LOCAL GROWTH MODEL IN MODELLING THE CROWN DIAMETER OF PLANTATION-GROWN *DRYOBALANOPS AROMATICA*

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AHMAD ZUHAIDI Y. 2009. Local growth model in modelling the crown diameter of plantation-grown *Dryobalanops aromatica*. The importance of crown data in improving the construction of growth models for stand management has long been established for many temperate and a few tropical species. Growth models will assist in determining the allometric relationship between crown and tree diameter, optimum planting distance and expected final crop tree density. This study examined the allometric relationship of plantation-grown *Dryobalanops aromatica* by regression of curvilinear models between projected crown and measured tree diameter at breast height (dbh). The study was carried out in 2005 at Bukit Lagong Forest Reserve, Selangor, Peninsular Malaysia. Results indicate that model as a function of dbh and dbh^2 explained a significant proportion of the variation in the crown diameter at 62.9%. The model possessed a standard error of estimate at 1.197. Overall results of the modelling were negatively biased and underestimated (0.266 m) the predicted crown diameter of the species. The information provided by this study could serve as a guide in formulating a standard growth model, realistic production targets, planting density and limiting stocking in future plantations of the species.

Keywords: Tree diameter, crown area, stand density, tropical species

AHMAD ZUHAIDI Y. 2009. Model pertumbuhan tempatan bagi pembinaan model diameter silara *Dryobalanops aromatica* yang ditanam di ladang. Kepentingan data silara untuk tujuan menambah baik pembuatan model pertumbuhan untuk pengurusan dirian ladang telah lama digunakan bagi kebanyakan spesies iklim sederhana dan beberapa spesies tropika. Pembinaan model pertumbuhan boleh membantu dalam menentukan hubung kait alometri antara silara dengan diameter pokok, jarak tanaman yang optimum dan jangkaan ketumpatan dirian akhir. Manuskrip ini meneliti hubung kait alometri spesies kapur (*Dryobalanops aromatica*) yang ditanam secara perladangan menggunakan regresi model melengkung antara anggaran silara dan diameter pokok yang diukur pada aras 1.3 m. Kajian ini dijalankan pada tahun 2005 di Hutan Simpan Bukit Lagong, Selangor, Semenanjung Malaysia. Keputusan kajian menunjukkan model yang berfungsikan diameter dan diameter kuasa dua berjaya menerangkan dengan signifikan variasi diameter silara pada kadar 62.9%. Model ini mempunyai ralat piawai pada kadar 1.197. Keputusan keseluruhan kajian unjuran adalah bias negatif dan kurang anggaran (0.266 m) ramalan diameter silara spesies. Maklumat yang didapati daripada kajian ini dapat digunakan sebagai garis panduan dalam mereka bentuk model pertumbuhan yang standard, sasaran pengeluaran yang realistik, ketumpatan dirian dan populasi ladang pada masa hadapan.

INTRODUCTION

The space for crown diameter is defined in terms of horizontal distance above ground surface area or crown projection area. Each individual tree in a stand requires a definite area of crown space, which to an extent is limited by the ground surface available and the direct neighbours of the tree that restrict lateral growth. The crown space concepts have been employed in growth modelling studies based not only on its measure as the ground area or resources available to the individual tree but also as an index of competition. Measurements on open-grown trees have been widely used to predict potential increments in stem diameter.

The use of tree crown size as a variable in growth models has long been established for many temperate (Krajicek *et al.* 1961, Francis 1966, Ayhan 1973) and a few tropical species (Dawkins 1963, Suri 1975). These studies confirmed the importance of crown size and its potential in improving the degree of accuracy and reliability of growth predictions. However, long-term studies of crown dynamics are lacking and data from which crown development models can be constructed are scarce. This general lack of information on tree crowns and their application in tree growth modelling is even more pronounced for tropical forests species. It is important, therefore, to be able to establish an allometric relationship between crown and tree diameter as this can provide a guide to optimum planting distance and possible crop density. This study was carried out to provide baseline information to facilitate the development of growth models and enhance management of indigenous species plantations in the future.

MATERIALS AND METHODS

Dryobalanops aromatica (Dipterocarpaceae), locally known as kapur, is an emergent canopy tree naturally distributed in Sumatra, Riau Archipelago, Borneo and Peninsular Malaysia (Symington 2004). In Peninsular Malaysia it occurs abundantly in lowlands but not in the hills > 365 m altitude. Here, the forests are confined to two large areas in the east coast as long belts just inside the beach area from Baloh Forest Reserve, Pahang northwards as far as Sungai Marang in Terengganu and the other area from just north of Sungai Rompin in south Pahang to Panti Forest Reserve in south central Johore. Further small pockets occur in the west coast, namely, in Bukit Lagong and Kanching Forest Reserves, Selangor. In gregarious stands, *D. aromatica* may make up to 90% of the total volume of timber (Foxworthy 1927).

