SOME MODELS FOR ESTIMATING RATTAN GROWTH AND YIELD

Y.F. Lee

Forest Research Centre, Forestry Department, P.O. Box 1407, 90008 Sandakan, Sabah, Malaysia

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LEE, Y.F. 1994. Some models for estimating rattan growth and yield. The following models for estimating growth and yield of rattan canes by counting the internodes are derived: two models in terms of cane length, each of which is based on the assumption of constant and variable internode length respectively; four models in terms of cane volume, each of which is based on the assumption of a different combination of constant and variable internode length and diameter; and four models in terms of cane weight with the same assumptions as those for models in terms of cane volume. The models were tested with data from a *Calamus caesius* plot. Some hints on the use of these models are given.

Key words: Palmae - rattan - model - growth - yield - internode - *Calamus caesius*

LEE, Y.F. 1994. Beberapa model untuk menganggar pertumbuhan dan hasil rotan. Beberapa model untuk menganggar pertumbuhan dan hasil rotan dengan mengira ruasnya telah diperolehi: dua model dari segi panjang rotan, masing-masing berdasarkan andaian kepanjangan ruas sama ada yang malar atau yang berubah; empat model dari segi isipadu rotan, di mana setiap satu berdasarkan andaian kombinasi berlainan, kepanjangan dan garispusat ruas yang malar atau yang berubah dan empat model dari segi berat rotan yang menggunakan andaian yang sama dari segi isipadu rotan. Model-model ini diuji dengan data dari satu plot *Calamus caesius.* Beberapa kegunaan untuk model ini diberi.

Introduction

Although rattan is an important forest product and several species have been planted on a large scale in many parts of Southeast Asia, mensurational research on these species is still at its infancy. The length and weight of harvested canes have been accurately measured, but hitherto the growth and yield of rattan stands have only been determined by measuring the length and diameter of the stems (*e.g.*, Manokaran 1977, Manokaran 1981, Manokaran 1982, Aminuddin 1985, Nur Supardi & Wan Razali 1989, Rahim & Phillipps 1989). (Note: in this paper, the term "rattan stand" is defined as a population of wild or cultivated rattan). As far as the author is aware, the reported trial plots were relatively young, or the species (*Calamus manan*) is large-diameter and single-stemmed. Under these circumstances, accurate measurement of the length with a tape or a pole is still feasible. In the older plots of multi-stemmed species, it is doubtful if these and other instruments can be used to measure the length accurately; this problem is compounded by the fact that trigonometrical formulae as used for measuring tree height cannot be applied to the twining stems. Accurate measurement is still hardly possible even if labourious climbing methods are used.

Rattans are conventionally sold either by weight of the canes of different grades for the small-diameter species (*e.g.*, *Calamus caesius* and *C. trachycoleus*) or by length of different diameter classes and grades for the large-diameter ones (*e.g.*, *C. subinermis* and *C. manan*). The potential grade of the rattan stand, which is a function of a multitude of factors such as the node size, and defects caused by pin-hole borers, and careless harvesting and inappropriate seasoning techniques, cannot be determined until some trial harvesting has been carried out, and is not dealt with in this paper. The models derived below for estimating rattan length, volume and weight of individual stems and rattan stands by counting the inter-nodes are proposed for use by rattan researchers and growers alike.

Derivation of models for rattan length, volume and weight in terms of number of internodes

Case 1

Cane diameter and internode length are constant

Nur Supardi and Wan Razali's work (1989) indicates more or less constant diameter in *C. manan*, and Shim's study (1989) shows that the internode length is rather constant for some canes of *C. trachycoleus.*

Thus, assuming that the internode length (I) is constant, the length (L) of the cane from internode at position m to that at n

$$L = I\Big[X\Big]_{m-1}^{n}$$ where X is the internode position from base

or $$L = I(n - m + 1)$$ .... Equation 1

Assuming further that the diameter (D) is constant and the cane is a cylinder; and that the weight (W) of the cane is a linear function of its volume (V), *i.e.*, W = kV, where k is a constant,

$$V = (\pi/4)D^2 I\Big[X\Big]_{m-1}^{n}$$

or $$V = (\pi/4)D^2 I(n-m+1)$$ .... Equation 2

and $$W = k(\pi/4)D^2 I(n-m+1)$$ .... Equation 3

Case 2

Either or both of internode length and diameter are variable

Assuming that the relationships of the internode length (I) and diameter (D) with the internode position (X) conform to the following asymptotic equations, as are indicated in some of the canes studied by Shim (1989) and Nur Supardi and Wan Razali (1989):

$$I = a - b/X \quad \text{................} \quad \text{Equation (i)*}$$

$$D = c - d/X \quad \text{................} \quad \text{Equation (ii)*}$$

where a, b, c and d are constants.

