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Elevation Effect on *Acacia mangium* Volume Estimation

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ABSTRACT

The objective of this study was to examine the effects of four different elevations on *Acacia mangium* volume in Bintulu, Sarawak. A total of 60 felled trees of *A. mangium* were used to develop a volume equation by measuring the volume at four different classes of elevation. The study of stand volume estimation in Malaysian plantations, particularly in Bintulu, is sparse. To get the average cross-sectional area, the volume of each tree in each part of the felled trees was estimated using Smalian's and Newton's formulas. Four equations were developed in this study to predict the volume from the diameter and analyze the effect of elevation on tree volume. According to the regression analysis, there was a significant relationship between the volume and diameter for each slope steepness. The *Very Slope* site had the highest volume with an R^2 value of 0.948 for the model's fit, which revealed that 94.8% of the data could be evaded. Volume estimation using the regression model can be used to determine and categorize according to its class of elevation, and there is an effect of elevation on standing volume. *A. mangium* has better growth performance in a very slope area in terms of tree volume compared to different elevations.

INTRODUCTION

Individual stem volume is required for forest management to obtain information on forest mensuration, growth, yield estimation, and forest volume estimation. Methods such as forest inventory measurement have been regularly used to measure height and diameter at breast height for the stand volume. Tree species, stem diameter-at-breast-height (dbh), and tree height are the most common tree parameters assessed in the field (Luoma et al., 2017). There are two commonly used formulas, Newton's formula and Smalian's formula for estimating the volume of trees. If the logs are precisely cylindrical, both formulas can produce similar values (Avery & Burkhart, 1994) . Tree volume equations or allometric models are used to estimate the volume valuable for forest plantations (Mugasha et al., 2016)respectively, this study developed site specific and general models for estimating total tree volume and aboveground biomass. Specifically the study developed (i. Currently, this regression model is the most widely used model for estimating tree volume (Giri et al., 2019).

Various methods have been used by researchers to estimate the tree or log volume and the log formula can be considered as one of the commonly-used methods (Ahmad et al., 2020). The selection of formulas is based on the reading measurements and the simplicity in calculating log volumes using the formula and the accuracy obtained using the formula (Alemdag, 1978). Based on recent

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studies, Newton's formula proved to be the most accurate. Although the formula is most accurate yet its use has been limited to research compared to other volumes because of the complicated procedure involved in taking its measurements (Loetsch *et al.,* 1973; Avery and Burkhart, 1983). Nowadays, with the help of computer facilities and programs, the problem of calculating the volume has been resolved to get instant results. Newton's formula was used to calculate bolt volumes for the standard method because it trusted precise reading with frustums of cylinders, paraboloids, neiloids and conoids (Alemdag, 1978; Cailliez, 1980; Rondeux, 1993; Philip, 1994). Some of the previously used methods such as tabular and graphic methods that are less commonly used in regression methods are favored (Laar & Akça, 2007)). Forest inventory is usually an acceptable method that is accurate, simple, and inexpensive (Philip, 1994).

Plantation forests are established and expanded to satisfy the increasing global demand for timber products (McEwan et al., 2020). Forest plantation industry is not a new venture in Malaysia. The Peninsular Malaysian Forestry Department began with the Compensatory Forest Plantation Program in 1982 through planting fast-growing tropical hardwood species such as *Acacia mangium, Gmelina arborea,* and *Paraserianthes falcataria*. Forest plantations were formed in the East Malaysian states of Sabah and Sarawak in 1973 and 1981, respectively, and some exotic tree species employed in commercial and forest plantation sectors have been cultivated (de Wit et al., 2001; Richardson, 2008). *Acacia mangium* is a fast-growing tree native to Australia that can reach a height of 15–20 m (Kirkup et al., 1996; Turnbull et al., 1998). This tree is a primary stand because of its fast growth in poor soils and nitrogen fixing (Turnbull et al., 1998; van Wilgen et al., 2001).

