Allometric equation of local bamboo for estimating carbon sequestration of bamboo riparian forest

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Abstract. The cause of global warming is the increasing carbon concentration arising from industrial activities, burning of fossils, and land-use change. The purpose of this research was to find out the allometric equation to calculate the local bamboo biomass and then to be able to calculate how much carbon sequestration at bamboo riparian forest since this area was rarely being explored. The parameters observed were the height and diameter of the bamboo stem at 1.3 m height of 6 types of local bamboo using destructive sampling, along with the measurement of bamboo weight. The carbon content of the bamboo biomass, litter, and soil was measured to complement the estimation of total carbon sequestration. The results showed that the allometric equation for estimating local bamboo biomass is $Y=0.6396 X^{1.6162}$ with $R^2=0.77$, obtained from the relationship equations between dry weight and the diameter. Total carbon sequestration of this system ranged between 81 to 215 tons C ha⁻¹.

1. Introduction

Global warming is one of the most severe issues discussed in the current era. In 100 years, CO₂ increased and reached 650-700 µmol⁻¹, causing an increase in global temperature from an average of 1.50 °C to about 4.50 °C [1]. The most significant cause of global warming is the increase in carbon emissions. It arises from industrial progress, human technology, land-use conversion, forest burning, and burning fossil fuels in oil and coal. In recent years, carbon sequestration has received significant attention as one of the efforts to deal with climate change [2–5].

Bamboo is one of the most productive and fast-growing plants, reaching up to 1.2 cm in one day [6]. Bamboo has the potential as a carbon sink that can be considered. Bamboo grows in 36 million hectares worldwide which is equivalent to 3.2% of the total forest area. More than 80% of the area covered by bamboo is in Asia, 10% in Africa, 10% in America. India is the largest bamboo-producing country in Asia, accounting for approximately 11.4 million hectares of the bamboo area [6]. In 2000, it was estimated that the area of bamboo plantations in Indonesia was 2,104,000 ha consisting of 690,000 ha of bamboo planted in forest areas and 1,414,000 ha of bamboo planted outside forest areas [7]. Indonesia has 143 species of bamboo, and 60 of them are found on the island of Java [8].

In contrast to woody plants, bamboo is one of the non-timber forest products from grass plants with basic characteristics that are not much different from wood. It has advantages and distinctive features that can be developed as alternative raw materials in processing wood-based products. More than 90%
of bamboo carbon can be in the form of durable products such as boards, panels, floors, furniture, buildings, fabrics, paper, and activated charcoal [6]. In addition, the use of non-timber forest products will reduce dependence on wood raw materials, which can reduce the rate of forest degradation and support forest sustainability [4].

Bamboo can play a significant role in carbon trading in developing countries like Indonesia. Carbon trading is a method designed to reduce carbon emissions that contribute to global warming [9–10]. Countries with excess carbon stocks can sell the carbon to countries that find it difficult to reduce their carbon emissions. Bamboo is becoming the best option to be involved in the carbon accounting mechanism [11]. The Kyoto Protocol facilitates developed countries to reduce greenhouse gas emissions by investing in afforestation and reforestation projects in developing countries in exchange for carbon stocks [6,12]. However, the information of carbon sequestration from tropical regions such as Indonesia was rarely reported. There is detailed information on developing an allometric equation for estimating the total biomass and carbon stock in Parring bamboo (Gigantochloa atter) using a destructive method from the community forest in Maros-South Sulawesi [13]. Nowadays, the development of allometric is focused on the development of widespread tree species [14–17]. It also applied even for a specific species such as coffee [18], cocoa [19], acacia [20], rubber [21], and only a limited number of studies that are interested in developing a specific allometric equation of local bamboo species [22–23]. The development of allometric equations is a vital instrument for the carbon accounting method [17]. There is a lack of allometric equations for specific geographic locations and positions [12]. However, some allometric equations to predict carbon storage on temperate bamboo have been implemented, such as makino bamboo [24]; moso bamboo [25,26], and ma bamboo [27].

