Improved Yield Prediction Model for Teak Plantations in Northeastern Thailand

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Abstract

To predict the yield of teak plantations in Northeastern Thailand, the new site index function was developed for predicting dominant tree height in teak stands. The Gompertz function was applied as the site index curve to improve the existing yield model. From the model, we computed the stem volume, stand basal area, stand volume, and stand density of the test plots were using site index values derived using the new site index function. These stand aggregates were compared to the previous model. The results revealed that the statistical indicators used to evaluate the performance of the two models provided smaller values in the present model than in the previous model. This confirmed that the improved yield model had greater accuracy and precision than the previous model. The improved yield model could be applied to generate a new yield prediction table for teak plantations in Northeastern Thailand.

Keywords: Non-linear regression model, Dominant tree height, Site index, Stand volume, Stem volume, Stand density, Stand age

Introduction

The Royal Forest Department launched the Economic Forest Plantation Extension Project to promote forest plantation areas in 1994. The goal was to cover 800,000 hectares (5 million rai) and was designed to encourage rural households to plant trees on their land. Farmers were granted subsidies of 3,000 baht per rai, over 5 years to plant trees, and they were allowed to harvest trees after a certain period. The project emphasized the planting of indigenous forest tree species. Teak has been the most popular because its high durability, good dimension stability, and aesthetic quality make it a very valuable species for forest plantations. Additionally, the price of teak wood is relatively high due to increasing demand. Teak was planted all over under this project covering 88,000 hectares during 1994–1996, even in Northeastern Thailand where this species is not naturally distributed. To reach the target of providing highly valuable timber to the owners of teak plantations, understanding growth and yield was essential to develop long-term plans for sustainable forest management. Thus, it was of high priority to distribute information on growth and yield.

The site index is commonly used as a measure of site productivity or site quality that is relatively independent of stand density (Vanclay 1994; West 2004), and it had been used extensively in forestry (West 2004). The site index is the top height at a prescribed age and has commonly been used in models that correlate site and soil characteristics with growth and yield predictions (Mailly et al. 2004; West 2004). The point in the life cycle of a forest when limiting factors may present themselves can significantly alter the shape of the growth curve (Fisher and Binkley 2000). Additionally, sites with a higher growth rate at a given point in the plantation life cycle compared with other sites do not necessarily mean that the same relationship will be the same subsequently.

In July 1992, a yield prediction table was constructed as part of the RFD-JICA REX II Project in order to predict the yield of teak plantations in Northeastern Thailand, and then the table was revised in the RFD-JIRCAS Program during 2009–2010 after more data from this region were obtained. This type of yield table was identified as an empirical yield table that shows average growth and yield data of forest stands. Because of the limitation that empirical yield tables may not provide reliable data, especially for data on old stands, a variable density yield table was constructed in 2011 to obtain more reliable data on growth and yield.

The existing variable yield density model was considered to be improved as a result of additional data from various teak stands in northeastern regions collected from 2012 to 2016. The new site index equation was constructed in order to cover a wider range of dominant height-age relationships of teak stands in this region.

The objective of this study was to improve the efficiency of the variable yield density model by developing a new site index equation for use in this model. The improved yield model will provide more reliable results for predicting the growth and yield of teak plantations located in Northeastern Thailand.

Materials and methods

Site index equation

The data was measured in 279 sample plots that were established from 1972 to 1997. Most of the sample plots were private plantations owned by farmer and the rest were owned by The Royal Forest Department and Forest Industrial Organization. The plots were located in the 10 provinces of Nakhon Ratchasima, Khon Kaen, Sakon Nakhon, Loei, Si Sa Ket, Ubon Ratchathani, Yasothon, Chaiyaphum, Udon Thani, and Nong Bua Lam Phu. Most of the sample plots were temporary plots, but 77 plots were semi-permanent plots that were measured annually for 2–3 years in order to estimate stand growth. The last measurement was conducted during the year 2015–2016 and there was an average of two measurements per plot. At each measurement, tree diameter at 1.3 m aboveground (diameter at breast height [DBH]), total tree height, and number of survival trees in each sample plot were recorded. The total stem volume of individual trees was computed using the formula developed by Ishibashi *et al*. (2002):

$$V = 0.00100712\, DBH^{1.89445042} H^{0.7163796917} \quad (1)$$

Where: V = individual stem volume (m^3); DBH = diameter at 1.3 m aboveground (m); H = total height (m).

Stand growth parameters (number of trees, average height, average DBH, dominant tree height [DTH; defined as the 100 largest trees by DBH per hectare], volume per tree and volume per hectare) for each measurement plot were calculated.

A total of 357 dominant tree height-age measurements for teak stands were recorded and computed and were separated into two data sets based on a random selection procedure. The first dataset consisted of 322 observations for constructing the site index model (equation), and the second data sets consisted of 35 observations (around 10% of the first data sets) used for model validation. Both data sets covered approximately the same ranges of DTH and age of the sample plots (Fig. 1).

