

Growth Performance and Biomass Accumulation of a *Khaya ivorensis* Plantation in three Soil Series of Ultisols

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Abstract: Problem statement: There was no information about the relationship between growth parameters, such as diameter and height and tree component biomass of *Khaya ivorensis* plantations with different soil types. The objectives of this study were, first, to determine and compare the growth of *K. ivorensis* in three different (Padang Besar, Durian and Rengam) soil series of Ultisols and, second, to develop an allometric equation that estimates the biomass accumulation of the *K. ivorensis* plantation in three different soil series five years after planting. **Approach:** This study was conducted at a *K. ivorensis* plantation in the Forest Research Institute Malaysia (FRIM) Research Station in Segamat, Johor, Malaysia. The tree height (H) and Diameter at Breast Height (DBH) were measured to evaluate the growth performance of the *K. ivorensis* plantation. Five sampled or trees stand of *K. ivorensis* in each soil series were destructively analyzed. **Results:** The highest growth rates in terms of MAI diameter and height, and basal area were found for the Padang Besar soil series, which was followed by the Durian and Rengam soil series. The best fit regression of site-specific equations developed from the independent variable D are recommended for estimating tree component biomass and stem volume in each site. A single allometric equation using D was applicable for the estimation of biomass and stem volume however, in Padang Besar, stem biomass and stem volume were estimated with an equation using D^2H . The highest stem volume and biomass accumulation value were recorded at Padang Besar ($77.99 \text{ m}^3 \text{ h}^{-1}$ and 63.16 t ha^{-1} , respectively), which was followed by the Durian ($53.10 \text{ m}^3 \text{ h}^{-1}$ and 46.33 t ha^{-1} , respectively) and Rengam soil series ($43.13 \text{ m}^3 \text{ h}^{-1}$ and 40.96 t ha^{-1} , respectively). **Conclusion:** Differences in the growth and biomass accumulation data indicate that forest productivity of *K. ivorensis* was affected by different site conditions. The higher growth performance and productivity of *K. ivorensis* in terms of the stem volume and biomass accumulation in Padang Besar compared those in the Durian and Rengam soil series shows that the species was able to adapt to the soil characteristics of the Padang Besar soil series.

Key words: Allometric equation, biomass accumulation, forest plantation, growth performance, *Khaya ivorensis*

INTRODUCTION

Sustainably managed natural or plantation forests have multiple environmental functions that are important both at the national and international scales and play a vital role in sustainable development (FAO, 2005). The tropical rainforests are one of the natural resources and most complex terrestrial ecosystems in

the earth surface in terms of structural and species biodiversity that are very important for human life (Montagnini and Jordan, 2005). However, the tropical forests have decreased at a rate of 16.9 million hectares annually (FAO, 2003). In Malaysia, the average annual rate of deforestation was 78,500 hectares of forest per year between 1990 and 2000, which is an average annual deforestation rate of 0.35% (FAO, 2005).

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Between 2000 and 2005, the rate of forest change increased by 0.65% per year. In total, between 1990 and 2005, Malaysia lost 6.64% of its forest cover, which is approximately 1,486,000 hectares (FAO, 2005). Deforestation is a worldwide environmental issue which occurred elsewhere particularly in tropical regions (Akbar *et al.*, 2010) of forests to non-forested land (Montagnini *et al.*, 1997).

Deforestation is the conversion of forests into other lands leads to declining soil fertility, which is indicated by a decrease in soil organic matter due to an imbalance between the input and output of carbon and other nutrients that originate from vegetations (Brown *et al.*, 1989; Arifin *et al.*, 2008a). Declining soil fertility levels at the local results in low growth performance and affects the wider environment. The Kyoto Protocol within the framework of the Clean Development Mechanism (CDM) Project of Forestry emphasizes the function of forests as carbon sinks to obtain economic compensation through carbon trading and forestry activities which ultimately reduce global warming through carbon conservation, sequestration and substitution (Brown, 1999).

In order to solve the problems associated with wood supply deficiencies and to reduce pressure on natural forests, forest plantation has been proposed as a tool for restoration of degraded lands by affecting the vegetation structure and soil (Pedraza and Williams-Linera, 2003; Arifin *et al.*, 2008b; Hamzah *et al.*, 2009; Saga *et al.*, 2010; Zaidey *et al.*, 2010). In the future, forest plantation is expected to replace the role of natural forests in providing raw materials for forest industries. In addition, Montagnini and Jordan (2005) and Akbar *et al.*, (2010) stated that forest plantation has potential and, that tree planting control soil erosion and improve soil fertility.

In Malaysia, forest plantation was first introduced in the beginning of the last century when rubber tree (*Hevea brasiliensis*) was planted at Kuala Kangsar, Perak for rubber production (Appanah and Weinland, 1993). Later, the Compensatory Forest Plantation Project through a loan from Asian Development Bank in early 1980 was initiated to plant fast growing hardwoods such as *Acacia mangium*, *Gmelina arborea* and *Paraserianthes falcataria*. The species were widely planted throughout Peninsular Malaysia (Appanah and Weinland, 1993). Another fast growing species, such as *Khaya ivorensis*, was selected by the Malaysian Timber Industry Board as one of eight species targeted for large-scale planting in Malaysia in 1992 (MTIB, 2010). *Khaya ivorensis* is a promising exotic tree species in the

forest plantation program in Malaysia (Appanah and Weinland, 1993). The species belongs to the family Meliaceae, which is one type of African mahoganies. It was initially in the States of Kedah and Selangor in Malaysia in the late 1950's and early 1960's and has adapted well to the local climatic conditions (Ahmad Zuhaidi *et al.*, 1999; Jeyanny *et al.*, 2009).