Bamboo plantations have great potential in carbon sequestration because bamboo is a group of plants capable of absorbing high concentrations of CO$_2$. The number of stomata on bamboo leaves is relatively dense and numerous, which is more than 500 stomata per mm$^2$ [28], but unfortunately, the management of bamboo land has not been appropriately managed even many have been converted into agricultural cultivation land or other uses. Thus, bamboo can be used as an effective plant to reduce carbon emissions in the atmosphere. Through the process of photosynthesis, bamboo plays an essential role in the carbon cycle so that it can reduce CO$_2$ in the atmosphere, and at the same time, increase oxygen levels. Given that bamboo plays a vital role in absorbing carbon from the air quickly, it is necessary to research to measure how much bamboo plants can store carbon stocks, especially in the Bangsri watershed (DAS) Wajak District (Malang Regency). The resulting data can be an essential source of information on how far the riparian forest can accumulate carbon and reduce climate change risk.

2. Research methods

2.1. Research sites

The research was conducted in Bambang Village, Wajak District, Malang Regency, which is included in the Bangsri sub-watershed coverage. The study area is at 8° 8'14.42"S, 112°47'8.85"E, located at 525 above sea level. The average mean temperature is about 32°C. Field research was conducted from April 2018 to May 2019. The location was situated at the west lower slope of the complex Mount Semeru and Bromo, which dominated various agroforestry systems, including bamboo riparian forest. The soil was developed from a volcanic activity which mainly dominated by sand and silt particle. The bamboo riparian forest stretches along the river Bulu with about 5 km, crossing Bambang village.

2.2. Experimental design

This research was carried out using a Randomized Block Design consisted of 4 types of local bamboo, namely Apus bamboo (Gigantochloa apus), Javanese bamboo (Gigantochloa atter), Petung bamboo (Dendrocalamus asper), and Rampal bamboo (Schizostachyum zollingeri), each with 3 replications, resulted in 12 experimental plots. This research was conducted along the Bangsri watershed, where each type has been surveyed beforehand. Soil analysis was carried out at the Soil
Biology Laboratory, Faculty of Agriculture, Universitas Brawijaya, to determine soil organic matter content and soil bulk density to determine total carbon sequestration.

The initial stage of the activity was carried out using a survey method along the riparian forest overgrown with bamboo. All types of bamboo that grow are recorded and classified according to their type. Some of the criteria for observing bamboo include: (a) every observation plot with the same type of bamboo was cultivated, (b) it was suitable for replication with a 20 m × 20 m plot. The initial survey indicated were 4 (four) bamboo land uses in the area, then from the 4 (four) land uses, the researchers repeated 3 (three) times, so that the entire observation plots were 12 plots. From 1929 bamboo sticks in 12 plots, 6 different types of bamboo were found, and 10 stands of each type were measured. The total number of bamboos measured for the development of the allometric equation was 60 bamboo stands.

2. Observation variables and their measurement techniques

Measurement of stand biomass was carried out on the aboveground part. Measurement of plant biomass can be done by:
1. Non-destructive method. If the type of plant being measured is known to the allometric formula.
2. Destructive method. Researchers used this method to develop allometric formulas, especially for stand types with specific branching patterns for which the general allometric equation is unknown. Allometric development is done by cutting down plants and measuring their diameter, length, and mass [12,29–31]. The variables measured and observed in this study are presented in Table 1.

| Table 1. Variables for measuring bamboo biomass |
|-----------------------------------------------|
| Non-destructive method | Bamboo diameter in DBH (diameter at breast height) or diameter at breast height measured at 1.3 meters from the ground in centimeters (cm). |
| Destructive method    | The circumference of the bamboo stem in centimeters (cm) |
|                      | The length of the bamboo stem is in meters (m). |
|                      | The weight of the bamboo stem is in kilograms (kg). |
|                      | The weight of the bamboo stem sample is in grams (g). |
|                      | Dry weight of bamboo stem samples in grams (g). |
|                      | The wall thickness of the bamboo stem samples is in centimeters (cm). |
|                      | The volume of the bamboo stem sample is in cubic centimeters (cm3). |

