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Full Length Research Paper

Growth and biomass accumulation of 5 years old *Hopeaodorata* plantation in three different soil series of ultisols

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Studies on growth and biomass accumulation were conducted in 5 years old *Hopeaodorata* plantation in Segamat, Johor. The objectives of this study are, firstly, to determine and compare the growth of *H. odorata* on three different soil series of Ultisols(Baling, Rengam and Kuala Berang) and secondly, to develop an allometric equation to estimate the biomass accumulation of *H. odorata*plantation in three different soil series five years after planting. Results of this study show that, the highest growth performances in terms of diameter and height was found in the Baling soil series, followed by the Rengam and Kuala Berang soil series. The highest stem volume and biomass accumulation were recorded at Baling (33.75 m^3 h^{-1} and 46.20 t ha^{-1}, respectively), followed by the Rengam (33.66 m^3 h^{-1} and 42.90t ha^{-1}, respectively) and Kuala Berang soil series (21.54 m^3 h^{-1} and 32.47 t ha^{-1}, respectively). The best model for site-specific equations developed from the independent variable D are recommended for estimating tree component biomass and stem volume in each site. The information of this study indicates that the productivity of forest plantation is correlated by soil type. This study also shows that, the good soil type for *Hopeaodorata* grow this in Baling soil series.

Key words: Growth, biomass accumulation, allometric equation, soil series, *Hopeaodorata*

INTRODUCTION

The world's forest plantation occupies about 7% or 264 million hectare of the total forest area comprising 78% of productive plantation and 22% of protective plantation (FAO, 2010). Most of these plantations were established through afforestation, where three-quarter of the area, was planted with native species, while one-quarter was planted with introduced species. According to the Montagnini and Porras (1998), forest plantations represent less than 10% of the deforested areas and tree planting compensated about 0.3% of the carbon released by deforestation. The growing expansion of forest plantation started in the early 21st century where the deforestation and climate change were the most concerned international issues.

Deforestation, especially in tropical forest area, is the most important international problem. The tropical forests decreased at a rate of 13 million hectares annually (FAO, 2010).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 (Arifinet al., 2008b;

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Hamzahet al., 2009). 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) stated that forest plantation has potential in controlling soil erosion and improving soil fertility.

Amidst the debate on the loss of the world tropical rain forest, the Government of Malaysia is committed to protect its forest, via establishing 375,000 hectares of forest plantation (MTIB,2007). To expand the plantation area, identification of suitable species to be planted is important to evaluate the growth performance and also their productivity especially biomass accumulation. As a forest institute, The Forest Research Institute Malaysia (FRIM) has taken this initiative to established forest plantation in Segamat, Johor in 2004 as a model area for future forest plantation development. This forest plantation consists with several exotic and indigenous species. In this study, *Hopeaodorata* which was planted on different soil series such as the Rengam, Durian and Padang Besar was selected and evaluate the growth performance as well as their biomass accumulation.

In this study, we evaluated growth performance and biomass accumulation of *Hopeaodorata* in different soil conditions. Despite that, the objectives of this study were to investigate the influence of soil series on the growth and biomass accumulation of *H. Odorata*plantation and develop allometric equation to estimate biomass of *H. odorata* plantation under different soil conditions. This information is useful for the future development of forest plantation for *Hopeaodorata* species.

MATERIALS AND METHODS

Site description

The study was conducted at the FRIM Research Station of Johor, Malaysia.. Generally, the mean annual humidity and temperature are 94% and 27°C respectively. The mean annual rainfall was 2508 mm year^{-1}from 2004-2008 and the dry season varied every year. The topography is flat to undulating. According to the United States Department of Agriculture soil taxonomy, the soil in the study site is classified as ultisols which is the most widespread one in Peninsular Malaysia (Paramananthan, 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 base deficient and the charge on the exchange complex varies with the pH (Table 1).

Sampling procedure

*H. Odorata*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}). In this study, three 40×30 m (0.12 ha/plot) were established in each soil series. All tree diameters at breast height (DBH) and total height in each plot were measured and recorded. Tree height was measured using an ultrasonic hypsometer and DBH was measured using diameter tape.

