Prediction of the Early Growth of Plantation Grown *G. walla*

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Abstract

Certain tree species of Thymalaeaceae family produce highly fragrant, valuable resin called agarwood inside the stems, branches and roots due to a defence mechanism to protect internal tissue damage from invading microorganisms. *Gyrinops walla* is the only native tree species bearing the agarwood resin production ability which is growing in the low and mid elevations of wet climates of Sri Lanka. After some years of discovering the ability to produce agarwood resins in of *G. walla*, private sector investors planned to establish small and medium scale plantations using this species. However, information on *G. walla* growth rates under plantations conditions were not available, which are essential for the effective management. Therefore the present study aimed at constructing height and diameter prediction models for the early stages of *G. walla* plantations. For this purse, monthly measured height and diameter data of 40 plants of an even-aged *G. walla* plantation were used. Several non-linear and 2nd and 3rd order polynomial models were initially tested, keeping age as the single explanatory variable. Among them, the best performances were given by the 2nd order polynomial models for both height and diameter variables. Both models had R^2 over 99.0 and root mean square error and mean absolute difference less than 0.10, proving high accuracy. Fitted line plots also did not indicate deviations of the residuals. Though the models built in this study are recommended for predicting the early plantation growth of *G. walla*, future research should be conducted to validate them till the maturity of the trees.

Keywords: G. walla, polynomial regression, growth modelling, plantation, height, diameter

1. Introduction

Agarwood is a highly valuable resin in incense and perfume markets of various parts of the world (Okudera and Ito, 2009; Kakino et al., 2010; Peng et al., 2015). It is produced by certain tree members of family Thymalaeaceae as a defence mechanism to protect the internal tissue damage from external microorganisms (Rogers, 2009; Chen et al., 2011). Agarwood is mainly sold in two forms in the market as black or brown colour chips and as extracted oils from the tissues. A good quality agarwood kilo of any form is sold for about USD 30,000.00.

Gyrinops walla, the only agarwood producing tree member of Thymalaeaceae family naturally growing in Sri Lanka is commonly found in the homegardens and natural forests of the wet zone of the country (Dassanayake and Fosberg, 1981). This species does not have any timber value and its ability of producing agarwood was scientifically proven by Subasinghe et al. (2012) and Subasinghe and Hettiarachchi (2013). They also found out for the first time that agarwood of *G. walla* has similar qualities to the agarwood available in the market which are produced from the other species of the same family growing in Southeast Asian countries (Espinoza et al., 2014). Due to the high value of agarwood produced in *G. walla*, private sector investors recently tend to cultivate this species in small and medium scale. This will create opportunity to obtain a considerable foreign income due to the high

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demand for raw agarwood and related products. Information on seed germination and nursery establishment of *G. walla* have already been identified via some research (Page and Awarau, 2012) which are helpful for plantation establishment. However, no studies have yet been conducted on plantation establishment using this species and its growth rates which are essential to determine the time for inoculation and harvesting age. Therefore, the present study aimed at building mathematical models to predict the height and diameter growth of *G. walla* during the early stages of plantation establishment.

A growth model can be considered as an abstraction of reality, by which the key relationships of a selected biological mechanism are being conceptualised (Vanclay, 2017). Forest growth models therefore, provide platforms for forest managers to predict the growth, even without years of experience (Vanclay, 1994, Chaudhuri et al., 1995). Thereby, growth models become powerful tools in quantification of tree variables which are helpful for the forest managers take effective decisions on their forests. However, model construction is a long term exercise because of the need of data measured at regular intervals to make proper forecasts of the tree growth via easily measureable variables.

The idea of tree growth modelling is to provide a simple platform for the users for forecasting required variables without much efforts (Adame et al., 2008). Linear models are useful in this aspect though they may not be accurate with long-term prediction of biological variables, especially against time. While non-linear regression allows greater flexibility in formulating models to ensure sensible extrapolation, it does have some limitations. One problem is that, unlike linear regression, non-linear regression does not necessarily provide a unique best unbiased solution for a given set of variables (Vanclay, 1994).

2. Methodology

2.1 Measurements

A 2 ha *Gyrinops walla* plantation established in 2017 in Kalutara district of the wet zone of Sri Lanka was selected for taking necessary measurements. The distance between plants was 3m×3m comprising 1,111 plants per ha. Height from the ground to the topmost growing position of the main stem and the diameter at 30 cm above the ground were measured using a calibrated pole and a calliper respectively at monthly intervals for four years. Randomly selected 40 plants were used for taking both measurements.

2.2 Building relationships

The intention of the present study was to develop simple, but robust models for redacting height and diameter growth of *G. walla* at the early years of plantation establishment. Therefore the model building was conducted using the general form given in equation 1. Selection of the suitable candidate models were done based on the scatter distribution of height and diameter values with the age. Then, logistic, Michaelis-Menten and second and third order polynomial models were fitted to the collected data to find the best fit.

$$height\ and\ diameter\ growth = f(Age) \tag{1}$$

2.3 Determination of the quality of the models

The quality of the models were determined quantitatively by coefficient of determination (R^2), root mean square error (RMSE), and mean absolute difference (MAD) and qualitatively by the distribution of the fitted lines on raw data.

$$RMSE = \sqrt{\frac{(\hat{y}_i - y_i)^2}{n}} \tag{2}$$

$$MAD=\frac{\Sigma|\hat{y_i}-y_i|}{n} \quad (3)$$

where:
n=Number of data
y_i=Observed variable
$\hat{y}_i$=Predicted variable

3. Results

Out of the tested models 2nd order polynomial equations produced the best results as shown in Table 1. Therefore those models were selected for further testing with fitted line plots (Figure 1-2).