Data collection on bamboo plants used a survey method where all types of bamboo were found, with a predetermined plot measured the tree DBH or measured the diameter at breast height at the height of 1.3 meters from the soil surface. Data was collected by making a plot measuring 20 m × 20 m along the riparian forest where the bamboo stand. For the destructive method, from the existing 3 replicate plots, 10 stands of each type were taken as cutting samples that would be used to obtain the wet weight of the stands and the total stand height, which was aimed at making allometric equations. Samples with a length of 15 cm were taken, which will be used for laboratory analysis to obtain data on the wet weight, the dry weight and can be used in calculations to obtain an estimate of the dry weight of the bamboo stalks (Figure 1). An equation between dry weight and DBH was made from the dry weight data obtained, and an equation between dry weight and height can be obtained. Furthermore, the equation that has been successfully created will be used to calculate biomass and proceed with the calculation of carbon stocks.

The data obtained from the results of this study were carried out by Analysis of Variance (ANOVA) using Genstat ver 20 software to determine whether there was a significant effect on the observed variables of all bamboo species studied along with LSD test to determine significant differences amongst the treatment.
3. Results and discussion

3.1. Characteristics of the research plot

The results of observations and calculations on a plot measuring 20 m × 20 m with 4 (four) different bamboo land uses, namely plot 1. Apus bamboo, 2. Javanese bamboo, 3. Rampal bamboo, and 4. Petung bamboo, then measurements were made in each plot with 3 replications so that the total number of observation plots is 12 plots. In the 12 plots, there are 6 (six) different types of mature bamboo whose dominant percentage values are presented in Table 2.

| Plot   | Test | Number of Apus bamboo (Gigantochloa apus) | Number of Petung bamboo (Dendrocalamus asper) | Number of Ampel Bamboo (Bambusa vulgaris) | Number of Rampal bamboo (Schizostachyum zollingeri) | Number of Javanese bamboo (Gigantochloa atter) | Number of plants Jabal bamboo (Schizostachyum brachycladum) | Total | % dominance |
|--------|------|-------------------------------------------|-----------------------------------------------|------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|------|-------------|
| Apus   | 1    | 160                                       | 25                                            | 0                                        | 0                                             | 0                                             | 0                                             | 185a | 86.5%       |
|        | 2    | 173                                       | 0                                             | 0                                        | 0                                             | 0                                             | 0                                             | 173a | 100%        |
|        | 3    | 140                                       | 34                                            | 0                                        | 42                                            | 0                                             | 0                                             | 216b | 64.8%       |
| Javanese bamboo | 1    | 0                                         | 0                                             | 0                                        | 128                                           | 0                                             | 0                                             | 128a | 100%        |
|        | 2    | 0                                         | 0                                             | 0                                        | 0                                             | 100                                           | 0                                             | 100a | 100%        |
|        | 3    | 0                                         | 23                                            | 16                                       | 0                                             | 139                                           | 0                                             | 178a | 78.1 %      |
| Rampal | 1    | 0                                         | 0                                             | 0                                        | 208                                           | 0                                             | 0                                             | 208b | 100%        |
| bamboo | 2    | 0                                         | 0                                             | 109                                      | 17                                            | 41                                            | 167a                                          | 65.2% |
|        | 3    | 13                                        | 9                                             | 0                                        | 93                                            | 17                                            | 0                                             | 132a | 70.4%       |
| Petung | 1    | 19                                        | 94                                            | 0                                        | 0                                             | 0                                             | 113a                                          | 83.1% |
| bamboo | 2    | 6                                         | 105                                           | 0                                        | 0                                             | 27                                            | 138a                                          | 76.1% |
|        | 3    | 0                                         | 145                                           | 0                                        | 0                                             | 46                                            | 191b                                          | 75.9% |
| Total  |      | 511                                       | 435                                           | 16                                       | 452                                           | 474                                           | 41                                            | 1929 |             |

Note: Figures followed by the same notation show that they are not significantly different (P>0.05) according to the LSD test at the 5% confidential level.

