the ground hierarchically was taungya practice of 84%>multilayer tree garden of 77%>home garden of 52%.

Table 2. Carbon stored from the three agroforestry practices in the different carbon pools

| Carbon Pools         | Carbon Stocks (Mg/ha) |
|----------------------|-----------------------|
|                      | TGY       | HMG       | MTG       |
| Trees                |           |           |           |
| Big Trees            | 1.35 (3%) | 9.59 (31%)| 3.63 (8%) |
| Small Trees          | 1.63 (4%) | 1.53 (5%) | 1.86 (4%) |
| Understory Vegetation| 0.8 (2%)  | 1.62 (5%) | 0.01 (0%) |
| Necromass            | 0.43 (1%) | 0.7 (2%)  | 1.23 (3%) |
| Litter               | 1.9 (5%)  | 1.53 (5%) | 3.212 (7%)|
| Soil                 | 32.7 (84%)| 16.44 (52%)| 34.8 (77%)|
| Total                | 38.81     | 31.41     | 44.47     |

Note: MTG=multilayer tree garden; TGY=taungya; HMG=home garden
According to research conducted by Saha and Pramod (2012) [1], the agroforestry system can potentially store the carbon stock between 12 Mg C/ha and 228 Mg C/ha with the median value of 95 Mg C/ha. The number of carbon stocks in the three agroforestry practices was still in the range, but it was still under the median value. Moreover, Gupta et al. (2017)[9] reported that in a small-scale agroforestry in the tropical region can sequester the carbon in the atmosphere of 1.5 to 3.5 Mg C/ha/y, meanwhile in the degraded subtropical area can sequester the carbon in the atmosphere of 1.6 Mg C/ha/y. According to this research, the agroforestry system with 14 years old can sequester the carbon in the atmosphere of 21-49 Mg C/ha and 22.4 Mg C/ha in the degraded area. The number of carbon sequestration in the three agroforestry practices of this research was higher than the carbon sequestration of the research conducted by Gupta et al (2017). Furthermore, the carbon stock below the soil in the three agroforestry practices was in the range of the research conducted by Roshetko et al. (2002)[8] namely 10.4 Mg C/ha - 103.7 Mg C/ha.

Based on research conducted by Labata et al. (2012), the carbon stocks above the ground of the several agroforestry systems are: (1) mixed multistory system can store the carbon of 37.23 Mg C/ha (2) taungya system can store the carbon of 14.01 Mg C/ha, and (3) falcate-coffee multistory system can store the carbon of 7.64 Mg C/ha. In this research, the carbon stock above the ground in the taungya (6.11 Mg C/ha) was the lowest among the taungya system (14.01 Mg C/ha) and mixed multistory system in the result of Labata's research. The carbon storage above the ground in the multilayer tree garden (9.67 Mg C/ha) of this research was highest than the falcate-coffee multistory system of Labata's research, but it was lower than the mixed multistory system. Moreover, the carbon storage above the ground in the home garden practice (14.97 Mg C/ha) of this research was also the highest than the taungya system and falcate-coffee multistory system of Labata's research, but it was lower than the mixed multistory system. Roshetko et al. (2002)[8] stated that the carbon storage above the ground in the home garden with 12-17 years old achieved 6.3-84 Mg C/ha with an average of 35.3 Mg C/ha. The carbon stock above the ground in the home garden practice of this research was in the range of Roshenko's research, but it was still lower than the average of its result.

Based on Table 2, the carbon stock in the multilayer tree garden was largely stored below the ground of 77%, the remaining 23% of carbon were stored above the ground. Hierarchically, the carbon pools with the carbon stock above the ground in three agroforestry practices of this research were big trees (3.63 Mg C/ha) (8%), small trees (1.86 Mg C/ha), litter (3.212 Mg C/ha), necromass (1.23 Mg C/ha), and the underlayer vegetation (0.01 Mg C/ha). The number of the carbon stock above the ground in the taungya practice of this research was 6.11 Mg C/ha stored in five carbon pools namely small trees of 1.63 Mg C/ha (4%), big trees of 1.35 Mg C/ha (3%), litter of 1.9 Mg C/ha (4%), understory vegetation 0.8 Mg C/ha (2%), and necromass 0.43 Mg C/ha (1%) respectively. Meanwhile, the number of carbon
stock above the ground in home garden practice of this research was 14.97 Mg C/ha stored in the five carbon pools namely in big trees of 9.59 Mg C/ha (31%), small trees 1.53 Mg C/ha (5%), understory vegetation of 1.62 Mg C/ha (4%), litter of 1.53 Mg C/ha (3%), and necromass of 0.7 Mg C/ha (2%) respectively. The tree was the largest carbon pool in the three agroforestry practices followed by litter and necromass. The lowest was in the understory vegetation.

