Allometric model to estimate biomass of leave-twigs cajuput (Melaleuca cajuput) at KPH Yogyakarta, Indonesia

B Mulyana1,3, R H Purwanto1, Rohman1, and R Reorita2

1 Department of Forest Management, Faculty of Forestry, Universitas Gadjah Mada, Jl. Agro No. 1, Bulaksumur, Depok, Sleman, Yogyakarta, 55283, Indonesia
2 Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Jenderal Soedirman, Jl. Dr. Soeparno Utara 61, Grendeng, Purwokerto, 53122, Indonesia
3 Corresponding author: budimulyana@ugm.ac.id

Abstract. Estimation of carbon storage in plantations is an alternative strategy to mitigate climate change. The carbon storage estimation model was developed by building a biomass allometric model with specific predictors. Utilization of cajuput plantations is harvesting the leave-twigs, which is different from the utilization of commons plantation forests that emphasize on timber forest products. Therefore, the objective of the research was to develop an allometric model of cajuput leave-twigs biomass. The study was conducted in KPH Yogyakarta on cajuput plants aged 23, 27, 31, 33, 40, 41, and 43 years. 210 samples were used to develop allometric models, and 60 samples were used as model validation materials. Leave-twigs biomass of cajuput (Y) was estimated with the predictors of the canopy height of cajuput (X1), mean quadratic of canopy diameter (X2), and mean quadratic of stem diameter (X3). The results showed that the allometric model of leave-twigs biomass of cajuput was $Y = 3,597X_1^{0.961}X_2^{0.145}X_3^{0.247}$. The results of the model validation test resulted in $R_{adj}^2$ value of 0.428; the aggregate deviation was 9.76%; the mean deviation was 0.50%; the bias was -2.16%, and RMSE was 0.47%. The allometric model was less accurate in predicting leave-twigs biomass of cajuput with the predictors of canopy height, canopy diameter, and stem diameter. Furthermore, it is important to build an allometric model of leave-twigs biomass by adding other predictors.

1. Introduction
Climate change adaptation and mitigation have become global issues. The Government of Indonesia has ratified Law No. 16 of 2016 concerning the ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change. Furthermore, the Government has sent the Republic of Indonesia’s First Nationally Determined Contribution (NDC) document, one of which is the Indonesian Government’s commitment to reduce greenhouse gas (GHG) emissions by 26% in 2020 [1]. An alternative strategy to support GHG reduction efforts is by estimating carbon stocks stored in plant biomass. Forest removes the CO$_2$ in the atmosphere through photosynthesis process and stores as biomass [2]. For instance, cajuput forest plantation in KPH Yogyakarta stores 0.87 ton/ha of carbon at leave-twigs [3].

The allometric model is one of the approaches in estimating tree dimensions by using predictors from that part of the tree. Krisnawati et al. [4] have compiled allometric models used in determining tree biomass in various ecosystem types in Indonesia from numerous existing studies. In general, the expected dimension is tree volume with the predictors are diameter at breast height (dbh) and tree height [5][6][7]. In some instances, allometric models are also applied in estimating woody biomass
with a diameter predictor as high as 30 cm above ground level (D$_{30}$) [8]. Also, Panzou [9] has developed an allometric model using diameter and canopy dimensions predictors in several forest types in Central Africa to increase the estimation of biomass and carbon.

The formulation of allometric models should consider accuracy in measuring predictors in the field. Inaccuracies in the measurement of predictors in the field can affect error in the developed allometric model; for example, estimation of tree height, which is relatively difficult to measure with a level of accuracy of 3-20% will affect errors up to 16% [10]. Furthermore, Tiryana [11] argues that the selection of predictors in the development of allometric models is a predictor that can be measured easily and accurately. Thus, the predictors chosen in this study are predictors that can be obtained from precise direct field measurements, namely stem diameter, crown diameter, and crown height.

An allometric model of cajuput leave-twigs biomass at ready-to-harvest age is important to be developed to assist the managers of cajuput plantations in planning sustainable forest management. The optimum cycle of harvesting cajuput leave-twigs in KPH Yogyakarta is at the age of 8 months [12], but the implementation in the field of harvesting cajuput leave-twigs is done at the age of the leave-twigs of 9 months. The purpose of this study was to determine the allometric model to estimate the biomass of cajuput leave-twigs at the age of the leave-twigs of 9 months and to assess the reliability of the allometric model.

2. Methods

2.1. Data collection

The study was conducted in the compartment of 31 Forest Management Unit Yogyakarta. The selection of compartment 31 was based on the normality degree of the cajuput stands [13]. Fieldworks were carried out in April 2018.

