Short communication

Stem Volume Equation and Tree Growth For Rubber Trees in Cambodia

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ABSTRACT

Rubber trees (*Hevea brasiliensis*) in Cambodia are important sources for not only natural rubber but also wood products. This study was conducted to set up stem volume equations to estimate the stand volume and the volume increment for rubber trees in Cambodia. Krek Rubber Plantation located in Kompong Cham Province was selected for study area. Sixty trees of the clone PR107 at the age of 36, 44, 45 and 46 were felled and cut into segments of one meter long to formulate the volume equation. The DBH and total height of 450 standing trees (15 plots) at different ages (6-10 and 36-48) were measured to estimate volume per hectare and the mean annual increment (MAI). This study revealed that the volume equation for standing rubber trees clone PR107 is $V = 0.00018381 D^{2.23961} H^{0.15334}$ or $V = 0.00024884 D^{2.29535}$ where V is the over bark volume (m^3), D is diameter at breast height (cm), H is total height (m). Using the two-variable equation, rubber wood volume at the rotation length of 25-30 years was estimated at about 240 - 270 $m^3 ha^{-1}$ with the MAI of 9.33 $m^3 ha^{-1} yr^{-1}$.

Keywords: rubber trees, volume equation, stem volume, tree growth, mean annual increment (MAI)

INTRODUCTION

Rubber tree (*Hevea brasiliensis*), which is indigenous to the Amazon basin and was named as "white gold" in the earlier twentieth century, has been playing a significant role in sustaining socio-economic base of many countries in the world, especially in South East Asia accounting for about 80% of the total areas under rubber worldwide. The exploitation of rubber trees focused solely on their resin called "Latex" during 25 to 30 years of their life expectancy before being cut down and replanted. Many researchers paid their attention to how to manage the rubber plantations to maximize latex through breeding, cloning or fertilizer application (SHORROCK

et al., 1965; COLLING and SOWCHING, 1967; NARAYANAN and HOCHAI, 1973; NARAYANAN *et al.*, 1973; NGA and SUBRAMANIAM, 1974; SAMSUDDIN *et al.*, 1987). In the past decades, some authors started to pay much attention to rubber wood (WESTGARTH and BUTTERY, 1965; TEMPLETON, 1969; MAINSTONE, 1970; SENGHUAT, 1981; SIM, 1989; NAJIB and OTHMAN, 1996) and from the 1980s, there has been growing interest in maximizing the utilization of rubber woods. Further, due to their potentials as a source of raw materials, much attention is being focused on rubber wood as a source of sawn timber to supplement the existing supply (WANRAZALI *et al.*, 1983). However, there has been very few information on volume equation and mean annual increment (MAI) of rubber trees. To our knowledge, there is only one paper on volume equation developed by WANRAZALI *et al.* (1983) as rubber wood, in the past, was burnt on the spot or mainly used as wood fuel for locomotive engines, brick burning or latex curing (FAO, 2001b).

In Cambodia, the first rubber plantation was established by a French national Mr. BOULLIARD in 1910 in Prey Nup district, Kompot province, but the establishment of grand rubber plantations for industrial purpose started in 1920 (TICHIT, 1981). Since then the share of rubber sector in national economy become more and more vital. In 1964, the exportation of rubber productions increased by 24% of agricultural share in GDP, ranked second after rice production (MAFF, 1965), and in 2004 rubber productions contributed to 4% of 33% of agricultural contribution to GDP, ranked second after forest productions (MAFF, 2004). Now around sixty

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thousands hectares have been occupied by rubber plantations throughout the country. In mid 1990s as the trend of rubber wood processing from foreign countries started in Cambodia, the central government set up a ten-year program of cutting and replanting of rubber trees. Thousands of hectares of old rubber trees per year were felled and sold to rubber wood processing companies. Unfortunately, little information is available concerning either individual tree volumes or mean annual increment (MAI). Therefore, there is an urgent need to develop volume equation and to know the growth rate of rubber trees planted in Cambodia for a better future management.