Table 1: Description of the resultant second order polynomial models.

Model	**R^2**	**RMSE**	**MAD**
height=0.9457+0.0050×age+0.0009×age^2	99.76%	0.032	0.024
diameter=0.4112+0.0292×age+0.0023×age^2	99.82%	0.084	0.071

The R^2 values of both height and diameter models were above 99% and root mean square error and mean absolute difference values were lower than 0.1 proving high accuracy and low bias of the selected models (Table 1). Fitted lines and measured data were also closely arranged indicating a very low deviations of the residuals.

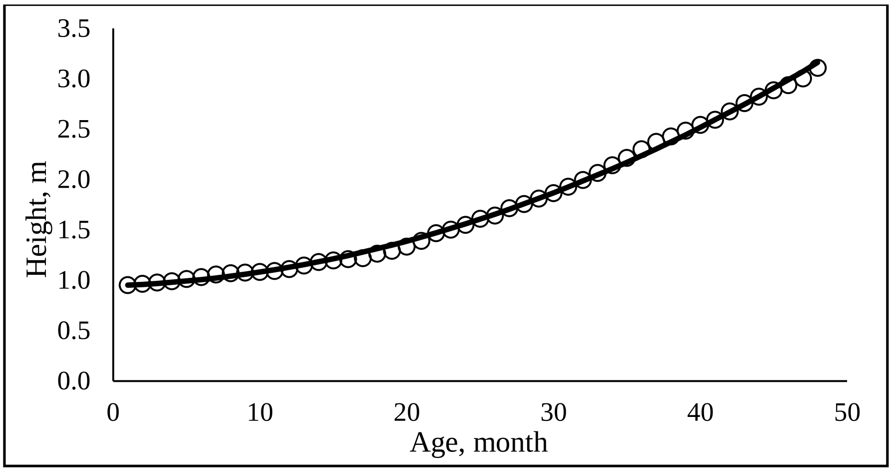

Figure 1. Averaged measured height values and the fitted line.

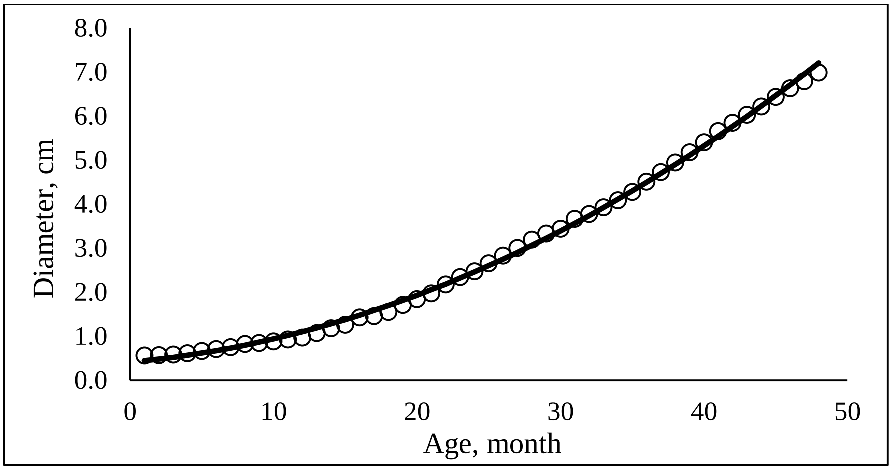

Figure 2. Averaged measured diameter values and the fitted line.

4. Discussion

Though Aquilaria plantations were established in Southeast Asian region, modelling the growth of those species was even not frequently studied in the past. In 1996, Hai and Yahya developed a linear equation to predict height of *A. malaccensis* from diameter. However, some researchers attempted to model the quality of agarwood oil against different extraction methods, e.g. Pornpunyapat et al., (2011).

The main requirement of a successful model is its ability of maintaining a high accuracy in predicting the response variable. Therefore, in modelling, it is a common practice to transform data into biologically accepted forms to minimise the prediction error (Subasinghe and Munasinghe, 2011, Vanclay, 1994). However, it was not necessary for the present study because the modelling error of the constructed 2^{nd} order polynomial models was negligible.

Though different non-linear modes were tested in this study, the best fit was obtained by second order polynomial equations. The main intention of model building for describing biological relationships is to establish simple, but robust relationships which is easy and accurate for the user (Vanclay, 1994). Some believe that, the behaviour of polynomial equations cannot be biologically explained because the same explanatory variable is entered into the equation with changing power value. However, many researchers, e.g. (Brown, 1997) successfully used polynomial equations for tree growth prediction. Therefore it is recommended to use the models developed in this study for the young stage of *G. walla* plantations to predict the height and diameter values against age. However, due to lack of data, the variation of the growth till the maturity of *G. walla* plantations were not available for this study. Further, the use of the models built in this study cannot be recommended for extrapolating the growth till the maturity due to the differences of the biological growth of the trees with the age. Therefore, it is recommended to continue similar research by collecting data till the maturity of *G. walla* trees so that the models built in this study can be further validated.

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