*Note: It is conceivable that other asymptotic equations can equally or even better describe the relationships among the variables I, D and X (*e.g.*, the exponential functions described in Hunt [1982]); but for simplicity and in the absence of adequate data for curve fitting, equations (i) and (ii) are chosen in this paper.

The length (L) of the cane from internode at position m to that at n

$$L = \sum_{m-1}^{n} I$$

$$\text{or } L = \int_{m-1}^{n} (a - b/X)\, dX$$

$$= \Big[aX - \log_e X \Big]_{m-1}^{n}$$

$$\text{or } L = a(n - m+1) + \log_e \left[\frac{m-1}{n} \right] \quad \text{............} \quad \text{Equation 4}$$

If we consider the internode to be a cylinder, the volume of the internode (v)

$$v = \pi\, (D/2)^2 I$$

The volume (V) of cane from internode at position m to that at n

$$V = \sum_{m-1}^{n} v$$

$$\text{or } V = \frac{\pi}{4}\int_{m-1}^{n} D^2 I \, dX \qquad \text{................} \qquad \text{Equation (iii)}$$

Substituting equations (i) and (ii) in equation (iii), and after simplification,

$$V = \frac{\pi}{4}\int_{m-1}^{n}\left[ac^2 - \frac{2acd + bc^2}{X} + \frac{ad^2 + 2bcd}{X^2} - \frac{bd^2}{X^3}\right] dX$$

$$= \frac{\pi}{4}\left[ac^2X - (2acd + bc^2)\log_e X - \frac{ad^2 + 2bcd}{X} + \frac{bd^2}{2X^2}\right]_{m-1}^{n}$$

$$\text{or } V = \frac{\pi}{4}\left[ac^2(n-m+1) + (2\,acd + bc^2)\log_e\left[\frac{m-1}{n}\right] - \frac{ad^2 + 2bcd}{n} + \frac{ad^2+2bcd}{m-1} + \frac{bd^2}{2n^2} - \frac{bd^2}{2(m-1)^2}\right] \qquad \text{................} \qquad \text{Equation 5}$$

$$\text{and } W = \frac{\pi k}{4}\left[ac^2(n-m+1) + (2acd + bc^2)\log_e\left[\frac{m-1}{n}\right] - \frac{ad^2 + 2bcd}{n} + \frac{ad^2+2bcd}{m-1} + \frac{bd^2}{2n^2} - \frac{bd^2}{2(m-1)^2}\right] \qquad \text{................} \qquad \text{Equation 6}$$

Supposing I is constant, as is indicated in 3 of the 7 canes studied by Shim (1989), but with D variable as expressed in equation (ii), derivation of V in the same manner gives

$$V = \frac{\pi}{4} I \left[c^2(n-m+1) - 2cd\log_e\left[\frac{m-1}{n}\right] - \frac{d^2}{n} + \frac{d^2}{m-1}\right] \qquad \text{.........} \qquad \text{Equation 7}$$

$$\text{and } W = \frac{\pi k}{4} I \left[c^2(n-m+1) - 2cd\log_e\left[\frac{m-1}{n}\right] - \frac{d^2}{n} + \frac{d^2}{m-1}\right] \qquad \text{.........} \qquad \text{Equation 8}$$

The volume and weight for a constant diameter and a variable internode length can be derived from equation 4 and are given below:

$$V = \frac{\pi D^2}{4}\left[a(n-m+1) - \log_e\left(\frac{m-1}{n}\right)\right] \quad \text{.......... Equation 9}$$

$$W = \frac{\pi D^2 k}{4}\left[a(n-m+1) - \log_e\left(\frac{m-1}{n}\right)\right] \quad \text{.......... Equation 10}$$

Determination of regression and other coefficients in equations

If equations 1-3 are adopted, the average internode length (I) and the diameter (D) can be estimated by measuring a sample of internodes with a ruler and vernier calliper respectively. Sampling can either be done destructively or otherwise, but for the latter, the method of measurement has to be modified. Exposed internodes or those which are covered by decaying leaf sheaths can be measured in the same manner after cleaning them. The length of internodes covered by intact leaf sheaths can be determined indirectly by measuring the distance between adjacent knees (swellings on the leaf sheaths at the base of the petioles) which are present in most of the commercially important species (*e.g.*, *C. manan* and *C. caesius*). Their diameter can be measured after carefully removing the several layers of leaf sheaths, but this may retard the future growth of the stem. Before deciding whether destructive or non-destructive sampling methods should be used, and whether or not to remove the intact leaf sheaths to measure the diameter of the covered internodes, one has to consider the following factors: convenience, accuracy and the significance of the adverse effects on future growth.

