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Allometric Equations for Estimating the Carbon Sequestration in Rubber Plantations

Engku Azlin Rahayu Engku Ariff[1]*, Mohd Nazip Suratman[1], Shamsiah Abdullah[2]

[1]Faculty of Applied Sciences and Centre for Biodiversity and Sustainable Development, Universiti Teknologi MARA, Shah Alam 40450, Malaysia.
[2]Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Shah Alam 40450, Malaysia.

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⌧*Corresponding author:
Engku Azlin Rahayu Engku Ariff, Faculty of Applied Sciences and Centre for Biodiversity and Sustainable Development, Universiti Teknologi MARA, Shah Alam 40450, Selangor, Malaysia.
Email: engkuazlin_87@yahoo.com

Abstract

Deforestation occurs due to agriculture and agroforestry. Since it can alter the whole ecosystem and can change regional and global climate, Malaysia is one of the members of United Nation Framework on Climate Change (UNFCCC) which applies Kyoto protocol to curb this problem. Despite the large number of studies on rubber plantation, only a few studies focus on the development of allometric equation for estimating carbon sequestration for rubber plantation in Malaysia. This research studies the correlation of carbon sequestration and plant physiology of rubber trees using non-destructive sampling. In this research, the data were collected from rubber plantations in Selangor. The rubber trees chosen were in the range between 1 to 28 years old. The number of trees sampled in this research was 150 for each selected age (1, 2, 3, 5, 6, 8, 10, 13, 15, 17, 19, 20, 23 and 28 years) totalling 2100 trees. Allometric equation of this research was developed by using carbon sequestration as a response variable (Y) and 8 of the chosen predictor variables, which are diameter at breast height (DBH), height (HT), chlorophyll content (CC), stomatal conductance (SC), photosynthesis (PN), transpiration (TRPT), leaf area index (LAI) and age (AG). Based on the statistical indicators, the most suitable model is $\ln(Y) = c + a\ln(DBH) + b\ln(HT) + c\ln(AG)$. This model is highly reliable for its accuracy in measurement for forest managers to estimate carbon sequestration in rubber trees. Therefore, the research findings can be extrapolated accurately for managing secondary forests related to carbon balance. As for the additional explanatory variables such as CC, SC, PN, TRPT and LAI they do not fit the indicators' goodness of fit for the equation. The research findings complement the previous research as well as the methodology of the Good Practice Guidance for Land Use and Land Use Change and Forestry (GPG-LULUCF).

1. Introduction

Global warming that lead to climate change has been debated and widely discussed over the past few decades by intelligence, researchers and leaders. This global issue refers to an increase in average global temperatures which is predicted by NAST (2000) that average annual global surface air temperature may increase by approximately 2.5°C by the end of the century. Consequently to mitigate climate change, UNFCCC produced an international environmental treaty at the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro from 3 to 14 June 1992. The objective of the treaty is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Then, in 1997 the UNFCCC proposed a meeting in Kyoto, Japan which established the Kyoto Protocol where six greenhouse gases were identified as the main causes of global warming or the greenhouse effect. These were carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6) (UNFCC, 2008) and the most

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important contributor to greenhouse effect is carbon dioxide (CO_2). Carbon dioxide is essential to life as part of the carbon cycle and plays a vital role in regulating earth's surface temperature through radiative forcing and the greenhouse effect by absorbing and emitting infrared radiation. However, the excess of carbon dioxide which is mostly produced by anthropogenic activities will lead to global warming since carbon dioxide maintains the earth's temperature.

Many countries have signed to mitigate the emission of greenhouse gases. Malaysia also has signed the United Nations Framework Convention on Climate Change (UNFCCC) on 9 June 1993 and ratified it on 17 July 1994 and was classified into non-Annex 1 countries. Malaysia are playing an active role in reducing CO_2 emission through national mitigation and intergovernmental (Nor Shaliza et al., 2010) and it is proven from the speech of the Prime Minister of Malaysia announced during the 2009 UNFCCC conference in Copenhagen (Bernama, 2009) that Malaysia is adopting an indicator of a voluntary reduction of up to 40% in terms of emissions intensity of Gross Domestic Product (GDP) by the year 2020 compared to 2005 levels.

