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Construction of a Standard Volume Table: A Case Study in Three Different Aged Teak Plantations in Bago Township, Bago Region, Myanmar

Yan Myo Naing[1*] **Patsi Prasomsin[2]**
Khwanchai Duangsathaporn[2] **Yenemurwon Omule[2]**

[1]Master Student, Tropical Forestry (International Program), Faculty of Forestry, Kasetsart University, Chatuchak, Bangkok 10900, Thailand
[2]Faculty of Forestry, Kasetsart University, Chatuchak, Bangkok 10900, Thailand
*Corresponding Author, E-mail: yanmyonaing7@gmail.com

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ABSTRACT

In Myanmar, scientific research related to construction of a standard volume table that represents teak plantations in a specific area are rarely found, although it plays significant role in sustainable management of teak plantations. Therefore, in this study, a standard volume table was constructed, based on three teak plantations established in Bago Township by Forest Department (FD) of Myanmar. This is one area of eastern part of Bago Yoma Range known as "home of teak". Ages of the plantations were 23, 27 and 31 years in 2013. Study methodology consisted of three main phases, namely, data collection, data preparation and, data analysis. In the first phase, the necessary data were collected using stratified random sampling technique. In the second phase, all the calculations needed for data analysis were prepared. In the last phase, data analysis was carried out to select the best volume model for construction of the standard volume table. Thirteen volume models were tested in this phase. Furnival's Index (FI) was applied to compare all the models. The best fit volume model was $V = - 0.0230361338 + 0.0000485831D^2H - 0.0000008400D^2H^2$ with the lowest FI of 0.0317. This model was used to construct a standard volume table of teak plantations in the study area. The developed volume table can be applied in the assessment of economic potential of standing teak trees in the study area. Therefore, this will lead to the achievement of the desired economic goal of the teak plantation management in Myanmar. Moreover, not only FD but also private sectors can effectively use the resultant volume equation and table in the prediction of growth and yield of teak plantations as a tool, particularly for the study area.

Keywords: Scientific research, Standard volume table, Teak plantations, Ages, Volume models

INTRODUCTION

In Myanmar, due to the rapid deforestation, large-scale plantation forestry began in 1980s although small-scale forest plantations started as early as late 1850s (Tint, 2002). In addition to the normal teak plantation scheme, Forest Department (FD) of Myanmar has launched a Special Teak Plantation Program since 1998 to maintain and increase teak production. Moreover, nowadays, FD has encouraged private sectors to establish teak plantations in large scale since 2005. Teak plantations are mainly concentrated in the Bago Yoma Range, a well known place of high quality natural teak forests. These plantations have been established for commercial purposes and on sustained yield basis. To achieve this, careful and continuous monitoring of the teak crop is very essential. However, in Myanmar, scientific research related to standard volume table construction for teak plantations in a specific area is very rare. Thus, to support the sustainable management of teak plantations established in the Bago Towhship, which is one part of Bago Yoma Range, there is still a need for a volume table that represents the area. This study is intended to achieve this goal. In this context, the present study focused on the construction of a standard volume table based on the three different aged teak plantations established in Bago Township.

MATERIALS AND METHODS

Study Area

This study was carried out in three teak plantations aged 23, 27 and 37 years in 2013. These plantations were established in Bago Township, Bago District, Bago Region of Myanmar. This area, the eastern part of Bago Yoma Range, was located at 17° 41′ 11″ and 17° 42′ 23″ N latitude, and 96° 13′ 23″ and 96° 16′ 51″ E longitude.

Data Collection

Stratified Random Sampling (STRS) was applied in this study. Each age (plantation) represented a stratum and the total was three strata. Sample plots had square shape and the area of each plot was 0.04 hectare (ha), which was equivalent to 20 m × 20 m. The area of the 31-year-old teak plantation was 14.24 ha (356 plots), the 27-year-old was 15.4 ha (385 plots), and the 23-year-old was 20.16 ha (504 plots). Total area of the three plantations was 49.8 ha (1245 plots). Sample size in each stratum was estimated using the proportional allocation rule, where the total sample of 30 plots was allocated to each stratum proportional to its area. Thus, the estimated sample size of 31-year-old plantation was 9 plots. The estimated sample sizes of the 27-year-old and the 23-year-old plantations were 9 and 12 plots, respectively.