If other equations are used, a number of stems (the number depends on the variability of the internodes of the canes and accuracy needed) should be sampled from the rattan stand. The diameter at the middle and the length of each internode are measured to determine the coefficients a-d by regression. It is necessary to note that as all models (equations 4-10) derived from equations (i) and (ii) contain the term $\log_e[(m-1)/n]$, and some of them have the $1/(m-1)$ term, in order to circumvent the problem of having to deal with ∞ in the estimation of L, V and W, internode number 1 must be excluded in the regression. This is shown in the example given below. Exclusion of this internode is also expedient because it is usually short and swollen, and is normally not harvested.

The value of k can be determined by weighing a few samples of seasoned canes and measuring their volumes by the water displacement method.

Application of the models

The choice of the model depends on the accuracy required and the effort one is prepared to put. Yield tables prepared with the most accurate models, equations 5 and 6, whose goodness of fit may be compared with the other models with the root mean square residual, are the most difficult to construct. Although equations 1- 3 are simplistic, they have the advantage that the coefficients I, D and k can be determined quickly. Equation 1 is particularly useful for rattan too long to measure with a tape or pole, because the first 5 *m* or so of the stem, for which internode length and diameter may be variable (Nur Supardi & Wan Razali 1989, Shim 1989; also the example below), can be measured quite accurately with these instruments; the length of the remaining part of the stem can be estimated by counting the number of internodes or/and leaves and measuring a number of internodes for estimating the mean and confidence interval of the internode length and stem length with the equation. The proportion of canes in the different diameter classes of the harvestable stems can be estimated by examining their distribution in the sample.

It should be pointed out that one may choose to apply different models for different parts of the stem: *e.g.*, the models derived from the asymptotic equations (i) and (ii) for the basal portion, and the linear equations (1 to 3) for the remaining portion. To demonstrate how this is done, and to show the application of the ten models derived above, data on the internode length and diameter of a random sample of five canes from a research plot of *C. caesius* in the Kabili-Sepilok Forest Reserve in Sabah (Figures 1 and 2) were used to estimate the yield in the plot as follows.

```
LENGTH  -
        -   *2
        -   **
      50+   354    *2       *
        -   2222    *22 **  2333**
        -   423*  2* *32223532  223332433 *              * *
        -   32*5 25633253334 366753*465655232*22   423*3766      *     *
        -  ** * 45445*4579627336546+87643*354342569236855553522333323332*
      25+  5  2222***5432 34242  *3    244354333*3*24 *3  *762* 233*
        -  * * * 23   *           2       25222  2 *2  **   ***233* *
        - *4  *  3            *           * * 2*****  *      **2*
        -  3   25*   *                   *  2*2**2  23       2**
        - 3*  *22  2 *                   2   5222  **          *    *
       0+ *     2   3                          2             **
          +---------+---------+---------+---------+---------+---------+----NO.

          0         30        60        90        120       150       180
```

Figure 1. Scatterplot of internode length (*cm*) versus position of five stems in a *C. caesius* research plot in Kabili-Sepilok Forest Reserve

(* = one point, 1 to 9 respectively shows number of points, + = more than 9 points)

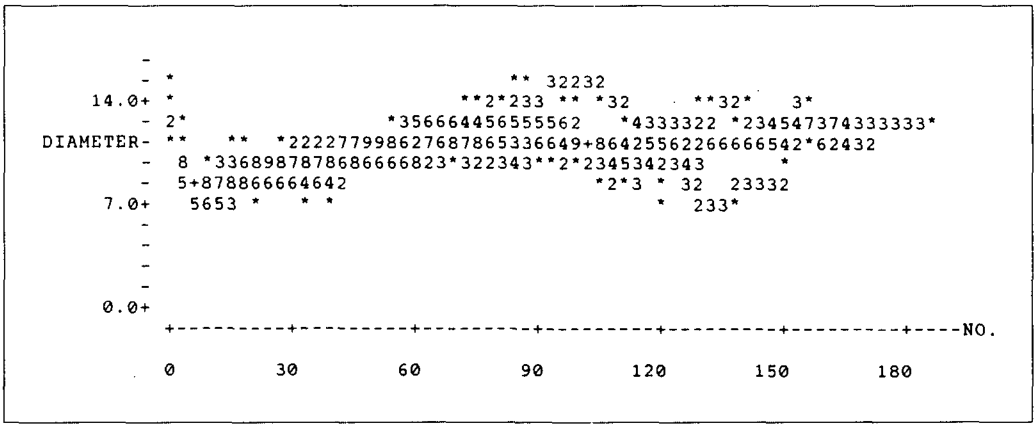

Figure 2. Scatterplot of internode diameter (*mm*) versus position of five stems in a *C. caesius* research plot in Kabili-Sepilok Forest Reserve

(* = one point, 1 to 9 respectively shows number of points, + = more than 9 points)

For internodes 2-10,

$$I = 0.562 - \frac{0.969}{X} , r^2 = 0.63$$

$$D = 0.00689 - \frac{0.00744}{X} , r^2 = 0.63$$

where I and D are internode length (*m*) and diameter (*m*) respectively, and X is the internode position from base.