Kyoto protocol established flexible market mechanisms and one of the mechanisms is Clean Development Mechanism (CDM). Under the CDM, UNFCCC offers the possibility of enhancing rubber plantations development and participating in the host country's sustainable development. In fact, since rubber tree plantations correspond to the definition of forest, the subsequent carbon sinks resulting from reforestation in degraded regions can be eligible as CDM. Rubber tree (*Hevea brasiliensis*), which is also known as hevea wood, is a major industrial crop grown in Southeast Asia with an estimated plantation area of 1.8 million ha (20% of global plantation) in Malaysia alone (Srinivasakannan and Zailani, 2004). Therefore, it is important to study the ecosystem function of rubber plantation in mitigating climate change.

In order to predict the biomass and carbon sequestration in the future, an allometric equation should be developed to avoid destructive sampling of rubber plantation. Even though numerous studies in allometric relationships have been developed for aboveground rubber tree parts (Chaudhuri et al., 1995; Dey et al., 1996; Schroth et al., 2002), limited variables and small samples were used to develop the biomass prediction equation. In those studies, destructive samplings were used. The reports presented in this paper are the results of a study carried out aimed at investigating the relationships between carbon sequestration and diameter at breast height (DBH), height (HT), chlorophyll content (CC), stomatal conductance (SC), photosynthesis (PN), transpiration (TRPT), leaf area index (LAI) and age (AG) of rubber trees.

2. Materials and Methods

2.1. Study site

The study site chosen was the State of Selangor (796,084 km^2) in the southwest of Peninsular Malaysia, located from latitudes of 2º 35' to 3º 55' N and longitudes of 100º 45' to 102º 00' E. The climate is wet tropical with a mean annual temperature of 26ºC and a mean annual rainfall of 3000 mm. The map of the study area is presented in Figure 1. State of Selangor consists of forested and non-forested areas which are 250,650ha and 542,160ha respectively. The forested area include inland forest (136,860ha), peat swamp forest (82,890ha), mangrove forest (18,899ha) and forest plantation (11,381ha), (Department of Forestry, 2013). Forest plantation area is 1.43% of the total land of Selangor which comprise of oil palm, rubber, grasslands and other mixed agricultural tree crops such as coconut, sweet potatoes and cassava (Department of Agriculture, 2013). The soil in Selangor is mostly made up of Rengam, Serdang and Munchong which are suitable for rubber plantations (Department of Agriculture, 1966).

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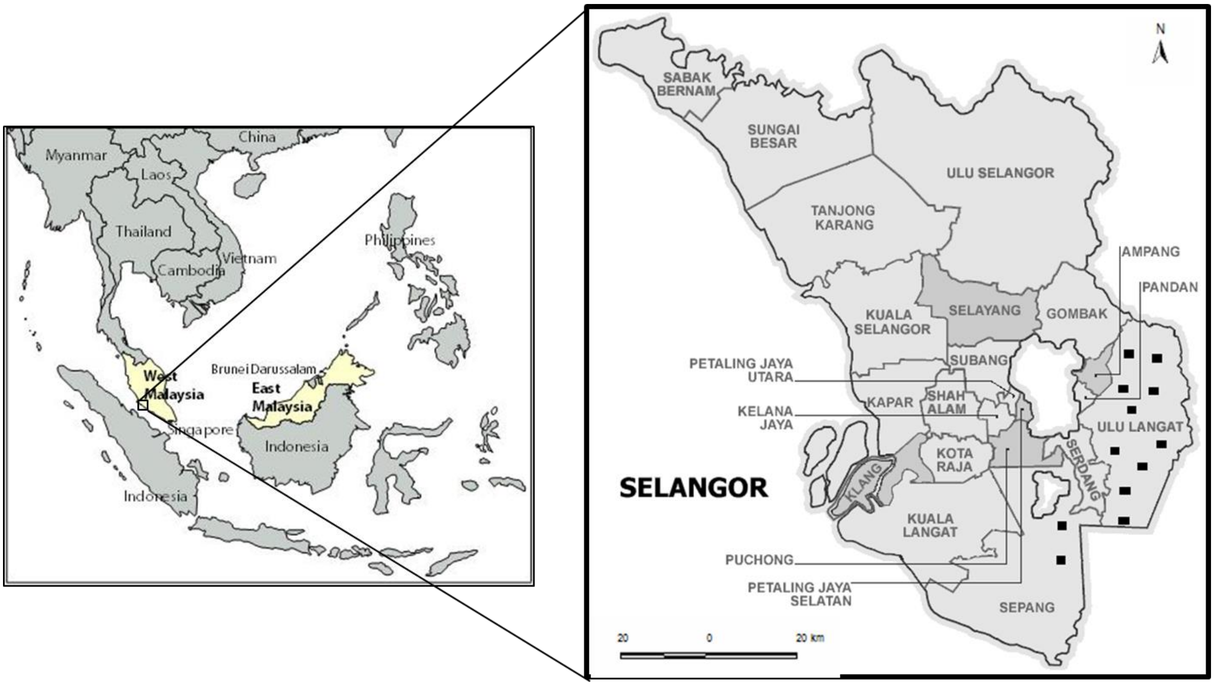

Figure1: Map of Selangor and study site (■).