The compartment of 31 was composed of several ages of cajuput plants, and their locations were spread out in the compartment. The selection of sample tree sampling locations refers to the research of Mulyana et al. [14] in the temporary plots sampling (TPS) numbers 9, 14, 23, 35, 39, 42, 49, 56, and 60. Fieldworks were conducted to collect the data of the stem diameter of the base and tips of cajuput, the diameter of the cajuput’s canopy, and the height of cajuput’s canopy (Figure 1).

![Figure 1](image.png)

**Figure 1.** Point measurements of the dimensions of cajuput plants (a) base diameter, (b) tip diameter, (c) canopy diameter, and (d) canopy height

2.1.1. Canopy height

Cajuput’s canopy height can be measured from the bottom of the canopy to the tip of the canopy. Canopy height measurements were carried out in the center of the canopy or a straight line with the cajuput trunk.

2.1.2. Stem diameter


Stem diameter at the base and tip was obtained by measuring the circumference of the stem at the base and tips using the tape. Stem diameter was measured at several locations, such as at the bottom, breast height, and under the canopy, and can be used as predictors for the preparation of biomass allometric models and carbon storage [15]. Furthermore, the diameter of the base and tip of the stem were calculated on the mean quadratic.

2.1.3. Canopy diameter
Canopy diameter was measured twice in the East-West and North-South directions. Measurement of canopy radius according to the wind direction was also carried out in Sadono's research in teak plantations [16], who calculated the mean radius of the teak canopy using the quadratic mean. The mean diameter was more suitable to use a mean quadratic than the mean of arithmetic, although the two mean values did not differ much [17].

3. Results and discussion

3.1. Data characteristics
Relationship between cajuput leave-twigs biomass (Y) and stem diameter (X) showed non-linear regression pattern. Meanwhile, relationship between cajuput leave-twigs biomass (Y) and canopy dimension (X) showed linear regression pattern (Figure 2).

![Figure 2](image_url)

**Figure 2.** Distribution pattern of cajuput leave-twigs biomass with predictors of stem diameter, canopy diameter, and canopy height

Productivity of cajuput leave-twigs decreased gradually at the age of 27 years to 31 years. The highest productivity rate was gained at the age of 33 years then showed a flat pattern at the age above 40 years (Figure 3).
3.2. Development of the allometric model

Fieldwork was conducted to collect data on canopy height, stem diameter, canopy diameter, and the fresh-cut weight of cajuput leave-twigs. The data were analyzed with the following stages:

3.3. Normality test

Hypothesis

\( H_0 \): residuals are normally distributed

\( H_1 \): residuals are not normally distributed

Criteria for decision

\( P\)-value \( > 0.05 \) thus \( H_0 \) accepted

\( P\)-value \( < 0.05 \) thus \( H_0 \) rejected

Based on the calculation, the \( p \)-value of 0.010 smaller than 0.05, so that \( H_0 \) was rejected. Thus the residual data were not normally distributed. Due to the residual data were not normally distributed, data transformation was needed to develop the allometric model.

3.3.1. Data transformation and development of the allometric model

Residual data collection was not normally distributed so that data transformation was carried out. The data transformation used was logarithmic transformation. Logarithmic transformation is one of the tools that is used in the preparation of allometric models by taking into account other tests [18]. The normality test for transformed data showed that the \( P\)-value of 0.15 was greater than 0.05; it can be concluded that the residual data from the transformation results were normally distributed.

The regression equation for estimating biomass of cajuput branches (\( Y \)) with a height predictor of cajuput canopy (\( X_1 \)), mean quadratic of canopy diameter (\( X_2 \)), and mean quadratic of stem diameter (\( X_3 \)) were as follows: \( \log Y = 0.556 + 0.961 \log X_1 + 0.145 \log X_2 + 0.247 \log X_3 \). Furthermore, many tests were applied to examine the allometric model such as multicollinearity test, autocorrelation test, partial test, simultaneous test.

Multi-collinearity test is performed on the preparation of equations with more than one predictor and has met the normality test [19]. If the value of the variance inflation factor (VIF) \(< 10\), then there are no symptoms of multicollinearity in the model [7]. Based on the VIF value of each variable smaller than 10 (VIF for \( \log X_1 \) was 1.123; \( \log X_2 \) was 1.120, and; \( \log X_3 \) was 1.003), it can be concluded that the relationship between variables in this study did not experience multicollinearity.

![Figure 3. Productivity of cajuput leave-twigs at several age of plant](image-url)
With \( k = 3, n = 210 \) then the Durbin Watson's table value is \( d_l = 1.75483 \) and \( d_u = 1.79326 \). Durbin-Watson calculation value obtained \( d_w = 1.17129 \), so that \( d_w \) was smaller than \( d_l \), it was concluded that there were autocorrelation symptoms. With a \( F_{\text{value}} \) of 62.39 higher than \( F_{\text{statistic}} (2.64843) \) in the significance level \( \alpha = 5\% \), it can be concluded that the independent variables simultaneously had a significant effect on the model.