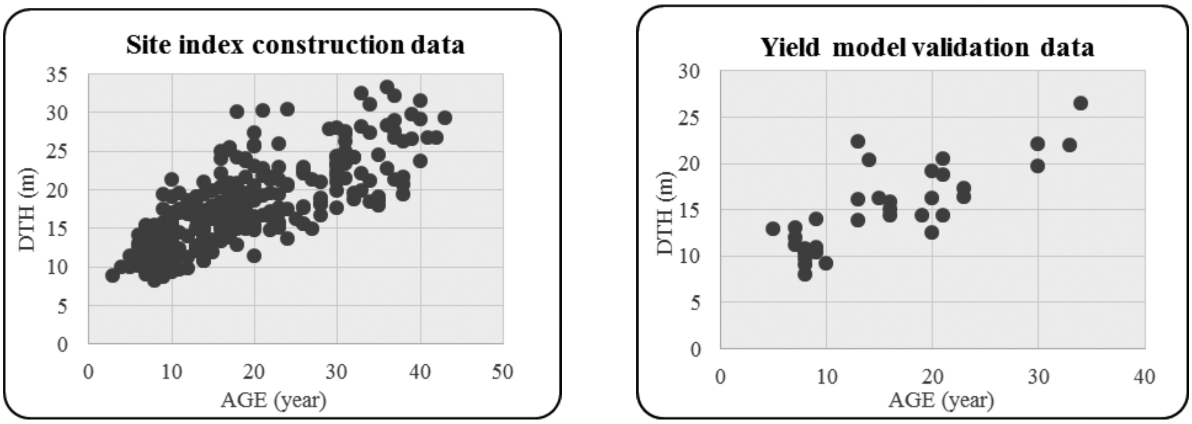

Fig. 1. Scatter plot of dominant tree height (DTH) against stand age for the two data sets used in the study.

A wide variety of non-linear regression models were employed to fit the site index model (for example, Philip (1994); Draper and Smith (1981); Phillips and Campbell (1968); Nelder (1961); Oliver (1964)). The non-linear estimation procedure in the statistical analysis was used to fit the models. Models where all parameters provided significant values ($p<0.05$) and provided higher coefficient of determination than the others were selected as candidate models. Multiple measurements of performance for the non-linear model were applied as various criteria in order to select the best model for constructing the site index equation. The various criteria were adjusted coefficient of determination ($\overline{R}^2$), root mean square error (RMSE), Akaike information criterion (AIC), mean residuals (MRES), absolute mean residual (AMRES), and mean square error (MSE). They were estimated as:

$$\overline{R}^2 = 1-(1-R^2)\frac{[n-1]}{[n-p-1]} \quad (2)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Hi-\widehat{Hi})^2}{(n-1)}} \quad (3)$$

$$\text{AIC} = n.\ln(\text{RMSE})+2p \quad (4)$$

$$\text{MRES} = \frac{\sum_{i=1}^{n}(Hi-\widehat{Hi})}{n} \quad (5)$$

$$\text{AMRES} = \frac{\sum_{i=1}^{n}|Hi-\widehat{Hi}|}{n} \quad (6)$$

$$\text{MSE} = \text{MRES}^2 + v \quad (7)$$

In the above equations: Hi = observed (actual) DTH; $\hat{H}$ = predicted DTH; p = number of parameters used in the model; n = number of observations; v = variance of the residuals; R = coefficient of determination; $\overline{R}$= adjusted coefficient of determination.

System of yield prediction equations

The mean height of each sample plot (Hm) was estimated by DTH at measurable time, and its relationship was fitted using the non-linear regression model. The mean DBH of each sample plot was estimated using a multiple linear regression model that used initial stand density, inverse age, and mean height growth as independent variables of the model.

In the present study, the yield prediction sub-models were the same pattern of sub-model as used in the previous study (Vacharangkura 2012). The sub-model was the natural logarithm of initial stand density, inverse age, and site index value, and the dependent variables were the natural logarithm of the stand aggregates;

$$\text{Ln } Y = \alpha + \beta_0 \text{ Ln } I + \beta_1 \text{Ln} 1/A + \beta_2 \text{ Ln } SI \quad (8)$$

Where: Y = volume/tree (m^3/tree) or volume per hectare (m^3/ha) or basal area per hectare (m^2/ha) or number of trees per hectare (trees/ha) at measurable time (survival); I = initial stand density (trees/hectare); $1/A$ = inverse age (1/years); SI = site index value (m); Ln = natural logarithm.

