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The allometric model to estimate biomass and carbon stock in top grafting young cacao plants

Andi Besse Poleuleng[1], Herdhata Agusta[2], Sudirman Yahya[2], Ade Wachjar[2] and Aiyen Tjoa[3]

[1]Study Program of Agronomy and Horticulture, Graduate School, IPB University (Bogor Agricultural University), Bogor, Indonesia
[2]Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University (Bogor Agricultural University), Bogor, Indonesia
[3]Department of Agrotechnology, Faculty of Agricultural Sciences, Tadulako University, Palu, Sulawesi Tengah, Indonesia

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ABSTRACT

Allometric model for biomass estimation have been reported in cacao plant derived from seed, while there is still limited study specifically for those from vegetative multiplication technique. This study aimed to formulate a simple and non-destructive model for estimating biomass and carbon stock of top grafting young cacao plants. A total of 54 samples of 2-3 years old cacao plants originating from SUL1, SUL2, MCC02 and MCC01 clones were randomly selected from 18 locations in South Sulawesi and Central Sulawesi Province of Indonesia, from January to August 2019. Measurements were taken at the stem/branches/twigs circumference as predictor variables and plant biomass/dry weight (g) as predicted variable. The result showed that among 23 developed models, there were 4 models selected as indicated by the high correlation coefficient (R^2), namely model of stem circumference at 10 cm, 20 cm, 10+20 cm and 10+20+30 cm. Among four selected model, the chosen model was a stem circumference at 20 cm (SC20) model because it had the highest value of R^2 and also involved only single predictor variable so that the model formed was simple and more efficient to apply. There was a close relationship ($R^2 = 0.914$) between the results of carbon stock based on actual biomass and Sc20 model derived biomass.

Key words : *Linear regression analysis, Model formulation, Non destructive, Stem circumference*

Introduction

Cacao is one of Indonesia's leading plantation commodities (Ditjenbun, 2016) which is introduced from tropical Amazon forest (Wood and Lass, 1985). This commodity has diverse functions either for food, beverage or cosmetics industries (Lima *et al*., 2011). In 2019, Indonesia's position as a cacao producer declined and ranked on the 4th position (ICCO, 2019) after being top 3 in 2018 (ICCO, 2018). The total area of cacao plantation in Indonesia reached 1,683,868 ha in 2018 with a total production for about 596,477 tons (BPS, 2018). Cacao is widely cultivated in Indonesia both monoculture and mixed cropping within agroforestry system.

Beside its economic value, cacao also has an environmental function as a carbon storage. The balance of carbon between the atmosphere and land is a big issue to be maintained for sustainability of environment. Carbon in form of CO_2 is absorbed by plants from the air and piled up in the body as carbon stores. Wessel (1985) reported that the rate of carbon fixation of cacao plants at optimal conditions can reach 7.5 mg CO_2 per 1 dm^2 leaf area. Abdoellah (2008) also reported that cacao plant is able to absorb 80,000 kg of CO_2 per ha per year and also release back in the amount of 63,000 kg of CO_2 per ha per year. In addition to respiration, the released of carbon from plant can be happened because of plant burning activities (Yusuf *et al.,* 2014). Maintaining the amount of carbon deposited on land including plant biomass, is one form of environmental services at the global level (Monde, 2009).

The measurement of carbon stock in plants can be done by various approaches with similar main principle, i.e referred to plant biomass. The amount of C stored in plant biomass can explain the level of CO_2 uptake from the atmosphere by the plant. The formula for calculating carbon storage of cocoa plants is plant biomass multiplied by 0.46 and expressed in kg or g units (IPCC 2006). In general, plant biomass is measured using the destructive method (Tackenberg, 2007), i.e. weighing the dry weight of entire plant body (Cornelissen *et al.,* 2003). The lack of destructive method is the limitation to apply at time series measurements (De Swart *et al.,* 2004). This method is also less efficient when applied in big size plants, a high amounts and challenging land conditions.

An alternative for estimating plant biomass is a non-destructive approach using allometric model. Schmildt *et al.,* (2017) once reported the use of allometric equations to determine cacao leaf area. Previous studies reported the use of allometric equations for estimating plant dry weight from its tree size, either diameter or height (Sutaryo, 2009). Yuliasmara *et al.,* (2009) have arranged an allometric model for biomass estimation of cocoa plants derived from generative propagation, i.e plant biomass (g) = 0.208 x $D^{1.98}$, with the D is the diameter value at a plant height of 130 cm. The model is no longer suitable to be applied to cacao plants derived from vegetative propagation technique. This condition is due to the limitations of the allometric method namely its very specific nature (Sutaryo, 2009). Therefore, new allometric models for plants from vegetative propagation technique are needed.