The Forest Research Institute Malaysia (FRIM) established a forest plantation in Segamat, Johor in 2004 as a sample area for future forest plantation development. The forest plantation was started on a small scale with several exotic and indigenous species. One of exotic species was *K. ivorensis* which was planted on different soils such as the Rengam, Durian and Padang Besar soil series. Various studies have been conducted on the growth performance of *K. ivorensis* (Appanah and Weinland, 1993; Ahmad Zuhaidi *et al.*, 1999; Jeyanny *et al.*, 2009). Although most studies investigated the effect of different silviculture treatments on growth performance, to our knowledge, a study has not been conducted on the growth performance and biomass accumulation under different soil conditions particularly soil series.

Information about the growth performance and biomass accumulation of *K. ivorensis* is important for future forest plantation establishment and is critical for the management of forest stands. Furthermore, information on biomass is essential for assessing the total and annual forest vigor capacity. Biomass is defined as the total amount of aboveground living organic matter in trees and is expressed as oven-dried tons per unit area (Brown, 1997). The estimation of aboveground biomass is necessary for studying productivity, carbon cycles, nutrient allocation and fuel accumulation in terrestrial ecosystems (Zhang *et al.*, 2007). In addition, root biomass data are scarce but necessary to complete estimate the total carbon sequestered by a forest. According to Brown *et al.* (1989) and Brown (2009), the variability in biomass data may caused by soil factors, stand age, stand history, structural differences and climatic factors such as temperature and precipitation. In addition, De Castilho *et al.* (2006) stated that around 30% of the AGLB variation was explained by soil factors. Therefore, the objectives of this study were to investigate the influence of soil series on the growth and biomass accumulation of a *K. ivorensis* plantation by comparing the growth of *K. ivorensis* in different soil series and developing an allometric equation that estimates biomass accumulation of the *K. ivorensis* plantation under different soil conditions. The information will be a reference point for the future development of forest plantations of *K. ivorensis*.

MATERIALS AND METHODS

Description of the study site: The study was performed at the FRIM Research Station at Johor, Malaysia. The station located about 250 km from Kuala Lumpur. Generally, the mean annual temperature and humidity are 27°C and 94%, respectively. The mean annual rainfall from 2004-2008 was 2508 mm year⁻¹ and the dry season varied every year. The topography is flat to undulating. Based on the United States Department of Agriculture soil taxonomy, the soil in the study site is classified as Ultisols which is the most widespread soil in Peninsular Malaysia (Paramanathan, 2000). The soils are extremely leached, highly weathered and well drained; therefore, the soil is dominated by clay minerals, which are acidic in nature and display pH values ranging from 4-5. The soils are reportedly high in aluminum saturation and base deficient and the charge on the exchange complex varies with the pH.

Soil series and silvicultural treatments: *K. ivorensis* was planted in three different soil series of Ultisols. The description of three soil series in terms of latitude, longitude and elevation are described. The Rengam soil series (02° 34' 683 N; 102° 58' 643 E; 82 m a.s.l.), the Durian soil series (02° 34' 927 N; 102° 58' 678 E; 74 m a.s.l.) and the Padang Besar soil series (02° 34' 908 N; 102° 58' 725 E; 78 m a.s.l.). The Rengam soil series is developed over acid igneous rocks, including granite. The soil is deep, strong brown, coarse sandy clay, friable and well drained. In contrast, the Durian soil series is developed on shale interbedded with sandstone and/or quartzite. The soil is moderately deep, brownish yellow to dark brown, friable, fine sandy clay to silty clay and well drained. Finally, the Padang Besar soil series is a closely related soil developed on shale parent materials. The soil is characterized by a brownish yellow (10YR 6/6) color, slightly firm consistency, fine sandy clay texture and good drainage.

The species was planted in 2004 using the land clearing and monoculture system. The initial planting spacing was 4 m x 3 m (about 833 trees ha⁻¹). All of the plants were applied the same dosage of fertilizer from early planting for three years. The treatment during cultivation was fertilizer 200 g of CIRP (Christmas Rock Island Phosphate) fertilizer/tree; after cultivation, 500 g of organic fertilizer/tree was applied every six months until the plant were three years old. Weeding was done once every three months.

Data collection: The method of field sampling was applied for collecting field data from three 40x30 m

(0.12 ha/plot) in each soil series. The tree height (H) and diameter at breast height (DBH) were measured to evaluate tree growth and to estimate the biomass of the planted *K. ivorensis*. Tree height was measured using an ultrasonic hypsometer and DBH was measured using diameter tape. The number of trees at each site was recorded.

To choose the representative trees for destructive sampling, the DBH and tree height data in each different site were sorted from the lowest to the highest and then they were used to calculate the basal area. The basal area data were summed and divided into five groups and each group had the same sum. In each group, one tree sample in the middle of each group was chosen.