The following equations derived from multiple linear regression model (n=157) were:

Vt (volume per tree) =
$$-11.1761 - 0.4421 \text{ Ln}I - 1.3977 \text{ Ln } 1/A + 2.7502 \text{ Ln}SI \quad (9)$$

V (volume per hectare) =
$$-7.3040+0.3123\text{Ln}I+0.9543\text{Ln}1/A+2.2898\text{Ln}SI \quad (10)$$

Ba (basal area per hectare) =
$$-6.4560+0.3353\text{Ln}I-0.6860\text{Ln}1/A+1.5440\text{Ln}SI \quad (11)$$

N (number of tree per hectare) =
$$3.8722+0.7544\text{Ln}I+0.4434\text{Ln}1/A-0.4603\text{Ln}SI \quad (12)$$

To estimate the stand aggregates of the sample plots used in the present study, the site index values derived from the site index function of the present study were employed in the yield model instead of the site index equation presented by Ishibashi et al. (2010). The site index values from this study will calibrate the stand aggregates predictions, thus the yield model will be improved in order to provide more reliable predictions.

Model validation and comparison

Using datasets from 35 independent sample units (observations) the goodness-of-fit of all sub-models was conducted using a bilateral paired t-test. It was used to perform a pair-wise comparison between the observed value and the predicted value computed by the sub-models. The null hypothesis was that there was no significant difference between the actual (observed) values and the predicted values. The difference between these values was evaluated to show whether there was a statistically significant different or not.

The performances of the improved yield model in the present study were compared with that of the model presented by Vacharangkura (2012). A quantitative evaluation involving the characterization of model error (bias) and precision was performed. In addition, residuals were examined to detect any obvious pattern and systematic discrepancies. Model bias and precision were evaluated by computing the MRES, RMSE, AMRES, and MSE. These were presented in Eq. (3), Eq. (5)-(7). MRES, RMSE, and AMRES were also expressed in relative terms as percentages of the predicted mean value for more obvious results.

$$\text{MRES\%} = 100\,\frac{[\sum_{i=1}^{n}(y_i-\hat{y_i})/n]}{\sum_{i=1}^{n}\hat{y}_i/n} \quad (13)$$

$$\text{RMSE\%} = 100\,\sqrt{\frac{[\sum_{i=1}^{n}(y_i-\hat{y}_i)^2/(n-1)]}{(n-1)}} \quad (14)$$

$$\text{AMRES\%} = 100\,\frac{[\sum_{i=1}^{n}|y_i-\hat{y}_i|/n]}{(\sum_{i=1}^{n}\hat{y}_i/n)} \quad (15)$$

Where: n = number of observations; y and ŷ = observed and predicted values, respectively.

Thereby determining the accuracy and precision of the two models.

Results

Stand characteristics

The characteristics of 322 observations derived from the measurement plots were employed to construct the site index equation in this study, as shown in Table 1.

The stand characteristics were given for the measurement time of all plots used to construct the site index equation. All of the observations covered various initial densities; however, most of them existed on 1,250 trees/ha (2×4 m spacing) and 625 trees/ha (4×4 m spacing). Most of stand ages ranged from 6 to 20 years, and old stands accounted for 69% of all datasets (Fig. 2). The limitations of our data included having only a small number of observations for stands over 40 years old and stands less than 5 years old. The number of measurement plots for which the initial stand densities were not 625, 1111, 1167, 1250, or 2500 trees/ha was very low and accounted for 3.4% of our dataset.

Table 1. Summary of characteristics of the sample plots, as computed from 322 observations used for constructing the site index function in this study.

Variable	Average (min, max)		S.D.
Stand age (year)	17.69	(3.00, 43.00)	9.29
Stand basal area (m^2/ha)	12.94	(3.02, 43.00)	7.87
Stand density (tree/ha)	797.67	(118.75, 2380.95)	420.62
Mean diameter (DBH, cm)	16.46	(5.95, 39.11)	7.61
Mean total height (m)	14.45	(5.13, 29.84)	5.33
Dominant tree height (m)	33.21	(8.21, 17.34)	5.31
Stand volume (m^3/ha)	124.51	(16.85, 483.28)	83.44