From Table 2, it can be seen that in the 1st plot, the percentage of Apus bamboo based on their dominance was between 64.8 to 100%. In the 2nd plot, the dominance of Javanese bamboo (78.1 to 100%), in 3rd plots and 4th, the dominance of Rampal bamboo and Petung bamboo ranged from 65.2 to 100% and 75.9 to 83.1%, respectively.

3.2. Fresh weight, moisture content, and dry weight of Bamboo stem

Table 3 showed that the fresh weight of bamboo is significantly different (P<0.01) for each type of bamboo. The highest fresh weight was found in Petung bamboo, with an average fresh weight of 39.82 kg stem⁻¹. Meanwhile, the lowest fresh weight was found in Rampal bamboo with an average of 13.51 kg stem⁻¹. Of the LSD test, it can be seen that the average fresh weight of Petung bamboo is significantly different (P<0.05) to other bamboos, which was almost 2 times greater.

The ANOVA results presented in Table 3 showed that the water content of bamboo is significantly different (P<0.05) for each type of bamboo. Jabal bamboo was the stand with the highest water content,
with an average total value of 31.802\% and ranging from 16-39\% in each stand, while the lowest water content was found in the type of Ampel bamboo with a value of the total average was 22.319\% and ranged from 16\%-31\% in each stand.

Table 3. Average wet weight, moisture content, and dry weight

| Type   | Fresh weight (kg stem⁻¹) | Water content (%) | Dry weight (kg stem⁻¹) |
|--------|--------------------------|-------------------|------------------------|
| Apus   | 18.84 a                   | 28.87 b           | 13.14 ab               |
| Petung | 39.82 b                   | 27.77 ab          | 28.17 c                |
| Ampel  | 21.93 a                   | 22.31 a           | 17.19 b                |
| Rampal | 13.51 a                   | 30.09 b           | 9.16 a                 |
| Javanese | 21.19 a                   | 31.16 b           | 14.27 ab               |
| Jabal  | 16.20 a                   | 31.80 b           | 10.92 ab               |

Figures followed by the same notation show that they are not significantly different (P>0.05) according to the LSD test at the 5\% confidential level.

In terms of the dry weight of bamboo, there was a significantly different (P<0.01) for each type of bamboo. The type of bamboo with the largest biomass component is Petung bamboo, with an average value of 28.171 kg stem⁻¹. The type of bamboo with the lowest biomass composition is Rampal bamboo, with an average value of 9.16 kg stem⁻¹. The content of biomass is closely related to the results of plant production obtained through photosynthesis.

3.3. Bamboo diameter and height

Based on the results of measurements of height and diameter, each type of bamboo has various values. The ANOVA results showed that each type of bamboo was significantly different (P<0.01) in bamboo height and bamboo diameter. The average height and diameter of each type of bamboo observed are presented in Table 4.

Table 4. Average height and diameter of bamboo at breast height (DBH)

| Type   | H (m)  | DBH (cm) |
|--------|--------|----------|
| Apus   | 12.2 a | 6.24 a   |
| Petung | 19.9 c | 9.52 b   |
| Ampel  | 10.1 a | 6.53 a   |
| Rampal | 13.1 ab| 5.51 a   |
| Javanese | 12.4 a | 6.56 a   |
| Jabal  | 14.5 b | 6.66 a   |

Figures followed by the same notation show that they are not significantly different (P>0.05) according to the LSD test at the 5\% confidential level. DBH = Diameter at Breast Height, H = Height of bamboo Stem

