Measuring the potential of biomass, carbon storage, and carbon sink of forest cloves

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Abstract. Forest clove (Syzygium aromaticum (L.) Merr& Perry) is a tree-shaped species that has been widely cultivated by farmers in its distribution area in Maluku. It grows relatively fast with large morphological sizes, giving it the potential of being a carbon sink plant. So far, information on the potential of biomass, carbon deposits, and carbon uptake of forest cloves is still limited. This study was aimed to determine the biomass potential, carbon deposits, and carbon uptake of forest cloves. It was carried out in the distribution area of Leihitu Subdistrict, Central Maluku Regency, from January to February 2019. The method used was a non-destructive one with a plot size of 20 x 20 m, chosen through purposive sampling and referring to carbon measurement standards, namely SNI: 7724 - 2011. Measurements were made on individual forest cloves and clove cropping systems. As a comparison, other land-use systems were used in the form of nutmeg gardens and mixed gardens. The study revealed a relationship pattern between the age of individual forest clove with biomass, carbon storage, and carbon uptake which were mathematically described as follows:  

\[ y_{(\text{biomass})} = 0.7707 \cdot (\text{age})^2 - 2.3947 \cdot (\text{age}) + 1.1255 \]  

\[ y_{(\text{carbon storage})} = 0.3622 \cdot (\text{age})^2 - 1.1255 \cdot (\text{age}) + 1.3294 \]  

\[ y_{(\text{carbon uptake})} = 4.1306 \cdot (\text{age}) - 4.1306 \cdot (\text{age}) + 1.1255 \]  

The results showed that biomass in the 15-year-old forest clove cropping system averaged 73.67 tons ha\(^{-1}\) with carbon deposits of 34.63 tons ha\(^{-1}\) and carbon absorption of 127.08 tons ha\(^{-1}\). Those results were slightly higher than those in the nutmeg cropping system, but lower compared to those of the mixed garden systems. The 15-year-old nutmeg cropping system had an average biomass of 44.30 tons ha\(^{-1}\) with carbon deposits of 20.82 tons ha\(^{-1}\) and carbon absorption of 76.41 tons ha\(^{-1}\). Meanwhile, the 15-year-old mixed garden system had a biomass of 259.59 tons ha\(^{-1}\), with carbon deposits of 122.01 tons ha\(^{-1}\), and carbon absorption of 447.77 tons ha\(^{-1}\).

Keywords: allometric, carbon, forest cloves, global warming, Syzygium aromaticum

1. Introduction

Global warming is one of the issues causing the greenhouse effect, which is an important environmental problem. It causes the energy received from sunlight to be absorbed as short-wave radiation and reflected into the atmosphere in the form of heat. Climate change occurs as a result of global warming, causing an increase in average air temperature and sea level. Forest damage is one of the causes of global climate change. This change is due to the reduced absorption of carbon dioxide (CO\(_2\)) in the atmosphere. Carbon dioxide (CO\(_2\)) in the atmosphere can be absorbed by plants through photosynthesis so that it can reduce the impact of global warming.

Maluku, as a province based on small islands, is highly vulnerable to the effects of global warming. Efforts to anticipate these impacts include the increasing of carbon absorption from the atmosphere.
through the increment plant biomass. The plant serves as a place to store and deposit carbon termed carbon sink. The process of storing carbon in growing plants is called carbon sequestration. The amount of carbon accumulated in plants depends on the type and nature of the plants themselves. One type of plant that has the potential to absorb and store carbon is forest cloves. The biomass of the plant can determine the ability of forest cloves to absorb carbon.

Forest clove (Syzygium aromaticum (L.) Merr& Perry) is an endemic species distributed in the area of Maluku islands and parts of Papua [1]. In Maluku, cloves have been cultivated by many farmers, especially in places such as Ambon Island (Hitulama, Hitumesing, Mamala, Morella) and Seram Island (Latu and Hualoy Villages) at an altitude between 100-500 m [2]. It is one of the woody vegetation characterized by larger morphological size and relatively fast growth. The morphological characteristic and rapid growth indicate the ability of forest cloves to absorb carbon. The absorbed carbon will be stored in the form of plant biomass. The amount of biomass can determine the amount of carbon stored and absorbed. The estimation of forest clove biomass can be done using allometric equations whose parameter is stem diameter.

