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Growth and Yield Models for Teak Plantations in Yedashe and Taungoo Townships, Taungoo District, Bago Region

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1. Introduction

Teak (Tectona grandis L. f.) is one of the most important tropical timber species and is suitable for multiple end-uses. The potential for growing and managing teak in different ecological zones and under different situations is being increasingly recognized, leading to intensive domestication and cultivation of the species in countries/regions beyond its natural habitat (Pérez LD. and Kanninen M, 2003). Between 2005 and 2014, the global annual trade of teak roundwood was more than one million cubic meters on average; the imports were valued at US $ 487 million per year, which is about 3 per cent of the value of the global timber trade (US $ 15.5 billion) (IUFRO, 2017). 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 Programme since 1998 to maintain and increase teak production. Moreover, nowadays, FD has encouraged private sectors to establish teak plantations in large scale since 2005. Since 2016, Forest department (FD) have prepared "Myanmar Reforestation and Rehabilitation Programme (MRRP) (from 2017-2018 to 2026- 2027)" with relevant measures (Natural Regeneration (NR), Assisted NR, Artificial Regeneration (AR) (FD,2016). In this program, establishment of teak plantations is also included as a large-scale. Most of teak plantations in Myanmar 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 purpose and 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 prediction of growth and yield for teak plantations in a specific area is very rare although it plays significant role in teak plantation management. In this context, it is clear that scientific research related to the prediction of growth and yield for teak plantations will satisfy this goal. Therefore, this study focused on application of growth and yield models developed by Borders and Bailey (1986) in order to predict current and future yield, especially established in the study area which is one part of Bago Yoma Range known as home of teak by achieving quantitative data and equations.

2. Objectives

1. To apply growth and yield models for the prediction of current and future yield of teak plantations in study area
2. To construct yield tables for teak plantations in study area

3. Materials and Methods

3.1. Study Site

Study site for this study is located in Yedashe and Taungoo Townships in Taungoo District, Bago Region. Figure 1 shows the location of study site.