Destructive sampling was performed following the methods of Heriansyah *et al.* (2007), where the five sample trees for each soil series were chosen. First, the roots were dug out and causing the tree to fall. After falling, the total height of the tree was measured and then the stems were separated into component logs, for example, 0-30, 30-130 and 130-330 cm and every 2 m to the top. The destructed trees were divided into four components as follows: stems, leaves, branches and twigs and roots. About 5 cm disc stem samples were taken from each part and the other component samples, such as branches, leaves and roots, were collected and brought to the laboratory to be oven dried. The total fresh weight of each component was weighed using a balance in the field. The sample components of the trees were oven dried at 85°C until a constant weight was reached (about 7 days for the stem and 4 days for the other components).

Biomass measurements: The dry weight/fresh weight ratios were used to estimate the dry weights of the biomass components for the individual trees. Total biomass of individual trees was calculated by the whole weight of the components as follows:

$$TDW = \frac{SDW}{SFW} \times TFW$$

Where:

TDW = The total dry weight (kg)

SDW = The sample dry weight

SFW = The sample fresh weight

TFW = The total fresh weight

The stem volume of an individual tree is the total volume of each stem log. Smalian's formula was adopted to estimate the volume of each stem log of a sample tree, which is given by Kusmana *et al.* (1992):

$$V_s = \frac{(G1+G2)}{2}$$

Where:

- V_s = The volume of the log
G1 and G2 = The cross-sectional areas at each end of the log
L = The log length

The allometric equation to estimate the biomass of the tree components and stem volume of the *K. ivorensis* plantation at each site was established using the independent variable D (DBH) or the combination of D squared and H. The relationship between the independent variable and the biomass of components and stem volume was described by a power function $Y_i = a(D)^b$ or $Y_i = a(D^2H)^b$, where a and b are the regression constants, D is the tree diameter at breast height (cm), H is the total height (m) and Y_i is the dry biomass (kg) of a tree component i (stem, branches, leaves and roots) or stem volume (m^3). To choose the most appropriate biomass prediction for each soil series, both methods for stand biomass prediction were compared.

The power functions were fitted by linear regression on log-transformed data using the model $\log(Y) = \log(a) + b[\log(X)]$. To transform the logarithmic regression back into a power function, the antilog of the intercept 'a' was multiplied by a correction factor (CF). The computation of a correction factor was necessary to correct the bias in the biomass estimation. The correction factor was calculated as given by Onyekwelu (2007): $CF = \exp[(SEE^2)/2]$ or $\exp[(variance)/2]$, where SEE is the standard error of estimate, variance is the square of the root mean square error (in the logarithmic form). The functions were compared using the coefficient of determination (r^2), the Standard Error of the Estimate (SEE) and significance of the F-ratio. Apart from the allometric equations established from each site, we developed an equation based on a single allometric parameter. The equation was used to estimate the stem volume and the amount of biomass of all plantations in the different sites. To determine whether the site-specific and single allometric equation was applicable for estimating tree component biomasses and stem volume in the Padang Besar, Rengam and Durian soil series, we used a t-statistical test to compare the biomass values of both allometric equations. The aboveground biomass was determined by calculating the sum of the biomasses of the stem, branch and leaf. The total biomass was calculated as the sum of the aboveground biomass and root biomass. The total biomass in each plot was

calculated from the summed biomasses of all trees in the plots. The biomass and stem data volume were converted into hectares.

To determine the significant differences in growth performance of the planted *K. ivorensis* between soil series, One-Way ANOVA followed by Least Significant Difference (LSD) was used. The regression analysis was conducted between tree growth parameters with tree component biomass and stem volume values. All of the data were analyzed using the (SAS) software ver. 9.1.

RESULTS AND DISCUSSION

Growth performance of *K. ivorensis*: The summary of the growth data for the *K. ivorensis* stands at five years old in the three different soil series are shown in Table 1. The survivals of the planted *K. ivorensis* in Padang Besar, Durian and Rengam soils were 94%, 97% and 97%, respectively. The high survival of the planted *K. ivorensis* in the Padang Besar, Durian and Rengam soil series shows that the land-clearing system is the most appropriate management strategy for this species. This indicates that the species demands full light (intolerant) for growth. According to Evans (1992), two major factors that influence the seedling survival are the light intensity and the amount of available moisture especially during the initial stage of stand establishment.

Forouhakhch *et al.*, (2006) showed that the diameter and height are good indicators of the site conditions (soil and climate); however, they are also dependent on other factors, such as interspecific competition, standard density (spacing) and climatic conditions. The analysis of variance of growth of *K. ivorensis* showed that there was a significant difference at $p \leq 0.05$ between sites. The result showed that the average diameter of the planted *K. ivorensis* in Padang Besar was significantly higher (14.40 cm) than that in Durian (12.37 cm) and Rengam (11.60 cm). The average height of *K. ivorensis* in Padang Besar was the highest (10.56 m) and was not significantly different from that in Durian (9.76 m); however, it was significantly different from that in Rengam (7.85 m).

In general, the growth rate is expressed as the Mean Annual Increment (MAI). According to Nishizono (2010), the age of the maximum MAI is a forest management indicator used to determine the optimal rotation length. Although the Mean Annual Increment of Height (MAIH) of the planted *K. ivorensis* in Padang Besar was higher compared with Durian and Rengam, it was not significantly different between sites.