The potential for carbon sequestration in the forest clove cropping system is quite important because it shows the importance of the role of community forests in Maluku in optimizing land functions, including the absorption of carbon from the atmosphere. As the center of origin, cloves have been cultivated by farmers, especially in the distribution areas of Maluku. The cultivation of forest clove is part of an effort to restore the glory of spices in Maluku. The effort aims to increase the productivity of forest clove and nutmeg based herbs and to address the issue of climate change in Maluku [3]. The forest clove planting system in Maluku was developed in the form of agroforestry so that it plays a role in maintaining the stability of the Maluku ecosystem based on small islands vulnerable to the effects of climate change.

Forest clove cropping systems play the role of plant forest in general, namely economic and ecological benefits. Economically, forest cloves produce clove flowers which are widely used in the fields of pharmacology, agriculture, culinary, cosmetics, and other industries [4,5]. Ecologically, forest cloves can be utilized to control global climate change through the absorption of carbon dioxide from the atmosphere. Forest clove plants as part of the agroforestry component in Maluku have a shared role with other forest vegetation to anticipate the effects of climate change through the uptake of carbon dioxide from the atmosphere [3]. The agroforestry system in Maluku is a tree-based mixed cropping system that can maintain carbon stocks (C-stock) because of the high biomass accumulation in tree components compared to monoculture systems. Measurement of carbon stocks on agroforestry types needs to be done to support the reduction of greenhouse gas emissions [21].

So far, research on the potential of forest cloves as carbon sink plants is still minimal. The aim of this study was to inform the potential of biomass, carbon storage, and carbon uptake of forest clove plants. This information is important for the development of forest clove plants as plants that have economic and ecological value.

2. Material and Methods

2.1. Time and Place.
The observation of biomass potential, carbon deposit, and carbon absorption of forest cloves was carried out in the distribution area of forest cloves in Hitulama and Hitumesing villages, Leihitu District, Maluku Regency, Maluku Province. Whereas the measurement of nutmeg and mixed gardens was carried out in Morella Village, Leihitu District, Central Maluku Regency. The study was conducted from January to February 2019.

2.2. Materials and tools.
The materials used in this study consisted of individual forest cloves (aged 5, 10, 15, 20, 25, and 30 years), forest cloves, nutmeg gardens, and mixed gardens aged 15 years old each. Tools used in field measurements include GPS for direction and coordinates, phi band for measuring tree diameter, meter for plot measurement, hagameter for measuring tree height, and other field support tools such as cuttings, rakes, stakes, labels, digital cameras, ovens, and stationery. The tool used in data processing
was in the form of computers that are equipped with ArcGIS, Microsoft Excel, and Microsoft Word facilities.

2.3. Data collection.
Primary data collection carried out during measurements in the field was in the form of diameters breast height (dbh) and tree height. The measurements were made on individual forest cloves based on plant age in the form of forest clove plantation system compared with nutmeg gardens and mixed gardens. Plant age in individual measurements of forest cloves was adjusted to plant diameter classes in six classes, namely: 5 years (5-10 cm), 10 years (11-15 cm), 15 years (16-20 cm), 20 years (21-25 cm), 25 years (26-30 cm), 30 years (31-35 cm). The measurements using sample plots were selected through purposive sampling in the form of squares referring to Indonesia National Standard (SNI): 7724-2011. The size of the plot was 20 m x 20 m (400 m²) for 5 plots. A plot of 20 m x 20 m was used to collect data on plants with a diameter of > 20 cm in the measurements of forest clove crop system and the comparison in nutmeg and mixed gardens. Furthermore, each of these plots was further divided into sub-plots according to the growth rate of 100 m² for diameters of 10-20 cm, 5 mx 5 m or 25 m² for diameters of 5-9 cm, and 4 m² for diameters <5 cm [6]. The allometric model for estimating the biomass of individual forest cloves, as well as in the form of forest clove plantation, nutmeg, and mixed garden planting systems, used the universal allometric equation proposed by Ketterings et al. (2001), namely for branching trees having no allometry:

\[ W = 0.11 \rho D^{2.62} \]  

