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CONTENTS

MODELING STAND VOLUME OF RUBBER (*HEVEA BRASILIENSIS*) PLANTATIONS IN MALAYSIA USING LANDSAT TM

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ABSTRACT

Effective management and appropriate policy for rubber trees (Hevea brasiliensis (Wild. ex Adr. de Juss.) Muell Arg.) require reliable forecasts of resource availability. This study was conducted to develop and validate models for estimating stand volume of rubber plantations in Malaysia. A total of 76 rubber stands were sampled and split into two independent groups: model-building and validation data sets. Regression analyses were used to explore relationships between rubber stand volume and Landsat TM bands and ratio-based indices. Statistically significant models for estimating stand volume were obtained. Coefficients of determination (R^2) for the models were all higher than 0.70 and standard error of estimate (SE_E) values were lower than 54 m^3/ha. Thus, Landsat TM provides an acceptable data source for estimating stand volume of rubber plantations in Malaysia.

Keywords: Landsat TM, modeling, rubber plantations, rubberwood, volume estimation

1. INTRODUCTION

In the last decade, industrial round wood production in Malaysia, primarily from natural forests, was halved from 41 million m^3 in 1990 to 21 million m^3 in 1999[1]. This amount of log production falls short of the capacity of the primary processing timber industries (i.e., 23 million m^3) in the country. The shortfall will need to be met by promoting sustainable use of existing

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woody material. Rubber tree (*Hevea brasiliensis* (Wild. ex Adr. de Juss.) Muell Arg.) crops have the potential to play an important role in this, as they provide sources of natural rubber and wood products, while producing other benefits that support basic human needs. To establish baseline information, research was conducted into supplementing traditional methods of ground-based survey with information from satellite remote sensing. The purpose of this study is to develop and evaluate models for estimating stand volume of rubber plantations.

2. MATERIALS AND METHODS

2.1 Field Data and Image Acquisition

Field data collection was conducted in 2000 and 2001 in Selangor, Malaysia located between latitudes of 2° 35' to 3° 55' N and longitudes of 100° 45' to 102° 00' E. The rubber plantations chosen for field sampling consisted of even-aged stands from 3 to 48 years old. The 76 sampled stands were randomly divided into two independent groups; a set of 49 stands for building the model, and 27 stands for validating the model. Fixed area circle plots, measuring 0.03 ha (20 m in diameter) were used. Diameter outside bark at breast height on all trees was measured in all plots. Estimates on total tree height were made from measurements on a subset of trees. Tree volume was estimated using rubberwood volume equations developed by Wan Razali *et al.*[2]. A Global Positioning System (GPS) was used to record the position of the field plots.

The image used was a full scene of Landsat-5 TM, path 157, row 58, recorded on February 11, 1999. The image was geometrically corrected to root mean squared error (RMSE) of less than 0.5 of a TM pixel. The boundaries of the stands in the imagery were delineated and corresponding spectral measurements for each stand were extracted from the TM bands for statistical analysis. Topographic and landuse map sheets were used as reference data.

2.2 Volume Modeling Approach

Prior to modeling, relationships between stand volume and TM data were analysed by calculating Pearson's correlation coefficients (r). Parameter variables related to stand volume are summarised in Table 1.

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Table 1. Variables used for regression models fitted to rubber stand volume.

Predictor variables	Variable labels
Individual TM band[a] (1, 2, 3, 4, 5 & 7)	B1, B2, B3, B4, B5, B7
Greenness indices	
1. (B4-B3)/(B4+B3)	GI1
2. B4/B3	GI2
3. B4/(B4+B5+B7)	GI3
4. [(B4-B3)/(B4+B3)+0.5]*0.5	GI4
Vegetation condition indices	
1. (B5-B4)/(B5+B4)	VCI1
2. B5/B4	VCI2
3. B5/(B4+B5+B7)	VCI3
4. (B7-B4)/(B7+B4)	VCI4
5. B7/B4	VCI5

Notes: [a]Band 1 (0.45–0.52μm; blue), Band 2 (0.52–0.60 μm; green), Band 3 (0.63–0.69 μm: red), Band 4 (0.79– 0.90 μm: near-infrared), Band 5 (1.55–1.75 μm; mid-infrared), Band 7 (2.08–2.35 μm; mid-infrared).