One of the most common vegetative propagation techniques applied in cocoa is top grafting. Top grafting is the vegetative propagation techniques which aim to combine the superior characteristics of both scion and rootstock through cambium fusion (Zakariyya and Yuliasmara, 2015). Cacao originated from top grafting technique has different plant performance compared to generative ones, such as the shorter plant height and also shorter *jorquette* branching height. Therefore, this study aimed to develop an allometric model of biomass to estimate biomass as an input for carbon stock calculation in top grafting young cacao.

Materials and Methods

This experiment was carried out from January to August 2019. The observation object was top grafting young cacao plants from 4 clones, namely SUL1, SUL2, MCC02 and MCC01. Cacao sampling was carried out at 18 locations spread across the provinces of South Sulawesi and Central Sulawesi, Indonesia. At each location, 3 plants were selected with a random age ranging from 2 to 3 years, so that in total there were 54 cacao plants observed.

The predictor variable used in this experiment was the circumference of the stem/ branches/twigs. The measurement of those predictors used a roll meter. The measurement was repeated every 10 cm starting from a height of 10 cm above ground level (agl) to 130 cm agl, referring to SNI 7724: 11. At a height of 10 cm and 20 cm, circumference measurements were still carried out on the main stem, but at subsequent heights (30 cm to 130 cm) measurements were made on branches or twigs and were expressed as the accumulation of branches/twigs circumferences. Researchers also noted the number of branches/twigs formed in every 10 cm plant height. After this measurement, plant roots were dug and the entire plants removed from the soil. Plants were cleaned, size reduced, and then packed prior to transfer to the laboratory for drying and weighing. The drying was carried out in oven at 75 ºC for 3 days and then weighed. The mean value of the plant dry weight and its partition in every 10 cm were depicted in Table 1.

The formulation of model to estimate cacao plant biomass used a simple linear regression analysis with the plant dry weight as dependent variable (Y) and stem/branches/twigs circumference as independent variable (X). There were 13 models obtained from a single predictor variable of circumference of stem/branches/twigs. In addition, there were 10 alternative models built based on the sum of multiple predictor variables, so that in total there were 23 model tested. The best model was selected based on the highest correlation coefficient (R^2).

Table 1. The mean value of dry weight and its proportion of top grafting young cocoa plant

Plant part	Partition (cm above ground level)	Dry weight (g)	Dry weight proportion (%)
Crown	10	159.07	7.98
	20	151.01	7.57
	30	125.81	6.31
	40	100.34	5.03
	50	95.84	4.81
	60	90.43	4.53
	70	85.48	4.29
	80	84.43	4.23
	90	81.89	4.11
	100	66.30	3.32
	110	72.82	3.65
	120	63.22	3.17
	130	61.88	3.10
	>130	365.30	18.32
Root		390.40	19.58
Total		1994.22	100.00

Model with a high R^2 was considered as a feasible model to estimate dependent variables (Mattjik and Sumertajaya, 2013). The carbon stock was calculated referred to IPCC (2006), i.e., plant biomass multiplied by 0.46 and expressed in kg or g units. Simple linear regression analysis was performed in MS Excel.

Result and Discussion

Plant biomass could be measured through various methods, i.e direct harvesting methods in the field (Ogawa 1977), tree volume and wood density approaches (Brown *et al.,* 1984) and allometric approaches (Purwanto *et al.,* 2012). The allometric approach displayed the relationship that occur harmoniously and proportionally between plant parts (Parresol, 1999). The advantage of allometric approach was easy to apply and suited for time series observations (De Swart, 2004). Previous studies by Martin *et al.,* (1998) showed an allometric approach to determine the relationship between trunk diameter, wood volume and tree biomass, or even carbon storage. Other studies also confirmed that plant biomass could be estimated by stem diameter (Ketterings *et al.,* 2001; McMahon and Kromauer, 1976). Present study constructed 23 allometric models from 23 predictor variables, i.e 13 single predictor models and 10 multiple predictor model (Table 2). The model was showed as matematicalequition and equipped with its R^2, P value and standard of deviation. The construction of model used a simple linear regression analysis that showed a varied relationship between plant biomass and predictors.