In each sample plot, trees showing crown damage, crook, forking, or prolong suppression, and the ones deviated from the normal form and dead trees were recorded; howver, special care was taken to exclude them from the sample trees selected for sectional volume calculation. Diameter at breast height over bark (D) and total height (H) were measured in all trees. Although the volumes required to develop the volume function are ideally obtained by direct stem measurements of felled trees, in this study, felled trees were not available so volume was computed from Pentaprism measurements of standing trees. The upper-stem diameters of each sample tree were read at two-meter intervals (log length), beginning at 0.3 m above ground to top diameter equal to approximately 10 cm. The height at 10 cm top diameter was measured in the trees selected for sectional volume calculation in order to get the last interval length of the stem.

Data Preparation

Total height and the height at a 10-cm top diameter for each tree were computed, based on the height calculation procedures for the Sunnto. To calculate the last interval length, firstly all successive interval lengths before the last interval length were added. After that, the last interval length was derived by subtracting the sum of the successive interval length plus 0.3 m from the height at 10 cm diameter.

Smalian's formula was used to compute the cubic volume of each section of each sample tree (sectional volume of the stem). Then, the cumulative volumes were added to obtain the merchantable volume up to an approximate 10-cm top diameter outside bark for each tree. The transformed variables D^2H, D^2, H^{-1}, $(D^2)/V$, D^3H, D^2H^2, ln (V), ln (D), and ln (H) of each sample tree selected for sectional volume calculations were calculated, based on diameter at breast height (D) and total height (H) of the respective sample tree; they are needed in regression analysis. Microsoft Excel 2007 was used for these calculations.

Data Analysis

Volume Models Studied

Most volume models are widely built from one variable, D only, or two variables, D and H. The purpose of this study was to construct the standard volume table, so the volume models based on two variables were considered for testing. These models had the functional form of V = f (D, H). A list of candidate volume models is shown in Table 1.

Transformation of Model (3) and Model (4) Outlined in Table 1

In this study, all volume models were considered as linear ones to facilitate further analyses and comparisons among the volume models so model (3) and (4) (Table 1) were linearized.

In this context, model (3) was transformed into its logarithmic form as follows:

$$\ln V = b_0 + b_1 \ln D + b_2 \ln H \quad (3.1)$$

where,

V = tree volume in cubic metres

D = tree diameter at breast height

H = tree total height

b_0, b_1 and b_2 are regression coefficients

ln = natural logarithm

Model (4) was also altered into the following form (Clutter *et al.* 1983).

$$\frac{D_2}{V} = b_0 + b_1 H^{(-1)} \quad (4.1)$$

where,

V, D, H, b_0 and b_1 were as defined in above.

In this form, the variable $\frac{D_2}{V}$ was assumed to have a constant variance.

Table 1 List of candidate volume models.

No.	Models	References
1.	$V = b_0 + b_1D^2H$	Clutter *et al*. (1983)
2.	$V = b_0 + b_1D^2 + b_2H + b_3D^2H$	Clutter *et al*. (1983)
3.	$V = e^{b1}D^{b2}H^{\ b3}$	Clutter *et al*. (1983)
4.	$V = D^2/(b_0 + b_1H^{-1})$	Clutter *et al*. (1983)
5.	$V = b_0 + b_1D^2H + b_2D^3H$	Bi and Hamilton (1998)
6.	$V = b_0 + b_1D^2H + b_2D^3H + b_3D$	Bi and Hamilton (1998)
7.	$V = b_0 + b_1D^2H + b_2D^2H^2$	Bi and Hamilton (1998)
8.	$V = b_1D^2H + b_2D^2H^2$	Bi and Hamilton (1998)
9.	$V = b_0 + b_1D^2H + b_2D^2H^2 + b_3H$	Bi and Hamilton (1998)
10.	$V = b_0 + b_1D^2H + b_2D^3H + b_3D^2H^2$	Bi and Hamilton (1998)
11.	$V = b_0 + b_1D^2H + b_2D^3H + b_3D^2H^2 + b_4D$	Bi and Hamilton (1998)
12.	$V = b_0 + b_1D^2H + b_2D^3H + b_3D^2H^2 + b_4H$	Bi and Hamilton (1998)
13.	$V = b_0 + b_1D^2H + b_2D^3H + b_3D^2H^2 + b_4D + b_5H$	Bi and Hamilton (1998)