Study area

The study was conducted in the Bukit Lagong Forest Reserve (3^o 14' N, 101^o 38' E). The area has a humid climate with average daily temperature ranging from 27 to 32 ^oC. The annual rainfall is between 2000 and 2900 mm. Study sites are located at an elevation of 90 to 130 m above sea level on the lower slopes of the Lagong range. Records of the stand, source and plot establishment are described in Ahmad Zuhaidi *et al.* (2003) and Ahmad Zuhaidi (2004, 2006).

The main component of the data used in this study comprised diameter at breast height (dbh) measured for trees $\geq$ 30 cm and their crown diameter. In 2005, 200 trees with dbh from 30 to 82 cm were measured.

Crown diameter

The tree crown diameter measurements were based on the assumption that the vertical projection of a tree crown is circular (Krajicek *et al.* 1961). Four radii were measured as in Ayhan (1973) and Ahmad Zuhaidi and Mohd Noor (1995) and in the direction forming equal angles. Three persons were required to measure the crown diameter following the method described by Alder and Synnott (1992) for closed-plantation forests. The average crown diameter (Cd) was then calculated as such:

$$Cd = \sum r_i/2 \quad (1)$$

where
Cd = average crown diameter
r_i = projected crown radii measured on four axes.

Tree diameter

Dbh was measured for all tree individuals > 30 cm. The point of the measurement was recorded from the uphill sides of the trees and on the inside of the lean for leaning trees. For trees with deformations at 1.3 m, the measurement was made at the sound point on the stem above the abnormality. For buttressed trees, a point of measurement was selected approximately 0.5 m above the convergence of the buttress (Husch *et al.* 1982). The point of measurement was permanently marked on the tree with a painted red band. The measurement was made exactly along the top line of the painted band. Diameter measurements of trees were recorded using a metal metric diameter tape graduated in centimeters. During the measurement, loose bark, climbers and epiphytes were lifted above the measuring tape.

Crown area

Based on the calculated Cd, the crown area (A) can be calculated and expressed in ha (Krajicek *et al.* 1961):

$$A = \{\pi \times Cd^2/10\,000\}/4 \quad (2)$$

Analyses of data

Equations were developed for the determination of crown area and limiting stocking of the species from the model. Statistical analyses to determine the relationship between the response (crown diameter) and the independent variables (dbh) were analysed using SAS/STAT 1989 PROC REG Procedure. The mean and standard error of the response variable was calculated using SAS/STAT 1989 PROC Summary. Several curvilinear models were tested for best fit and magnitude of error associated with the regression. The models were

$$Cd = \alpha_0 + \alpha_1 dbh + \varepsilon \quad (3)$$

$$Cd = \alpha_0 + \alpha_1 dbh^2 + \varepsilon \quad (4)$$

$$Cd = \alpha_0 + \alpha_1 \ln dbh + \varepsilon \quad (5)$$

$$Cd = \alpha_0 + \alpha_1 dbh + \alpha_2 dbh^2 + \varepsilon \quad (6)$$

$$\ln Cd = \ln\alpha_0 + \alpha_1 \ln dbh + \varepsilon \quad (7)$$

where
α_1 and α_2 = regression coefficients
ε = errors associated with regressions.

Model comparison

The best model was selected based on the goodness of fit as indicated by R^2, mean of the residuals (the magnitude of the errors associated with regressions) and root mean square error or standard error of fitted regression. Residual analyses were used to determine the lack of fit and bias (West 1980, Wan Razali 1988). This method of selection is acceptable for simple models involving one or two functions (Alder 1995) and having the same response or dependent variable but it is not suitable when they differ. The index of fit of untransformed function is the standard error of the regression. However, transformed model will be analysed based on the value of the Furnival index (Furnival 1961) as it has different and transformed response variable (Vanclay 1994, Phillip 1994). The index adjusts the standard error of the regression in order to facilitate the comparison. The index is calculated by multiplying the standard error of the fitted regression (root mean square error) by the geometric mean and reciprocal of the derivative of the transformed variable and weighted with respect to the untransformed variable.