The objectives of this study were to set up volume equations and to estimate stand volume and the mean annual increment per hectare for the rubber trees in Cambodia. In this study, we investigated the clone PR107, one of the most common clones in Cambodia.

STUDY SITE

The study area is in Krek Rubber Plantation (105°53'38"E-106°00'18"E and 11°46'23"N-11°53'27"N), located in Kompong Cham Province around 190km from Phnom Penh, the capital city (Fig. 1). Large part of the plantation's soil is red basaltic with the average of PH=4.57 (RRIC, 1968) and the climate is tropical with a bi-annual change of monsoonal systems, the

rainy season (May-October) and the dry season (November-April). Mean annual rainfall and temperature have been 1,700mm and 28°C respectively. The total areas under rubber from one to 54 years old in 2005 were 3899.63ha. Due to the civil war during 1970-1990, there are no stands of the age from 15 to 35 years old in 2005.

MATERIALS AND METHODS

To make the volume equations, we used 60 trees from 4 stands at different ages 36, 44, 45 and 46 (Table 1). Before felling, we measured total height and diameter at breast height (DBH at 1.3m) using Vertex III (Haglof, Finland) and diameter tapes, respectively. Then we felled them down, cut into segments of one meter in length (up to 10cm diameter of branches), measured and recorded diameters of both end sides of each segment. Volumes per segment and per tree were calculated by SMALIAN's formula as follows;

$$V_s = \frac{A_1 + A_2}{2} L, \quad (1)$$

where V_s is segment volume (m^3), A_1 and A_2 are cross sectional areas of both end sides of segment (m^2), and L is length of segment (m). We developed the widely used volume equations; one variable formula (2) and SCHUMACHER-HALL's formula (3), and the coefficients were estimated by standard

Fig. 1 Location of study site

linear regression methods by applying a logarithmic transformation, the formulae (4) and (5), using the statistic software R;

$$V = a_1 D^{b_1}, \quad (2)$$

$$V = a_2 D^{b_2} H^{c_2}. \quad (3)$$

$$\log V = \log a_1 + b_1 \log D, \quad (4)$$

$$\log V = \log a_2 + b_2 \log D + c_2 \log H, \quad (5)$$

where V is total volume, D is dbh (cm), H is total height (m), and a_1 , b_1 , a_2 , b_2 , c_2 , are constants.

In order to estimate stand volume and its increment, we established 15 sample plots at different ages (6-10 and 36-48). Each sample plot included three planting lines; each has 10 trees as shown in Fig. 2. The planting points were designed regularly equidistant from one stem to one stem and from one line to another line. However, in the sample plots some trees

Table 1 Summary of data for volume equation

Stands	A	B	C	D
Age (years)	36	44	45	46
DBH (cm)				
mean	34.5	44.8	42.4	39.8
min	26.0	28.0	29.8	26.5
max	41.0	62.0	56.4	52.0
Total Height (m)				
mean	23.5	32.0	28.0	27.8
min	16.2	25.3	18.4	16.9
max	25.3	42.1	35.9	47.3
Stem volume (m ³) estimated by Smalian's formular				
mean	0.90	1.84	1.29	1.22
min	0.25	0.60	0.65	0.41
max	1.37	3.41	2.21	2.30