Remarks: V = volume over bark in cubic meters
D = diameter at breast height over bark in centimeters
H = total height in meters
b_0, b_1, b_2, b_3, b_4 and b_5 are parameters which will be estimated

Application of Weighted Least Square Analysis

The unweighted least squares techniques are fully efficient only in the absence of heteroscedasticity, a term denoting a correlation between average error magnitude and the magnitude of the predicted value of a model (Furnival 1961). Therefore, an alternative common technique to combat the non-homogeneity of the variance in tree volume table construction is to use weighted least squares.

Experience with tree populations has shown that one of the two variance assumptions will usually be satisfied. They are (1) the standard deviation of stem content (volume in this study) is proportional to D^2H and (2) the standard deviation of stem content (volume in this study) is proportional to square root of D^2H (Cunia, 1964; Smalley and Bower, 1968). Therefore, two weight functions were considered under this study. They were $\left(\frac{1}{D^2\,H}\right)$ and $\left(\frac{1}{(D^2\,H)^2}\right)$ respectively.

According to the points mentioned above, in the present study, weighted least square regression analysis was used by applying weight functions to volume models named as 1,2,5,6,7,8,9,10,11,12 and 13. In this case, each model needed to be analyzed two times, i.e., one time using the weight function $\left(\frac{1}{D^2\,H}\right)$ and the other time using the weight function $\left(\frac{1}{(D^2\,H)^2}\right)$. For comparison purposes, and for differentiation between two weight functions applied to these volume models, each model were given new names in relation to weight function. These new names were 1.1, 1.2, 2.1, 2.2, 5.1, 5.2, 6.1, 6.2, 7.1, 7.2, 8.1, 8.2, 9.1, 9.2, 10.1, 10.2, 11.1, 11.2, 12.1, 12.2, 13.1 and 13.2. Moreover, it should be noted that model (3) was transformed into model (3.1) and model (4) was altered to model (4.1).

Model Fitting

All statistical analyses for all volume models were carried out using SPSS 16. Model (3.1) and Model (4.1) were analyzed by using linear regression option in SPSS. The other twenty two models, namely 1.1, 1.2, 2.1, 2.2, 5.1, 5.2, 6.1, 6.2, 7.1, 7.2, 8.1, 8.2, 9.1, 9.2, 10.1, 10.2, 11.1, 11.2, 12.1, 12.2, 13.1 and 13.2 were analyzed using the application of weight estimation in linear regression option of SPSS. According to this procedure, weight variable and the power of this variable for each model was needed for the weight estimation as in SPSS, Weight Function was 1/(Weight Variable)**Power. Therefore, weight variable for all models in this study was D^2H. For eleven volume models among these models, the power of weight variable was one and the power for the other eleven models was two.

Preliminary Examination of Volume Models

Firstly, F-test was used to determine the strength of linear relationship of each model. Each model with variance ratio (F) significant at the 0.05 level was selected for further examinations.

Secondly, all parameters in each volume model were examined using t-test. Each model containing the parameters that were not significant at 0.05 level was excluded and not considered for further comparisons.

Testing Goodness-of-Fit

Alder (1980) pointed that for comparison of regressions for goodness-of-fit when several transformations of the dependent variable are involved, the Furnival's Index must be used.

This study followed the fact mentioned above. The volume models selected to test goodness of fit had the same dependent variable (volume) with different transformations. Therefore, the volume models were examined for goodness of fit by applying Furnival's Index in order to choose the most suitable volume model for the construction of a standard volume table.

