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Construction of Standard Volume Table: A Case Study in Three Teak Plantations with Different Ages in Bago Township, Bago District, Bago Region, Myanmar

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ပဲခူးတိုင်းဒေသကြီး၊ ပဲခူးခရိုင်၊ ပဲခူးမြို့နယ် သစ်တောဦးစီးဌာနမှ တည်ထောင်ထားရှိသော အသက်အရွယ်မတူညီသည့် ကျွန်းစိုက်ခင်း (၃) ခုအား အခြေပြုလျက် ကျွန်း၏ သစ်ထုထည် စံပုံသေဇယားတည်ဆောက်ခြင်း

ရန်မျိုးနိုင်
တောအုပ်ကြီး
သစ်တောစီမံအုပ်ချုပ်ရေးနှင့်စိုက်ပျိုးပြုစုရေးဌာနစု
သစ်တောဖွံ့ဖြိုးရေးဌာနခွဲ
သစ်တောသုတေသနဌာန

စာတမ်းအကျဉ်း

မြန်မာနိုင်ငံတွင် ကျွန်းစိုက်ခင်းများအား ထာဝစဉ်တည်တံ့စေသော သစ်တောစီမံ အုပ်ချုပ်မှုဖြင့် စီမံအုပ်ချုပ်ရာတွင် ဒေသတစ်ခုအား ကိုယ်စားပြုနိုင်သော ကျွန်းစိုက်ခင်း များအား အခြေပြုလျက် တည်ဆောက်ထားသော ကျွန်း၏သစ်ထုထည်စံပုံသေဇယားများမှာ မရှိမဖြစ် လိုအပ်လျက် ရှိသော်လည်း အဆိုပါ သစ်ထုထည်စံပုံသေဇယားများမှာ အနည်းငယ်သာ တွေ့ရှိရပါသည်။ ထို့ကြောင့် ဤစာတမ်းတွင် ဒေသတစ်ခုအား ကိုယ်စားပြုသည့် ကျွန်း၏ သစ်ထုထည် စံပုံသေဇယား တည်ဆောက်နိုင်ရန်အတွက် ပဲခူးရိုးမအရှေ့ဘက်ခြမ်းရှိ ကြိုးဝိုင်းတောများအတွင်း ပဲခူးမြို့နယ် သစ်တောဦးစီးဌာနမှ တည်ထောင်ထားရှိသော ကျွန်းစိုက်ခင်း (၃) ခုအား အခြေပြု၍ လေ့လာခဲ့ပါသည်။ စိုက်ခင်းများ၏ သက်တမ်းမှာ ၂၀၁၃ ခုနှစ်တွင် ၂၃ နှစ်၊ ၂၇ နှစ် နှင့် ၃၁ နှစ် တို့ အသီးသီး ဖြစ်ကြပါသည်။ ဆောင်ရွက်သည့် နည်းလမ်း၌ ဖော်ပြပါ ကျွန်းစိုက်ခင်း (၃) ခုအား ကွင်းဆင်းလျက် ကိန်းဂဏန်းအချက် အလက်များကောက်ယူခြင်း၊ ကောက်ယူရရှိလာသော ကိန်းဂဏန်းအချက်အလက်များအား စီစစ်၍ ပြင်ဆင်ခြင်း နှင့် ဆန်းစစ်လေ့လာခြင်းဟူ၍ အဆင့် (၃) ဆင့်ခွဲခြား ဆောင်ရွက်ခဲ့ပါ သည်။**ဤစာတမ်းတွင်** ထုထည် ညီမျှခြင်း (၁၃) ခုအား ဆန်းစစ်လေ့လာခဲ့ပါသည်။ ထုထည် ညီမျှခြင်း (၂) ခုမှာ (non-linear nature) ရှိသောကြောင့် (heterogeneity of variance) အား ရှောင်ကျဉ်ရန် နှင့် ကျန်ရှိသော ထုထည် ညီမျှခြင်း(၁၁)ခုနှင့် နှိုင်းယှဉ် နိုင်ရန် အတွက် (linearized) ပြုလုပ်၍ ဆန်းစစ်လေ့လာ ခဲ့ပါသည်။ ဆက်လက်၍ ထုထည် ညီမျှခြင်း (၁၁) ခုအားလည်း(homogeneity of variance) အားရရှိစေရန်နှင့် (linearized) ပြုလုပ်ခဲ့ပြီးသော ထုထည် ညီမျှခြင်း(၂)**ခု**နှင့် နှိုင်းယှဉ်နိုင်ရန် (weighted least squares) ကို အသုံးပြု၍ ဆန်းစစ်လေ့လာခဲ့ပါသည်။(Furnival' Index)အားအသုံး ပြုလျက် ထုထည် ညီမျှခြင်းများ အားလုံးကို နှိုင်းယှဉ် လေ့လာခဲ့ပါသည်။ လေ့လာတွေ့ရှိ ချက်အရ ကောက်ယူ ရရှိသည့် ကိန်းဂဏန်း အချက်အလက်များနှင့် အကိုက်ညီဆုံး ထုထည် ညီမျှခြင်းမှာ (Furnival' Index) အနည်းဆုံးဖြစ်သည့် $V= -0.0230361338 + 0.0000485831D^2H - 0.0000008400D^2H^2$ ဖြစ်ပါသည်။ အဆိုပါညီမျှခြင်း၏ (Furnival' Index) တန်ဖိုးမှာ 0.0317 ဖြစ်ပါသည်။ ဤထုထည်ညီမျှခြင်းတွင် (V) မှာ ကျွန်းပင်၏အခေါက်အပါအဝင် ထုထည် (ကုဗမီတာ)၊ (D) မှာ ကျွန်းပင်၏ ရင်စို့အချင်း (မီတာ) နှင့် (H) မှာ ကျွန်းပင်၏ အမြင့် (မီတာ) (Total Height) တို့ အသီးသီး ဖြစ်ကြပါသည်။ ဤထုထည်ညီမျှခြင်းအား အသုံးပြုလျက် လေ့လာသည့် နေရာဒေသရှိ ကျွန်းစိုက်ခင်းများအား ကိုယ်စားပြုပေးနိုင်မည့် ကျွန်း၏ သစ်ထုထည် စံပုံသေဇယားအား တည်ဆောက်ခဲ့ပါသည်။ **အဆို**ပါ ဇယားအား အသုံးချလျက် လေ့လာမှုပြုလုပ်ခဲ့ရာ နေရာဒေသရှိ ကျွန်းပင်များ၏ ပင်ထောင်များအတိုင်း စီးပွားရေးအရ အလားအလာများအား တန်ဖိုးဖြတ်သတ်မှတ်ရာတွင် လွန်စွာအသုံးဝင်မည်

