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Juvenile Stem Volume Equations for Planted *Azadirachta excelsa* in the State of Johore, Peninsular Malaysia

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ABSTRACT

Azadirachta excelsa or sentang is one of the important tree species grown in Malaysia. Equations for the predicting stem volume, from the ground to the tip for this species, are not available and hence this paper attempts to apply and examine the suitability of the existing volume equations for the species which can be used by plantation growers in Malaysia. Furthermore, the performances of available volume equations in Malaysia are seldom investigated. Evaluation is important to determine the usefulness and increase the confidence of using a model. Three commonly used models were compared using the data derived from 36 harvested trees to fit the equations. The addition of the weight function of $1/(d^2h)$ was used to fit the Spurr's combined variable volume equation. Then, the performances of the models were evaluated based on R^2, PRESS, bias and RMSE values. The Schumacher and Hall's equation was found to be the most appropriate for determining the total and merchantable underbark stem volume of *A. excelsa,* whereas the Spurr's equation was indicated as more suitable to determine the merchantable overbark volume.

Keywords: ***Azadiractha excelsa*, height and diameter, model evaluation, Schumacher and Hall's Volume Equation, Spurr's Volume Equation**

INTRODUCTION

The Malaysian government has been promoting the planting of *Azadirachta excelsa* (Jack) Jacobs since 1996. In 2000, it was estimated that 5000 ha of *A. excelsa* plantation has been establishedw in Peninsular Malaysia with most planted at a small scale of less than 20 ha. In the state of Johore alone, a total of 653 ha of the plant have been established (T.H. Ong, *pers. comm.*). The shift took place rather quickly and many fundamental management issues were not properly addressed.

The ability to estimate the current yield production of a stand is one of the most important issues in the forest plantation management, in order to plan for proper silvicultural activities. In forestry, volume is perhaps one of the most common used parameters to estimate stand output. In order to have a good forecast on the forest growth and yield, equations which provide accurate tree volume prediction are therefore needed. The conversion of volume predictions into biomass, for example, can be used as the basis for calculating carbon storage and sequestration rates of the forest stands.

Although a good estimation of volume can be achieved by integrating the taper function, commonly used volume equations, related to the stem or total wood volume to the diameter at breast height (d) and height (h), are also useful.

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Logarithmic volume equation (Schumacher and Hall, 1933) and Spurr's (1952) combined variable equation are two most commonly used forms of volume equations. However, the performances of available volume equations in Malaysia have limitedly been investigated. Further investigation is therefore necessary to determine the usefulness of a model and to increase the confidence level in using it for an intended purpose and in larger areas (Reynolds *et al*., 1981; Reynolds and Chung, 1986). Thus, the objective of this study was to apply and examine the performance of the existing volume equations in an *A. excelsa* stand.

MATERIALS AND METHODS

Site Description

A small plantation covering an area of 2.9 ha was selected for this study. The plantation was located about 9 km south of Labis (2˚21'N and 103˚02'E) in the state of Johore, Peninsular Malaysia, and it is owned by a small-holder. The average monthly temperature varies from 24.3 to 27.3˚C. The rainfall data, over a period of 10 years (1990-1999), suggested a bimodal distribution (March – May and October – December), with a mean annual rainfall of 2181 mm. The area has an average elevation of less than 50 m a.s.l. and the slopes ranging from 1 to 50%. The landform can be grouped into three slope classes, namely (1) nearly level – 50%, (2) undulating – 25%, and (3) steep – 25%.

The plantation was established following a clear cutting of the second rotation rubber trees in March 1998. Debris on the site was burned prior to planting. Seedlings were planted at a spacing of 2.0 × 2.0 m. The seedlings were fertilized with 50 g of 15(N)-15(P)-15(K) at the time of planting. The operational schedules for the application of fertilizers, prior to the beginning of the experiment, are as presented in Table 1. The weeds were cleared by herbicide application each time before fertilization, leaving no ground cover for most of the time. Selective thinning was carried out in December 1999, with approximately 4% of the small trees removed. Thus, the stand was left with 2400 trees ha^{-1} before the starting of the experiment in May 2000 (Table 1).