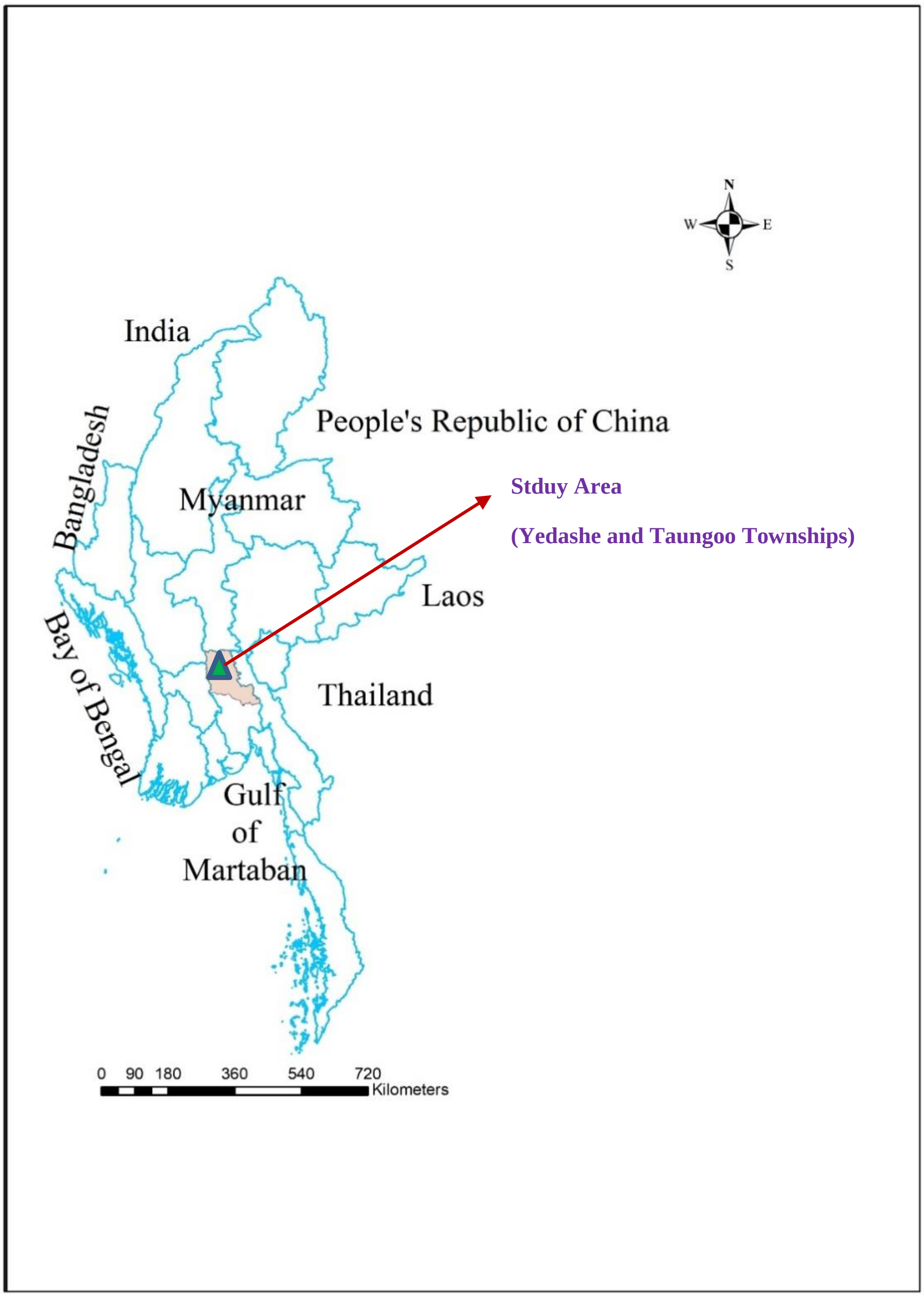

Figure 1. Location of study site

3.2. Growth and Yield Models

The simultaneous system fitted by Borders and Bailey (1986) was used as an interdependent, multi-equation system of growth and yield equations throughout the analysis. At first, they specified models for predicting volume and basal area for planted stands:

$$lnV = b_0 + b_1 lnH_t + b_2 lnG \quad (1)$$

$$lnG = a_0 + a_1 lnH_t + a_2 lnN$$

(2)

Where;

ln = natural logarithm

V = volume per hectare (cubic meter)

G = basal area per hectare (square meter)

H_t= top height (average height of 100 largest diameter at breast height (DBH) trees per hectare) (meter)

N = number of trees planted per hectare

$b_0, b_1, b_2, a_0, a_1, a_2$ are unknown parameters to be estimated.

Equations (1) and (2) are yield equations. These equations can be differentiated to define analytically compatible growth equations. Differentiating (1) and (2) with respect to age(A) one obtains:

$$\frac{\left({dV}/{dA}\right)}{V} = \left(\frac{b_1}{H_t}\right)\left(\frac{dH_t}{dA}\right) + \left(\frac{b_2}{G}\right)\left(\frac{dG}{dA}\right)$$

(3)

$$\frac{\left({dG}/{dA}\right)}{G} = \left(\frac{a_1}{H_t}\right)\left(\frac{dH_t}{dA}\right)$$

(4)

Relative volume growth is dependent upon relative changes in both dominant height and basal area while relative growth rate of basal area is dependent upon relative growth rate of dominant height. Therefore height-age prediction and projection components are also needed. The following height-age model was adopted:

$$lnH_t = c_0 + c_1 A^{-1} \qquad (5)$$

Where;

A= age in years

c_0 and c_1 are parameters to be estimated.

H_t has been already defined.