The height and DBH of each bamboo plant are significantly different (P<0.05). Based on the data obtained, the plant height with the highest value is Petung bamboo, with an average height of 19.9 m. Meanwhile, for the lowest height value, there is Ampel bamboo with an average height value of 10.1 m. For plant DBH data obtained with the largest DBH value, the Petung bamboo species is 9.52 cm, while the smallest DBH is Rampal of 5.51 cm. *Oxytenanthera abyssinica* has the height and diameter at about 7.3 m and 4.5 cm, respectively [23]. This value was relatively similar to those average Thorny bamboo diameter and height at about 8.8 cm and 18.8 m, respectively [22], which is greater than all bamboo species in this study except the bamboo species of Petung bamboo.
3.4. Relationship between bamboo diameter and their dry weight
Table 5 illustrates the relationship between DBH and the dry weight of bamboo. The highest coefficient of determination was found in the type of bamboo Jabal with a value of $R^2 = 0.92$, and the lowest value was found in Java bamboo with a value of $R^2 = 0.50$ following the power model.

Table 5. The relationship equations between bamboo diameter and their dry weight

| Name of bamboo                  | Equations         | $R^2$  |
|---------------------------------|-------------------|--------|
| Gigantochloa apus               | $Y = 0.9802X^{1.3984}$ | 0.7305 |
| Dendrocalamus asper             | $Y = 1.2974X^{1.3512}$ | 0.9129 |
| Bambusa vulgaris                | $Y = 1.3553X^{1.3378}$ | 0.7820 |
| Schizostachyum zollingeri      | $Y = 0.3725X^{1.8413}$ | 0.8468 |
| Gigantochloa atter              | $Y = 1.0668X^{1.3539}$ | 0.5029 |
| Schizostachyum brachycladum    | $Y = 0.5437X^{1.5648}$ | 0.9240 |

3.5. Relationship between height (H) and dry weight
The relationship between H and dry weight of bamboo was presented in Table 6. The highest value was found in the type of Javanese bamboo with an $R^2$ value of 0.91, and the lowest was found in the Ampel bamboo species with an $R^2$ value of 0.71. All relationships followed power function.

Table 6. The relationship equations between bamboo height and their dry weight

| Name of bamboo                  | Equations         | $R^2$  |
|---------------------------------|-------------------|--------|
| Gigantochloa apus               | $Y = 0.0818X^{2.0135}$ | 0.8559 |
| Dendrocalamus asper             | $Y = 0.0028X^{3.0625}$ | 0.9150 |
| Bambusa vulgaris                | $Y = 0.0268X^{2.7716}$ | 0.7140 |
| Schizostachyum zollingeri      | $Y = 0.0174X^{2.4094}$ | 0.7529 |
| Gigantochloa atter              | $Y = 0.0121X^{2.7886}$ | 0.9198 |
| Schizostachyum brachycladum    | $Y = 0.0017X^{3.2640}$ | 0.8626 |

Figure 2 shows the relationship between DBH and dry weight of all bamboo species across different plots, which then were compared to those relationships between H and dry weight of bamboo. It can be seen from Figure 2, that the relationship between DBH and dry weight of bamboo was found to have a better coefficient determination value ($R^2=0.77$) than those values of the relationship between H and dry weight of bamboo ($R^2=0.42$).

![Figure 2](image)

Figure 2. The relationship between diameter and height to bamboo dry weight

The calculation of bamboo biomass using the allometric equation using a formula $Y = 0.6396X^{1.6162}$ was plotted. It was compared to the biomass calculation using the allometric equation $Y=0.131X^{2.28}$ [32]. We can see in Figure 3 that it is explained that the bamboo biomass estimation determined by the formula of this study has a significant gap compared to the allometric equation formula developed by
which showed a lower estimation of bamboo biomass when the diameter increased. This may result from the diameter of bamboo collected only covered bamboo with small diameter [32]. In this study, bamboo's greatest diameter could reach about 16 cm, and the bamboo diameter is a good predictor for estimating their aboveground biomass.