TABLE 1
Schedule for the application of fertilizers and monitoring of growth and foliar nutrients for *Azadirachta excelsa* at Sungai Karas plantation

Age (months)	Month	Operation	Fertilizer application rate (g $tree^{-1}$)/(kg ha^{-1} elemental)
0	March 1998	Planting	50 g N(15)-P(15)-K(15)
4	July 1998	Routine fertilizer application	50 g N(15)-P(15)-K(15)
8	November 1998	Routine fertilizer application	50 g N(15)-P(15)-K(15)
12	March 1999	Routine fertilizer application	50 g N(15)-P(15)-K(15)
16	July 1999	Routine fertilizer application	50 g N(15)-P(15)-K(15)
20	November 1999	Routine fertilizer application	50 g N(15)-P(15)-K(15)
26	May 2000	Establishment of experimental plots	
		1st fertilizer application	N50 P_{50} K_{50} $Lime_{250}$
30	September 2000	2nd fertilizer application	N_{50} P_{25}
34	January 2001	3rd fertilizer application	N_{50} P_{25}

Fertilizer was broadcasted along planting lines

Measurement

In order to assess the growth performance, six plots of 0.1 ha were established based on the land formation of the area. Three plots were established on the level site, two plots on the undulating site and one plot on the steep site. Prior to the establishment of the plantation, the owner had planted *A. excelsa* seedlings under the existing *Durio zibethinus* trees which covered most of the steep site. Thus, only a single plot could be established in such a site.

The diameter at breast height (d) and the total or merchantable height (h) of all the trees in the plot were measured every three month. The d was measured using a diameter tape, while h was determined using a clinometer, at a distance of 10 m. The top of the tree (total height) and its first branch (merchantable height) were determined by shaking the tree briefly prior to the measurement. In August 2002, six trees were selected, based on the mean d and their standard deviation from each plot, after the last growth measurement to estimate the tree volume. A total of 36 trees were harvested as close to the ground level as possible, and were therefore used in the development of the volume equations. Each tree was divided into ten equal sections to obtain the sub-samples of the stem, based on the h. A 5 cm thick disc was obtained from the base of each section. In addition, a disc was also sampled near the first live branch. The overbark (with bark) diameter of all discs was first measured. Later, the bark of the disc was removed to determine the diameter of the underbark. Smalian's formula (Equation 1) was used to calculate both the overbark and underbark sectional volumes for each tree (in m^3), up to 90% of the total h of the tree or up to the first branch to determine the merchantable volume. The volume of the last stem section was calculated as a geometric cone.

$$V = \frac{g_l - g_u}{2} \cdot l \quad (1)$$

where V is sectional volume, g_l is cross-sectional area at the lower end, g_u is cross-sectional area at the upper end, and l is length of section log.

Tree volume predictions can be achieved by integrating d and h as variables. Although the inclusion of the third variable, such as the upper-stem diameter or taper function could further improve the volume estimates, the equations which express stem volume as a power function of d and h are still commonly employed (Bi and Hamilton, 1998; Fonweban *et al*., 1995; Tewari and Kumar, 2003; Wan Razali *et al*., 1989). The volume equation which relates the stem volume to d is also used when h is not available (Husch *et al*., 1982), particularly in a dense forest condition. Therefore, three basic equations to predict the stem volume with a constant stem, formed at a given diameter and height, were chosen and examined:

$$V = \mathrm{a} + \mathrm{b}d^2h \quad (2)$$

$$V = \mathrm{a}d^{\mathrm{b}} \quad (3)$$

$$V = \mathrm{a}d^{\mathrm{b}}h^{\mathrm{c}} \quad (4)$$

where V is stem volume, either overbark or underbark, d is diameter at breast height overbark, h is tree height, either merchantable or total. Equation (2) is Spurr's (1952) combined variable equation, equation (3) is adopted from Husch *et al*. (1982), while equation (4) is according to Schumacher and Hall's (1933).

Two equations, namely equations (3) and (4), were transformed logarithmically after fitting them with the least squares method to satisfy the assumption of homoscedasticity. A test for heteroscedasticity was carried out, together with equation (2), according to the method by White (1980). The results of the test indicated that heteroscedasticity was present in equation (2). Equation (2) was fitted using the weighted least squares regression, with $1/(d^2h)$ as the weight. The weight was selected by adopting Furnival's (1961) index of fit from $1/(d^2h)$ and $1/(d^2h)^2$. Residuals were evenly spread above and below the zero line, with no systematic trend (*Fig. 1*), suggesting that the weighted least squares are effective in stabilizing the error variance.