Changes in tree growth and volume in forest plantations are caused by a variety of factors that alter the structure and function of the environment. It has been suggested that forests on ridge tops are stunted when compared to those on slopes due to lesser mineral fertiliser availability than on surrounding slopes (Bruijnzeel & Veneklaas, 1998; Tanner et al., 1998)small and tough leaves, low diversity . There is currently a lack of research on the impact of elevation on tree growth or volume.

The goal of this research was to see if any modifications in the form of slope comparison (elevation) had an impact on the tree volume equations. The relief is typical of the Bintulu, Sarawak plantation, and four different types of elevation were tested to see how heights affected the volume of standing *A. mangium* trees. Therefore, this study conducted on *A. mangium* plantation in Bintulu, Sarawak, Malaysia by comparing the four different slope steepness to partition their respective effects on volume of standing trees. The goal of this research was to find out four various elevations affected the *A. mangium* volume in Bintulu, Sarawak.

MATERIALS AND METHODS

Study Area

The data available for this study were collected from A. mangium stands located in Bintulu, Sarawak state of Malaysia (Fig. 1). The site is located between latitudes 3.002251 and 3.008129 N and longitudes 3.0473833 and 113.0396555 E. The Acacia mangium, Eucalyptus pellita, Gmelina abrorea and Parasentiasis falcataria were among the fast-growing species planted in the forest plantations, which of 6989.2 ha. The area of the sample was about 3 ha.

Classification of Elevation

Data used in this study were obtained from the matured categorized *Acacia mangium* standings. *Acacia mangium* standings in selected plot were described as mature as eight years from the planting date. The selected samples were planted on 2009, with planting distance of 3 by 3 m and was readily to be harvested. In total, 60 sample trees were subjectively selected to represent the mature age of the tree based on the planting date.

Based on Barcelona Field Study Center, the measuring of slope steepness for were classified into four major category as shown in Table 1. Class of Elevation for sample trees were determined into four different category which is nearly level, moderate slope, very slope and extreme slope. Each site there were 15 sample trees subjectively selected where, in total 60 trees individually selected before felling and the slope steepness was determined by using the Clinometer.

Fig. 1. A map of State of Sarawak showing the location of the study site (Source: *http://www.wonderfulmalaysia.com/maps/map-sarawak.gif*)

Table 1. Number of tree according to Class of Elevation

Number of trees	Class of elevation	Degree of Elevation (%)
15	Nearly Level	0-5
15	Moderate Slope	5-15
15	Very Slope	15-24
15	Extreme Slope	>24

Measurement of Sample Trees

The base diameter (0.3 m above ground level) and diameter at breast height (DBH - 1.3 m above ground level) of each selected tree were measured prior to felling. After that, measurements of total height in metres and diameter over bark at 1 m intervals along the stem length were collected (Fig. 2). A diameter tape was used to measure all of the diameters. For this study, a total of 60 felled trees with height-diameter data were provided.