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. Then, five tree samples for each soil series were felled and weighed.

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 estimation

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:

Total dry weight (kg) = $a\,(c\,/\,b)$

Where:

a= the total fresh weight

b = the sample fresh weight

c = the sample dry weight

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

$$V_S = (G1+G2)/2$$

Where:

V_s = the volume of the log

Table 1: Soil series of ultisols used in experiment

Soil series	Location	Soil description
Rengam	02° 34' 788 N; 102° 58' 670 E; 82 m a.s.l.	Rengam soil series is developed over acid igneous rocks, including granite. The soil is deep, strong brown, coarse sandy clay, friable and well drained.
Baling	02° 34' 796 N; 102° 58' 665 E; 77 m a.s.l.	Baling 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.
Kuala Berang	02° 34' 916 N; 102° 58' 528 E; 100 m a.s.l.	Kuala Berang 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.

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 *H. odorata* plantation at each site was established using the independent variable D (DBH) or the combination of D squared and H (D^2H). The relationship between the independent variable and the biomass of the components and stem volume were described by a power function $Yi = a(D)^b$ or $Yi = a(D^2H)^b$, where a and b are the regression constants, D is the tree diameter at breast height (cm), H is the total height (m) and Yi 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 of the 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 CF = exp [(SEE2)/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) (Onyekwelu, 2007). 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. 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.

DATA ANALYSIS

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

RESULTS AND DISCUSSIONS

Growth and performance

Table 2 shows the average diameter and height of *Hopeaodorata* growth in different soil series at five years old. The highest diameter and height were recorded in Baling soil series, followed by Rengam and Kuala Berang. The growth of *Hopeaodorata* is significantly differed between sites ($p \leq 0.05$). The result showed that the average diameter of the planted *H. odorata*in Baling (10.89 cm) and Rengam(10.64 cm) was significantly higher than Kuala Berang (9.70 cm). The average height of *H. odorata* in Baling also the highest (6.93 m) one were not significantly different from Rengam (6.84 m),

Table 2: Growth performances of five years old *Hopeaodorata* plantation in three different soil series

Sites (Soil series)	Diameter (cm)	Height (m)
Baling	10.89±0.16[a]	6.93±0.10[a]
Rengam	10.64±0.16[a]	6.84±0.10[a]
Kuala Berang	9.70±0.17[b]	6.02±0.11[b]