ဖြစ်ပါသည်။ ထို့ကြောင့် မြန်မာနိုင်ငံရှိ ကျွန်းစိုက်ခင်းများအား စီမံအုပ်ချုပ်ရာတွင် စီးပွားရေး ရှုထောင့်အရ လိုအပ်သော ရေရှည် ရည်မှန်းချက်များအား ဖော်ဆောင်ရာတွင် အောင်မြင်မှု များအား ရရှိစေရန်ပိုမိုဖြည့်ဆည်း ပေးနိုင်မည်ဖြစ်ပါသည်။ ထို့ပြင် ကျွန်းစိုက်ခင်းများ တည်ထောင် လျက်ရှိသော သစ်တောဦးစီးဌာနအတွက် သာမက ပုဂ္ဂလိကကုမ္ပဏီများ အတွက်လည်း လေ့လာတွေ့ရှိခဲ့သော ကျွန်း၏ထုထည်ညီမျှခြင်းနှင့် အဆိုပါ ညီမျှခြင်း အပေါ် အခြေခံလျက် တည်ဆောက်ခဲ့သော ကျွန်း၏ သစ်ထုထည် စံပုံသေဇယားအား အသုံးပြုလျက် လေ့လာမှု ပြုလုပ်ခဲ့သော နေရာဒေသ ဝန်းကျင်ရှိ ကျွန်းစိုက်ခင်းများ၏ ကြီးထွားနှုန်း နှင့် တောထွက် တို့အားခန်းမှန်းရာတွင် ထိရောက်စွာ အကျိုးပြုနိုင်မည် ဖြစ်ပါသည်။

Construction of Standard Volume Table: A Case Study in Three Teak Plantations with Different Ages in Bago Township, Bago District, Bago Region, Myanmar