Table 1: Growth performances of the *K. ivorensis* plantation five years after planting at three different soil series

Sites (Soil series)	Survival (%)	Stand density (trees ha ⁻¹)	Diameter (cm)	MAID (cm year ⁻¹)	Height (m)	MAIH (m year ⁻¹)	Basal Area (m ² ha ⁻¹)
Padang Besar	94	783	14.40±0.29a	2.88±0.18a	10.56±0.55a	2.11±0.11a	13.41±0.48a
Durian	97	808	12.37±0.91b	2.47±0.06b	9.76±0.54a	1.95±0.10a	10.98±0.34b
Rengam	97	808	11.60±0.31b	2.32±0.06b	7.85±0.50b	1.57±0.10a	9.65±0.31b

Note: Means followed by the same letter are not significantly different at P≤0.05 as determined by Least Significant Different (LSD). Values are expressed as mean ± standard error. MAID; Mean annual increment diameter. MAIH; Mean annual increment height

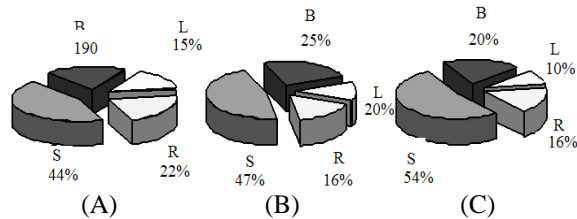


Fig. 1: Biomass storage of different tree component of *K. ivorensis* at three different sites. (A) Rengam; (B) Durian; (C) Padang Besar (S= Stem; B= Branches; L= Leaves; R= Roots)

There was a significant difference in the Mean Annual Increment of Diameter (MAID) of *K. ivorensis* between sites ($p \leq 0.05$). The MAID of *K. ivorensis* in Padang Besar was 2.88 cm year⁻¹ which was significantly different from that in Durian (2.47 cm year⁻¹) and in Rengam (2.32 cm year⁻¹). Based on the criteria defined Mindawati *et al.* (2002) the growth of *K. ivorensis* in all sites was very fast because the MAID of *K. ivorensis* in all soil series was higher than 1.4 cm year⁻¹.

The basal area in the Padang Besar soil series was 13.41 m² ha⁻¹, which was significantly higher than that in the Rengam and Durian soil series (9.65 and 10.98 m² ha⁻¹, respectively). It has been shown that stand density reflects the size of basal area. The stand density of the *K. ivorensis* stand in Padang Besar was 783 trees ha⁻¹ less than that in Rengam was 806 trees ha⁻¹ and the Durian had a stand density of 808 trees ha⁻¹. In fact, there was a relationship between the basal areas and stand densities. In this case, the basal area was higher in a stand with a lower density. According to Ahmad Zuhaidi *et al.* (1999) one of management characteristics in a developing forest stand is the silviculture activities of periodical thinning and pruning before harvest. Thinning is the selective removal of trees, which is primarily undertaken to improve the growth or health of the remaining trees. Thinning provides the optimum growth space so that stem diameter can increase, while pruning is used to increase the stem quality. In addition, thinning might be applied to increase the resistance of the stand to environmental stress such as drought, insect infestation or extreme temperature.

According to Appanah and Weinland (1993) *K. ivorensis* prefers to be planted on moderately cool land with wet alluvial soils and moderate clays, while all of the soil series in this study were derived from sandy clay with good drainage but different parent materials. The Padang Besar and Durian series are derived from shale material, whereas Rengam series is derived from granite material. *K. ivorensis* is naturally found along rivers and streams (Appanah and Weinland, 1993). In this study, the location of the Padang Besar soil series was close to the river; this closeness to the river is why the growth of *K. ivorensis* in Padang Besar was higher than that in Durian, although the soil in both locations was derived from the same parent material.

Compared with the growth performance of *K. ivorensis* at several sites in Malaysia, the growth performance in this study was significantly higher in the Padang Besar soil series. For example, in the Bukit Lagong Forest Reserve, the species achieved an average diameter of 12.3 cm 4 years after planting (Ahmad Zuhaidi, 1999), whereas in Mata Ayer, Perlis, the species had an average diameter of 9.1 cm at a similar age. According to Evans, 1992, soil is one of the factors that influence the growth rate of species in addition to the stand density, the age of the trees and climate.

Biomass storage and allometric equation: The proportions of the component biomasses of *K. ivorensis* in the three sites were different. Figure 1 shows the calculated biomass distributions of each tree component. The results show that the stem biomass was the greatest proportion in Padang Besar (54%), followed by that in Durian (47%) and in Rengam (44%). The amount of stem biomass was closely related to the production of trees through photosynthesis which is generally stored in the trunk. The first stem segment measured from the base of the stem, which is composed of wood substances, is generally wider than at the end of the stem, which is more dominated by juvenile wood.

The proportion of the tree component biomasses compared to the total biomass was different from the distribution of component biomasses of the trees, such as mahogany stem (*Swietenia macrophylla*) which constitute 73% of the total aboveground biomass (Adinugroho and Sidiyasa, 2002).