Remarks:
- \( W \): biomass (kg tree⁻¹)
- \( \rho \): density (g cm⁻³)
- \( D \): plant diameter

The density of clove species used followed the density of Syzygium spp, which is 0.69 g cm⁻³, while the density of the nutmeg plants followed that of myristica spp wood, which is 0.46 g cm⁻³. For the other types of plants in mixed gardens the densities of which are unknown, the species density for trees in Asia was used as suggested by [8] in [7], which is 0.57 g cm⁻³. Biomass measurements in mixed gardens, in addition to using the allometric equation [7] for branching trees, also used allometric equations developed by [9] for coconut (Cocos nucifera); [10] for bananas (Musa paradisiaca); and [11] for zalacca plants (Salacca zalacca).

2.4. Carbon deposits and Carbon uptake.
The results of measurements of plant biomass are then calculated carbon deposits and uptake. The determination of carbon deposits from plant biomass used the biomass conversion formula referring to SNI: 7724 - 2011[6], while the calculation of CO₂ absorption using formulas from [12].
Carbon storage equation used:

\[ Cb = B \times \% C_{organik} \]  

where:
- \( Cb \): carbon content of biomass (kg)
- \( B \): total biomass (kg)
- \( \% C_{organik} \): percentage value of carbon content (0.47).

Carbon absorption:

\[ W_{CO_2} = C \times FK_{CO_2} \]  

where:
- \( W_{CO_2} \): amount of CO₂ absorbed
- \( C \): carbon (ton ha⁻¹)
- \( FK_{CO_2} \): the conversion factor of the element carbon (C) to CO₂ = 3.67
2.5. Data analysis.
Data on the measurements of individual forest cloves at various ages were correlated with age and biomass, carbon storage, and carbon uptake. Meanwhile, the results of the measurements on biomass, carbon deposits, and carbon uptake in forest clove cropping systems were compared with other land-use systems, namely nutmeg and mixed gardens.

3. Results and Discussion

3.1. Biomass, carbon deposits, and individual plant carbon uptake above the ground based on the age of the plant.

The estimation of the individual biomass of forest cloves above the ground in this study followed the allometric equation proposed by [7], while the estimation of plant carbon deposits referred to the SNI biomass conversion formula: 7724 - 2011 [6]. The evaluation of carbon uptake was based on formulas by [12]. The results of the non-linear regression analysis of the relationship between the age of forest clove and biomass, carbon deposits, and surface carbon uptake in forest cloves revealed a very significant correlation with biomass, carbon storage, and carbon uptake.

The estimation results of biomass, carbon deposits, and carbon uptake of forest cloves based on the age of the plant are presented in Table 1. The estimation results showed that the average biomass, carbon deposits, and individual carbon uptake of forest cloves increase along with the age and diameter of the plants.

| Age (year) | dbh (cm) | Biomass (kg plant\(^{-1}\)) | C. deposits (kg plant\(^{-1}\)) | C. uptake (kg plant\(^{-1}\)) |
|------------|----------|-----------------------------|-------------------------------|-----------------------------|
| 5          | 6-10     | 18.83 ± 8.13               | 8.85 ± 3.82                  | 32.49 ± 14.00              |
| 10         | 11-15    | 60.0 ± 18.56               | 28.20 ± 8.72                 | 103.49 ± 32.01            |
| 15         | 16-20    | 116.41 ± 20.58             | 54.71 ± 9.67                 | 200.80 ± 35.50            |
| 20         | 21-25    | 250.10 ± 53.94             | 117.55 ± 25.35               | 356.37±76.86              |
| 25         | 26-30    | 425.04 ± 87.58             | 199.77 ± 41.16               | 431.39 ± 93.04            |
| 30         | 31-35    | 638.33 ± 14.63             | 300.02 ± 6.88                | 733.15 ± 151.07           |

Growth patterns: Q** Q** Q**

Note: Growth pattern test using a quadratic polynomial model; ** significantly correlated at α 1%; Q: quadratic.