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ABSTRACT

In Myanmar, scientific research related to construction of standard volume table which represents teak plantations in a specific area can rarely be found although it plays significant role in sustainable management of teak plantations. Therefore, in this study, standard volume table was constructed, based on three teak plantations established in Bago Township by the Forest Department (FD) of Myanmar. These plantations are located in the eastern part of Bago Yoma known as home of teak. Ages of the plantations in 2013 were 23, 27 and 31 years. Study methodology consisted of three main phases: data collection, data preparation and data analysis. The necessary data were collected by using stratified random sampling technique. Then, all the calculations needed for data analysis were prepared. Data analysis was carried out to derive the best volume model for the construction of a standard volume table. Thirteen volume models were tested. Although two models have non-linear nature, they are linearized to avoid the heterogeneity of variance and for comparison purposes. Moreover, in order to maintain the same reason, the other eleven models were analyzed by using weighted least squares. 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 the standard volume table of teak plantations which 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, Heterogeneity of variance, Weighted least squares, Furnival' Index

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Construction of Standard Volume Table: A Case Study in Three Teak Plantations with Different Ages in Bago Township, Bago District, Bago Region, Myanmar

1. 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 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 BagoYoma Region, a well-known place of high quality natural teak forests. These plantations have been established for commercial purpose and on a sustained yield basis.In order to achieve this, careful and continuous monitoring of the teak crop is very essential. However, in Myanmar, scientific research related to standard volume table constructed for teak plantations in a specific area is very rare. So, in order to support the sustainable management of teak plantations establishedin the BagoTowhship which is located in Bago Yama Range, there is still a need for the volume model which represents the area. Therefore, it is clear that thisstudy will satisfy 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.

2. Materials and Methods

2.1. Descriptions of study teak plantations

This study was carried out in three teak plantations with different ages. Ages of the plantations were 23years (located in Compartment No.19 of South Zarmayi Reserved Forest), 27 years(located in Compartment No.1 and 2 of South Zarmayi Reserved Forest) and 31 years (located in Compartment No.55 and 56 of ShwelaungKo Du Gwe Reserved Forest) . These plantationswereestablished in Bago Township, Bago District, Bago Region of Myanmar.This area, the eastern part of Bago Yama Range, was located between 17° 41´ 11" and 17° 42´ 23" N latitude, and 96° 13´ 23" and 96° 16´ 51" E longitude. Elevation above sea level ranged from 41 m to 71 m. From Year 1980 to Year 2010, mean annual temperature was 27. 2 ℃ and mean annual rainfall was 3138 mm. Soil texture up to 10 cm was found as sandy-loam in 31-year old plantation, and as loamy sand in 27- and 23-year old plantations. The spacing of the plantations was 2.59 meters (m) x 2.59 meters(m). 31 year-old plantation had been thinned three times while 27- and 23-year old ones had been thinned two times and one time respectively.

2.2. Data collection

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

Special care was taken in order to exclude trees with crown damage, crooked, forked, suppressed and dead in the sample trees selected for sectional volume calculation. Diameter at breast height (DBH) over bark and total height(H) were measured in all trees. Although the diameters, heights, and 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 diameters of each sample tree were read at two- meter intervals (log length), beginning at the (0.3) m above ground up to the top of the tree stem where the diameter was approximately 10 cm. The height of every sample tree up to 10- cm top diameter was measured in order to get the length of the last section.

2.3. Data preparation

Total height and the height to a 10-cm top diameter for each tree were computed,based on the height calculation procedures for Sunnto Clinometer. 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 interval 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 value of 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 as they are needed in regression analysis. Microsoft Excel 2007 was used for these calculations.

2.4 Data analysis

2.4.1. Volume models studied

Stem volume is a function of a tree's height (*H*), diameter at breast height (*D*) and tree shape or form factor (*F*). The general formula for the volume of a tree is

$$V = \frac{\pi}{4} D^2 HF,$$

and a common expression for tree volume equations is

$$V = f(D, H, F) .$$

However, *F* is rarely used in tree volume model construction. Even though form (*F*) is required in some formulae for the volume of a tree, it is not a truly independent variable; like volume, form factor is usually estimated from other measurements of a tree's dimensions and form factor can be neither measured nor calculated without first measuring the volume (Philip 1994).

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

***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)

Notes: 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 areparameters which will be estimated

2.4.2 Transformation of model (3) and model (4) outlined in table 1

Performances of non-linear or logarithmic volume equations are not affected by non-homogeneity of the variance (Cunia 1964). 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) were linearized.