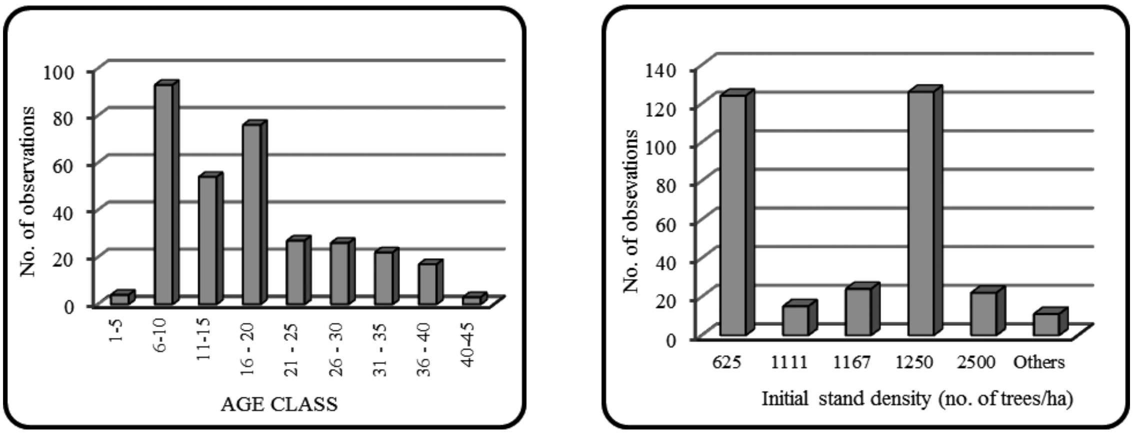

Fig. 2. The characteristics of the measurement plots.

Site index equation

A wide variety of non-linear models were employed for modeling the relationships between stand age and dominant tree height of teak stands. Based on the procedure of non-linear estimation, four non-linear height-growth functions were selected as candidate site index models. These four non-linear growth functions have been widely used because of their appropriate mathematical properties and promising predictive performances for height–age relationships. The datasets from the site index construction data (n=322) were used to perform the non-linear functions. The four candidate non-linear models are presented in Table 2.

The results of the four non-linear dominant height growth functions for teak stands in Northeastern Thailand are presented in Table 3.

The coefficients of all the models were highly statistically significant at $p<0.001$. The differences in R^2 values among the Gompertz, Hossfeld, and Logistic models were negligible, but those of the three models were rather higher than the Negative exponential model.

Table 4 shows the measures of performance for all four candidates site index functions modeled in this study. The models with the lowest RMSE and AIC values and the R^2 and adjusted R^2 closest to unity are known to perform best (Aertsen et al. 2010). The adjusted R^2 values indicated that all models, except for the Negative exponential model produced nearly identical fits explaining approximately 34% of the total variation in dominant height. The MRESs ranged from -0.0019 to 0.0900, whereas AMRESs ranged from 1.9606 to 2.875. In general mean residuals were small for all four candidate non-linear models.

Table 2. Non-linear mathematical models considered the candidate models.

Model	Standard form	Sources
Gompertz	$DTH = a\exp(-b_1\exp(-b_2 AGE))$	Draper & Smith (1981)
Hossfeld	$DTH = (aAGE^{b1})/(b_2+AGE^{b1})$	Kimberly & Ledgard (1998)
Logistic	$DTH = a/(1+ b_1\exp(-b_2 AGE))$	Nelder (1961), Oliver (1964)
Negative exponential	$DTH = a(1-\exp(-b\,AGE))$	Phillip (1994)

Table 3. Parameter estimates for the non-linear dominant height–age model.

Model	Parameter	Estimate	S.E.	R^2
Gompertz	a	31.4788	3.8654	0.5877
	b	1.3173	0.0685	
	c	0.0471	0.0118	
Hossfeld	a	0.1568	0.0101	0.5872
	b	-0.0039	0.0003	
	c	-0.9800	0.0010	
Logistic	a	29.1193	2.3333	0.5859
	b	2.5703	0.1725	
	c	0.0703	0.0128	
Negative exponential	a	24.9841	0.7463	0.5572
	b	0.0785	0.0053	

Table 4. Performance criteria of the four non-linear dominant height-age model for constructing site index equation.

Model	Adj. R^2	RMSE	AMRES	MRES	AIC	$\sqrt{v}$	MSE
Gompertz	0.3393	3.4098	1.9606	-0.0019	796.96	3.4098	11.6264
Hossfeld	0.3387	3.4118	2.6751	0.0415	797.35	3.4119	11.6430
Logistic	0.3371	3.4173	2.7009	-0.0043	798.38	3.4173	11.6780
Negative exponential	0.3062	3.5338	2.8752	0.0810	817.96	3.5326	12.4874

Fig. 3 shows the curved shapes of all four candidate models. The Gompertz and Logistic models showed similar predictions of dominant tree height; however, for older stands the Gompertz model tended to provide a greater height growth than the logistic model. This was confirmed by the larger asymptotic coefficient of the Gompertz model (Table 3). The Negative exponential model gave a smaller value than the others for younger stands (less than 10 years old) and older stands (more than 30 years old). The Hossfeld model showed larger height growth prediction than the others when the stand age was more than approximately 35 years.

Referring to Table 4, it is evident that the Negative exponential model gave poorer performance criteria values more than the others. Therefore, the Negative exponential model was omitted in the first step of this approach. The differences in values among the other three models were small; however, the Gompertz model gave the smallest values, especially for the AIC value. AIC value is considered as one of the most reliable criteria for comparing models with a range of parameters (Burnham et al. 2002; Sharma 2009). The model with the smallest AIC is considered optimal. Therefore, the Gompertz model was the best to use as a guide curve for site index construction.