The research conducted by Labata et al. [7] reported that the number of carbon stock sequestrated by tree pool in the three agroforestry practices was in the mixed multistory of 35.16 Mg C/ha (22%), in the taungya practice of 12.79 Mg C/ha (7%), and in the falcate-coffee multistory practice of 6.88 Mg C/ha (7%). The carbon stock and its percentage stored by big tree and small tree pools in multilayer tree garden of this research was relatively lower than in mixed multistory of Labata’s research; the carbon stock stored by tree pool in the multilayer tree garden practice was relatively lower than carbon stock stored by tree pool in taungya practice as well as the falcate-coffee multistory of Labata’s research. Although the percentage of carbon stock stored by tree pool in taungya practice of this research was higher than in Labata’s research, the number of carbon stocks stored by tree pool in the taungya of this research was lower than the result of Labata’s research. Although the percentage of carbon stock sequestrated by tree pool in the home garden practice was higher than in mixed multistory practice, in the taungya practice, and in the falcate-coffee multistory of Labata’s research, the number of its carbon stock was relatively lower than Labata’s research.

In this research, both the carbon stock stored in the litter pool at the multilayer tree garden and the percentage was higher than in the mixed multistory system, taungya, and falcate-coffee multistory system of Labata's research. Similar as the carbon stored in the home garden practice, the carbon stock stored in the litter pool in the taungya practice was higher than in the taungya practice and falcate-coffee multistory practice of Labata's research, yet it was lower than in the mixed multistory practice of Labata's research. In the home garden practice, the carbon stock stored in the understory pool was higher than the result of Labata's research. Similarly, in the taungya practice, the carbon stock stored in the understory pool was also higher than the result of Labata's research. In the multilayer tree garden, the carbon stock stored in the understory vegetation pool was lower than the result of Labata's research.

According to Figure 4, the percentage of the carbon stock above the ground in the multilayer tree garden practice of this research was stored in the tree pool (55.22%), the litter pool (32.31%), the necromass pool (12.37%), and in the understory vegetation pool (0.1%). The percentage of the carbon stock stored in the litter pool was higher than the other pools, whereas the percentage of carbon stock stored in the understory vegetation pool in the multilayer tree garden practice was lower than the other pools. The carbon stock above the ground stored in the taungya practice in this research was highest stored in the tree pool (48.77%) than in the litter pool (31.10%), understory vegetation pool (13.09%), and necromass pool (7.04%). The carbon stock in the home garden practice in this research was stored the highest in the tree pool (11.02 Mg C/ha) than in the understory vegetation pool (1.62 Mg C/ha), the litter pool (1.53 Mg C/ha), and in the necromass pool (0.7 Mg C/ha). The percentage of carbon stock stored in the tree pool in the three agroforestry practices of this research was the highest stored in the home garden practice (74.28%) than in the multilayer tree garden practice (55.22%), and in the taungya practice (48.77%). In addition, the percentage of the carbon stock stored in the litter pool in the three agroforestry practices was stored the highest in the multilayer tree garden practice (32.31%) between the taungya practice (31.10%) and in the home garden practice (10.22%). The percentage of the carbon stock stored in the understory vegetation pool in the taungya, home garden, and multilayer tree garden practice was 13.09%, 10.82%, and 0.3%, respectively. Furthermore, the percentage of the carbon stock stored in the necromass pool in the three agroforestry practices namely in the multilayer tree garden, taungya, and home garden practice, respectively was 12.37%, 7.04%, and 4.68%.
In the multilayer tree garden practice in this research, the big tree storing the highest carbon stock was *M. zapota* of 1.98 Mg C/ha (58.5%), followed by *T. grandis* of 0.75 Mg C/ha (22.04%), and *E. aquea* of 0.36 Mg C/ha (10.76%); the small tree storing the highest carbon stock was *G. versteegii* of 1.73 Mg C/ha (92.46%). In the home garden practice in this research, the big tree storing the highest carbon stock was *M. elengi* of 7.67 Mg C/ha (80.01%), then *S. dulcis* of 1.24 Mg C/ha (12.95%); the small tree storing the highest carbon stock was *S. macrophylla* of 0.97 Mg C/ha (63.07%), then *G. versteegii* of 0.56 Mg C/ha (36.32%). Moreover, in the taungya practice, the big tree storing the highest carbon stock was *G. versteegii* of 1.34 Mg C/ha (100%); the small tree storing the highest carbon stock was *G. versteegii* of 1.12 Mg C/ha (68.74%), then *T. grandis* of 0.51 Mg C/ha (31.25%) (See table 3).