According to these facts, 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, D, H, b_0, b_1 and $b_2$were as defined above.

ln = natural logarithm

Model (4) was also transformed into the following form, referred to as Clutter et.al. (1983).

$$\frac{D^2}{V} = b_0 + b_1H^{-1} \quad (4.1)$$

where,

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

In this form, the variable $\frac{D^2}{V}$was assumed that it had constant variance.

2.4.3 Application of weighted least square analysis

One of the common assumptions underlying least squares methods of regression, that all data points contribute equally to the estimation of the regression coefficients, is not satisfied. Even though heterogeneity of variance does not necessarily introduce bias, it may increase model statistics such as the standard errors of regression coefficients and imply that estimates for small trees are less precise than they actually are. In addition, when the residual error increases with the size of prediction, estimates for small trees may be biased because measurements of small trees would have less influence on estimated coefficients than those of large trees. This may be one reason that 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.

Wright (1964) and Cunia (1964) discuss the need to weight volume equations in most circumstances in order to equalize the variance in volume along the regression line or surface, this being necessary before valid tests of significance can be applied to the regression equation. Wright concluded that the variance of volume is usually proportional to the square of tree size as expressed by $(D2)^2$, V^2 or $(D^2H)^2$. The general rule for weighting equations to induce homogeneity of variance is that if the variance is directly proportional to a function then the equation should be weighted by the reciprocal of that function. In this case the weighting functions for volume equations become $1/D^4$, $1/V^2$ or $1/(D^2H)^2$ (Greaves, 1978).

Moreover, experience with tree populations (Cunia,1964; Smalley and Bower,1968) 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. Therefore, two weight functions were considered under this study. They were $\left(\frac{1}{D^2H}\right)$ and $\left(\frac{1}{(D^2H)^2}\right)$ 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 and13. In this case, each model needed to be analyzed two times i.e. one time by the use of weight function $\left(\frac{1}{D^2H}\right)$and the next time by the weight function$\left(\frac{1}{(D^2H)^2}\right)$. For comparison purposes and for differentiation between two weight functions applied to these volume models, each model wasgiven 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).

2.4.4 Model fitting

All statistical analyses for all volume models were carried out by 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 by 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 because in SPSS, Weight Functionwas 1/(Weight Variable)**Power. So, 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 0.5.

2.4.5 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) which was significant at 0.05 levelwas selected for further examinations.

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

2.4.6 Testing goodness of fit

The precision of a regression equation is usually measured by the standard deviation from regression or the coefficient of determination (R^2). However, these statistics do not take into account other factors such as heterogeneous variance. A more suitable index for comparing regression equations has been devised by Furnival (1961). Furnival's index is based on the concept of maximum likelihood. Its value is increased by large residuals, departures from linearity, non-normality, and heterogeneous variance. Thus a decrease in its value indicates an improved fit to the data.

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

2.4.7 Calculation of Furnival's index

Furnival' Index was calculated by using the following formula.

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

where,

FI = Furnival' Index

Exp = exponent

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 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 $f'(V)^{-1}$ with D^2H as follow.

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

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

Therefore,

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

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

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

Therefore,

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

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

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

2.4.8 Standard volume table construction

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

3. Results and Discussion

3.1 F-ratio result

The analysis of the results has shown that F-ratios in all volume models were significant at 0.01 level. Therefore, all models were considered to examine further examinations.

3.2 Parameters estimated for the volume models

Among the models studied, one model consisted of six parameters and so it 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 these models have t-values which are 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 the models were shown in Table 2.

Table 2: *Residual Mean Square Error (RMSE), Coefficient of Determination (R^2) , F- ratio and Significant Level of Each SelectedModel*

Model	RMSE	R^2	F-value	P-level	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	**

Remark: ** = highly significant at 0.01 level

3.3 Furnival's index

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

Table 3*Furnival's Index and Rank of Each Model*

Model	$\sqrt{RMSE}$	Transformation	$f'(V)^{-1}$	n	$\frac{(\sum \ln f'(V)^{-1})}{n}$	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

3.4 The best fit volume model

Among the models shown in Table 3, model 7.1 met the first rank since it had the lowest Furnival's Index. Therefore, this model was considered as the most suitable volume model for construction of the standard volume table because of having the best fit to the data. The best fit statistics of this model are shown in Table 4. Figure 1, 2 and 3 presented the performance of the model and also illustrated a relationship between independent variables of this equation (D^2H and D^2H^2) and the volumes of trees within the data set. Both variables were plotted against both observed and predicted volumes. The model with its estimated parametersis presented below-

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

where,

V	=	stemvolume (over bark) up to about 10-cm top diameter excluding stump
D	=	diameter over barkat breast height, in centimeters
H	=	total height in meters

This equation was applied to construct the standard volume table in the present study. The standard volume table constructed by using this equation is presentedin Table 5.