The first derivative of equation (5) with respect to age is

$$\frac{\left({dH_t}/{dA}\right)}{H_t} = -c_1 A^{-2} \qquad (6)$$

Equations (3), (4), and (6) were solved as separable linear differential equations and integrated from A_1 to A_2 to produce the following growth (projection) equations (Borders and Bailey, 1986):

$$lnV_2 = lnV_1 + b_1(lnH_{t2} - lnH_{t1}) + b_2(lnG_2 - lnG_1) \qquad (7)$$

$$lnG_2 = lnG_1 + a_1(lnH_{t2} - lnH_{t1}) \qquad (8)$$

$$lnH_{t2} = lnH_{t1} + c_1(A_2^{-1} - A_1^{-1}) \qquad (9)$$

Where;

V_i = volume per hectare at age A_i

G_i = basal area per hectare at age A_i

H_{ti} = top height at age A_i

A_i = age in years at time i

i = 1,2

In order to predict average diameter at breast height, the following model is used.

$$lnD = g_0 + g_1 A^{-1} \tag{10}$$

Where;

D = average diameter at breast height in centimeters

g_0 *and* g_1 are parameters to be estimated.

A has been already defined.

For the estimation of number of trees from D , the model is as follow.

$$N = kD^n$$

(11)

Where;

k and n are parameters to be estimated.

Other variables have been already defined.

3.3. Data Collection

Data collection was carried out in 2016. Ten teak plantations in Yedashe and Taungoo Townships, Taungoo District, Bago Region were selected. In each plantation, ten sample plots were established in order to represent the site condition of the whole plantation. Sample plot size is 20m x 25m (0.05 ha). In each sample plot, diameter at breast height (DBH) of all the trees were measured to calculate basal area and height of five biggest DBH trees were also measured by Vertex IV height measuring instrument to calculate top height. Top height is defined as the average height of a specified number per unit area of the trees of a stand the largest diameters at breast height (usually over bark) (West P.W. (2009)). In this study, top height is average height of 100 largest DBH trees per hectare. Number of trees were recorded. In order to estimate volume, from stump height (0.03m) above the ground, diameter of stem was measured at every two meter up to approximate 10 cm top diameter. Stand statistics are shown in table 1.

Table 1: Stand statistics

Variable	Minimum	Maximum
Age(yr)	13	52
Volume(m^3ha^{-1})	18.31	601.80
Basal Area (m^2 ha^{-1})	3.79	73.56
Top Height(m)	10.70	38.70
Number of Trees	120	640
Average Diameter at Breast Height	16.33	67.7

3.4. Data Analysis

Volume for individual teak tree was calculated by Smalian's Formula. Individual tree volume was summed to get the plot volume. Volume per plot, basal area per plot and number of trees per plot were converted to per hectare level. Data analysis was carried out by SPSS 16 software and other calculations were done by Microsoft Excel 2019.

4. Results and Discussion

Parameters in equation (1), (2), (5), (10) and (11) were shown in table 2. In equation (1), b_0 is not significant at 0.05 probability level and so it was excluded and analyzed again. In equation (1), (2), (5), and (10), all the parameters are significant at 0.05 probability level. F-test for equation (1), (2), (5) and (10) is also significant at 0.05 probability level. r^2 value is also reasonably high in all equations. Figure 2,3, and 4 show observed values versus predicted ones for equation (1,2 and 5).

Borders and Bailey (1986) fitted the five equations (1,2,7,8 and 9) individually using ordinary least square (OLS) in their study. These same models were also fitted as a system using unrestricted three-stage least square (3SLS) and restricted 3SLS. Results showed that although the 3SLS estimates generally had smaller predicted standard errors, parameter estimates were similar for all three cases Therefore, in this study, only OLS was used for parameter estimation in analysis for this reason.