Examining several different forms of regression models, the hyperbolic relationship[3], $Y = b_0 + b_1(\frac{1}{X}) + b_2X$, seemed to be the most reasonable. Four criteria were used to draw the statistical inference about the performance of final models: coefficient of determination (R^2), adjusted coefficient of determination (R_a^2), standard error of estimate (SE_E) and significance level. The performance of each model was evaluated by calculating the root mean squared error (RMSE) defined as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

and correlation index squared (I^2):

$$I^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}$$

where n is the number of stands, y the measured volume, $\bar{y}$ the mean of the measured volume and $\hat{y}$ is an estimated value of the volume.

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3. RESULTS AND DISCUSSION

3.1 Volume Model Development

The rubber trees stand volume was inversely correlated to spectral radiance, indicating that as volume increased, spectral radiance decreased. Four of the six bands studied (TM bands 2 – 5) were found to be significantly correlated with volume, ranging in r values from -0.32 to -0.46 (Table 2). The response of the TM data to stand volume found in this study also agrees with the findings of Ardö[4]. Based on this study, low stand volumes were associated with young, open stands with a highly reflective understory layer (leguminous cover crops in this case), and higher volumes were associated with older stands with higher crown closure.

The final volume models (Table 3) were derived based on theory and accuracy reported in other studies, which indicated the combinations of TM bands and/or ratio based indices that could be useful in providing stand volume-related estimations[5,6,7,8]. The R^2 values for the models ranged from 0.71 to 0.73 (Table 3). These values indicated how well the predictor variables explained the variations within the volume models. These results were expected based on the known biophysical relationships between red, near-, and mid-infrared reflectance and green vegetation. As can be seen in Table 3, despite having different numbers of predictor variables (5, 6, 7, and 8), all models showed only small differences in R^2, R_a^2, and SE_E values. Adding the sixth, seventh, and eighth predictor variables to the equations (Models 3 – 6) did not improve the Models 1 and 2 significantly. Based on our analyses, Model 2 is recommended because it provides a good balance between practicality, predictive ability, and simplicity.

3.2 Volume Model Validation

Based on the relationships between observed and predicted stand volumes, the different models predict equally well (Fig. 1). The validation summary presented in Table 4 suggests that reliable estimates of rubber tree stand volume using this approach can be obtained. The I^2 value for each model ranged between 0.61 – 0.66. These indices indicate reasonable accuracy and were well within the range found by previous studies of 0.64, 0.66, and 0.30, respectively[4,8,9]. Model 5 appeared to provide slightly better estimates of wood volume indicated by slightly higher I^2 (0.66) and lower RMSE (61.65 m^3/ha). This is expected because the model contains more combinations of TM bands and spectral vegetation indices, however the improvement over simpler models is minor.

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Table 2. Correlation matrix of volume and TM bands (n=49 stands).

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7	Volume (m^3/ha)
Band 1	1.00						
Band 2	0.73^a	1.00					
Band 3	0.68^a	0.84^a	1.00				
Band 4	0.28	0.37^b	0.01	1.00			
Band 5	0.52^a	0.70^a	0.73^a	0.11	1.00		
Band 7	0.49^a	0.63^a	0.82^a	-0.27	0.89^a	1.00	
Volume (m^3/ha)	-0.16	-0.40^b	-0.32^c	-0.46^a	-0.46^a	-0.18	1.00

Notes: [a, b,] and [c] are significant at the 0.001, 0.01 and 0.05 probability levels, respectively.

Table 3. Comparison of models fitted to stand volume (n=49 stands).