Table 2 Primary data of 450 standing trees in 15 sample Plots

Ages in 2005	Plot Areas (m ²)	No. trees per ha	DBH (cm)			Total Height (m)			Volume m ³ /ha	MAI m ³ /ha/year
			Max	Min	Mean	Max	Min	Mean		
6	538	558	19.2	15.2	14.3	9	8.2	12.8	61	10.10
8	521	575	24.0	9.9	17.1	18.8	10.5	15.5	98	12.19
9	597	502	22.7	9.0	16.0	19.6	9.0	15.2	74	8.22
10	594	505	23.7	10.9	16.3	18.1	9.0	14.8	78	7.78
37	1,049	286	73.0	19.7	39.1	37.8	15.7	26.6	366	9.88
38	783	383	50.5	17.4	35.2	39.6	16.9	27.7	374	9.85
39	620	484	52.7	19.8	33.6	41.5	14.1	22.9	398	10.20
40	812	369	41.7	20.7	34.4	39.6	23.0	30.6	331	8.26
41	1,120	268	61.1	49.5	38.8	19.2	14.6	26.3	336	8.19
42	817	367	50.8	17.2	35.2	41.7	14.8	27.9	356	8.48
44	945	318	62.3	17.4	41.5	50.4	15.1	31.5	455	10.33
45	699	429	50.5	20.8	37.2	37.2	15.6	25.6	448	9.96
46	971	309	54.6	24.0	40.6	42.2	17.6	31.9	412	8.95
47	851	352	52.0	25.1	38.1	42.5	16.4	31.6	406	8.64
48	740	405	60.2	19.9	37.5	50.1	17.0	33.4	473	9.86

Fig. 2 Lay out of Sample Plots

The circle and cross symbols indicate living and dead or removed trees, respectively.

were dead or removed out and therefore the area of each plot was calculated in the form of three rectangles while each length of every 10 trees was made by the direct measurements, and the width was based on the records of the interval of planting lines which varied from 6m, 7m to 8m. The areas of sample plots varied from 538m² - 971m² (Table 2). DBH and total height of 450 standing trees in 15 sample plots were measured by the diameter tapes and Vertex III tools, respectively. Volume per hectare in each sample plot was calculated by the more reliable set up volume equation.

RESULTS AND DISCUSSION

Volume Equations

Table 1 shows summary of data used for developing volume equations for 4 stands. The range of data is 20-62cm for DBH, 16.7-47.0m for total height, and 0.25 to 3.41m³ for stem volume. Fig. 3 showed the relationship between log *V* and log *D*, and the one variable formula was

$$\log V = -3.6041 + 2.2953 \log D \quad (R^2 = 0.9233, N = 60), \quad (6)$$

$$\text{or } V = 0.00024884 D^{2.2953}, \quad (7)$$

SCHUMACHER-HALL's formula was

$$\log V = -3.73563 + 2.23961 \log D + 0.15334 \log H, \quad (R^2 = 0.9245, N = 60), \quad (8)$$

$$\text{or } V = 0.00018381 D^{2.23961} H^{0.15334}. \quad (9)$$

Statistically, the results of the two formulae found no much difference ($R^2 = 0.9233$, $R^2 = 0.9245$), and this may be due to high correlation between *D* and *H*. This result indicates that the one variable formula using only DBH is applicable for the studied clone.

To check the applicability of the volume equations

Fig. 3 Volume of 60 felled trees based on DBH

Fig. 4 Comparison of wood volume for the 60 sample trees estimated using the one-variable equations developed for the clone PR107 in this study (Eq. 6) and by WAN RAZALI *et al.* (1983) for the three clones; RRIM623 (Eq.10), RRIM605 (Eq.11) and RRIM600 (Eq. 12)

Note: The broken line indicates 1:1.

developed in this study to other clones, we compared wood volume for the 60 sample trees estimated using the one-variable equations developed for the clone PR107 in this study (Eq.6) and by WANRAZALI *et al.*, (1983) for the three clones; RRIM623 (Eq.10), RRIM605 (Eq.11) and RRIM600 (Eq. 12) as follows;

$$\log V = 2.4627 \log D - 3.88570656$$

(for RRIM623, $R^2 = 0.4280$), (10)

$$\log V = 2.01461 \log D - 3.151701113$$

(for RRIM605, $R^2 = 0.5754$), (11)

$$\log V = 1.97473 \log D - 3.321792547$$

(for RRIM600, $R^2 = 0.5148$). (12)

As shown in Fig. 4, the relationship of the estimated volume between Eq.10 for RRIM623 and Eq.6 for PR107 is very close to the 1:1 line, indicating that the volume equation developed in this study can be applied not only for PR107 but also for RRIM623. However, our PR107-equation tends to slightly underestimate and overestimate the volume from the RRIM605 equation for trees with smaller and larger than about 1.2m³, respectively, while consistently overestimating the volume estimated from the RRIM600 over all range of tree size (Fig. 4). Due to the existence of more different clones of rubber trees (about 25 clones), we need more comprehensive and intensive research on the volume equations as in AKINDELE and LEMAY (2006) who classified the volume equations for 77 common timber species in the tropical rain forests into 5 species groups.