Models with single predictor of stem/branches/twigs circumference at a height of ≥ 50 cm above ground level categorized as inferior models, indicated by the low R^2 and insignificant P value. While model with a single predictor of stem/branches circumference at a height of 10 cm (SC10) and 20 cm (SC20) showed to be feasible models because pf its high R^2. For the multiple predictor class, all models have a significant P value because they constructed from 4 types of single predictor that previously also reported to have significant P value. The best two selected models in multiple predictor class were model with a stem circumference of 10+20 cm (SC10+20) and a stem circumference of 10+20+30 cm (SC10+20+30) because of its high R^2 value.

Among four selected models (Figure 1), the best model was chosen with consideration not only R^2 but also the easiness of application. The higher R^2 indicated the closer the relationship between two regressed variables, and vice versa (Sembiring, 1995). Models that were composed of a single predictor variable were easier to apply than multiple variables, because of time and energy efficiency consuming during the observation. The simplest model but still had a high R^2 value is a SC20 model.

Biomass estimation become an important issue because of its role as an input for carbon stock calculation. Carbon stores was defined as the amount of carbon stored in the plant body. The carbon stock on cacao plant was assumed to be 0.47 of the entire plant dry weight (IPCC, 2006). By having SC20 model to estimate biomass, we could also calculate the carbon stock of top grafting cocoa plant. Our result showed that there was a close relationship (R^2=0.914) between the actual biomass and SC20 model derived biomass and similar pattern was shown in term of carbon deposits (Figure 2). The increase of cocoa plant biomass was followed by the increase of plant carbon stock.

In addition, the increase of plant carbon storage could occur with the increasing of plant age (Stephenson *et al.,* 2014; Yuliasmara *et al.,* 2009). Carbon stock in cacao plantation with plant age less than 3 years old was only 0.45 tons per ha, whereas in plants aged 7 years and more than 12 years their carbon deposits had increased to be 1.23 tons per ha and 2.08 tons per ha, respectively (Monde, 2009).

Table 2. Mathematical equations produced by simple linear regression analysis between actual measurement of plant dry weight and stem/branch/twig circumference

Stem/branch/twig circumference (cm above ground level) Single predictor	Mathematical equation	P *value*	R^2	SE
10	y = 156.76x-2739.4	0.000	0.884^t	7.85
20	y = 161.99x-3093.8	0.000	0.914^t	6.89
30	y = 48.568x-995	0.000	0.775	3.63
40	y = 23.615x-51.729	0.000	0.595	2.70
50	y = -458x+2345.6	0.681	0.025	3.42
60	y = -4.58x+2293.4	0.095	0.023	3.21
70	y = -3.9257x+2243.9	0.562	0.021	3.11
80	y = -3.435x+2197.2	0.222	0.024	3.32
90	y = -3.435x+2172.5	0.275	0.026	3.41
100	y = -3.0533x+2117.5	0.476	0.027	3.81
110	y = -3.8664x+2108.09	0.914	0.049	2.36
120	y = -31.47x + 2072.4	0.995	0.037	2.21
130	y = -4.1264x+2026.2	0.415	0.038	2.86
Multiple predictor				
10+20	y = 81.088x - 3000.5	0.000	0.915^t	3.426
10+30	y = 39.037x-1584.5	0.000	0.886	2.339
10+40	y = 21.738x-542.55	0.000	0.804	2.112
20 +30	y = 39.171x-1644.6	0.000	0.896	2.321
20 +40	y = 22.006x-600.15	0.000	0.830	2.089
30+40	y = 18.557x-747.16	0.000	0.800	1.431
10+20 +30	y = 32.257x-1974.9	0.000	0.914^t	1.665
10+20 +40	y = 20.029x-970	0.000	0.874	1.685
20 +30+40	y = 17.078x-1063.8	0.000	0.878	1.187
10+20 +30+40	y = 15.658x-281.6	0.000	0.897	1.013

Note: ^{t} in the end of R^2 value showed the selected model. P *value* and standard of error (SE) were produced from PASW Statistic 18, while mathematical equation and coefficient of regression (R^2) were produced from linear regression analysis in MS Excel.