2.2. Field Measurement

Data were collected in 2011 and 2012. The rubber plantations chosen for field sampling are owned by the government and by private small landholders and mostly under Rubber Industry Smallholders Development Authority which is known as RISDA. RISDA is under the Ministry of Rural and Regional Development of Malaysia. The list of rubber plantations in Selangor was obtained from RISDA and from the list, the most suitable rubber stands were chosen based on several factors, such as location, cost, topography, and approval by owner. The best stands chosen range between 0.1 to 3 ha with rubber trees aging from one to 28 years.

For each selected stand, circular plots were used to sample the rubber trees. Rubber trees of one age are sampled from one stand. The sizes of the plots depended on the volume of the stands. The starting point of the circular plot was determined randomly. The sizes of the plots depended on the volumes of the stand which is determined by simple calculation. The total number of plots per stand was between 15 to 17 plots and the total number of rubber trees sampled from each stand was 150 trees.

In all plots, the stem diameters were measured using a DBH tape, with the readings taken 1.3m from the ground. Heights of the samples were measured using a digital spectrometer from the tip of the shoot to the ground. Measurements of stomatal conductance, chlorophyll content index, photosynthesis and transpiration were made on ten randomly selected, matured and fully expanded leaves for each predictor variables. The ten leaves were selected from each rubber tree for all growth stages. Positions of measurements were at the centre of the leaves surface (away from the main vein). The leaves were chosen from the middle and upper parts of the rubber trees to synchronize the readings. Leaves with signs of insect damage or other damages were avoided.

Stomatal conductance, photosynthesis and transpiration were measured on the abaxial surfaces of the leaves using TPS-2 Portable Photosynthesis System. This instrument is a completely self-contained unit for measuring the CO2 assimilation (photosynthesis) and transpiration (water loss by evaporation). Chlorophyll content index was measured using a chlorophyll meter (Minolta SPAD 502 Plus). It measured absorption at 650 and 940 nm wavelengths

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to estimate chlorophyll levels. Measurements for all variables were made between 8:00am to 12:00pm each day to minimize diurnal influences with temperature range between 25°C to 35°C.

2.3 Data Analysis (steps involved in building the model)

Step 1: Model Building

Analysts must have a prior knowledge of the variables to identify as independent variables to be included in the model. The independent variables (x) can be first-order or second-order terms, interaction terms, and dummy variables. Best fit model candidates were selected based on analysis of the usefulness of the variables in prediction, associated with various subset selection method s in the PROC REG procedures (SAS version 9.3), such as R-square selection, forward selection, backward elimination, and stepwise selection method (SAS institute Inc. 2000). R^2 represent the fraction of the sample variation of the y values that is explained by the independent variables. One drawback of R^2 is adding more independent variables in the model will increase R^2 eventually to 1.

Step 2: Model Adequacy

The following criteria are important for checking the utility of the model:

a) Global F test: To test the significance of the independent variables as a group for predicting the response variable.
b) 100(1-α)% Confidence intervals and t-tests: Inferences about the β parameters.
c) R^2adj: The total sample variation of the response variables y that is explained by the model after adjusting for the sample size and the number of parameters. Both R^2 and R^2adj are indicators of how well the prediction equation fits the data.
d) Root MSE or s: The estimated standard deviation of the random error. The interval is an approximation of the accuracy in predicting y based on a specific set of independent variables.
e) Coefficient of variation (CV): The ratio of the estimated standard deviation of ε to the sample mean of the response variable ȳ. Models with CV values of 10% or smaller usually lead to accurate predictions.