Similar to this finding, log-transformed DBH was the best approach to estimate bamboo biomass of (*Oxytenenthera abyssinica*), and it was the easiest measured variable [23]. Culm and aboveground biomass have been reported successfully predicted using the allometric equation of Thorny bamboo (*Bambusa stenostachya*) [22]. The diameter and Paring bamboo biomass (*Gigantochloa atter*) were strongly correlated with a coefficient determination of $R^2=0.85$ following the formula: $W = 0.348 D^{1.830}$ [13].

### 3.6. Carbon stocks

The ANOVA results showed that the carbon produced by leaf litter in each bamboo plot was not significantly different ($P<0.05$). The largest average mass of carbon produced by leaf litter was found in the Petung bamboo with a value of 4.26 ton ha$^{-1}$ and the smallest average mass of carbon produced by leaf litter was found in the Apus bamboo with a value of 2.49 ton ha$^{-1}$ (Table 7).

**Table 7. Carbon in litter, branches, understory, soil and bamboo biomass (ton C ha$^{-1}$)**

| Plot      | Leaf litter (tons C ha$^{-1}$) | Branch litter (tons C ha$^{-1}$) | Understory (tons C ha$^{-1}$) | Soil (tons C ha$^{-1}$) | Bamboo biomass (ton C ha$^{-1}$) | Total carbon stock (ton C ha$^{-1}$) |
|-----------|-------------------------------|---------------------------------|-------------------------------|------------------------|---------------------------------|-------------------------------------|
| Apus      | 2.49                          | 1.15$^{ab}$                     | 3.35$^b$                       | 16.31                  | 105.38$^a$                      | 128.68$^b$                          |
| Petung    | 4.26                          | 0.57$^a$                        | 2.99$^{ab}$                    | 17.82                  | 189.84$^b$                      | 215.48$^c$                          |
| Rampal    | 4.07                          | 1.20$^{ab}$                     | 0.71$^a$                       | 11.36                  | 63.96$^a$                       | 81.30$^a$                           |
| Javanese  | 4.05                          | 2.10$^b$                        | 0.64$^a$                       | 11.59                  | 85.22$^a$                       | 103.60$^{ab}$                       |

Values followed by the same notation show that they are not significantly different ($P>0.05$) according to the LSD test at the 5% confidential level.

Table 7 showed that the average value of carbon produced by branches litter in each bamboo plot is significantly different ($P < 0.05$). The largest mass of carbon produced by litter is Javanese bamboo plots (2.10 C ton ha$^{-1}$), and the smallest was found in the Petung bamboo (0.57 ton C ha$^{-1}$). The values were not significantly different for the average mass of carbon produced understory ($P<0.05$). The largest average carbon mass value produced by understory is found in the Apus bamboo plot with a value of 3.35 ton C ha$^{-1}$. In comparison, the smallest average carbon mass value produced by understory was found in the Javanese bamboo plot with a value 0.64 ton C ha$^{-1}$.
Factors causing the amount of litter vary due to the general increase in litter biomass and the increase in tree age and canopy density. The density of the canopy or stands is a factor that affects the fall of forest litter due to competition for sunlight. The denser a stand or canopy will produce a greater amount of litter. Trees that grow in a relatively dense forest quickly release branches and leaves from below because the light is not enough for them to carry out photosynthesis. In addition to increasing the tree's age and the density of the litter canopy, litter fall is also influenced by both quantity and quality, controlled by environmental factors (climate, altitude, soil fertility). Litter productivity is also affected by vegetation and rainfall. Rainfall affects the physiology of vegetation because the higher the rain, the lower the fall of leaves, twigs, flowers, and fruit. When the rainfall is high, the humidity will increase, the evaporation of the leaves will decrease so that the leaves remain fresh and do not fall easily [33].

The biomass content of litter varies annually; the silvicultural system can cause this applied, planting density, the composition of stand age, diameter, height, soil fertility and then also due to the factor of logged-over forest 1 year before planting so that the litter that has not been decomposed causes litter biomass becomes larger.