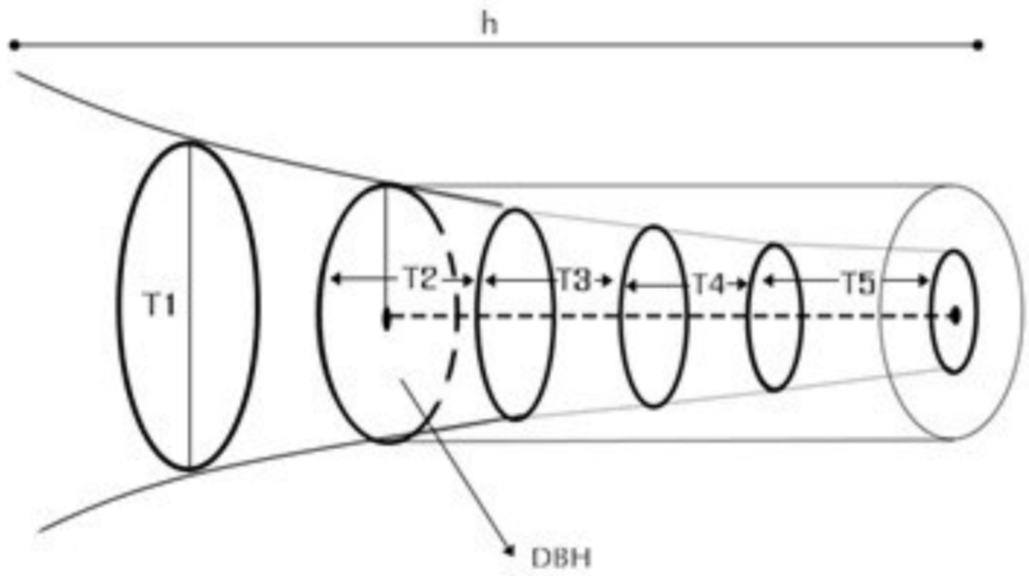

Fig. 2. Diagram of the log taper measurement by cross-session view

Volume Measurement

Newton's and Smalian's formulas were used to compute the volume of each felled tree in each segment. These formulas describe average cross-sectional area and were utilised for log sections with two sectional areas at felled log measurements (Avery. & Burkhart. 1994). The volume was determined using the following Smalian's formula. (1).

$$V_{log} = \left[\frac{S1+S2}{2}\right] x\ l \quad ....1)$$

Where: *S*1 = Sectional area at the thick end in square units; *S*2 = Sectional area at the thin end in square units; *l* = Length of the log or height of the solid in linear units.

The volume was determined using the Newton's formula as presented in formula 2.

$$V_{\log} = \left(\frac{S + 4S_{1/2} + s}{6}\right) \quad ....2)$$

Where: S = Basal area at the large end cross-section; S½ = Basal area at the midpoint cross-sectional area; s = Basal area at the small end cross session; L = Length of the log or height.

Data Analysis

Regression analysis was carried out to analyze relation between diameter, volume and impact of elevation to *Acacia mangium* trees. A linear regression model was developed using Excel and SPSS software to obtain the association between diameter and volume of trees based on the slope steepness and volume calculated from tree data. Data of elevation subjected to two-way ANOVA (volume and different class of elevation) to assess their respective effects and also the interaction between them. For statistical significance, P = 0.05 was chosen. SPSS version 26.0 statistical package application was used for all statistical analysis of data.

RESULTS AND DISCUSSION

In total, 60 trees were felled and they represented *A. mangium* species. The DBH and total height of the sample trees ranged from 20.0 to 40.6 cm and 19.40 to 34.80 m, respectively. The volume of total tree calculated using based on Smalian's and Newton's formula and the range of volume in-between 0.3519 to 1.740 m³. Table 2 shows the summary of total mean and standard deviation for different four classes of elevation.

In comparing the elevation on tree volume of *A. mangium* species, Table 2 provides the mean volume and standard deviation results. The highest mean was found on very slope category with the value of 0.9097 m^3 and lowest was observed in moderate slope category with the mean of 0.7227 m^3. In nearly level and extreme category, the mean was 0.8686 and 0.8543 m^3. The overall of 60 tree samples calculated from various parameters based on Smalian's and Newton's formula. Table 3 show the summary of mean, standard deviation, minimum and maximum value of DHB based on Smalian's and Newton's formula.

Overall, the relationship between volume and diameter of a tree was analyzed using logarithmic regression linear medium with equation model as formula 3

Log V = a+b logD ....3)

Following the analysis, a simplified equation model can be expressed as formula 4)

Y = a+b X ....4)

Table 4 demonstrates that all regressions have a significance level of less than 0.05. These results show a strong linear relationship between volume (log V) and diameter (diameter) (log D). The *Very Slope* steepness has R^2 of 0.948 and became the highest among the four different slope steepness category. For *Very Slope* category has highest R^2, the coefficient determinant was resulted on *Acacia mangium* samples, R^2 = 0.9.48, where the 81.9% of the total variation in log V could be mentioned by linear equation LogV= -0.991 + 0.065D.