Step 3: Model Assumption

a) Linearity: Linearity defines the dependent variable as a linear function of the predictor (independent) variables.
b) Independence of Errors: Independence of errors refers to the assumption that errors are independent of one another, implying that subjects are responding independently.
c) Homoscedasticity: The assumption of homoscedasticity refers to equal variance of errors across all levels of the independent variables (Osborne and Waters, 2002). This means that researchers assume that errors are spread out consistently between the variables.
d) Normality: Multiple regressions assume that variables have normal distributions. This means that errors are normally distributed, and that a plot of the values of the residuals will approximate a normal curve. Shapiro-Wilk and Kolmogorov-Smirnov test were run to examine if the residuals were normally distributed.
e) Collinearity: Collinearity (also called multicollinearity) refers to the assumption that the independent variables are uncorrelated.

Step 3: Model Validation

Plots of predicted value against measured values, and the prediction error of response variables against predicted values in the validation data set were examined to find any areas of poorer prediction data by calculating RMSE and estimated correlation index square (I^2) as define as:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(yi - \hat{y}i)^2}$$

$$I^2 = 1 - \frac{\sum_{i-1}^{n}(yi - \hat{y}i)^2}{\sum_{i-1}^{n}(yi - \bar{y}i)^2}$$

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Where n is the number of stands, y the measured response variable, ȳ the mean of the measured response variable, and ŷ is an estimated value of the response variable.

3. Results and Discussion

3.1 Response Variables, Predictor Variables and Descriptive Statistic

Independent variables (X) of plant physiology of rubber tree were identified through literature review. The independent variables consisted of diameter at breast height (DBH), height (HT), chlorophyll content (CC), stomatal conductance (SC), photosynthesis (PN), transpiration (TRPT), leaf area index (LAI) and age (AG). In this study, the dependent variable (Y) that has to be predicted is carbon sequestration (CS) and all the variables involve are summarized in Table 1. Descriptive statistics is often used in the initial phase of a statistical analysis. These tools enable to identify relationships in the data and to determine directions for further analysis. The Summary Statistics task provides the following information, i.e; mean median, standard error and standard deviation, variance, minimum, maximum. Table of the descriptive statistic is shown in Table 2. Table shows descriptive statistics for model building data and model validation data.

An ordinary least square (OLS) estimator was used to develop multiple linear regression models (Neter et al., 1996). Data exploration and preliminary model fitting were carried out to get models that best fit the data. Various models were initially developed using the original untransformed data, but only those that met regression assumptions (homogeneity of variance, linearity, normality, and nonautocorrelation) and had high goodness of fit were retained. Subsequently, a series of data transformation were carried out to find out whether better models could be developed from the transformation of data. Logarithmic transformation (ln) and weighting of the independent variables (diameter and length) and the dependent variable (biomass) were found to be the best transformations which produced models that did not violate regression assumptions and at the same time had high goodness of fit. Homogeneity of variance and linearity of data were checked from residual plots whereas autocorrelation and normality were checked with Durbin-Watson statistics and probability plot, respectively. Though logarithmic transformation is reported to increase the statistical validity of regression analysis by homogenising variance, it introduces a slight downward bias when data are back-transformed to arithmetic units (Baskerville, 1972).

3.2 Pearson's Correlation Coefficient

The correlation coefficient r is a summary measure that describes the extent of the statistical relationship between two variables X and Y which is known as bivariate. The correlation coefficient is scaled so that it is always between -1 and +1. When r is close to 0 this means that there is a little relationship between the variables and the farther away from 0, r shows (in either the positive or negative direction) the greater the relationship between the two variables. For interval or ratio level scales, the most commonly used correlation coefficient is Pearson's r. In order to illustrate how the two variables are related, the values of X and Y are pictured by drawing the scatter diagram. This scatter diagram is shown in Figure 2 which is in the form of scatter plot matrix. A correlation matrix is generated summarising the relationships found to exist between carbon sequestration (CS) data versus DBH, HT, CC, SC, PN, TRPT, LAI, and AG.

The highest positive correlation coefficient, r is CS versus DBH followed by CS versus HT, AG, LAI, CC, whereas PN, SC and TRPT have negative correlation coefficient. Most of the independent variables involved in the study are significantly correlated ($p \leq 0.001$) with carbon sequestration, ranging in correlation coefficient from 0.98701 to -0.26417 except for PN. There is no significant correlation between CS and PN. Results showed that, CS is linearly correlated to DBH, HT, AG and LAI, indicating that as DBH, HT, LAI and AG increased (r=0.98701, 0.95774, 0.86400 and 0.85491 respectively), carbon sequestration increased. CS is inversely correlated to PN, SC and TRPT, indicating that when PN, SC and TRPT decreased, CS increased. The Pearson's Correlation, r for SC, PN and TRPT were -0.2072, -0.0665 and -0.2642 respectively.