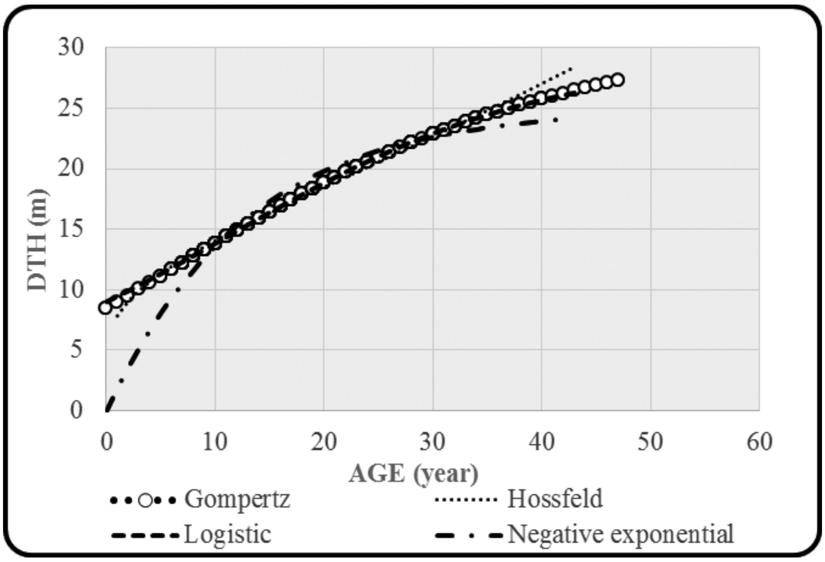

Fig. 3. Dominant height-growth curves derived from the four candidate non-linear models.

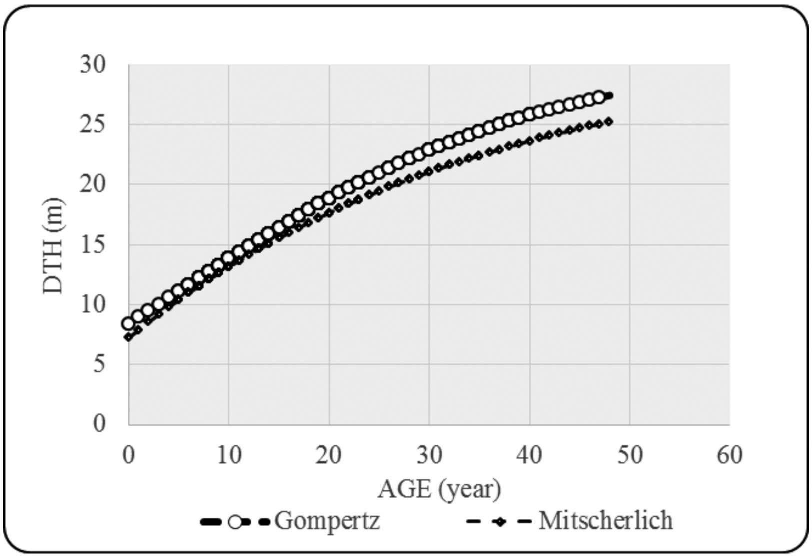

Fig. 4. SI curve (Gompertz model) constructed in this study versus the SI curve (Mitschelich model) from theprevious study

Fig. 4 shows the comparison between site index guide curves in the present study (Gompertz model) and the guide curves (Mitschelich model) used in the previous study (Ishibashi et al. 2010). The curved shapes of the two guide curves looks similar. These two guide curves showed similar prediction, and the difference was small when the stand was young. The convergence of the two guide curves clearly occurred when the stand age was approximately 15 years. The guide curve used in this study gave a larger dominant height prediction than the previous study. The site index function developed in this study was used to produce a guide curve for constructing site index curve were:

$$DTHgt = 31.4788[\exp(-1.3728(\exp(-0.047126t)))] \qquad (16)$$

Where: t = stand age (year); $DTHgt$ = dominant tree height at age t on the guide curve (m).

The site index was defined as DTH at the base age. The rotation age is often used as the base age; therefore, 30 years was adopted as the base age. Because the use of the system of equations required the estimation of DTH of each plot at the measurement time, the estimated DTH was computed using the following equation:

$$DTHt = \mathrm{SI}\,\frac{DTH\,gt}{DTHg30} \qquad (17)$$

Where: SI = site index value (m); $DTHt$ = estimated dominant tree height at age t (m); $DTHgt$ = dominant tree height at age t on guide curve (m); DTHg30 = dominant tree height at age 30 years old on the guide curve.