Table 2: Single allometric equations to estimate the stem volume and biomass of *K. ivorensis* five years after planting

Trees component	Independent variables	A	B	r ²	CF	SEE	Sig.
Stem	D	0.08462	2.28884	0.94	1.016	0.180	**
	D ² H	0.05459	0.85711	0.98	1.006	0.112	**
Branch	D	0.00400	3.05460	0.81	1.121	0.478	**
	D ² H	0.00311	1.09985	0.78	1.159	0.543	**
Leaf	D	0.02248	2.23872	0.78	1.076	0.383	**
	D ² H	0.02243	0.78222	0.70	1.115	0.466	**
Root	D	0.03547	2.23582	0.89	1.033	0.254	**
	D ² H	0.03387	0.78698	0.82	1.061	0.344	**
Stem volume	D	0.00021	2.26234	0.95	1.013	0.162	**
	D ² H	0.00014	0.84469	0.98	1.005	0.101	**

Note: **: Highly significant at $p \leq 0.01$

The differences in the proportions were also observed in the different age classes and sites. Heriansyah *et al.* (2007) reported that *Acacia mangium* at 3 - 10 years old in West Java has stem biomasses between 63 and 71% of the total biomass, whereas 2.5 - 10.5 years old plants in South Sumatra had stem biomasses between 58 and 77% of the total biomass.

The contributions of stems, branches, leaves and roots to the total biomass of *K. ivorensis* in all sites were 44-54, 20-25, 10-15 and 16-19%, respectively. Differences in the proportions were affected by the model/form and size of the branches and structure of large and small branch sizes in the canopy (Heriansyah *et al.*, 2007). Based on the field observations; of morphology, *K. ivorensis* stands in the present study had more branches, twigs and leaves, whereby the trees did not have a big tree trunk with straight stem architecture and fewer branches than those reported by Ahmad Zuhaidi *et al.* (1999).

Several authors have used regression models for estimating biomass using only D, which was accurately measured in the field (Hashimoto *et al.*, 2004; Aboal *et al.*, 2005; Segura, 2005; Pilli *et al.*, 2006; Onyekwelu, 2007; Zianis, 2008). In addition, they concluded that tree biomass is primarily a function of DBH and that biomass is relatively insensitive to the tree height; consequently, DBH is widely used in biomass functions. The advantage of biomass functions that incorporate DBH alone in their estimation is that they are simple, practical and economical (Onyekwelu, 2007). However, according to Brown *et al.* (1989) and Brown (1997), models that incorporate tree height (H) usually give good fits. Andre *et al.* (2005) stated that the advantages of regression models that use combination of D squared and H always resulted in a lower SSE and heteroskedasticity was reduced when D²H was used in the regression for the stem, bark, stump and fine roots. Even according to Terakupinsut *et al.* (2007), the accuracy to estimate biomass by using allometric containing both D and H was better than the diameter alone.

Based on the biomass sample data from each site, the allometric equation for biomass and stem volume of *K. ivorensis* was developed. The allometric equation to the estimate volume and biomass of each tree component (stem, branch, leaf and root) was formulated using the independent variable D and combination of D squared and the total height (D²H). A summary of the allometric equation is presented in Table 2 and the graphical relationships between the growth parameter and tree component biomass or stem volume are shown in Fig. 2. Table 2 shows that in the Padang Besar soil series, both regression models of the stem volume, stem biomass, leaf biomass and root biomass had r-square value close to 1, except for the branch biomass, which had an r-square < 90%. In the Durian and Rengam soil series, both regression models of the stem volume, stem biomass and root biomass had r-square values close to 1, but the branch and leaf biomass r-square values were <90%. Both model equations can be applied to estimate the biomass and stem volume in each site. However, considering that measuring the diameter alone makes field-work easier, the regression model that only uses D as an independent variable is highly recommended.