Model no.	[a]Predictor variables	p	R^2	R_a^2	SE_E (m^3/ha)
1	B1, rB5, rB7, GI4, VCI4	5	0.71	0.67	53.92
2	B1, rB5, rB7, GI1, VCI4	5	0.71	0.67	53.86
3	RB1, rB5, rB7, GI1, GI4, VCI4	6	0.72	0.68	53.26
4	B1, rB5, rB7, GI1, GI4, VCI4	6	0.72	0.68	53.31
5	rB1, rB2, rB5, rB7, GI1, GI4, VCI2	7	0.72	0.68	53.46
6	rB1, rB2, rB4, rB5, rB7, GI1, GI4, VCI2	8	0.73	0.68	53.32

Notes: [a]Descriptions of predictor variables are shown in Table 1, r=reciprocal, p= number of predictor variables in the model.

Table 4. Summary of regression model validation results for stand volume (n=27 stands).

Model no.	P	r^2	RMSE (m^3/ha)
1	5	0.61	65.72
2	5	0.61	65.75
3	6	0.63	63.85
4	6	0.64	63.73
5	7	0.66	61.65
6	8	0.65	62.74

Note: p= number of predictor variables in the model.

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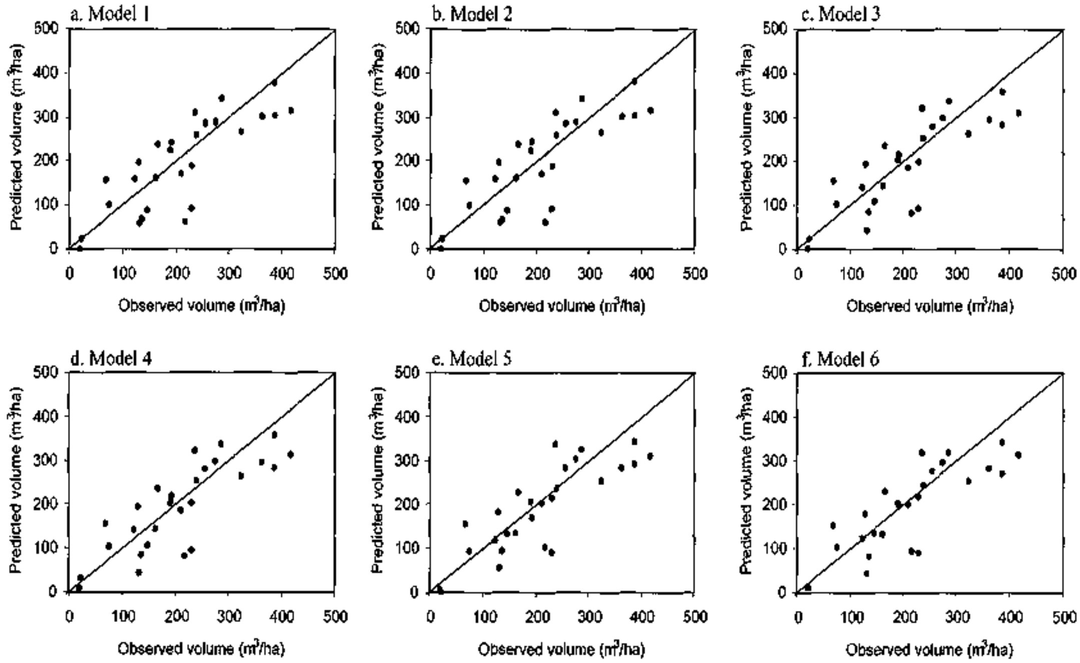

Figure 1: Predicted volume versus the residuals of the estimation (n=27 stands).

5. CONCLUSION

The good fit of stand volume models gives an indication of the potential of TM band data for estimating rubber stand volume in Malaysia. The relationships identified in this research contribute to the development of tools linking ground and satellite data. The methods provide convenient and useful tools for resource planners to forecast resources, and should eventually assist in the development of policy recommendations to fully utilize the potential benefits of rubber tree resources. The approach also provide an important platform for future research especially in terms of model refinement and a study on other types of tree crop components either in Malaysia or other countries with similar resource management issues and constraints.

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