A generalized form of R^2 was calculated to compare the percentage of variation in the stem volume, as explained by the regression equations, due to the use of the logarithmic transformation and weighted least squares regression.

$$R^2 = 1 - \sum_{i=1}^{n} (V_i - V_p)^2 / \sum_{i=1}^{n} (V_i - V_m)^2 \qquad (5)$$

where V_i is the observed volume of tree *I*, V_p is the predicted volume of tree *I,* and V_m is the mean volume of all trees (Bi, 1994).

Snowdon's (1990) bias correction factor, a ratio of the arithmetic sample and back-transformed predicted means from the regression, was calculated to correct the systematic bias brought about by the logarithmic transformation after fitting the equations. The best-fit model was selected based on the precision of the equation on the basis of the following evaluation criteria.

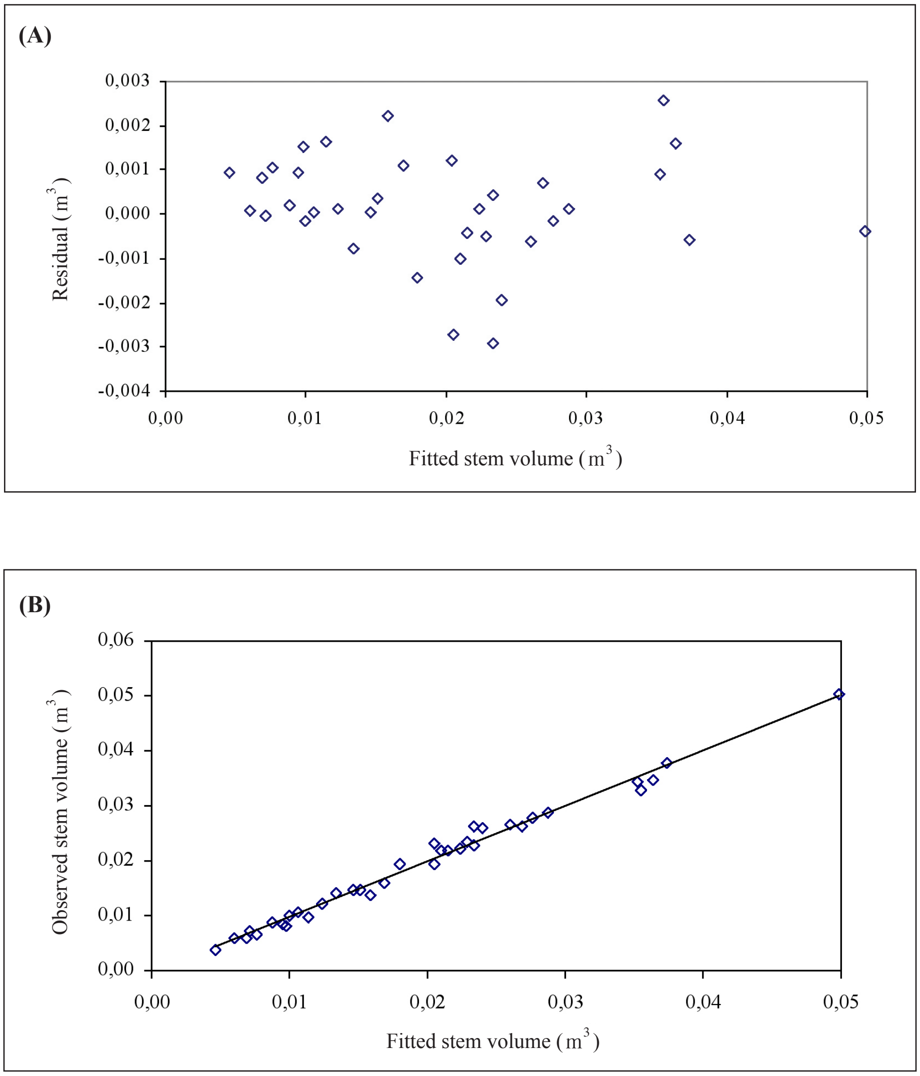

Fig. 1: Residual plot (A), and the relationship between the observed and predicted stem volumes (B) of the weighted least squares regression (Equation 2)

Average residual or prediction bias (B):

$$B = \sum_{i=1}^{n} r_i / n \qquad (6)$$

Where, r_i represents the difference between the observed and the predicted volume of tree *i* in the sample data set.