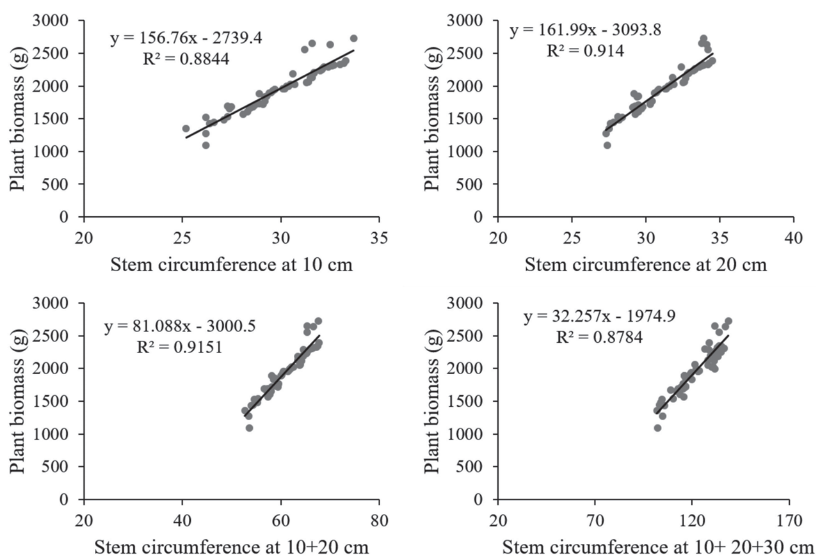

Fig. 1. The linear regression scatter chart that showed mathematical equation and coefficient of regression of 4 selected models, i.e stem circumference at 10 cm, 20 cm, 10+20 cm and 10+20+30 cm.

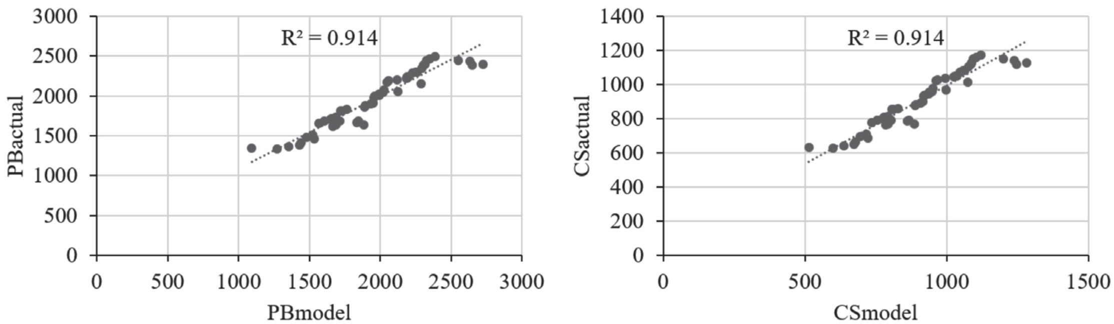

Fig. 2. The comparison of plant biomass and carbon stock obtained from actual measurement and modelling calculation by using selected model of stem circumference at 20 cm above soil ground.
Note: PB actual – plant biomass actual, PBmodel – plant biomass model, CSactual – Carbon stock actual, CSmodel – carbon stock model.

The amount of carbon stored in a land was also affected by the biodiversity and complexity of ecosystems. The ability of plants to accumulate and distribute photosynthetic carbon could also determine carbon inputs in an ecosystem (Kerdkankaew, 2003). Complex ecosystems with higher plant biodiversity had a higher carbon deposits compared to man-made ecosystems that were generally monoculture with low biodiversity. It was consistent with the results of Monde (2009) which reported that carbon storage of natural forests, cacao-agroforesty land (cacao age > 12 years) and cacao monoculture land (cacao age > 12 years) were 16.03 tons per ha, 3.37 tons per ha and 2.08 tons per ha, respectively. Calculation of carbon deposits was aintial step to support the big program such as reducing emissions from deforestation and forest degradation (REDD) (Raty *et al.,* 2011). The success of terrestial carbon stock mapping program highly depended on the availability of accurate and reliable allometric models for estimating biomass (Chave *et al.,* 2014). Thus, model formulation specific for top grafting young cocoa was worthy and helpful for the carbon mapping program.

Conclusion

A simple and feasible model to estimate plant biomass of top grafting young cocoa was comes from a single predictor, i.e a stem circumference at 20 cm (SC20), with following equation, y = 161.99x-3093.8 (R^2 = 0.914 and Pvalue = <0.01). This predictor was chosen as the simplest biomass estimator model for top grafting young (2-3 years) cacao plants originated from 4 clones, namely SUL 1, SUL 2, MCC02 and MCC01. There was also a close relationship between the result of SC20 model derived biomass and its actual biomass, so do carbon stock.

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