Calculation of Furnival's Index

Furnival' Index was calculated using the following formula.

$$FI = \left\{ Exp\left[\frac{(\sum \ln f'(V)^{-1})}{1} \right] \right\} * \sqrt{RMSE}$$

where,

FI	=	Furnival' Index
Exp	=	exponential function
ln	=	natural logarithm
n	=	number of data points
RMSE	=	residual mean square error from fitted regression
$f'(V)^{-1}$	=	the reciprocal of the first derivative of the transformation applied to the V (volume) variable with respect to V.

For the calculation of FI of weighted regression models, this formula was used as follows:

$$FI = \left\{Exp\left[\frac{(K\sum \ln D^2H)}{n}\right]\right\}*\sqrt{RMSE}$$

where,

FI, Exp, ln, n, RMSE are the same as defined in the above formula.

D^2H = the weight variable in this study

K is the scalar that is half of the value of the power used in weight variable.

The above formula was derived by replacing with D^2H as follows:

For weight variable D^2H with the power of one,

$$f'(V)^{-1} = D^2H$$

Therefore,

$$\sum \ln f'(V)^{-1} = \sum \ln D^2 H$$

For weight variable D^2H with the power of two,

$$f'(V)^{-1} = (D^2H)^2$$

Therefore,

$$\sum \ln f'(V)^{-1} = 2\sum \ln D^2 H$$

In this case, the power values (one and two) of weight variables were moved to in front of the summation symbol according to logarithmic rule.

In order to get K value, the power values of weight variables were divided by 2 as it was being used in the weighted linear regression model.

Standard Volume Table Construction

The best-fit volume model with the lowest Furnival's Index was used for the construction of the standard volume table.

RESULTS AND DISCUSSION

F-ratio Results

From analysis results, F-ratio in all volume models was significant at 0.01 level. Therefore, all models were considered to examine further examinations.

Parameters Estimated for the Volume Models

Among the models studied, one model had six parameters, which was the highest number of parameters in a single equation tested in the present study.

Many volume models contained parameters that were not useful. Examination of the parameters revealed that some volume models could be eliminated from the list of candidates, and they were not examined further. These models contained the parameters which had t-values that were not significant at the 0.05 level. Those insignificant parameters were distributed within 19 models referring to 1.1, 1.2, 2.1, 2.2, 4, 5.1, 5.2, 6.1, 6.2, 9.1, 9.2, 10.1, 10.2, 11.1, 11.2, 12.1, 12.2, 13.1 and 13.2 respectively.

For further examination, model 3.1, 7.1, 7.2, 8.1 and 8.2 were selected because all parameters in each model contained t-values which were significant at 0.05 level. This avoided over and under estimations of parameters. F-ratios, R^2 values, significant levels, and residual mean square errors (RMSE) of respective models were shown in Table 2.

Furnival's Index

The results for weighted and logarithmic transformation were shown in Table 3.

The Best Fit Volume Model

Among the models shown in Table 3, model 7.1 was the best fit since it had the lowest Furnival's Index. Therefore, this model was considered as the most suitable volume model for construction of standard volume table because of having the best fit to the data. The model with its estimated parameter was as follow.

$$V = -0.0230361338 + 0.0000485831D^2H - 0.0000008400D^2H^2$$

where,

V = volume (over bark) up to approximate 10 centimeters of top diameter excluding stump in cubic metres

D = diameter at breast height in centimeters over bark

H = total height in meters

This equation was applied to construction of a standard volume table in the present study. The standard volume table constructed using this equation i s shown in Table 4.

Table 2 Residual mean square error (RMSE), coefficient of determination (R^2), F-value and significant level of each model selected

Model	RMSE	R^2	F-value	P-value	Remark
3.1	1.8225×10^{-02}	0.92	1285.892	0.00	**
7.1	1.1049×10^{-07}	0.94	1538.071	0.00	**
7.2	1.3010×10^{-11}	0.93	1320.942	0.00	**
8.1	1.1491×10^{-07}	0.99	7853.181	0.00	**
8.2	1.4346×10^{-11}	0.98	6272.712	0.00	**

Note: **Highly significant

Table 3 Furnival's Index and rank of each model.