When $DTHgt$ and DTHg30 were substituted in Eq. 17, $DTHt$ could be estimated using Eq. 18:

$$DTHt = \mathrm{SI}\,\frac{31.4788[\exp(-1.3728\ (\exp\ (-0.047126Xt)))]}{31.4788[\exp(-1.3728\ (\exp\ (-0.047126X30)))]} \qquad (18)$$

The site index curves were then produced for an SI of 14 to 30, and the results are presented in Fig. 5. Stand growth and yield parameters (stand density, stand basal area, stem volume, and stand volume) were computed for each sample plot using SI values derived from the site index function developed in this study instead of SI values derived from the site index function used in the previous study.

Average DBH and total height estimation

The average total height of each sample plot was computed using a non-linear regression model and used the same datasets as for construction of the site index function. The relationship between total height and DTH was:

$$Hm = 0.4776\ DTH^{1.1922} \qquad (R^2 = 0.9439) \qquad (19)$$

Where: DTH = dominant tree height (m); Hm = average height (m).

The average DBH of each stand was computed using a multiple linear regression model:

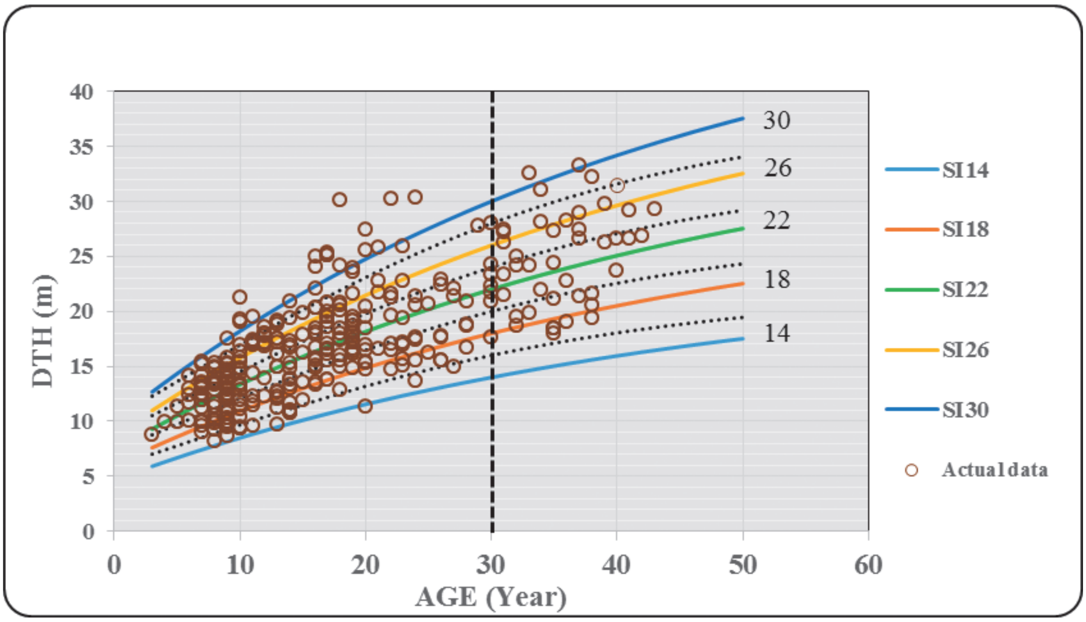

Fig. 5. Site index curve constructed in this study.

$$\text{Ln } DBH = 1.7718 - 0.2028 \text{ Ln}I - 0.0753 \text{ Ln } 1/A + 0.7879 \text{ Ln}Hm \quad (R^2 = 0.9330) \qquad (20)$$

Where: I = initial stand density (trees/ha); $1/A$ = inverse age (1/year); Hm = average height growth (m); Ln = natural logarithm

Statistical test of yield model

Using model validation data sets, the 35 independent sample units were used for computing stand density, stand basal area, stem volume (volume per tree), and stand volume. The characteristics of the 35 temporary sample plots used in the study are shown in Table 5.

These stand aggregates were computed using a system of multiple linear regression equations presented in Eq. 9–Eq. 12. The average total height and average DBH of the sample plots were independent of the system of equations. They were computed using Eq. 17 and Eq. 18. A statistical comparison of the goodness-of-fit of all sub-models was then performed. The observed values of the 35 sample plots were compared with the corresponding values predicted by the yield prediction equations. The comparisons were made with the help of paired sample t-test. These implied that the observed values of all predictions (stem volume (Vt), stand volume (V), stand basal area (Ba), and stand density (N) were not significantly different from those predicted value at 0.05 level. The results are shown in Table 6. Thus, the system of yield prediction model was judged acceptable.

Using the graphical method, the residuals of the model predictions were evaluated. The distribution of residuals in the stem volume, stand basal area, stand volume, and stand density versus the predicted values are shown in Fig. 6. There were no serious patterns in the distribution of the residuals for all stand aggregates, although some predicted values had rather larger residuals than others.