Clutter J.L. (1963) predicted growth and yield of loblolly pine (*Pinus taeda L.*) plantations by the combination of age, site index and basal area based on permanent sample plots. And also Clutter J.L. *et.al* (1983) suggested that this kind of growth and yield estimation must be done, based on data collected from permanent sample plots in their literature. However, in this study, permanent sample plots are not available and due to some limitations, such as time and budget, the research related to prediction of growth and yield for teak plantations was conducted by mainly focusing on top height, basal area and number of trees according to models by Borders and Bailey (1986) which were described in Burkhart H.E and Tome M. (2012) literature. In Myanmar, Tint K. (1981) developed dynamic growth and yield models for planted teak however his study did not focus on specific area and also it is not clear to relate growth and yield as mentioned in this study. Moreover, it is not easy to predict future yield in term of basal area and volume as in this research. Naing Y.M (2020) applied growth and yield models by Clutter J.L. et.al (1983) to predict growth and yield for teak plantations in Taungoo District of Myanmar. Although his study should be carried out in permanent sample plots, he focused only on temporary sample plots and calculated basal area growth based on increment cores (reading annual rings) and number of trees which will be left after thinning. Therefore, when compared to this study with Naing's one, in the sense, both studies were conducted in temporary sample plots but this study is more reliable than Naing's one because permanent sample plots are not needed for this research.

Table 2: Statistical analysis results

Equation	**Parameters**	**Value**	**P-Level**	**F-Test (P-Level)**	$\mathbf{r^2}$
1	b_1	0.59	0.01	0.01	0.99
	b_2	1.00	0.01		
2	a_0	-7.26	0.01	0.01	0.88
	a_1	2.14	0.01		
	a_2	0.63	0.01		
5	c_0	3.89	0.01	0.01	0.87
	c_1	-17.44	0.01		
10	g_0	4.22	0.01	0.01	0.78
	g_1	-17.32	0.01		
11	k	6210.00	-	-	0.96
	n	-0.83	-		