The estimation results showed that a 5-year-old individual forest clove had average biomass of 18.83 kg plant\(^{-1}\) with a carbon storage of 8.85 kg plant\(^{-1}\) and carbon uptake of 32.49 kg plants\(^{-1}\). The weights of the biomass, carbon deposits, and carbon uptake continued to increase along with the increasing age of plants to reach a biomass weight of 638.33 kg plants\(^{-1}\) at 30 years old (plant) with carbon deposits and carbon uptake of 300.02 kg plants\(^{-1}\) and 733.15 kg plants\(^{-1}\), respectively. This increase was due to an increase in plant age along with the increasing stem diameter. The biomass will increase to a certain age (the representative class diameter expresses age) and then will steadily decrease until it finally stops producing (dead) [13]. Also, other factors such as the diversity of tree species, soil type, and age of trees, as well as management, also determine the amount of carbon stored [14].

The biomass is determined by the diameter of the plant, which will directly determine the carbon storage and carbon uptake of the plant. There is a suggestion that the larger the diameter of plants (in stands), the greater the carbon storage [15]. Furthermore, it is also believed that the older the stand, the greater the carbon storage. This result showed that the carbon deposits and carbon uptake (in
stands) highly depend on the biomass because the biomass is composed of carbon at 45-50% [8]. Therefore, an increase in biomass is followed by an increase in carbon deposits and carbon uptake.

3.2. Relationship between the age of individual forest clove and biomass, carbon deposits, and carbon uptake on the surface.

The age of individual forest cloves in the study was determined by measuring the plant stem diameter. The stem diameter can be used to predict the biomass, carbon deposits, and carbon uptake of forest clove. The measurement of the stem diameter as an independent variable is needed to build a regression equation. Biomass, carbon deposits, and carbon uptake of forest clove increase along with the age of plants following the sigmoid plant growth curves. The results of the regression analysis estimating the biomass, carbon storage, and carbon uptake were mathematically as follows:

\[ y_{\text{biomass}} = 0.7707_{\text{age}}^2 - 2.3947_{\text{age}} \]
\[ y_{\text{carbon uptake}} = 0.3622_{\text{age}}^2 - 1.1255_{\text{age}} \]
\[ y_{\text{carbon uptake}} = 1.3294_{\text{age}}^2 - 4.1306_{\text{age}} \]

The coefficient of determination \((R^2)\) between the age and the biomass content, carbon deposits, and carbon uptake was quite high at 0.96; showing that the relationship between age and biomass content, carbon storage, and carbon uptake is real, where more than 96% of plant age diversity can explain the diversity of biomass, carbon storage, and carbon uptake.

The results showed that the plant biomass content would increase with the age of the plant. As the plants grow older, the biomass content will increase. Plant age can be described based on the diameter of the plant. The increasing diameter influences biomass and carbon absorption [16]. Stem biomass generally makes the largest contribution compared to biomass in other parts. This aspect is because of the stem stores, most of the photosynthetic food reserves for plant growth. The amount of plant biomass, in addition to being influenced by plant stem diameter, is also determined by the number and type of plants [17]. The results revealed that the older the plant, the higher its carbon intake. The amount of carbon stored is a picture of the size of the plant biomass. The suggestion said that around 45–50% of plant biomass is composed of carbon whose quantity is the result of a reduction from photosynthesis and respiration [8]. Besides, it was shown that the older the plant, the higher its carbon intake. Increased carbon uptake will follow an increase in carbon deposits in the form of plant biomass. It is suggested that the amount of CO\(_2\) absorbed by plants from the atmosphere can be illustrated by the amount of carbon stored in the body of living plants (biomass) in a field [14]. The amount of biomass and carbon uptake of the plant is influenced by several factors, including plant density and stem diameter [18].

3.3. Biomass content, carbon deposits, and carbon uptake in forest clove cropping systems with various types of land use

The results of observations on biomass, carbon deposits, and carbon uptake of various types of land use, vary based on plant growth rates (table 2). The table compares the biomass content, carbon storage, and carbon uptake between the forest clove cropping system, the nutmeg cropping system and mixed farms belonging to farmers located around the forest clove distribution area. The measurement of each population from the type of land use consists of 5 plots (20 m x 20 m) following the standard for carbon measurement, namely SNI: 7724 – 2011 [6].