Mean internode length (I) = 0.35 *m*
Mean internode diameter (D) = 0.0085 *m*

From the 11th internode onwards,

Mean internode length (I) = 0.288 *m*, std. err. = 0.003 *m*
Mean internode diameter (D) = 0.0109 *m*, std. err. = 0.00006 *m*

Air-dry density of *C. caesius* cane as determined by the water displacement method = 600 $kg\ m^{-3}$

In the research plot with 150 stems suitable for harvesting and with an estimated total of 17,000 internodes, there are 1,350 internodes whose position from the base is from 2 to 10, and 15,500 from position 11 onwards. By substituting the values given above into equations 1-10, the total length, volume and weight of the harvestable canes in the plot were calculated and are shown in Table 1.

Table 1. Estimates of cane length, volume and weight in a *C. caesius* research plot in Kabili-Sepilok Forest Reserve

Estimate	Internodes 2-10 (for 150 stems)	Internode 11 to tip (for 15 500 internodes)	Model Used
(i)		L = 4464 *m*	Equation 1
(ii)		V = 0.417 m^3	Equation 2
(iii)		W = 250 *kg*	Equation 3
(iv)	L = 413 *m*		Equation 4
(v)	V = 0.021 m^3		Equation 5
(vi)	W = 13 *kg*		Equation 6
(vii)	V = 0.010 m^3*		Equation 7
(viii)	W = 6 *kg**		Equation 8
(ix)	V = 0.063 m^3*		Equation 9
(x)	W = 38 *kg**		Equation 10

Estimated total cane length = (i)+(iv) = 4,877 *m*

Estimated total cane volume = (ii)+(v) = 0.438 m^3
or = (ii)+(vii) = 0.427 m^3
or = (ii)+(ix) = 0.480 m^3

Estimated total cane weight = (iii)+(vi) = 263 *kg*
or = (iii)+(viii) = 256 *kg*
or = (iii)+(x) = 288 *kg*

* These estimates are very different from (v) or (vi) because it is wrongly assumed that the diameter or internode length is constant, but they are given here to show how equations 7-10 can be applied.

(Explanation of symbols in text)

Other estimates for the 16,850 internodes based on equations 1-3 and the overall mean internode length of 29.0 *cm* and quadratic mean diameter of 10.9 *mm* are L = 4,887 *m*, V = 0.456 m^{-3} and W = 274 *kg*.

It is realised that normally the density decreases from the basal portion of the cane to the tip (Renuka *et al.* 1987, Ani & Lim 1991). However, in the absence of adequate data to determine the mathematical relationship between the internode density and position, it is assumed that the density is constant in models 3, 6, 8 and 10.

It may be argued that the equations derived above are not reliable without destructive sampling because (a) measuring internode lengths near the base and the distances between the adjacent knees or leaf axils leaves the internodes beneath the oldest intact leaf sheath unaccounted for, and (b) counting the number of leaves borne by the elongating and/or immature internodes overestimates the utilizable yield of the stems. Argument (a) can be shown to be fallacious if we consider that near the stem apex, the number of leaves with expanded pinnae counted, whose externally visible part of the sheath does not enclose any internode, compensates for the number of internodes covered by the oldest intact leaf sheath. Objection (b) is valid, but the problem can be circumvented in the estimation of the utilizable yield of a stem by subtracting the number of leaves with expanded pinnae and borne by the elongating or immature internodes, which can easily be determined by destructively sampling a few stems (as is done by Shim [1989] for *C. trachycoleus*; but, of course, not the stems whose growth is being monitored), from the total number of internodes (= number of internodes + number of leaves with expanded pinnae; internodes bearing leaves with unexpanded pinnae are ignored in the models as it is expedient to exclude these short and elongating internodes which, together with other soft internodes, are useless as canes).

It is conceded that these models will not solve all the problems encountered in using non-destructive means for estimating rattan growth and yield, which is desirable under some circumstances, *e.g.*, in breeding studies, because the visibility of the internodes and leaves is greatly reduced when the stem has reached the forest canopy, unless one resorts to the tedious task of climbing up the supporting trees or other means of reaching the canopy (*e.g.*, the tree boom system used by Appanah and Chan [1982]).

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