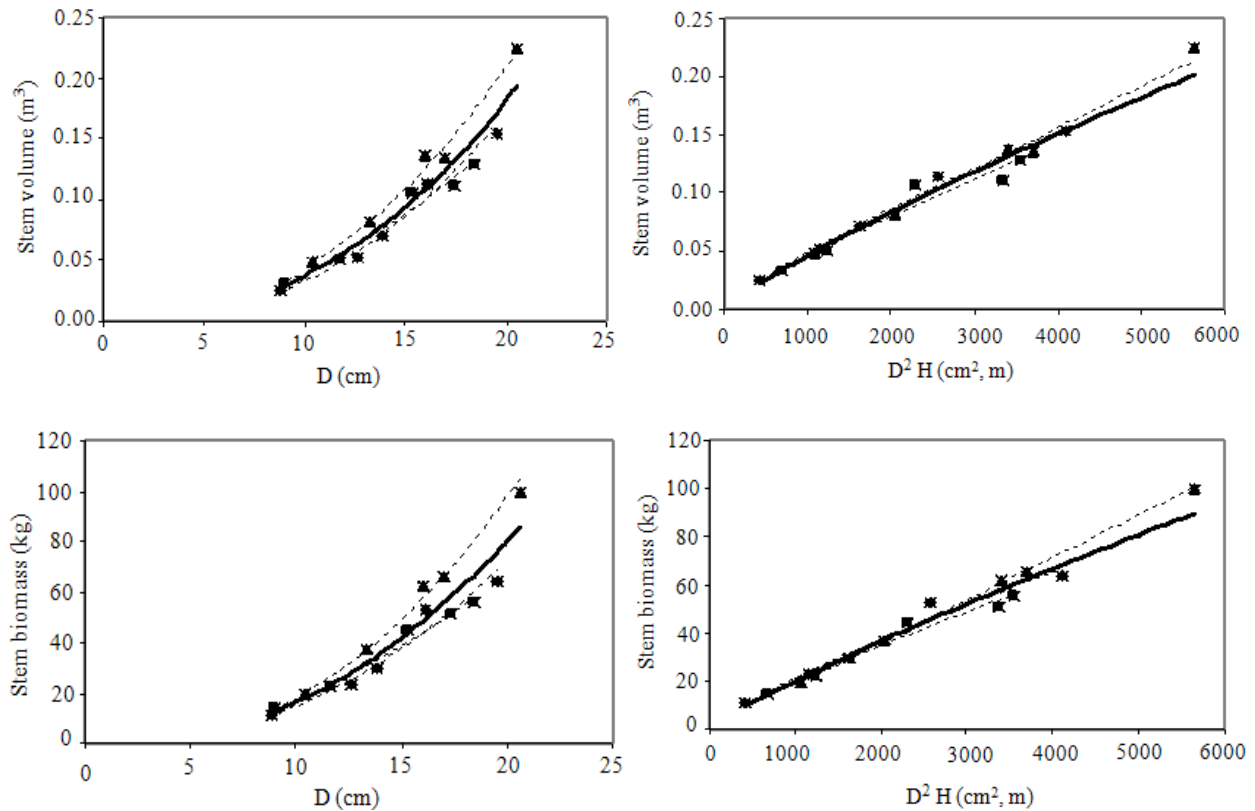
Van *et al.* (2000) reported that most biomass equations that are developed for specific sites cannot be assumed to apply to other location, but there is some justification for producing a generalized equation that is applicable to many sites. For example, Levia (2008) developed a generalized allometric equation for estimating and predicting the foliar dry weight of eastern white pine, whereas Heriansyah *et al.* (2007) found a single allometric equation for the estimation of root and stem volumes of *Acacia mangium* under different management practices in Indonesia. We developed a generalized allometric equation to estimate all plantations of *K. ivorensis* in the three different soil series (Table 3). The regression models were formulated using the independent variable D and a combination of D² and height (D²H).

Table 3: Site specific allometric equations used to estimate the biomass and stem volume of *K. ivorensis* five years after planting at three different soil series

Trees component	Independent variables	Padang Besar					Durian					
		A	B	r ²	CF	SEE	Sig	A	B	r ²	CF	SEE
Stem	D	0.06970	2.41922	0.99	1.012	0.152	**	0.18438	1.97233	0.99	1.010	0.143
	D ² H	0.01960	0.98891	0.99	1.001	0.043	**	0.06220	0.83286	0.98	1.020	0.198
Branch	D	0.00288	3.18721	0.82	1.707	1.034	*	0.00212	3.30397	0.83	1.645	0.998
	D ² H	0.00052	1.30794	0.83	2.013	1.183	*	0.00035	1.39213	0.82	2.131	1.230
Leaf	D	0.00537	2.73022	0.92	1.157	0.540	**	0.08266	1.74706	0.78	1.215	0.624
	D ² H	0.00135	1.10994	0.92	1.238	0.653	**	0.03117	0.73942	0.78	1.329	0.754
Root	D	0.02484	2.36058	0.94	1.090	0.416	**	0.04757	2.07044	0.93	1.075	0.381
	D ² H	0.00724	0.96433	0.94	1.111	0.458	**	0.01560	0.87083	0.92	1.130	0.494
Stem volume	D	0.00025	2.25213	0.99	1.013	0.158	**	0.00041	1.98331	0.98	1.018	0.189
	D ² H	0.00008	0.91750	0.99	1.010	0.143	**	0.00014	0.83534	0.97	1.038	0.273

		Rengam							
		Sig	A	B	r ²	CF	SEE	Sig	
Stem	D	**	0.07315	2.30400	0.98	1.029	0.239	**	
	D ² H	**	0.08596	0.79971	0.99	1.017	0.182	**	
Branch	D	*	0.01079	2.65330	0.78	1.531	0.923	*	
	D ² H	*	0.01316	0.91917	0.79	1.481	0.886	*	
Leaf	D	*	0.01266	2.49264	0.76	1.524	0.918	*	
	D ² H	*	0.01776	0.84276	0.73	1.567	0.948	ns	
Root	D	**	0.03004	2.36025	0.92	1.105	0.447	**	
	D ² H	**	0.03599	0.81710	0.93	1.093	0.422	**	
Stem volume	D	**	0.00014	2.36435	0.99	1.012	0.157	**	
	D ² H	**	0.00017	0.81925	0.99	1.005	0.098	**	

*: Significantly different at p<0.05; **: Highly significantly different at p<0.01; r²: Coefficient of determination; CF: Correction Factor; SEE: Standard Error of the Estimates; D: Diameter at breast height; D²H: Square of D and Height