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

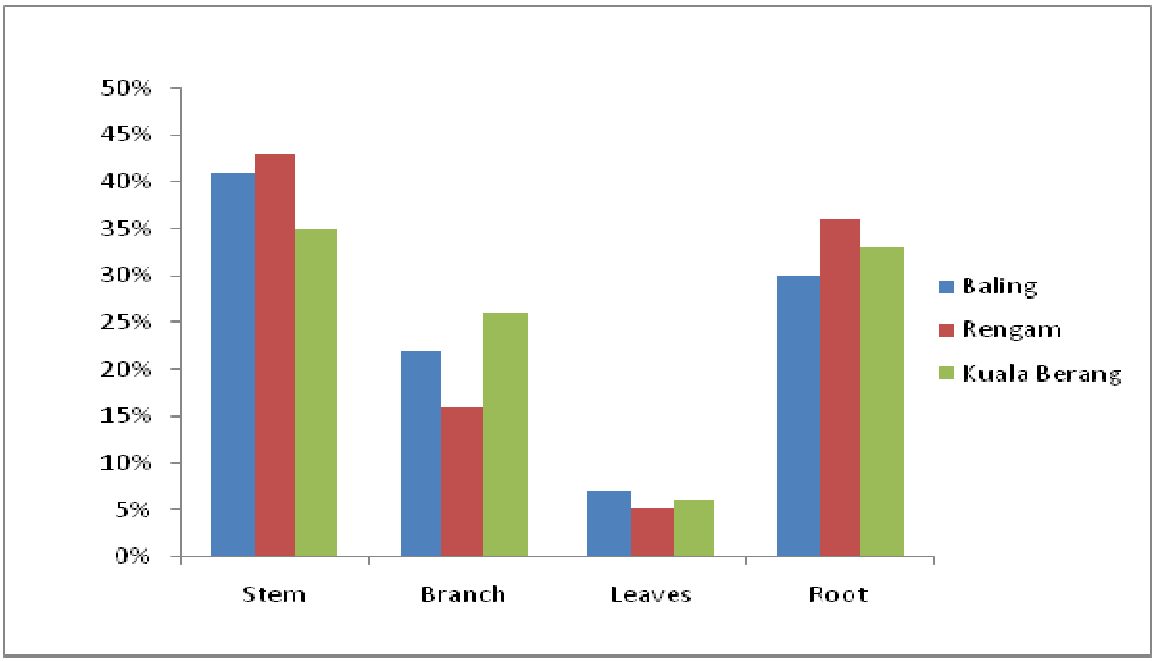

Figure 1: Biomass in different tree components inthree different sites

however, there were significantly different from Kuala Berang (6.02 m). According to the Forouhbakhchet al., (2006), diameter and height are good indicators to evaluate the site condition, as well as interspecific competition, spacing distance and climatic conditions.

Between these three soil series, *Hopeaodorata* showed the good growth performance in Baling and Rengam. According to Appanah and We inland (1993) *H. odorata* prefers to be planted on moderately cool land with wet alluvial soils and moderate clays, while all of the soil series in this study are sandy clay with good drainage but derived from different parent materials. The Kuala Berang and Baling series are derived from shale material, whereas Rengam series is derived from granite material. *H. odorata* naturally found along rivers and streams (Appanah and We inland, 1993). In this study, the location of the Baling soil series was close to the river; which is the reason for the growth of *H. odorata* in Baling that was higher than that one in Rengam, although the soil in both locations was derived from the same parent material.

Biomass accumulation

The proportions of the biomass component of *H. odorata* in three sites were different (Figure 1). The results showed that the stem biomass hadthe greatest proportion in Rengam (43%), followed by that in Baling (41%) and in Kuala Berang (35%). The amount of stem biomass was closely related to the production of trees through photosynthesis which was generally stored in the trunk.

Table 3: Site specific allometric equations used to estimate the biomass and stem volume of *H.odorata*five years after planting in Baling soil series

Trees Component	Independent variables	a	b	r^2	CF	SEE	Sig.
Stem	D	0.04132	2.59062	0.94615	1.0126	0.1583	*
	D^2H	0.02035	1.01639	0.99024	1.0023	0.0674	*
Branch	D	0.02137	2.61434	0.88833	1.0286	0.2375	*
	D^2H	0.01786	0.94859	0.79521	1.0531	0.3216	*
Leaves	D	0.03436	1.93905	0.86429	1.0196	0.1969	*
	D^2H	0.02824	0.71265	0.79379	1.0299	0.2427	*
Root	D	0.04823	2.41096	0.93883	1.0125	0.1577	*
	D^2H	0.04042	0.87644	0.84357	1.0323	0.2521	*
Stem volume	D	0.00012	2.40095	0.92639	1.0151	0.1734	*
	D^2H	0.00006	0.95108	0.98840	1.0024	0.0688	*

*: Significantly different at $p<0.05$; r^2: Coefficient of determination; CF: Correction Factor; SEE: Standard Error of the Estimates; D: Diameter at breast height; D^2H: Square of D and Height

Table 4: Site specific allometric equations used to estimate the biomass and stem volume of *H.odorata*five years after planting Rengam soil series