The correlations between CS versus DBH and HT were high in this study, which is in accordance to a study done by Mulugeta et al., (2009). His study

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showed positive relationship between biomass of *Eucalyptus globulus Labill* with diameter and height. Another example is from Antonio et al., (2007) who also found a significant increase in the predictive ability of biomass estimation models for Eucalyptus when including height as an additional predictor to diameter. Previous study on allometric relationships of different tree species and stand above ground biomass in the Gomera Laurel Forest stated the highly significant relationship ($p \leq 0.001$) between aboveground biomass and diameter at breast height (Jesus et al., 2005).

In this study, the correlation coefficient of CC although positive is not strongly correlated with CS (r=0.300). However, it is comparable with a study carried out by Suharja and Sutarno (2009) where the correlation analysis of plant dry weight of chilli and chlorophyll a, b and c showed positive relationship. This means that if the fresh weight of plants increased then the dry weight will increased too, and so do the chlorophyll a, chlorophyll b and total chlorophyll leaves of both varieties of chili.

The correlation coefficient of CS versus SC in this study was negative as stated above. This is due to whole-plant water flux estimations (Köstner et al., 1996; Hubbard et al., 1999; Ryan et al., 2000; Schäfer et al., 2000) which demonstrated that foliar stomatal conductance is consistently lower in larger and older trees than in smaller and younger trees in common environmental conditions. Lower stomatal conductance in taller trees has been explained by greater water limitations as a consequence of a larger restriction to water flow from soil to leaves because of increased path lengths in stems and branches of taller trees (Ryan and Yoder, 1997; Bond and Ryan, 2000; Mencuccini and Magnani, 2000).

Table 1: The variables and symbols used.

Symbol	Variables
Ln Y	Carbon sequestration (CS)
Ln X1	Diameter at breast height (DBH)
Ln X2	Height (HT)
Ln X3	Chlorophyll content (CC)
Ln X4	Stomatal conductance (SC)
Ln X5	Photosynthesis (PN)
Ln X6	Transpiration (TRPT)
Ln X7	Leaf area index (LAI)
Ln X8	Age (AG)

Table 2: Descriptive statistics of rubber trees parameters and carbon sequestration used for model-building and validation.

Variable	Model-building data set					Validation data set				
	No. of rubber trees	Mean	SD[a]	Min.[b]	Max.[c]	No. of rubber trees	Mean	SD[a]	Min.[b]	Max.[c]
Carbon Sequestration (tons)	1402	5.82	1.31	1.8	7.5	698	5.26	1.32	1.9	7.5
DBH (cm)	1402	2.89	0.58	1.2	3.8	698	2.87	0.59	1.3	3.8
Height (m)	1402	2.56	0.58	1.0	3.5	698	2.56	0.58	1.0	3.5
Chlorophyll Content (index)	1402	70.49	7.33	49.2	96.5	698	70.47	7.33	50.3	96.1
Stomatal Conductance (mmol/m-1)	1402	750.29	1162.00	1.0	9135.0	698	709.06	1004.00	2.0	8453.0
Photosynthesis ()	1402	10.90	14.77	-24.5	98.7	698	11.26	14.86	-51.0	94.3
Transpiration ()	1402	2.18	1.39	0.02	9.26	698	2.14	1.33	0.02	9.5
Leaf Area Index (index)	1402	2.15	0.84	0.62	3.41	698	2.13	0.86	0.62	3.4
Age (year)	1402	12.20	8.17	1.0	28.0	698	12.02	8.15	1.0	28.0

Note: [a]Standard Deviation, [b]Minimum, [c]Maximum

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Table 3: Pearson's correlation coefficients, N=1402