The last stage was the partial test for each predictor. The \( t_{\text{value}} \) of canopy height was 11.48, the mean quadratic diameter of the canopy was 2.51, and the mean quadratic stem diameter was 2.77 at the significance level \( \alpha = 5\% \). The \( t_{\text{value}} \) for each predictor were higher than \( t_{\text{statistic}} \), it can be concluded that each predictor significantly influences the cajuput's leave-twigs biomass.

The allometric equation with multi variables in estimating biomass of cajuput leave-twigs is:

\[
\log Y = 0.556 + 0.961 \log X_1 + 0.145 \log X_2 + 0.247 \log X_3
\]

or

\[
Y = 3.597X_1^{0.961}X_2^{0.145}X_3^{0.247}
\]

Where Y is cajuput biomass (kg), \( X_1 \) is the height of cajuput canopy (cm), \( X_2 \) is the mean quadratic of cajuput canopy diameter (cm), \( X_3 \) is mean quadratic of stem diameter (cm).

The allometric model of multi-variable cajuput woody biomass is the equation of the power function. Picard et al. [20] states that the allometric model in the form of the power function equation is one form of a simple allometric whose equations include:

\[
\ln(M) = k + b \ln(B) + c \ln(C)
\]

\[
\log (M) = k + d \ln(D) + e \ln (E)
\]

\[
M = kF^g
\]

Where M is biomass, \( k \) is a constant, \( b, c, d, e, f, g \) as coefficients, while \( B, C, D, E, F, \) and \( G \) are predictors.

### 3.4. Validation of the allometric model

Evaluation of the model using the parameters of the coefficient of determination \( (R^2) \), Root Mean Square Errors (RMSE), aggregate deviations, mean deviations, and bias can be applied in the validation of allometric models and the preparation of volume tariffs [5][21][22]. The evaluation model results for estimating biomass of cajuput leaves with a predictor of canopy height, canopy diameter, and diameter of cajuput stem are presented in the following table.

| Table 1. Criteria for allometric model validation. |
|-----------------|-----------------|
| Criteria        | Value (%)       |
| \( R^2_{\text{adj}} \) | 42.80           |
| Aggregate deviation | 9.76       |
| Mean deviation   | 0.50            |
| Bias             | -2.16           |
| RMSE             | 0.47            |

The coefficient of determination \( (R^2_{\text{adj}}) \) of 0.428 indicated that the estimation model of cajuput leave-twigs biomass \( Y \) was affected by predictors of canopy height \( (X_1) \), quadratic average crown diameter \( (X_2) \), and quadratic average stem diameter \( (X_3) \) which the value wa 42.8\%. The remaining 58.2\% was influenced by other predictors that were not included in this study. Thus, to improve the reliability of the cajuput biomass estimator model, further research is needed with the addition of other predictors.
The bias value was -2.16%, and the RMSE value was 0.47%, indicating that the model had a small error. RMSE values close to zero, then the error distribution approaches the actual value so that the resulting model is more reliable [23]. Although there is no specific value limit in the validation of the model with the criteria of the coefficient of determination, bias, and RMSE, the preparation of allometric models generally takes into consideration the high coefficient of determination, as well as the small bias and RMSE values as consideration in the reliability of the model [24].

The mean deviation had met the criteria in model validation (below 10%), while the aggregate deviation had not met the requirements in the model validation (below 1%). With the criteria not yet met in the model validation, the compiled equation can produce bias on specific observations [22]. The higher the mean deviation and aggregate values, the difference between the estimated value will be different from the actual value [25] so that the accuracy of the model is less useful [26].

Meanwhile, the allometric model of leave-twigs cajuput is less accurate, but it is vital to elaborate the role of cajuput plantation on climate change mitigation. Allometric model has been used widely around the world to estimate the carbon storage in the plant organs. Decreasing the amount of CO₂ in the atmosphere can be estimated by the concept of carbon storage in bioproducts [27]. Allometric models are used in Indonesia to estimate the biomass of forest as the basis for calculating forest carbon stocks [4].

4. Conclusion
The allometric model for estimating the biomass of cajuput leave-twigs was the Power model. The model was \( Y = 3.597 X_1^{0.961} X_2^{0.145} X_3^{0.247} \). The allometric model can be used to calculate the dynamic of cajuput plantation carbon storage. This allometric equation only applies in the cajuput plantations at KPH Yogyakarta which the age of leave-twigs is 9 months.

Due to climate change mitigation through calculating the carbon storage, a reliable and accurate allometric model of cajuput leave-twigs is important. Further research on development of leave-twigs cajuput allometric model should be emphasized on finding the best predictors to estimate the biomass of cajuput leave-twigs.

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