The variance:

$$Var(B) = \sum_{i=1}^{n} (r_i - B)^2 / (n - 1) \qquad (7)$$

Root mean squared error of the volume prediction (RMSE):

$$RMSE = (B^2 + Var(B))^{1/2} \qquad (8)$$

In case of a small sample size, Green (1983) suggested the use of the predicted residual sum of squares (PRESS) statistic, a prediction-oriented statistics.

RESULTS AND DISCUSSION

Data on the stand growth (Lim and Ong, 2005) and biomass (Ong *et al*., 2004) of the same stand have been reported previously. The summary of the data set used in this study (based on the 2060 trees ha^{-1} available before harvesting) are shown in Table 2. The *d* of the sampled trees ranged from 4.8 to 10.4 cm, while the total height ranged from 4.8 to 11.8 m, and the merchantable height ranged from 1.7 to 6.8 m.

The volume equations for the merchantable overbark stem volume and the results of the precision of the equations are presented in Table 3. The Spurr's combined variable equation (Equation 2) has the smallest PRESS, RMSE and average bias than the logarithmic equation. Meanwhile, the Schumacher and Hall's equation (Equation 4) showed the smallest PRESS, average bias and RMSE, but the highest R^2 for both the total overbark stem volumes (Table 4), and the merchantable underbark stem volume equations (Table 5). As for the total underbark stem volume equation (Table 6), the Schumacher and Hall's equation was also found to record the smallest PRESS, but with slightly higher average bias and RMSE than the Spurr's combined variable equation.

The Schumacher and Hall's equation recorded the highest R^2 in all the regression models. However, based on the PRESS statistics, the Spurr's combined variable equation can be considered as the best equation to accurately predict the merchantable overbark stem volume. The combined variable equation has been reported to be the most appropriate equation to determine the total underbark stem volume of *Eucalyptus fastigata* regrowth in New South Wales, Australia (Bi, 1994). Meanwhile, Tewari and Kumar (2003) also indicated that the best equation to estimate the total tree volume of *Eucalyptus camaldulensis,* planted in an arid area in India, was the combined variable equation. Similarly, the same equation was also reported to be the best equation for the total underbark volume prediction for *Eucalyptus paniculata* (Bi and Hamilton, 1998).

As compared to the Husch *et al*.'s equation and the Spurr's combined variable equation, the Schumacher and Hall's equation generally

TABLE 2
A summary of the parameters used

Parameters	Mean	SD	Min	Max
DBH (cm)	7.1	1.5	4.8	10.4
Merchantable height (m)	4.9	1.3	1.7	6.8
Total height (m)	7.9	1.5	4.8	11.2

TABLE 3
Regression coefficients of the merchantable overbark stem volume equations and R^2, PRESS, bias and RMSE for the equations

Equation number	Model	Parameter			R^2	PRESS	Bias	RMSE
		a (±S.E.)	b (±S.E.)	c (±S.E.)				
2	$V = a + bd^2h$	1.42×10^{-3} (8.55×10^{-4})	6.59×10^{-5} (0.17×10^{-5})		0.9879	0.0197	1.08×10^{-4}	1.50×10^{-4}
3	$V = ad^b$	1.34×10^{-4} (1.23×10^{-5})	2.48 (0.1079)		0.7860	0.7435	5.53×10^{-4}	7.85×10^{-4}
4	$V = ad^bh^c$	-1.06×10^{-4} (1.81×10^{-5})	1.75 (0.4281)	1.06 (0.2740)	0.9914	0.0274	5.94×10^{-5}	5.61×10^{-4}

TABLE 4
Regression coefficients of total overbark stem volume equations and R^2, PRESS, bias and RMSE for the equations

Equation number	Model	Parameter			R^2	PRESS	Bias	RMSE
		a (±S.E.)	b (±S.E.)	c (±S.E.)				
2	$V = a + bd^2h$	2.32×10^{-3} (8.38×10^{-4})	5.83×10^{-5} (0.26×10^{-5})		0.9886	0.0626	9.40×10^{-5}	1.37×10^{-4}
3	$V = ad^b$	1.99×10^{-4} (1.40×10^{-5})	2.35 (0.2155)		0.6410	0.6988	1.13×10^{-3}	1.60×10^{-3}
4	$V = ad^bh^c$	9.85×10^{-5} (1.08×10^{-6})	0.97 (0.0423)	1.81 (0.0296)	0.9888	0.0307	6.62×10^{-5}	9.95×10^{-5}

TABLE 5
Regression coefficients of the merchantable underbark stem volume equations and R^2, PRESS, bias and RMSE for the equations