Table 2. Mean volume and standard deviation for different four classes of elevation

Class of Elevation	Number of trees (N)	Mean (m^3)	Standard Deviation (STD)
Nearly Level	15	0.8686	0.2741
Moderate Slope	15	0.7227	0.1211
Very Slope	15	0.9097	0.4388
Extreme Slope	15	0.8543	0.2499
Total	60		

Table 3. Summary of results calculated from various parameters based on Newton's and Smalian's formula for *Acacia mangium* tree

Parameters	Felled Trees			
	Mean	S.D	Min. (m)	Max. (m)
DBH (cm)	25.6317	4.1923	20.0	40.6
Height (cm)	26.3905	3.5267	18.4	33.8
Total tree volume (m^3)	0.55408	0.2142	0.3519	1.740

Table 4. Relationship between volume and diameter using Newton's and Smalian's Formula

Class of elevation	N	Regression Equation	R^2	F	Significant
Nearly Level	15	LogV= -0.827 + 0.059D	0.882	97.363	$<0.0001^b$
Moderate Slope	15	LogV= -0.111 + 0.03D	0.334	6.512	$<0.0001^b$
Very Slope	15	LogV= -0.991 + 0.065D	0.948	263.071	$<0.0001^b$
Extreme Slope	15	LogV= -0.384 + 0.043D	0.838	67.240	$<0.0001^b$

On the other hand, R^2 value in the Moderate Slope category has a variable value of less than 0.900. The coefficient determinant for the Class of Elevation for Moderate Slope samples was R^2 = 0.334, which explains 33.4 percent of the overall variation in log V with the linear equation LogV= -0.111 + 0.03D. On *Acacia mangium* samples, the coefficient determinant was R2 = 0.882 and R^2 = 0.838 for Nearly Level and Extreme Slope, respectively. LogV= -0.827 + 0.059D and LogV= -0.384 + 0.043D are the linear equations that describe the overall variation in log V of 88.2 percent and 83.8 percent. Overall, the regression resulting on *Acacia mangium* species had the lowest coefficient determinant: r^2 =0.786, which suggests that the linear equation LogV= -0.626 + 0.05D can explain 79 percent of the overall variation in log V. Another 21% of the cases are still unsolved. The regression analysis demonstrates the link between volume and diameter using the SPSS statistical package application. To resolve the volume of regression where it shows a straight line in a graph, a diameter value was included into the equation. The estimated volume gained from Smalian's and Newton's formulas was compared to the volume calculated using regression.

Regression Analysis

For each slope steepness, the regression analysis shows the link between volume and diameter (Nearly Level, Moderate Slope, Very Slope and Extreme Slope). The regression equation was created using the SPSS statistics package programme and regression analysis. To estimate the volume of regression, a diameter value is included into the equation, which exhibits a straight line in a graph. The volume using regression was compared to the volume measured manually using Smalian's and Newton's formulas. Previous researchers such as Kurz et al. (1992) and Vanclay (1994) have confirmed this finding and stated that individual tree height and diameter are important forest inventory variables for determining tree volume.

Total Volume of Standing Trees by Class of Elevation

Table 5 shows the total volume of standing tress by Class of Elevation of Nearly Level, Moderate Slope, Very Slope and Extreme Slope of *A. mangium* sample using the developed regression equation on Table 4. In comparing four different slope steepness, the *Very Slope* have highest total volume with total 13.800 m^3. The lower total volume was 10.971 m^3 for *Moderate Slope* condition of topography. Overall, the sum of sample collected volume was 50.820 $m^{3.}$

The primary outcome of this study was to find out if there elevation has an effect on the volume of *A. mangium* and tree volume estimation. From all 60 *A. mangium* tree samples, the elevation sample from the Very Slope location has the largest volume compared to the Nearly Level, Moderate Slope, and Extreme Slope samples. Since 2009, *A. mangium* has been developing well, with the largest differences in size represented by diameter and height. The elevation of the Moderate Slope site, which was planted the same year, had a lower volume. The not significant reading was more than 0.05 in the regression analysis.