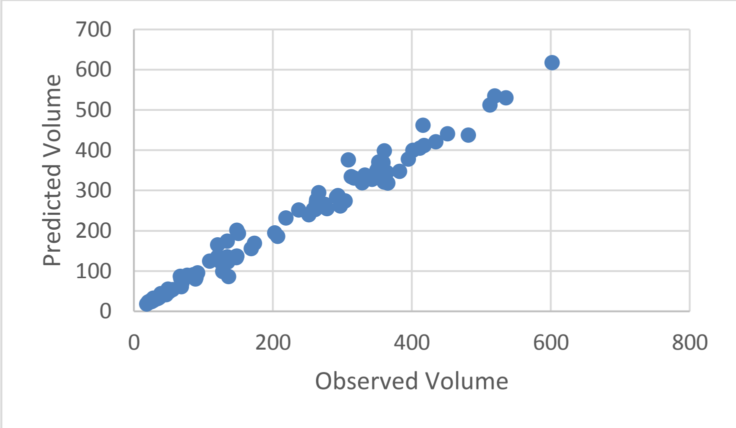

Figure 2: Observed versus predicted volume

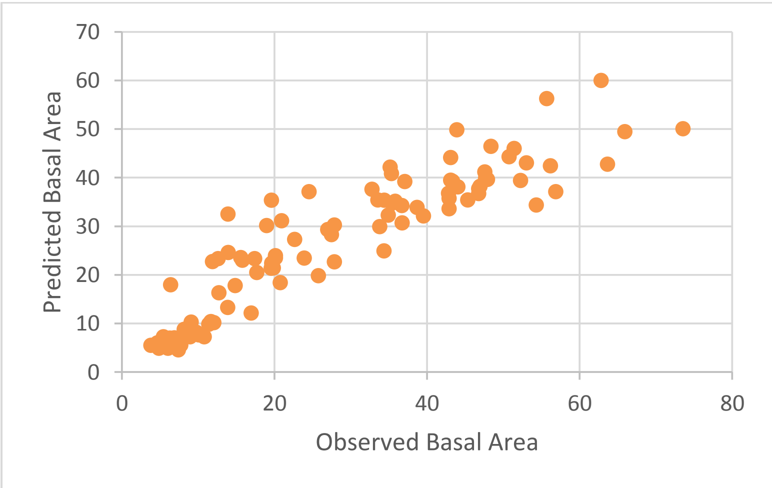

Figure 3: Observed versus predicted basal area

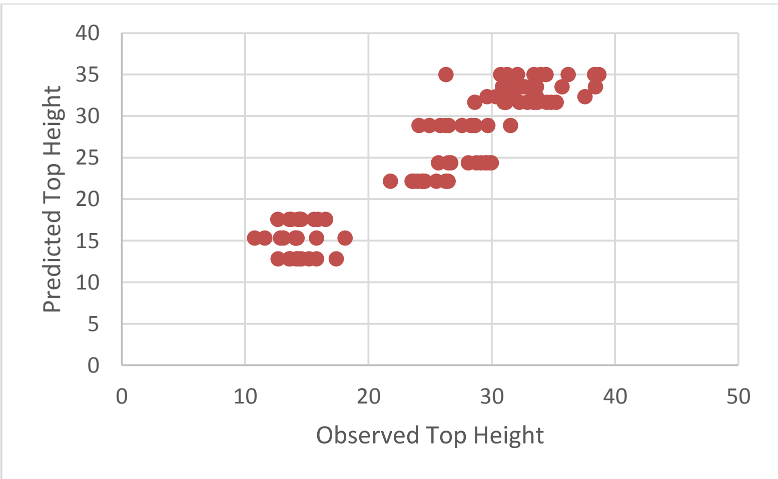

Figure 4: Observed versus predicted top height

5. Final Yield Equations with their Parameter Values

$$lnV = (0.59)lnH_t + (1)lnG \quad (12)$$

$$lnG = (-7.26) + (2.14)lnH_t + (0.63)lnN \quad (13)$$

$$lnH_t = (3.89) + (-17.44)A^{-1} \quad (14)$$

$$lnD = (4.22) + (-17.32)A^{-1} \quad (15)$$

$$N = (6210)D^{(-0.83)} \quad (16)$$

$$lnV_2 = lnV_1 + (0.59)(lnH_{t2} - lnH_{t1}) + (1)(lnG_2 - lnG_1) \quad (17)$$

$$lnG_2 = lnG_1 + (2.14)(lnH_{t2} - lnH_{t1}) \quad (18)$$

$$lnH_{t2} = lnH_{t1} + (-17.44)(A_2^{-1} - A_1^{-1}) \quad (19)$$

6. Applications

(a) Yield Prediction (First Option) (When field measurement can be carried out)

- (i) Set (20 m x 25 m) (0.05 ha) sample plot and measure diameter at breast height.
- (ii) Record no. of trees and convert them into one hectare basis.
- (iii) Calculate basal area (G) and convert it into one hectare basis.
- (iv) Note plantation age(A).
- (v) In order to get top height (H_t), solve equation (14) according to A.
- (vi) Then volume (V) can be calculated by equation (12) based on G and H_t.

(b) Yield Prediction (Second Option) (If only age is available)

- (i) Calculate average diameter at breast height(D) according to equation (15) base on A known.
- (ii) Then, enter equation (16) to get no. of trees per hectare(N).
- (iii) Estimate H_t by equation (14).
- (iv) Predict G by equation (13) according to H_t and N.
- (v) V can be solved by equation (12) based on the values of H_t and G.

(c) Future Yield Prediction

- (i) To solve equation (19), define projected age (A_2). For example, if current age of plantation (A_1) is 20 years and want to know future yield for next 20 year, A_2 will be 40 years.
- (ii) From (v) of (a), H_{t1} is available and find H_{t2} by equation (19).
- (iii) By using G_1 From (iii) of (a) and H_{t1} and H_{t2} from (ii) of (c), solve equation (18) to get projected basal area G_2.

(iv) Finally, projected or future volume (V_2) can be predicted by equation (17) based on current volume (V_1) resulted from (vi) of (a), and H_{t1}, H_{t2}, G_1 and G_2.