RESULTS AND DISCUSSION

Measurements for the 200 individual crown and tree diameter are summarized as in Table 1. The graphical relation of both parameters is as shown in Figure 1 while the summary of the regression analyses from the models are as in Table 2. The results of the analyses showed that the models significantly explained the variation in crown diameter and correlated well with tree diameter. The data behaved accordingly with increasing crown diameter and tree diameter size.

Model 3 has the lowest residual with an ideal prediction of unbiased or zero residual. However, the coefficient of the intercept was not significant. Models 4, 5 and 7 were slightly better than 6 but for simple quadratic model with dbh as explanatory variables, the positive coefficient of dbh^2 and negative coefficient of dbh, the model predicts ever-increasing and unrealistic crown diameter for large and larger trees, which is biologically untenable. These models may provide reliable prediction of periodic crown diameter growth over a limited range of diameter but it is clearly unsuitable for trees with large diameters and, thus, not useful for long-term extrapolation.

In model 7, the calculated index of Furnival was 1.1066 lower than standard errors of models

Table 1 Summary of dbh and crown diameter

Parameter	Values
Diameter (cm)	
Mean	47.3 ± 0.8
Max	82.0
Min	30.0
Crown diameter (m)	
Mean	7.60 ± 0.17
Max	14.25
Min	0.55

Means are reported ± 1 standard error

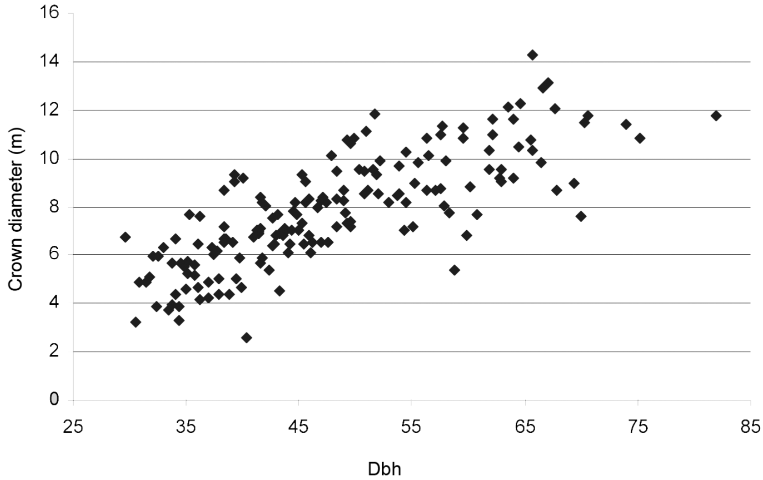

Figure 1 Scatter relationship between raw data of crown diameter and dbh

Table 2 Parameter estimates and coefficients for regression of crown diameter on tree dbh

	Models				
	3 $Cd = \alpha_0 + \alpha_1 dbh$	4 $Cd = \alpha_0 + \alpha_1 dbh^2$	5 $Cd = \alpha_0 + \alpha_1 lndbh$	6 $Cd = \alpha_0 + \alpha_1 dbh + \alpha_2 dbh^2$	7 $lnCd = ln\alpha_0 + \alpha_1 lndbh$
R^2	0.615	0.582	0.628	0.629	0.524
α_0	-0.058ns	3.908***	-22.199***	-4.528*	-2.292***
α_1	0.162***	0.002***	7.787***	0.351***	1.115***
α_2	-	-	-	-0.002	-
σ(Cd)	1.208	1.283	1.197	1.197	0.251
E	0.005648	-1.02697	-0.34896	0.26663	0.15482
FI	-	-	-	-	1.1066

*** = significant at $p \leq 0.001$; * = significant at $p \leq 0.05$; ns = not significant; R^2 = coefficient of determination; E = average residual (observed – predicted); σ(Cd) = standard error of estimate; FI = index of Furnival

3, 4, 5 and 6. As the model is selected by comparing the goodness of fit as measured by R^2, the lowest standard error of estimate of the fitted regression (Krajicek *et al.* 1961, Dawkin 1963) and index of Furnival, model 6 was therefore the preferred model. The preferred model should have the lowest standard error or Furnival index. The model explained the variation in crown diameter adequately with coefficient of determination (R^2) at 62.9%. The preferred model is shown as in Equation 8.

$$Cd = -4.528 + 0.351 \times dbh - 0.002 \times dbh^2 \quad (8)$$

Results were negatively biased as indicated by the positive mean residual in model 6 (the difference between observed and predicted) of 0.266, which is a clear indication of underestimation by the models. For growth modelling studies, ideal results should be unbiased or have zero mean residuals with no consistent trends left unexplained for dependent variables in the model (West 1980, Alder 1995).