Equation number	Model	Parameter			R^2	PRESS	Bias	RMSE
		a (±S.E.)	b (±S.E.)	c (±S.E.)				
2	$V = a + bd^2h$	2.03×10^{-3} (6.63×10^{-4})	7.92×10^{-5} (0.13×10^{-5})		0.9749	0.0603	1.81×10^{-4}	2.59×10^{-4}
3	$V = ad^b$	1.68×10^{-4} (1.26×10^{-5})	2.46 (0.1194)		0.7570	0.8518	7.79×10^{-4}	1.11×10^{-3}
4	$V = ad^bh^c$	1.01×10^{-4} (1.13×10^{-5})	1.65 (0.0775)	1.11 (0.0849)	0.9829	0.0575	1.05×10^{-4}	1.53×10^{-4}

TABLE 6
Regression coefficients of total underbark stem volume equations and R^2, PRESS, bias and RMSE for the equations

Equation number	Model	Parameter			R^2	PRESS	Bias	RMSE
		a (±S.E.)	b (±S.E.)	c (±S.E.)				
2	$V = a + bd^2h$	2.78×10^{-3} (7.85×10^{-4})	5.92×10^{-5} (0.24×10^{-5})		0.9685	0.1724	1.00×10^{-4}	1.53×10^{-4}
3	$V = ad^b$	2.13×10^{-4} (1.43×10^{-5})	2.33 (0.2275)		0.6764	0.6732	1.13×10^{-3}	1.59×10^{-3}
4	$V = ad^bh^c$	0.91×10^{-4} (0.11×10^{-5})	1.02 (0.0599)	1.72 (0.0420)	0.9717	0.0636	1.28×10^{-4}	1.89×10^{-4}

predicted both, the total overbark and underbark stem volume and merchantable underbark stem volume with higher accuracy and less bias. In Peninsular Malaysia, Wan Razali *et al*. (1989) reported that the logarithmic equation was the best model to estimate both the merchantable overbark and underbark stem volume of a 5-year-old *Acacia mangium* plantation. Fonweban *et al*. (1995) also found the logarithmic equation was the most suitable for predicting merchantable volume of *Eucalyptus saligna* found in two forest reserves in Cameroon. Shiver and Brister (1990) reported similar findings for *E. saligna* stands in Western Kenya.

Spurr's combined variable equation and Schumacher and Hall's equation are the two equations which were most commonly used in the development of the stem volume equations. The superiority of these equations was clearly demonstrated in this study, with the R^2 value above 0.95 for all the prediction models. Generally, based on the R^2 value and the volume prediction, the logarithmic equation was found to be the best in determining the stem volume of *A. excelsa* in this study. However, the combined variable equation seemed to be the most appropriate to determine the merchantable overbark stem volume of *A. excelsa,* based on its overall predictive performance. Thus, the best equations to be used in predicting the total or merchantable stem volume are as follows:

$$V_{mob} = 1.42 \times 10^{-3} + 6.59 \times 10^{-5}(d^2 h_m) \quad (9)$$

$$V_{tob} = 9.85 \times 10^{-5}(d^{0.9737} h_t^{1.8106}) \quad (10)$$

$$V_{mub} = 1.01 \times 10^{-4}(d^{1.6527} h_m^{1.1116}) \quad (11)$$

$$V_{tub} = 0.91 \times 10^{-4}(d^{1.0240} h_t^{1.7232}) \quad (12)$$

Where, V_{mob} is merchantable overbark volume, V_{tob} is total overbark volume, V_{mub} is merchantable underbark volume, V_{tub} is total underbark volume, d is diameter at breast height, h_m is merchantable height and h_t is total height.

The volume equations selected in this study for a 53-month-old *A. excelsa* stand are limited by the size and age factors, as well as the silvicultural treatments (e.g. fertilization) involved. The extrapolation outside the range of the data, age and/or under other conditions or silvicultural practices should be made with caution, since the prediction accuracy of the equations in other situations is unknown.

CONCLUSIONS

Yield (volume) estimates could provide the basis for a better management of plantations. The Schumacher and Hall's equation, which is commonly used to develop stem volume equations, has been proven to be the best equation for determining *A. excelsa* stem volume in this study. Based on the results obtained, it is suggested that future studies be done for stands which represent a wider range of site quality, age, management practices. More trees per site should also be considered to improve the accuracy of the yield estimation and develop a more comprehensive yield table.

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