	Pearson correlation coefficients, N = 1402								
	Ln Y	**Ln X1**	**Ln X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**
Ln Y	1.00000								
Ln X1	0.98701 <.0001	1.00000							
Ln X2	0.95774 <.0001	0.90389 <.0001	1.00000						
X3	0.30078 <.0001	0.34758 <.0001	0.20042 <.0001	1.00000					
X4	-0.2072 <.0001	-0.1988 <.0001	-0.2056 <.0001	-0.037 0.1668	1.00000				
X5	-0.0655 0.0142	-0.0555 0.0376	-0.0775 0.0037	-0.006 0.8219	0.05151 0.0538	1.00000			
X6	-0.2642 <.0001	-0.2507 <.0001	-0.2716 <.0001	-0.0125 0.6409	0.47778 <.0001	0.12312 <.0001	1.00000		
X7	0.8640 <.0001	0.83315 <.0001	0.85817 <.0001	0.1704 <.0001	-0.2492 <.0001	-0.081 0.0024	-0.3127 <.0001	1.00000	
X8	0.85491 <.0001	0.80976 <.0001	0.87301 <.0001	0.10506 <.0001	-0.2531 <.0001	-0.0816 0.0022	-0.3181 <.0001	0.94953 <.0001	1.00000

3.3 Developing allometric equations

Regression models for carbon sequestration are all highly significant (all $p \leq 0.001$). The models initially developed are presented in Eq. (1) and Eq. (2):

$$Ln(CS) = c + a ln(DBH) \quad (1)$$

$$Ln(CS) = c + a ln(HT) \quad (2)$$

Where CS is in tons/rai, DBH is in cm, HT is in m, c is the intercept, and a is the slope coefficient of the regression. The values of the coefficients determination, R^2 are presented in Table 3. For model 1, the value R^2 is 0.9742 which uses only DBH as a predictor variable. However, tree biomass is affected by its height as well. Hence in model 2, HT is incorporated as the predictor variable. The R^2 of the model 2 is 0.9173.

By combining DBH and HT in Model 3, it becomes a multiple linear regression as follows:

$$Ln(CS) = c + a ln(DBH) + b ln(HT) \quad (3)$$

Since the correlation coefficients, r between CS versus DBH and CS versus HT are high, the incorporation of both DBH and HT in Model 3 only increased R^2 slightly which is 0.9977. The relationship between CS and AG is strongly correlated, hence the latter is an important predictor variable when calculating biomass. It is therefore added in equation 4:

$$Ln(CS) = c + a ln(DBH) + b ln(HT) + c(AG) \quad (4)$$

Where AG is age of rubber tree measured in years.

Leaf area index (LAI) is also an important factor that is highly correlated to CS. The value of $R^2 = 0.9978$ and the equation 5 is as below:

$$Ln(CS) = c + a ln(DBH) + b ln(HT) + c(LAI) \quad (5)$$

The four independent variables in this study, DBH, HT, LAI and AG are found to be strongly correlated to CS. Thus, by using all the four variables, the prediction equation is as stated below. The value of R^2 for Model 6 is 0.9978.

$$Ln(CS) = c + a ln(DBH) + b ln(HT) + c(LAI) + d(AG) \quad (6)$$

The last variable of this study is TRPT. Even though the correlation coefficient, r is low between CS and TRPT, the R^2 value is high i.e. 0.9978 when TRPT is

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incorporated into the prediction Model 7 together with predictor variables, DBH, HT and AG.

$$Ln(CS)= c + aln(DBH) + bln(HT)+ c(TRPT) + d(AG) \quad (7)$$

To choose the best prediction model for CS, comparisons are carried out between the above seven models. The parameters compared are R^2, Adjusted R-square (R^2adj), Milow C(p), SSE (Sum of square error), SE_E (Sum square error estimate) and MSE (Mean square error) and the results are as presented in Table 3. Adding the fifth, sixth, seventh, and eighth predictor variables to the equations did not improve the models appreciably.

The validation summary presented in Table 4 suggests that reliable estimates of rubber tree CS can be obtained using the above model. The I^2 values for each model ranged between 0.92 and 0.99. Model 2 to 7 appeared to provide strong estimates of CS indicated by high I^2 (0.99) and lower RMSE (0.06tons/rai).

Table 3: Model candidates

No.	Predictor Variabes	R-square	Adjusted R-square	C(p)	SE_E	MSE	SSE	No. Predictor Variables
1	DBH	0.9742	0.9742	15016.4	0.02845	0.04464	62.4916	1
2	HT	0.9173	0.9172	51205.5	0.04583	0.14305	200.267	1
3	DBH and HT	0.9977	0.9977	69.0082	0.00850	0.00399	5.57745	2
4	DBH, HT and AG	0.9978	0.9978	0.8661	0.01181	0.0038	5.31041	3
5	DBH, HT and LAI	0.9978	0.9978	29.4667	0.00988	0.00388	5.41929	3
6	DBH, HT, TRPT and AG	0.9978	0.9978	1.967	0.01228	0.0038	5.30698	4
7	DBH, HT, LAI and AG	0.9978	0.9978	2.5977	0.01211	0.0038	5.30939	4

Table 4: Summary of regression model validation results for stand volume (n=698)

Model No.	p^a	I^2	RMSE (tons/rai)
1	1	0.97	0.21
2	1	0.92	0.37
3	2	0.99	0.06
4	3	0.99	0.06
5	3	0.99	0.06
6	4	0.99	0.06
7	4	0.99	0.06

Note: [a]number of predictor variables in the model.