Crown diameter and diameter relationship should conform to Dawkin's type 2 graph behaviour, i.e. positive intercept with crown diameter–tree diameter ratio decreasing with tree size, implying that stand basal area increases towards maturity (Dawkin 1963). As indicated from the graph (Figure 2), model 6 behaves accordingly with decreasing ratio and tree diameter size. Models 4 and 7, as explained earlier, predicts ever-increasing and unrealistic crown diameter for large and larger trees.

The results also provide a means of computing the crown area (A) of each tree expressed as a function of crown diameter, thus,

$$A = \{\pi\, Cd^2/10\,000\}/4 \qquad (9)$$

$$A = \pi(-4.528 + 0.351 \times dbh - 0.002 \times dbh^2)^2/40\,000$$

where
A = crown area required by the tree
40 000 = the conversion of crown diameter in m to area in ha.

Based on Equation 9, a tree having a dbh of 50 cm would require a projected crown area of 0.0051 ha for even-aged *D. aromatica* stands (Table 3).

Subsequently, the limiting stocking ha^{-1} required for producing a complete canopy can be expressed as the inverse of crown area. From Equation 9, the limiting stocking of the stand in terms of total occupancy by tree crowns can be determined. A stocking of 196 dominant trees with dbh 50 cm will fully occupy an area of 1 ha. The estimated crown diameter, crown area and stocking per hectare of the species are summarized in Table 3. The results from the modelling showed that the model was more elastic between 30 and 50 cm, and gradually decreased as the diameter size increased.

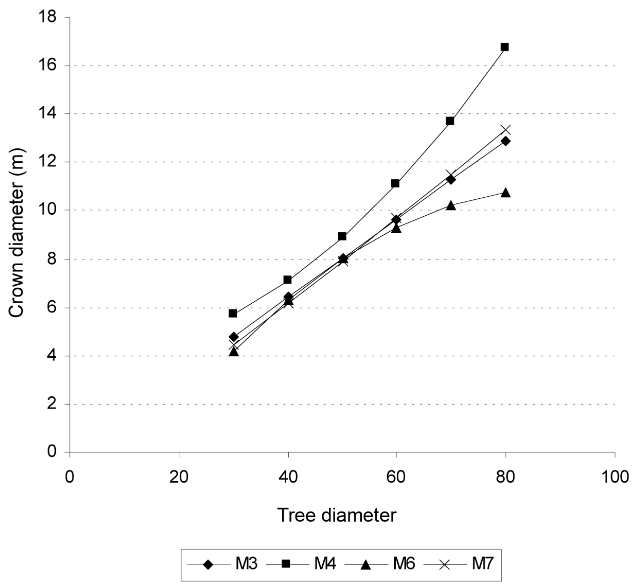

Figure 2 Relationship between crown diameter and tree diameter; M3, M4, M6, M7 = Models 3, 4, 6 and 7 respectively

Table 3 The estimated crown diameter (Cd), crown area (A) and stocking (N ha^{-1}) from the modelling (model 6) of crown data of *Dryobalanops aromatica*

Dbh (cm)	Cd (m)	Cd/dbh	A (ha)	N ha^{-1} (= 1/A)
30	4.202	0.1401	0.0014	714
40	6.312	0.1578	0.0031	323
47.3	7.599	0.1607	0.0045	222
50	8.022	0.1604	0.0051	196
60	9.332	0.1555	0.0068	147
70	10.242	0.1463	0.0082	122
80	10.752	0.1344	0.0091	110

Model Cd = $-4.528 + 0.351 \times dbh - 0.002 \times dbh^2$

CONCLUSIONS

The crown diameter and tree diameter regressions in Bukit Lagong Forest Reserve were highly significant and showed a high linear relationship between response and independent variables. Modelling by crown diameter helps in the determination of an appropriate management regime for the species. Overall results of the modelling were negatively biased and underestimated the crown diameter of the species. In interpreting the results, it must be pointed out that the model may not be suitable for extrapolation to extreme values, i.e. values which are lower or higher relative to the extent of the original data. The importance of the relationship has been examined since the crown diameter can be predicted from the measurement of tree diameter. This is further illustrated by the possibility of estimating crown area and stand density of the species for plantation work.

It must be emphasized that this assumption holds only for the experimental plots from where the data were collected, and the essence of this study was to provide a guide for crown size and related stand density in plantations of the species. More data will be collected for the whole of Peninsular Malaysia to cover all stands of *D. aromatica* for the possibility of developing a standard growth model for the species.

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