The calculation of the value of forest clove biomass and nutmeg used the allometric equations developed by for branching trees [7], while the mixed gardens, in addition to using allometric equations Ketterings et al. (2001) for branching trees, also used allometric equations developed by for coconut (Cocos nucifera) [9], by for bananas (Musa paradisiaca) [10], and for malacca plants (Salacca zalacca) [11].

Based on the results of the measurements, it was observed that the biomass content, carbon deposits, and carbon uptake in forest clove, nutmeg, and mixed garden planting systems varied depending on the type of plant and growth rate. The plant diameter shows the plant growth in all types of land use. The greater the diameter of the plant, the greater the biomass, carbon deposits, and carbon uptake will be. In the plot of forest cloves with a diameter of <5 cm, the average biomass content was 0.43 tons ha\(^{-1}\) with carbon deposits of 0.20 tons ha\(^{-1}\) and carbon uptake of 0.74 tons ha\(^{-1}\). This value will increase until it reaches the highest value in sizes > 20 cm diameter, where the biomass content
The increase in biomass, carbon deposits, and carbon uptake according to plant growth rates also occurred in nutmeg and mixed garden planting systems. In all three types of land use, the measurement values of biomass, carbon storage and carbon uptake of forest cloves were slightly higher than those in the nutmeg cropping system but lower than those of the mixed garden system (overall growth rate). The results of the study revealed that a 15-year-old mixed garden with a diameter of > 20 cm, consisting of plants such as walnuts, coconuts, durians, langsat, and others, stored 114.53 tons ha\(^{-1}\) carbon. The above-ground carbon content was slightly lower than the 30-year-old mixed garden system in Malasari, Bitung Curug, and Nanggung Villages with kebo, kisaninten, Africa, puspa, albizia, Kemang rubber species, amounting to 185.76 tons ha\(^{-1}\).[19]

### Table 2. Average biomass, carbon storage, and carbon uptake above the ground-based on growth rate (ton ha\(^{-1}\)).

| Types of land use       | Diameter <5 cm | Diameter 5-9 cm | Diameter 10-20 cm | Diameter >20 cm |
|-------------------------|----------------|-----------------|-------------------|-----------------|
| Forest cloves           | 0.43 ± 0.44    | 2.90 ± 1.50     | 21.25 ± 11.50     | 49.09 ± 16.99   |
| Nutmeg                  | 0.23 ± 0.12    | 3.26 ± 1.92     | 16.74 ± 5.04      | 24.06 ± 13.84   |
| Mixed gardens           | 0.08 ± 0.04    | 1.26 ± 1.43     | 14.57 ± 1.77      | 243.68 ± 103.93 |

| Types of land use       | Diameter <5 cm | Diameter 5-9 cm | Diameter 10-20 cm | Diameter >20 cm |
|-------------------------|----------------|-----------------|-------------------|-----------------|
| Forest cloves           | 0.20 ± 0.21    | 1.37 ± 0.71     | 9.99 ± 5.40       | 23.07 ± 7.98    |
| Nutmeg                  | 0.11 ± 0.06    | 1.53 ± 0.90     | 7.87 ± 2.37       | 11.31 ± 6.50    |
| Mixed gardens           | 0.04 ± 0.02    | 0.59 ± 0.67     | 6.85 ± 0.83       | 114.53 ± 48.85  |

| Types of land use       | Diameter <5 cm | Diameter 5-9 cm | Diameter 10-20 cm | Diameter >20 cm |
|-------------------------|----------------|-----------------|-------------------|-----------------|
| Forest cloves           | 0.74 ± 0.76    | 5.01 ± 2.59     | 36.65 ± 19.83     | 84.68 ± 29.30   |
| Nutmeg                  | 0.40 ± 0.20    | 5.63 ± 3.31     | 28.87 ± 8.69      | 41.51 ± 23.87   |
| Mixed gardens           | 0.14 ± 0.06    | 2.17 ± 2.47     | 25.13 ± 3.05      | 420.33 ± 179.27 |

3.4. Comparison of the biomass, carbon deposits and carbon uptake between forest clove cropping systems and types of land use