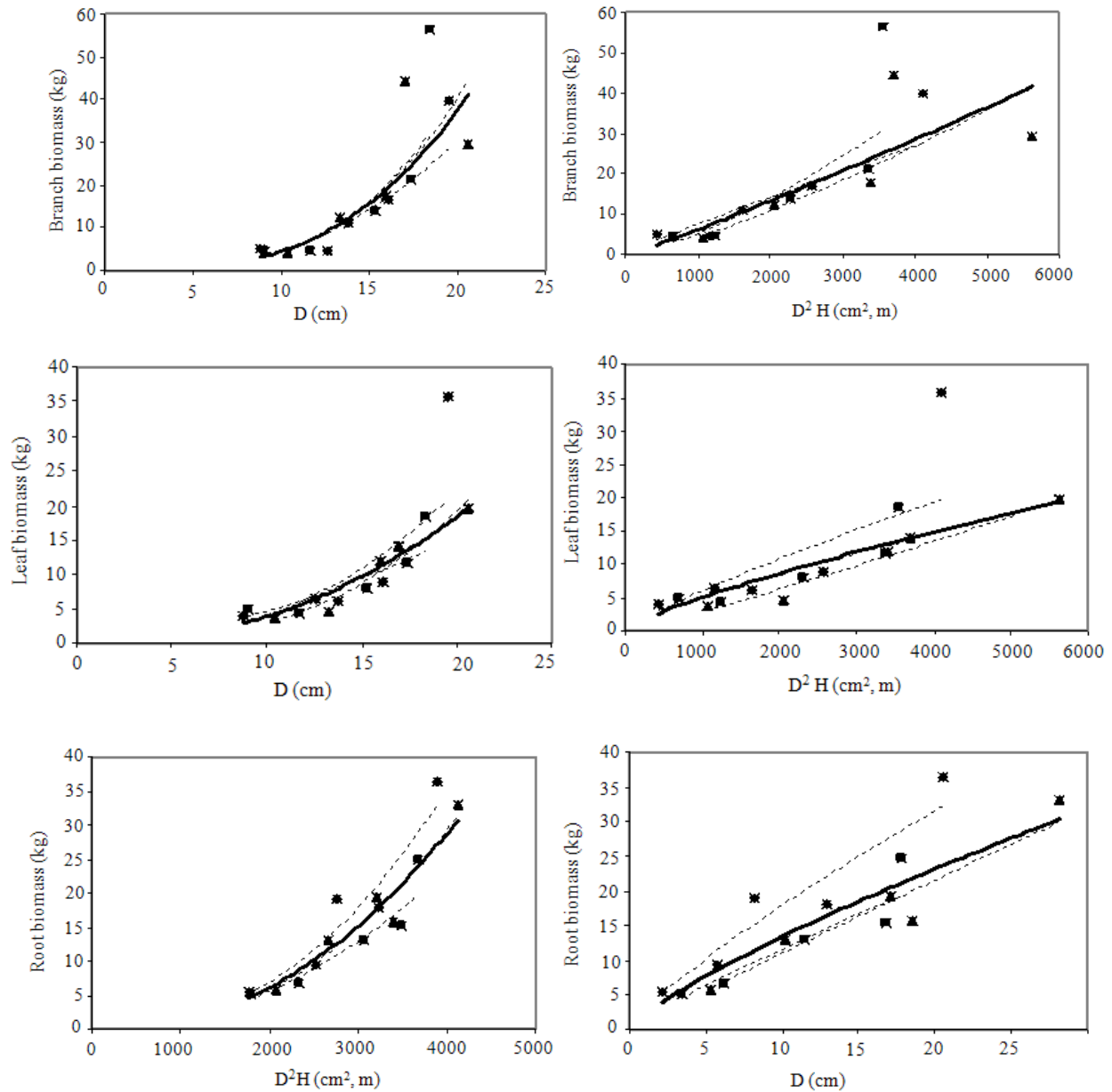


Fig. 2: Graphical relationship between stem volume and biomass of tree components (stem, branch, leaf, and root) of the planted *K. ivorensis* with D and the combination of D squared and height (D^2H) in three different sites. (◆: Rengam ■: Durian and ▲: Padang Besar). Black dotted lines represent the site equation (site-specific equation). Black solid lines represent all sites combined (single allometric equation)

The regression models of the stem biomass and stem volume using the independent variable D^2H had r-square values of 98%, while the r-square of the independent variable D only were 94 and 95%, respectively. The regression models of the branch, leaf and root biomasses using D as the independent variable had slightly higher r-square values than those with the

independent variable that incorporated the total height (D^2H). These models are based on the consideration that regression model of stem biomass and stem volume using the independent variable D^2H has a slightly higher r-square value, Correction Factor (CF) and Standard Error of the Estimation (SEE) than those with the independent variable D.

Table 4: Estimated biomass of tree components and stem volume of *K. ivorensis* stands five years after planting under three different soil series

Sites (soil series)	Stem volume (m ³ h ⁻¹)	Biomass (ton ha ⁻¹)					Total (a+b+c+d)
		Stems (a)	Branches (b)	Leaves (c)	Above ground (a+b+c)	Roots (d)	
Padang Besar	77.699±5.39a	34.43±2.65a	12.02±1.58a	6.27±0.58a	52.72±3.80a	10.44±0.77a	63.16±5.37a
Durian	53.10±3.15b	23.19±1.37b	9.63±1.38b	5.74±0.31a	38.57±2.52b	7.76±0.47b	46.33±3.10b
Rengam	43.13±3.72b	19.25±1.61b	7.10±0.71b	5.46±0.50a	31.80±2.81b	9.16±0.79a	40.96±3.20b

Note: Means followed by the same letter are not significantly different at P≤0.05 as determined by Least Significant Different (LSD). Values are expressed as mean ± standard error

However, according to the t-statistical test, the branch, leaf and root biomass estimation using the site-specific and single allometric equations that incorporate the independent variable D were not significantly different ($p = 0.184-0.975$) in the Padang Besar, Rengam and Durian soil series. The stem volume and stem biomass estimations using the single allometric equation were not significantly different in the Rengam and Durian soil series ($0.075-0.994$), whereas at Padang Besar were significantly different ($p = 0.021-0.034$). Similarly, the estimated stem volume, stem biomass, branch biomass, leaf biomass and root biomass using the site-specific and single allometric equations that incorporate using D²H as the independent variable were not significantly different at all sites ($p = 0.112-0.988$).