Tree Growth

Table 2 shows summary for 15 sample plots. Fig. 5a, 5b and 6 indicate the changes in total height, DBH and stand volume in relation to stand age, respectively. The ranges of mean values are 14.3 to 41.6cm for DBH and 12.8 to 33.4m for total height. The stand volume per hectare is from 60.6 to 473.5m³. Due to no planting during civil war (1970-1990), we can not exactly predict tree size at the age 25-30 years old that is common rotation age. To get rough information at the age 25-30, linear regression lines are indicated in the Fig.5 and 6.

There were not large differences between different stands in the mean annual increment (MAI), which is stand volume at a given age divided by the age (Table 2). The average MAI of all plots was 9.33m³/ha/yr, which was larger than the value of 7m³/ha/yr for Indonesia, Malaysia, Thailand and Vietnam reported in the FAO working paper (FAO, 2005). It was described that stand volume of rubber wood is about 250m³ in Thailand (CHANTUMA *et al.*, 2002) and 207.9m³ in Malaysia (SURATMAN *et al.*, 2004) at 25-30 year old trees that are common rotation age. Based on the regression line shown in Fig. 6 of our results, the stand volume was estimated to be 240m³-270m³ at 25-30 years old trees, indicating that there are not large differences among those three countries. However,

stand volume per hectare depends upon numerous factors such as clones, sites, and management system (FAO, 2001a), so we need more investigation for each clone and site covering wide range of age classes.

Is the growth potential of rubber tree higher than other plantation tree species in tropical forests? The mean annual increment (MAI) of volume/ha for rubber trees in Cambodia was also not remarkably lower if compared to teak plantations (*Tectona grandis*) - a world's premier hardwood timber planted mostly in tropical zones. MAI of teak plantations in Indonesia and Myanmar with 50 year rotation age were found 13.8m³ha⁻¹y⁻¹ and 8.7m³ha⁻¹y⁻¹ (PANDEY and BROWN, 2000) respectively while *Acacia mangium* has 24m³ha⁻¹y⁻¹ of the MAI in Malaysia (FAO, 2005). According to this 2005 FAO working paper, the MAI of *Eucalyptus robusta* is 21m³ha⁻¹y⁻¹ in Malaysia, India and Papua New Guinea, and *Casuarina equisetifolia* in Asia has 7-10m³ha⁻¹y⁻¹ of the MAI. Based on these references, the growth potential of rubber tree in

Fig. 5 Relationship between DBH (a), TH (b) and Ages. The dots and error bars indicate mean and standard deviation, respectively.

Fig.6 Volume of 15 stands by ages

Cambodia is lower than the fast growing species such as *Acacia mangium* and *Eucalyptus robusta*, but not so large different from the other species.

CONCLUSIONS

This study is the first trial to develop wood volume equation and growth information of rubber trees in Cambodia, being very essential for better management of rubber forests. Although our samples were lack of the middle ages (15-30 years old) due to internal war, we obtained the following findings;

- 1) Both of the one - and two - variable volume equations were well-fitted.
- 2) The developed one-variable equation for the clone PR107 can be used for the clone RRIM623.
- 3) The MAI was about $9\text{m}^3\text{ha}^{-1}\text{y}^{-1}$, being smaller than the fast-growing species and similar to other species such as Teak.
- 4) The stand volume estimated for common rotation ages (25-30 years old) may be about 240-270 m^3/ha , similar to the value reported in Malaysia and Thailand.

However, our result calls for further research to develop volume equations and predict stand growth for other clones in various regions.

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