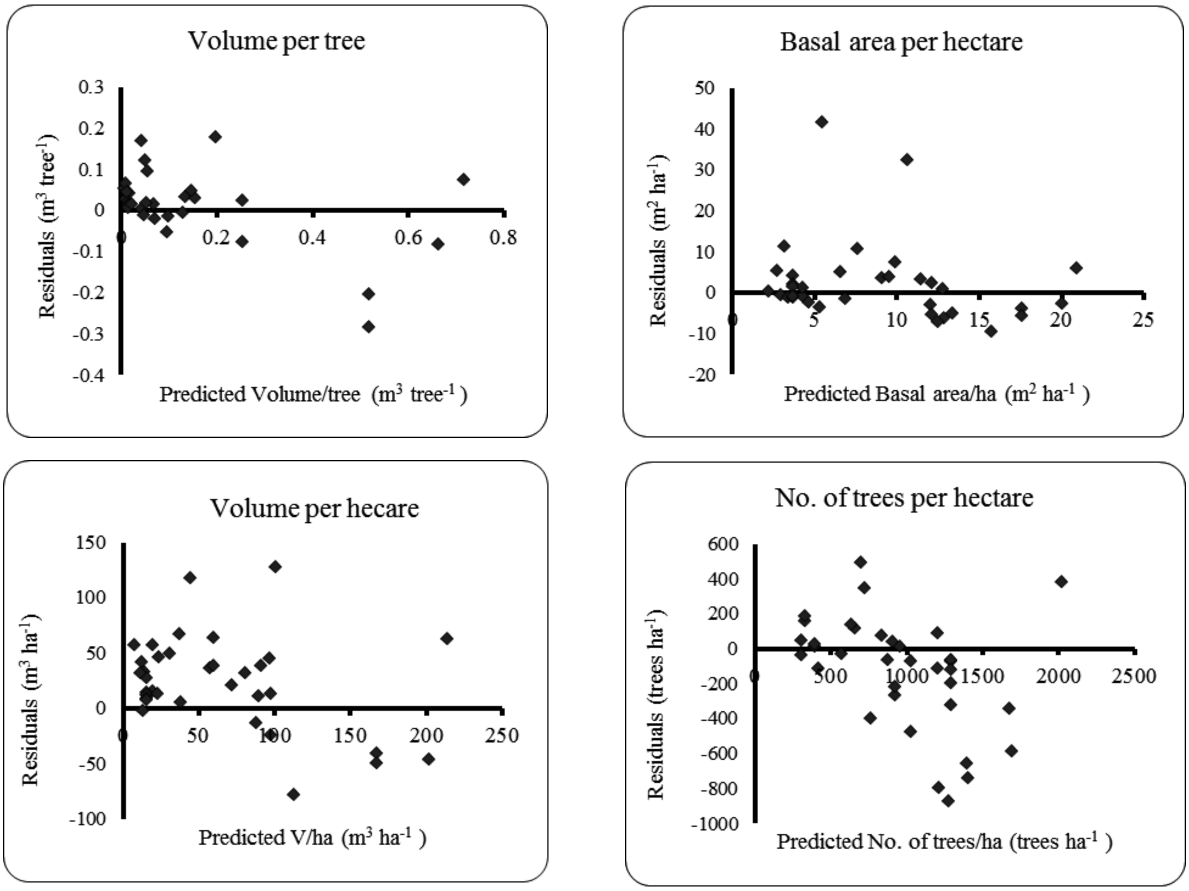

Fig. 6. Residuals versus predicted values for the sub-model of stem volume, stand volume, stand basal area and stand density.

Table 5. Summary of the characteristics of 35 temporary plots used for model validation

Variable	Average (min, max)		S.D.
Stand age (year)	15.49	(5.00, 34.00)	8.02
Stand basal area (m^2/ha)	10.32	(2.35, 26.82)	5.07
Stand density (tree/ha)	828.77	(268.75, 2404.76)	422.06
Mean diameter (DBH, cm)	13.37	(7.25, 30.39)	5.56
Mean total height (m)	11.91	(6.19, 23.85)	4.22
Dominant tree height (m)	15.01	(8.03, 26.46)	4.52
Stand volume (m^3/ha)	87.83	(10.48, 276.45)	58.10
Stand volume (m^3/tree)	0.14	(0.0202, 0.7898)	0.166

Table 6. The results of paired sample t-test of the yield predictions

	t-value	p-value
V	1.80180	0.0760 ^{ns}
Vt	0.30840	0.7588 ^{ns}
Ba	1.28080	0.2046 ^{ns}
N	-1.20451	0.2326 ^{ns}

Table 7. Summary of the indicator values used to evaluate the performance of the yield prediction models.