It was shown that the carbon contained in the soil in each bamboo plot was not significantly different (P>0.05), in which the sample was collected from the depth of 0-20 cm. That value was lower than soil carbon stock values in 0-60 cm of Moso bamboo stands with values ranging from between 87.83 ton C ha\(^{-1}\) to 119.5 ton C ha\(^{-1}\), with an average of 103.6 ton C ha\(^{-1}\), which is significantly higher than rice 69.24 ton C ha\(^{-1}\) and dry soil of 49.91 ton C ha\(^{-1}\) in China [34]. This average amount is even higher than the average forest stock of 97.8 tons ha\(^{-1}\). Soil organic carbon below the bamboo surface could be an important factor that results in high C uptake. Therefore, bamboo forests can play an important role in effective CO\(_2\) absorption [34].

The carbon biomass produced is significantly different according to different bamboo plots (P<0.05). The largest average carbon bamboo biomass was found in the Petung bamboo, with a value of 87.32 ton C ha\(^{-1}\). The smallest carbon mass average was found in the Rampal bamboo with a value of 29.42 ton C ha\(^{-1}\). These differences are caused by differences in diameter, height, and different places of growth. This finding is also in accordance with a previous study, in which the differences in the place of growth can cause the difference in biomass [35]. For comparison, 1 hectare of bamboo stands can absorb about 17 tons of carbon (C) per year. Several studies revealed that the accumulation of carbon in *Chusquea culeou* species in Chile was 156-162 tons ha\(^{-1}\), *Phyllostachys pubescence* in Japan was 138 tons ha\(^{-1}\) and *Gigantochloa alter* in Indonesia was 45 tons ha\(^{-1}\). Meanwhile, the lowest carbon accumulation ever reported was 0.35 ton ha\(^{-1}\) in species by *Bashania fangiana* in China [6].

Environmental conditions can also be very influential on the amount of biomass content and carbon mass contained in bamboo. The high mass and carbon uptake are closely related to the diameter, density, and natural forests' environmental factors. Community plantation forests, especially bamboo plants, also have good potential to absorb carbon. The bamboo plantations are harvested so that the stands continue to regenerate [36]. The carbon bamboo biomass of various types of bamboo is closely related to the high potential of biomass for each kind of bamboo. This increase indirectly indicates that the greater the biomass, the greater the mass of carbon. Referring to the water content data of the plant components presented in Table 3, it can be stated that the higher the water content, the lower the percentage of biomass, or in other words, the water content is inversely proportional to the percentage of biomass.

The amount of carbon stored between lands varies depending on the diversity and density of existing plants, type of soil, and management. It can be seen from Table 7 that the largest total carbon stock value is in the Petung bamboo with a value of 215.48 tons C ha\(^{-1}\), then followed by the Apus bamboo with a value of 128.68 tons C ha\(^{-1}\), and the lowest was found on the plot of Rampal bamboo with a value of 81.30 tons C ha\(^{-1}\). The carbon storage becomes greater when the soil fertility conditions are suitable, or in other words, the amount of carbon stored above the soil (plant biomass) is determined by the amount of carbon stored in the soil (soil organic matter) [12,30,31].
4. Conclusion

Allometric equations were successfully constructed to estimate the biomass potential of various types of bamboo using the relationship between dry weight and DBH. The relationship between dry weight and D (diameter) is better than the relationship between dry weight and H. Plant diameter is a good choice and easy to determine plant biomass and carbon content. Measurement of diameter is easier and more accurate in the field when compared to measuring the variable height so that it produces the following allometric equation \( Y = 0.6396 \times 1.6162 \). Using this equation, it was found that the largest biomass value was in the Petung bamboo of 189.84 ton C ha\(^{-1}\), and the smallest biomass content was in the plot of Rampal bamboo of 63.96 ton C ha\(^{-1}\) which was only 1/3 from Petung bamboo. The total C stock of riparian bamboo forest at Bambang village ranged between 81 to 215 tons C ha\(^{-1}\).

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