Table 4 *The Best Fit Statistics of Model 7.1*

Best fit statistics	
Model	$V = b_0+b_1D^2H+b_2D^2H^2$
Coefficient of determination (R^2)	0.94
F-value	1538.071**
b_0	-0.0230361338**
b_1	0.0000485831**
b_2	-0.0000008400**
Furnival's Index	0.0317

Remark: ** = highly significant at 0.01 level
b_0, $b_1$and b_2 are parameters.

Table 5: *Standard Volume Table for Teak Plantations of Study Area Constructed using Volume Model 7.1*

D	Total height in meters													
(cm)	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, cm
The unit of volume is cubic meter.
Total number of sample trees is 213.

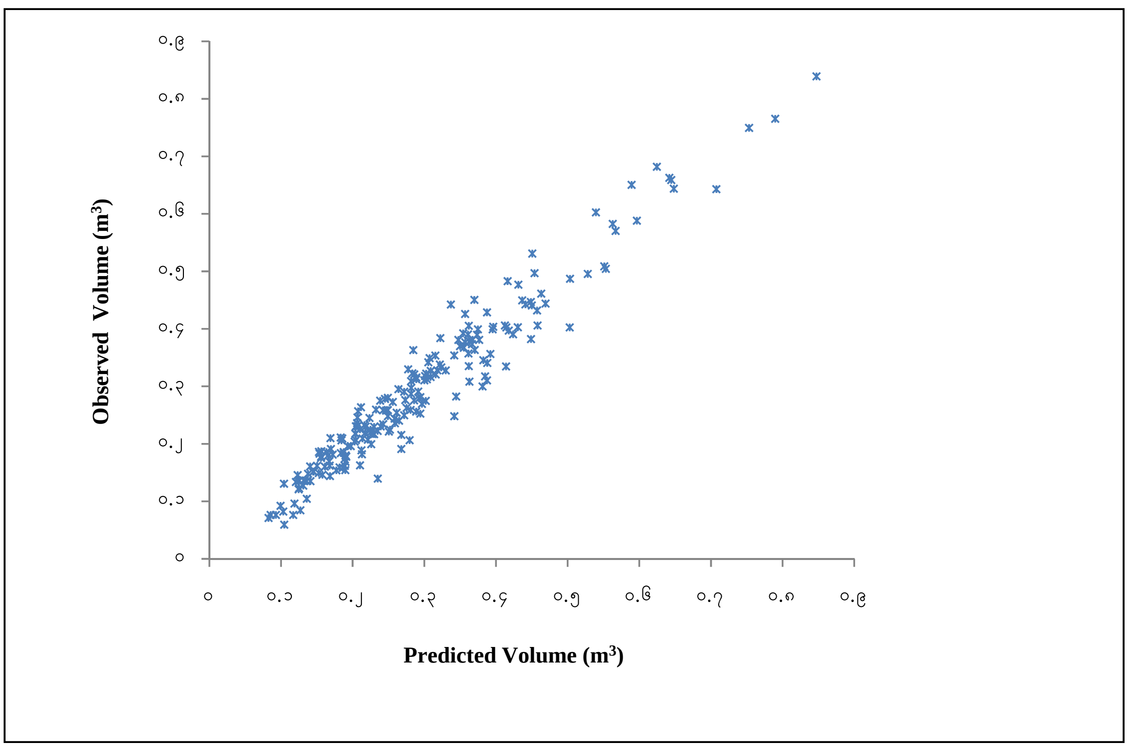

Figure 1 Predicted Volume against Observed Volume

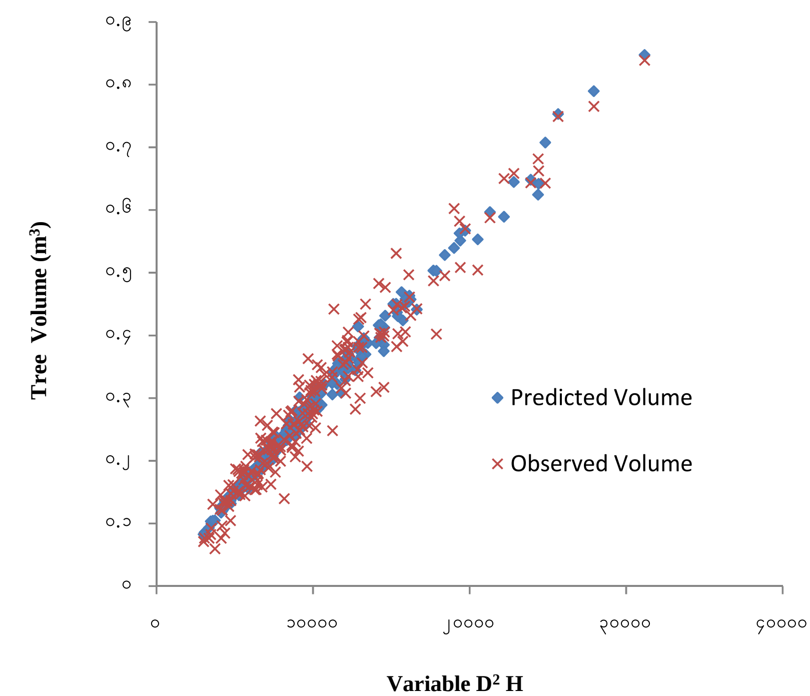

Figure 2: Predicted Volume and Observed Volume against D^2H

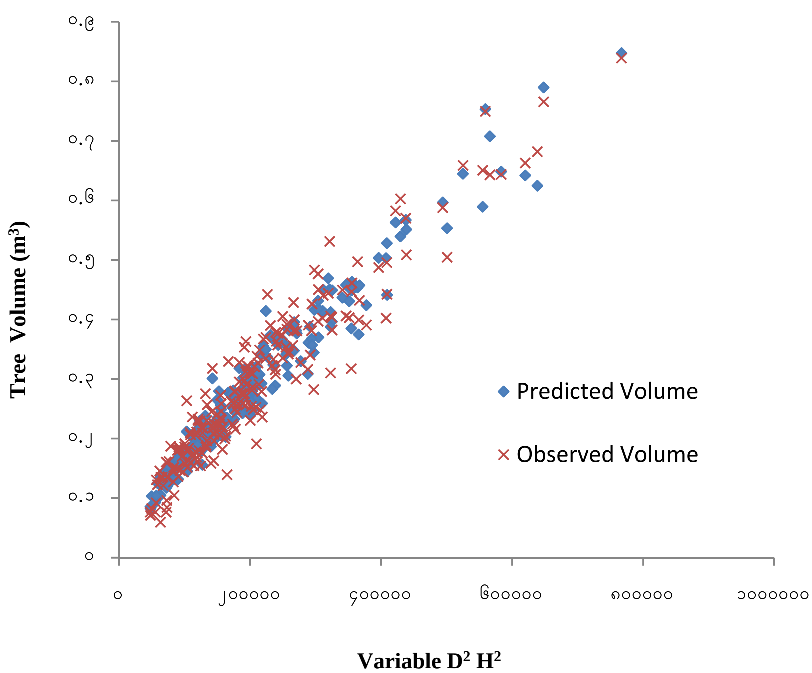

Figure 3: Predicted Volume and Observed Volume against D^2H^2

3.5 Applicability of the result

The volume equation should only be applied in circumstances similar to theconditions of the original sample data. The volume sample trees were selected from three teak plantations having planting spacings of 2.59 m x 2.59 m (8.5 ft x 8.5 ft), and aged 23, 27 and 31 years. Diameters at breast height (DBH) of the sample trees ranged from 13.7 to 35.6 cm, while total tree heights varied from 14.4 to 26.2 meters. Mean annual rainfall over the study area is 3138 mm with a distinct dry season from January to April. Mean annual temperature is 27 degrees Celsius. The application of this volume table should reflect these conditions. Before the equation can be used in other conditions both its accuracy in the new environment, and applicability to tree dimensions outside those of the original sample must be verified.

4. Conclusions

By using the best fit volume model to the data, standard volume table based on diameter at breast height (DBH) and total height (Ht) was constructed. This volume table can be applied in the assessment of economic potential of standing teak trees in the study area. Therefore, this research reflects the economic goal of the teak plantation management. Moreover, this study plays a significant role in the sustainable management of teak plantations by assistingFD and private sectors in the prediction of growth and yield of teak plantations in Myanmar.

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