Table 5. otal volume of standing trees for different class of elevation

Class of Elevation	N	Regression equation	Total Volume (m^3)
Nearly Level	15	$V= 10^{-0.827}D^{0.059}$	13.018
Moderate Slope	15	$V= 10^{-0.111}D^{0.03}$	10.971
Very Slope	15	$V= 10^{-0.991}D^{0.065}$	13.800
Extreme Slope	15	$V= 10^{-0.384}D^{0.043}$	13.031

With a confidence level of 95%, it shows that there was a significant discrepancy between diameter and volume. The results show that the dependent variable (diameter) in the regression equation has a relationship with the independent variable (diameter) (volume). The regression graph with a 5% coefficient determinant remains unexplained in the Very Slope elevation class, where it is significantly scattered out from the linear graph. This shows that the relation between diameter and volume were less correlated compared with the linear graph from other plot. The Class of Elevation on Undulating has the highest R^2, with a coefficient determinant of 0.819, implying that the linear connection can explain 81.9 percent of the variation in Y. The entire volume of a felled tree can be calculated using the discrepancies in diameter measurements. Most of the volume in undulating area seems to fit the linear graph. This indicates that there is a great correlation between diameter and volume of the tree. Then just using the regression equation (-0.991 + 0.065D logD), the volume other felled *A. mangium* can be estimated precisely. The result showed that the unity in diameter growth of standing undulating elevation which has 94.8% fit the linear graph.

Meanwhile, when comparing the elevation on tree volume of *A. mangium* species in an undulating environment, the mean of 30 trees samples was 0.86, with the undulating sample having a higher mean. Awang and Taylor (1993) found that *A. mangium* species exhibit faster growth rates and shorter rotation lengths, as well as acceptable physical and mechanical qualities such basic density, shrinkage, and hardness (Shanavas and Kumar 2006). This species' adaptation may explain why it grows better in any sort of topography, particularly in Bintulu's plantations.

As a result, the *Very Slope* site has a higher advantage than the *Moderate Slope* site because nutrient accumulation is better in the undulating area of the *Very Slope* site. This could help *A. mangium* thrive better at the *Very Slope* site, which is between 15^0 to 24^0 steepness. This site may contribute to soil fertility to promote plant growth compared to the other four sites, which are represented by the average volume of *A. mangium*. As a result, the volume of *A. mangium* trees in the *Very Slope* area grows faster in terms of volume, which is influenced by topography and environmental conditions. Other than that, the *Very Slope* site have lesser water runoff which could make the nutrient leaching occur slower compared to the *Nearly Level, Moderate Slope, and Extreme Slope* areas resulting the fertility of soil is better. As a result, trees in Very Slope area have better growth performance in the term of tree volume compared to different elevations.

In general, *A. mangium* grows best in locations with steep terrain. These findings could be used to mitigate erosion in forest plantation areas with steep terrain. As a fast growing species, *A. mangium* can accelerate the tree stocking rates, so the duration of the vulnerability of the steep terrain area can be shorten by planting *A. mangium*.

CONCLUSION

In this study, four equations were devised to provide mean for estimating volume from diameter and to compare the effect of elevation on the volume of *A. mangium* trees. According to the regression analysis, there is a significant relationship between volume and diameter for each slope steepness. The *Very Slope* site found highest volume with the value for R^2 was 0.948 for this fit of the model, which showed 94.8% of the data could be evaded. The volume estimation using the regression model can be used to determine and categorize the calculated vales accordingly to its class of elevation, and there is an effect of elevation into standing volume of *Acacia mangium* in Bintulu, Sarawak. *Acacia mangium* has better growth performance in a very slope area in term of tree volume compared to different elevations. In general, *Acacia mangium* have better growth at the steep terrain areas. The finding equations can be used by the management to estimate the tree volume by only using diameter (DBH) and the volume total of *Acacia mangium* plantation, a part or the whole forest plantation area. In relation to the elevation ,the findings could potentially be implemented for erosion mitigating at the steep terrain of forest plantation areas.

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