7. Example Yield Tables

Two yield tables are shown in table (3 and 4). Table 3 is constructed by equation (12) and table 4 is constructed, based on equation (12 to 16).

Table 3: Yield table constructed according to equation (12)

	Basal Area(m^2ha^{-1})									
	5	10	15	20	25	30	35	40	45	50
Top Height (m)	Volume (m^3ha^{-1})									
5	13									
10	19	38								
15	24	49	73							
20	29	58	86	115						
25	33	66	98	131	164					
30	37	73	110	146	182	218				
35	40	80	120	160	199	239	279			
40	43	87	130	173	216	259	302	344		
45	47	93	139	185	231	277	323	369	415	
50	50	99	148	197	246	295	344	393	442	490

Table 4: Yield table constructed by equation (12,13,14,15 and 16)

A	H_t	D	N	G	V
10	8.56	12.04	787.51	4.75	16.68
15	15.30	21.44	487.69	12.21	60.05
20	20.46	28.62	383.79	19.57	113.95
25	24.36	34.03	332.40	25.97	167.35
30	27.36	38.19	302.02	31.36	216.22
35	29.73	41.48	282.04	35.88	259.65
40	31.64	44.12	267.92	39.70	297.85
45	33.21	46.30	257.44	42.95	331.41
50	34.52	48.12	249.34	45.74	360.96
55	35.63	49.65	242.91	48.15	387.08

A = plantation age in year; H_t = top height in meter; D=average diameter at breast height in centimeter; N= number of trees per hectare; G= basal area in square meter per hectare; V= volume in cubic meter per hectare

8. Current and Future Yield Estimations for Six Teak Plantations Studied

In table 5, based on age in 2016 and equation (12,13,14,17,18 and 19), current yield yield at 2016) for each of six teak plantations is elucidated and future yield is also predicted up to rotation age (40) years.

Table 5: Current and Future Yield

No.	Location	Age in 2016	Yield at 2016 (m^3ha^{-1})	Future Yield at Rotation Age (m^3ha^{-1})
1	Saiya Reserved Forest, Compartment No. (76), Yedashe Township	17	54.62	272.07
2	Saiya Reserved Forest, Compartment No. (77), Yedashe Township	15	56.13	405.67
3	Saiya Reserved Forest, Compartment No. (79), Yedashe Township	33	175.25	225.42
4	Saiya Reserved Forest, Compartment No. (78), Yedashe Township	13	22.63	266.13
5	Saiya Reserved Forest, Compartment No. (39), Yedashe Township	22	140.51	371.02
6	Thandaung Reserved Forest, Compartment No. (3), Taungoo Township	25	129.11	263.14

9. Conclusion and Recommendations

By applying the above equations (12 to 19), for teak plantations in Yedashe and Taungoo Townships, top height, average DBH, number of trees per hectare, current basal area per hectare, current volume per hectare, future basal area per hectare, future volume per hectare, instantaneous basal area growth($m^2h^{-1}yr^{-1}$), instantaneous volume growth($m^3ha^{-1}yr^{-1}$), and instantaneous top height growth (myr^{-1}) can be easily predicted. In this study, due to time limitation, analysis was done by OLS. Therefore, 2SLS, and unrestricted and restricted 3SLS should be carried out and the results also should be verified. However, if other models are not available to estimate growth and yield for Taungoo District, the models in this study should be applied in this situation. Based on the above growth and yield models, it is suggested that the growth and yield analysis and prediction should be focused on each commercial species in each district. In future, if possible, permanent sample plots should be established to know stand dynamic (e.g.basal area changes during a time interval) and also Clutter J.L. et.al (1983) models should be analyzed by the data from these kinds of permanent sample plots and compared the results with the above growth and yield models to realize which models are suitable for the specific area and species under a particular management objective.

10. Acknowledgements

I would like to express my sincere thanks to all organizations and personnel who support to conduct this study.

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