Stand aggregates	Model	MRES	MRES%	RMSE	RMSE%	AMRES	AMRES%	MSE
V (m^3/ha)	Previous	33.919	62.916	52.591	98.767	40.369	74.880	2731.925
	Present	24.631	38.973	48.929	87.989	38.905	61.559	2376.241
Vt (m^2/tree)	Previous	0.037	35.514	0.083	89.714	0.057	55.030	0.007
	Present	0.013	10.296	0.085	81.981	0.055	43.417	0.007
Ba (m^2/ha)	Previous	3.367	42.566	10.389	114.600	5.687	71.896	107.588
	Present	2.511	28.647	10.252	108.143	5.804	66.209	104.914
N (trees/ha)	Previous	-149.629	-15.293	363.945	60.990	257.214	26.289	131797.286
	Present	-123.885	-13.004	349.111	60.536	247.609	25.992	121426.766

Comparison of the yield models

The yield model in this study provided stand-level growth and yield predictions for teak plantations in Northeastern Thailand. The sub-models employed site index values that were computed from the new site index function developed in this study. Therefore, stem volume, stand volume, stand basal area, and stand density were fitted simultaneously using multiple linear regression, whereas the DTH of the stand was predicted independently by the new site index function. It had to be assured that the improve yield model provided more reliable predictions than the model developed in the previous study. Therefore, the bias and the precision of previous and present models were evaluated. MRES, MRES%, RMSE, and RMSE% were applied to assess the accuracy of both models whereas the AMRES, AMRES% and MSE were applied for the evaluation of precision. All indicators were computed and were used to compare the performances of the yield prediction models. The results are presented in Table 7.

Referring to this table, MRES, MRES%, RMSE, and RMSE% were applied to evaluate the accuracy or bias of the yield models. The values of MRES, MRES%, RMSE, and RMSE% of all the stand aggregates produced from the present model were smaller than those of values produced from the previous model. The decreases in MRES% values ranged from approximately 2% to 25%, whereas RMSE% decreased by approximately 0.5% to 11%. The decrease in

MRES% and RMSE% produced stand density predictions that were very small compared with the predictions of others stand aggregates. The apparent effect of these results confirmed that the present yield model clearly provided smaller bias than those of the previous model. This meant that the predictions from the present model had greater accuracy than the previous model.

AMRES, AMRES%, and MSE were indicators applied to evaluate the precision of the yield models. All of yield predictions produced smaller MSE values than the previous model, except for the prediction of stem volume (Vt). The previous model gave smaller MSE values than those of the present model, but the difference was negligible. Therefore, it could be concluded that the present model had greater precision than the previous model; however, the higher precision provided from the present model was not as clear as its accuracy.

Discussion

In this study, the guide curve method was applied to construct a site index curve using 322 observations. This method, when applied directly to all observations, will naturally give low R^2 values and high RMSE values (the mean residuals values for the model used in this study equaled 11.6 m). The reason was due to the effect of the repeat run, *i.e.* different observed values of DTH at the same age. It is impossible to attain a high value for R^2 in such cases, no matter how appropriate the model is, because any model can explain only the variations due to lack of fit and not the pure error variations resulting from repeat runs (Draper and Smith 1981). In a future study, the difference equation method, described by Draper and Smith (1981), should be applied to construct a site index function, and all observations from various sample plots could be checked for the extent of pure error and lack of fit.

The limitation of this study was the small size of the dataset used to evaluate the yield model. We had only 35 observations from 35 sample plots. If unusual evidence occurred in some sample plots the outcome predictions would be less robust. For example, when the stand volume prediction was evaluated it was found that there were two predictions that gave very higher residuals compared with the others (Fig. 6). This evidence could explain that unusual residuals that were caused by the unusually small number of trees in the sample plots at the measurement time. This may be caused by illegal cutting or cutting by the owners of private plantations for utilization or by poor plantation management. If the sample size could be increased, the outcome predictions will show better stability and greater accuracy. In this study, site index values derived from the new site index function had smaller effects on the precision of the yield predictions compared with the effect on accuracy because the system of equations used in the yield model was the same as in the previous study.

Conclusions

In this study, 322 observations collected from various teak stands in Northeastern Thailand were employed to develop a site index function. Four non-linear models, i.e. Gompertz, Hossfeld, Logistic, and Negative exponential, were selected as candidate models for constructing the site index curve. The Gompertz model was the best at predicting the dominant height growth of teak stands because this model provided greater accuracy and precision predicted values than the others. Therefore, the Gompertz model was used as a guide curve to construct the new site index curve for teak stands. The yield prediction model developed in this study applied site index values derived from the new site index function (set of multiple linear regression models) as one of the independent variables in the system of equations to predict stem volume, stand basal area, stand volume, and stand density of teak stands. The site index value, the average DBH and total height of the teak sand were independently estimated from the system of equations. The comparison between the present model and the previous model revealed that the improved yield model provided greater accuracy and precision for yield predictions than the previous model. The results of this study could be applied to generate a yield prediction table for teak plantations in Northeastern Thailand.

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