The averages biomass, carbon deposits, and carbon uptake per hectare in various types of land use are presented in table 3. The table showed that the 15-year-old forest clove cropping system had an average biomass content of 73.67 tons ha\(^{-1}\) with carbon deposits of 34.63 ton ha\(^{-1}\), and carbon uptake of 127.08 tons ha\(^{-1}\). Those values were slightly higher than those in the nutmeg cropping system but lower than those in the mixed garden system. The 15-year-old nutmeg cropping system had an average biomass content of 44.30 tons ha\(^{-1}\) with carbon deposits of 20.82 tons ha\(^{-1}\), and carbon uptake of 76.41 tons ha\(^{-1}\). Meanwhile, the 15-year-old mixed garden system had a biomass content of 259.59 tons ha\(^{-1}\) with carbon deposits of 122.01 tons ha\(^{-1}\) and a carbon uptake of 447.77 tons ha\(^{-1}\).

### Table 3. Averages biomass, carbon and carbon uptake of various types of land use *

| Types of land use        | Biomass (ton ha\(^{-1}\)) | Carbon deposits (ton ha\(^{-1}\)) | Carbon uptake (ton ha\(^{-1}\)) |
|-------------------------|--------------------------|----------------------------------|--------------------------------|
| 15-year-old forest clove| 73.67 ± 12.82            | 34.63 ± 6.02                     | 127.08 ± 22.11                 |
| 15-year-old nutmeg      | 44.30 ± 15.46            | 20.82 ± 7.27                     | 76.41 ± 26.67                  |
| 15-year-old mixed garden| 259.59 ± 102.48          | 122.01 ± 48.16                   | 447.77 ± 176.76                |

* not including C litter, C-humus, and C-soil

The comparison of carbon forest clove deposits with various types of land use is presented in table 4. The table compared carbon stocks between forest clove plantation systems, nutmeg cropping systems, and mixed gardens. The results of the measurement of primary forest carbon were used [20].
on the PSP (Permanent Sampling Plot) of Ambon City Soya Forest as comparisons for the whole cropping systems. Compared, carbon deposits do not include litter carbon, topsoil carbon, and soil.

The comparison of carbon deposits, of various types of land use at the study site towards primary forest carbon deposits, is presented in figure 1. The comparison of the carbon stocks between various types of land use toward carbon stocks in primary forest systems revealed that 15-year-old forest clove cropping systems had only 15.78% of carbon reserves compared to primary forest. Whereas nutmeg and mixed garden planting systems had only 9.49% and 55.61%, respectively.

| Types of land use         | Carbon deposits (ton ha⁻¹) | % of | 15-year-old forest cloves | 15-year-old nutmeg | 15-year-old mixed garden |
|---------------------------|---------------------------|------|---------------------------|--------------------|-------------------------|
| Primary forest            | **219.37**                | **100** | **633.47**               | **1 053.65**       | **179.80**              |
| 15-year-old forest cloves | 34.63                     | 15.78 | 166.33                    | 28.38              |
| 15-year-old nutmeg        | 20.82                     | 9.49  | 60.12                     | **100**            | 17.06                   |
| 15-year-old mixed garden  | 122.01                    | 55.61 | 352.32                    | 100                |

*) not including C litter, C-humus, and C-soil; **)measurement results [20]

![Figure 1. Comparison of biomass, carbon deposits, and carbon uptake at various levels of land use](image)

When compared with the forest clove plantation system (aged 15 years old), the carbon deposits of nutmeg cropping systems were 60.12% at the same age, while the mixed gardens had higher carbon storage (352.32%) at the same age. Carbon forest clove deposits are lower than those of mixed gardens in this study because the forest clove cropping system in the area of Ambon Island is often pruned when the plant is 7 years old, aiming to shorten trees and facilitate harvesting. Also, in a mixed garden plantation system uses more than one type of plant so that the potential for carbon storage is higher compared to the forest clove and nutmeg cropping systems. However, the forest clove cropping system in this study still has a high potential for carbon storage. In addition to having economic benefits as a commercial dried forest clove flower, the forest clove forest planting system also has the potential to be developed as a C sequester and carbon conservation for environmental sustainability.
4. Conclusion
The biomass content, carbon deposits, and carbon uptake of forest cloves will increase along with the age of the plants. Also, the biomass content, carbon deposits, and carbon uptake in the forest clove cropping system are slightly higher than those of the nutmeg cropping system but lower than those of the mixed garden system.

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