This study is comparable to a study from Shorrocks et al., (1965) which studied on the relationship between diameter at 1.50m from soil surface and aboveground dry biomass of rubber. The research was done in Malaysia. They found the relationship of the linear function between diameter (log G) and dry biomass (log Md) as Log Md = 2.786 log G – 2.5843. Another research which determined the relationship between girth and the above ground biomass of *Hevea brasiliensis* was done by Chaundhuri et al. (1995) in India. The clones involved in this study were RRIM 600 and RRII 118. A set of relationships were developed using the biomass as a power function of girth for different age groups from first year after planting up to fifth year. A general equation was thus developed and is given g(W) = $2.278479 X^{2.200}$ (where X is the girth at 15 cm height from bud union).

Study in Cambodia by Khun et al. (2008) revealed that the volume equation for standing rubber trees clone PR107 is $V = 0.00018381D^{2.23961} H^{0.15334}$ or $V = 0.00024884D^{2.29535}$ where V is the over bark volume (m^3), D is diameter at breast height (cm), H is total height (m). Besides, there was a study from Choba, Port Harcourt, Nigeria that evaluated a set of height-diameter models from twenty plots of *Hevea*

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brasilliensis plantation. Oyebade and Ebitimi (2011) used nonlinear techniques to develop the functional models with models coefficients derived from 198 sampled standing trees. The predictive models gave a good height-diameter relationship with coefficients of determination (R^2) indicating strong relationships with values ranging between 0.62 - 0.98. The equation developed was y = βo + β1ln(D).

The other study was on *Eucalyptus pilularis* from seven different study sites in Australia. The significant site differences in (1) partitioning of biomass between the stem, branch wood and foliage; (2) stem wood density and (3) relationship between diameter at breast height (DBH) and height were observed. For all predictor variables, examination of the model residuals of the site-specific and general relationship indicated that using DBH alone as the predictor variable produced the most stable general relationship. The general relationship determined was $\ln$ (AGB) = $\ln(\beta_0) + \beta_1 \ln$ DBH (where AGB is aboveground biomass (kg)) (Montagua et al., 2005).

Previous research in Sumatra used 18 trees of *Eucalyptus grandis* to formulate allometric equation both aboveground biomass and carbon stock of 1 to 9 year old *E. grandis* trees. The results showed that allometric equation both biomass and carbon stock was in good relation with stem diameter (D) as log-linear equation. The best allometric equations for aboveground biomass and carbon stock of planted E. grandis were WAG = 0.0678D2.5794 (R^2 98.8%) and CAG = 0.0266D2.6470 (R^2 98.0%), respectively (Onrizal et al., 2009).

There were also studies that use the method of non-destructive sampling as in this study. One of the study was the research done in Sumatra, Indonesia. The methods of choosing values for a and b (constant parameter) do not require destructive measurement because the parameter b can be estimated from the site-specific relationship between height (H) and diameter, $H=kD^c$ as b=2+c while the parameter a can be estimated from the average wood density (ρ) at the site as a=rρ, where r is expected to be relatively stable across sites. The allometric equation of biomass proposed was therefore $B=r\rho D^{2+c}$ (Quirine et al., 2000).

4. Conclusion

A systematic screening of regression models for the showed that combination of these variables, DBH, HT, LAI, TRPT and AG could be used as predictor variables. Model 4, Ln(CS)= c + aln(DBH) + bln(HT)+ c(AG) is the most suitable allometric equation for estimation of carbon sequestration. This allometric equation can be used to improve and complement the Good Practice Guidance, especially for rubber plantation forests. DBH, HT and AG are the explanatory variable in model 4, which are to measure and generally available in standard forest inventory. Model 4 is the most suitable allometric equation in determining carbon sequestration in rubber tree (*Hevea brasilliensis*) since it meets the requirement of best fit model.

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