Model	$\sqrt{RMSE}$	Transformation	$f'(V)^{-1}$	n	$\frac{(\sum \ln f' D^2H)}{n}$	K	Weighted Model Exp $\frac{(K\sum \ln D^2H)}{n}$	Logarithmic Model Exp $\frac{(\sum \ln V)}{n}$	Furnival's Index	Rank
3.1	1.3500×10^{-01}	ln V	V	213	$\frac{(\sum \ln V)}{213}$			0.2618	0.0353	5
7.1	3.3240×10^{-04}	$V/(D^2H)$	(D^2H)	213	$\frac{(\sum \ln D^2H)}{213}$	0.5	95.3663		0.0317	1
7.2	3.6070×10^{-06}	$V/(D^2H)^2$	$(D^2H)^2$	213	$\frac{(0.5\sum \ln D^2H)}{213}$	1	9094.7382		0.0328	3
8.1	3.3898×10^{-04}	$V/(D^2H)$	(D^2H)	213	$\frac{(\sum \ln D^2H)}{213}$	0.5	95.3663		0.0323	2
8.2	3.7876×10^{-06}	$V/(D^2H)^2$	$(D^2H)^2$	213	$\frac{(0.5\sum \ln D^2H)}{213}$	1	9094.7382		0.0344	4

Table 4 Standard volume table constructed from volume model 7.1

D (cm)	Total height in meters													
	14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
13	0.064	0.068												
14	0.078	0.083	0.087	0.091										
15	0.093	0.098	0.103	0.108	0.112	0.116								
16	0.109	0.115	0.121	0.126	0.131	0.136	0.140							
17	0.126	0.133	0.139	0.145	0.151	0.156	0.161	0.165						
18	0.144	0.152	0.159	0.166	0.172	0.178	0.183	0.188	0.192					
19	0.163	0.172	0.180	0.187	0.194	0.201	0.206	0.212	0.216	0.220	0.223			
20	0.183	0.193	0.201	0.210	0.218	0.225	0.231	0.237	0.242	0.246	0.250			
21		0.215	0.225	0.234	0.243	0.250	0.257	0.264	0.269	0.274	0.278	0.281	0.284	
22			0.249	0.259	0.268	0.277	0.285	0.291	0.298	0.303	0.307	0.311	0.313	
23				0.285	0.296	0.305	0.313	0.321	0.327	0.333	0.338	0.342	0.345	0.347
24					0.324	0.334	0.343	0.351	0.358	0.365	0.370	0.374	0.377	0.380
25						0.364	0.374	0.383	0.391	0.398	0.403	0.408	0.412	0.414
26						0.396	0.407	0.416	0.425	0.432	0.438	0.443	0.447	0.450
27							0.440	0.451	0.460	0.468	0.474	0.480	0.484	0.487
28							0.475	0.486	0.496	0.505	0.512	0.518	0.522	0.525
29								0.523	0.534	0.543	0.551	0.557	0.562	0.565
30								0.562	0.573	0.583	0.591	0.598	0.603	0.606
31									0.613	0.624	0.633	0.640	0.645	0.649
32									0.655	0.666	0.675	0.683	0.689	0.693
33										0.710	0.720	0.728	0.734	0.739
34										0.755	0.766	0.774	0.781	0.785
35											0.813	0.822	0.829	0.834
36												0.871	0.878	0.883

Remarks: D = Diameter at breast height over bark. The unit of volume is cubic meters. Total number of trees is 213.

CONCLUSION

In this study, a standard volume table based on diameter at breast height (D) and total height (H) was constructed using the best fit volume model. The developed volume table can be utilized in the assessment of economic potential of standing teak trees in the study area, to meet the economic goal of the teak plantation management. Moreover, this volume table plays a significant role in the sustainable management of teak plantations because the volume table developed can contribute to FD and private sectors in the prediction of growth and yield of teak plantations in Myanmar.

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