### Table 3. The number of carbon stocks of each species at the multilayer tree garden, taungya, and home garden

| Land Use       | Species                 | C stock (Mg C/ha) | DBH>30 cm | DBH<30cm |
|----------------|-------------------------|-------------------|-----------|----------|
| Multilayer Garden Tree | *Gyrinops versteegii*    | -                 | 1.73 (92.46%) |
|                | *Mangifera indica*      | -                 | 0.14 (7.54%)  |
|                | *Eugenia aquea*         | 0.36 (10.76%)     | -          |
|                | *Tectona grandis*       | 0.75 (22.04 %)    | -          |
|                | *Dimocarpus longan*     | 0.04 (1.21%)      | -          |
|                | *Aleurites moluccana*   | 0.17 (4.48%)      | -          |
|                | *Mangifera indica*      | 0.08 (2.51%)      | -          |
|                | *Manilkara zapota*      | 1.98 (58.50%)     | -          |
|                | *Paraserianthes falcataria* | 0.005 (0.14%)  | -          |
| Home Garden    | *Gyrinops versteegii*    | -                 | 0.56 (36.32%)  |
|                | *Eugenia aquea*         | -                 | 0.009 (0.6%)   |
|                | *Spondias dulcis*       | 1.24 (12.95%)     | -          |
|                | *Swietenia macrophylla* | 0.68 (7.04%)      | 0.97 (63.07%) |
|                | *Minusops elengi*       | 7.67 (80.01%)     | -          |
| Taungya        | *Gyrinops versteegii*    | 1.34 (100%)       | 1.12 (68.74%) |
|                | *Tectona grandis*       | -                 | 0.51 (31.25%)  |
In the multilayer tree garden practice, the big tree of *G. versteegii* did not give any carbon storing result, but the small tree of *G. versteegii* stored the highest carbon stock. Similar case in the multilayer tree garden practice, in the home garden practice, the big tree of *G. versteegii* did not result in carbon storing, yet the small tree of *G. versteegii* could have the potential in storing the carbon stock. Both the big and small trees of *G. versteegii* in the taungya practice had the highest carbon stock. The carbon stock stored by *G. versteegii* in the taungya practice, in the multilayer tree garden practice, and in the home garden practice was 2.46 Mg C/ha, 1.73 Mg C/ha, and 0.56 Mg C/ha, respectively. The average of the stock carbon stored by *G. versteegii* was 0.175 Mg C/ha/y.

### 3.3. The Relationship between Basal Area and Carbon Stocks

Based on Figure 5a and 6a, the correlation between the basal area of the big trees with the carbon stock in the multilayer tree garden was significantly positive with the linear regression equation of $y=1.025x - 0.2512$ with $R^2=0.9334$; the basal area of the small tree was formulated with the linear regression equation $y=1.725x - 0.024$ with $R^2=0.9526$. The correlation between the basal area of the big tree composing the taungya practice with the number of carbon stock was also significantly positive ($y=0.988x - 1.007$ with $R^2=0.8745$); the correlation of basal area of the small tree and the number of the carbon stock was also significantly positive with the linear regression equation of $y=1.8295x - 0.024$ with $R^2=0.9464$ (See Figure 5b and 6b). In addition, the basal area of the big trees composing the home garden practice was significantly positive correlation with the number of the carbon stock formulated with the regression equation $y=7.3603x - 1.3038$ with $R^2=0.9964$; the basal area of the small trees was also significantly positive correlation with the number of the carbon stock formulated with the linear regression equation $y=10.484x - 0.2499$ with $R^2=0.9464$ (See Figure 5c and Figure 6c).

The correlation between the basal area and the carbon stock in home garden practice had the highest correlation value with the average of $R^2=0.971$, then in the multilayer tree garden practice with $R^2=0.943$, and in the taungya practice with $R^2=0.905$. The correlation of the basal area and the carbon stock in three agroforestry practices was high. Similarly, the research conducted by Natalia et al. (2017) reported that the correlation between the basal area and the carbon stock in the agroforestry and the secondary forest had a significantly positive correlation with $R^2=0.9605$.

![Figure 5](image.png)

**Figure 5.** Correlation of carbon stocks with the basal area (dbh>30 cm) at a. multilayer tree garden (MTG), b. taungya (TGY), and c. home garden (HMG)
Figure 6. Correlation of carbon stocks with the basal area (DBH<30 cm) at a. multilayer tree garden, b. taungya, and c. home garden.

4. Conclusion

Land management using an agroforestry system gives not only economic benefits but also environmental benefits especially for increasing carbon stock. An agarwood-based agroforestry practice can potentially store both in the above-ground and underground carbon. One of the agroforestry practices selected for planting agarwood-producing species of *Gyrinops versteegii*, the agroforestry practice of multilayer tree garden has the highest carbon stock both in above-ground and underground than those in taungya and home garden. Because the multilayer tree garden practice has the highest species composition, structure crown, wood species gravity, and tree basal area, it has the highest carbon stock.

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