Based on this analysis, a single allometric equation using the independent variable D was moderately applicable for branch, leaf and root biomass estimates of *K. ivorensis* in the Padang Besar, Durian and Rengam soil series and stems volume and stem biomass estimates in the Rengam and Durian soil series. Furthermore, a single allometric equation using the independent variable D²H was moderately applicable for stem volume and stem biomass of *K. ivorensis* in the Padang Besar soil series only.

Forest productivity of *K. ivorensis*: Based on the site-specific equation with only D as the independent variable, the productivity of *K. ivorensis* stands in the present study was calculated. We estimated the biomass and stem volume at the sample plots in each soil series. The aboveground biomass of the trees was estimated by calculating the sum of the biomass of the stem, branch and leaf. The total biomass was calculated as the sum of the aboveground biomass and root biomass. The total biomass in each plot was calculated from the summed biomass of all trees in the plots. Table 4 shows the summary of the mean tree component biomass values and stem volumes of the planted *K. ivorensis* at five years old in three different sites. The results show that the Padang Besar soil series produced the highest stem volume (77.99 m³ h⁻¹), which was followed by Durian (53.10 m³ h⁻¹) and Rengam (43.13 m³ h⁻¹), while the accumulated aboveground biomass and total biomass in

Padang Besar were also higher compared with Durian and Rengam. In Padang Besar, the accumulated aboveground and the total biomass were 52.72 and 63.16 t ha⁻¹, respectively, while in Durian, the accumulated aboveground and total biomass were 38.57 and 46.33 t ha⁻¹ respectively. In Rengam, the accumulated aboveground and the total biomass were 31.80 and 40.96 t ha⁻¹, respectively.

The accumulated biomass and stem volume were related to tree diameter and height. The average tree diameter and height of *K. ivorensis* in the Padang Besar soil series were the highest, followed by those in the Durian and Rengam soil series. This indicates that the accumulation of biomass and stem volume increase with increasing diameters and heights. Differences in biomass potential at each location can be caused by various environmental factors, such as climate, rainfall and temperature (Kusmana *et al.*, 1992). The altitude from above sea level and type and soil fertility also affect the standing stock biomass. Fehse *et al.* (2002) studied the relationship between forest biomass and altitude. They found that total above ground biomass from forest stands decreased with increasing site altitude, whereas De Wait and Chave, (2004) studied the relationship between forest biomass and type and soil fertility. Their results showed that forest biomass increases with an increasing level of soil fertility. In this study, *K. ivorensis* was planted on different soil types but in similar environmental conditions, such as rainfall, temperature, humidity and altitude.

The differences in biomass accumulation and stem volume of *K. ivorensis* at five years old in three different soil series in Segamat, Johor were caused differences of soil characteristics. Higher productivity of biomass accumulation in Padang Besar shows that the species is highly adapted to the soil characteristics of the Padang Besar soil series.

CONCLUSION

We found a significant response in terms of growth performance and biomass accumulation of *K. ivorensis* of five years old in different sites. In general, the growth rate of the planted *K. ivorensis* in this study

performed well in terms of mean annual increment of height, mean annual increment of diameter and basal area. However, the growth performance in terms of height, diameter and basal area in Padang Besar was significantly higher compared with the Durian and Rengam soil series. The diameter at breast height was recommended as the independent variable for biomass and stem volume prediction of planted *K. ivorensis* in Segamat, Johor. However, a single allometric equation using the independent variable D was moderately applicable to the estimate branch, leaf and root biomass estimations of *K. ivorensis* in all sites, while it was moderately applicable for stem volume and stems biomass estimations in the Rengam and Durian soil series. However, the single allometric equation using the independent variable D²H was moderately applicable to the estimation of stem volume and stem biomass in Padang Besar. Differences in the growth and biomass accumulation results indicate that forest productivity is affected by different site conditions. The highest growth performance and stem volume as well as biomass accumulation of *K. ivorensis* in Padang Besar compared with that in the Durian and Rengam soil series shows that the species is highly adapted to the soil characteristics of the Padang Besar soil series. This finding indicates that the soil in Padang Besar is more fertile and suitable for the growth of *K. ivorensis*.

ACKNOWLEDGMENT

We wish to thank the Forest Research Institute Malaysia (FRIM), who provided funds for the research project. Part of this study was financially supported by the Fundamental Research Grant Scheme (grant no. 07-11-09-965) from the Ministry of Higher Education of Malaysia (MOHE) through the University Putra Malaysia (UPM), Malaysia. We also appreciate the FRIM staff who helped us with the fieldwork.

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