Trees Component	Independent variables	a	b	r^2	CF	SEE	Sig.
Stem	D	0.07230	2.39017	0.99825	1.0007	0.0381	*
	D^2H	0.06070	0.8658	0.99430	1.0024	0.0689	*
Branch	D	0.04428	2.18764	0.94774	1.0193	0.1954	*
	D^2H	0.03840	0.78970	0.93760	1.0231	0.2135	*
Leaves	D	0.02098	2.03042	0.86360	1.0483	0.3070	*
	D^2H	0.01685	0.7456	0.88410	1.0409	0.2830	*
Root	D	0.06274	2.37628	0.95039	1.0216	0.2066	*
	D^2H	0.05576	0.85264	0.92890	1.0311	0.2473	*
Stem volume	D	0.00010	2.50375	0.99768	1.0011	0.0459	*
	D^2H	0.00008	0.90841	0.99698	1.0014	0.0524	*

*: Significantly different at $p<0.05$; r^2: Coefficient of determination; CF: Correction Factor; SEE: Standard Error of the Estimates; D: Diameter at breast height; D^2H: Square of D and Height

The first stem segment was measured from the base of the stem, which was composed of wood substances, was generally wider than at the end of the stem, which was more dominated by juvenile wood.

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 *H. odorata* in all sites were 24-50%, 11-31%, 3-9% and 26-44%, respectively. Differences in the proportions were affected by the form and size of the branches and structure of large and small branch sizes in the canopy (Heriansyah et al., 2007).

Biomass allometric equation

Table 3, Table 4 and Table 5 shows the developed site specific allometric equations used to estimate tree biomass and stem volume of *H. odorata* five years after planting based on soil series. In the Baling soils series, regression models that used D as the independent variables gaver-square values greater than 80% for each tree component compared to the model that used D^2H as independent variables. For the branch and leaves components, the r-square value for the model that used D^2H were slightly lower but still approximate around 80%. In the Rengam 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 leaves biomass, which had an r-square value less than 90%.

Table 5: Site specific allometric equations used to estimate the biomass and stem volume of *H.odorata*five years after planting in Kuala Berang soil series

Trees Component	Independent variables	a	b	r^2	CF	SEE	Sig.
Stem	D	0.00697	2.49488	0.91242	1.02704	0.23098	*
	D^2H	0.00487	1.26475	0.93556	1.01087	0.14701	*
Branch	D	0.00113	3.92896	0.92637	1.02819	0.23579	*
	D^2H	0.00011	1.79579	0.83781	1.06315	0.34995	*
Leaves	D	0.00047	3.69860	0.84288	1.05948	0.33992	*
	D^2H	0.00005	1.70710	0.77734	1.08532	0.40465	*
Root	D	0.00763	3.23299	0.85078	1.04241	0.28822	*
	D^2H	0.00152	1.43103	0.72162	1.08057	0.39366	*
Stem volume	D	0.0005	1.8112	0.91260	1.00714	0.11931	*
	D^2H	0.00011	0.87853	0.92954	1.00575	0.10713	*

*: Significantly different at $p<0.05$; r^2: Coefficient of determination; CF: Correction Factor; SEE: Standard Error of the Estimates; D: Diameter at breast height; D^2H: Square of D and Height

Meanwhile, in Kuala Berang soil series, the model that used D as the independent variables also gaver-square values greater than 80% for each tree component compare to the model that used D^2H as independent variables. For the leaves and root components, the r-square value for the model that used D^2H were below than 80% and higher standard error of estimate compare to the other two soil series using the same model. Both model equations can be applied to estimate the biomass and stem volume in each site. However, considering that measuring the diameter alone made field-work easier, the regression model that only used D as an independent variable was highly recommended. This also recommended by another author (Swamy et al., 2004; Onyekwelu, 2007).

In addition, they concluded that tree biomass was primarily a function of D and that biomass was relatively insensitive to the tree height; consequently, D was widely used in biomass functions. The advantage of using D alone to estimate tree biomass was being simple, practical and economical (Onyekwelu, 2007). However, according to Brown (1997), models that incorporated tree height (H) usually gave good fits. Meanwhile, Andre et al. (2005) stated that the advantages of regression models that used the combination of D squared and H always resulted in a lower SSE and hetero skedasticity was reduced when D^2H 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.

Van et al. (2000) reported that most biomass equations that were developed for specific sites couldn'tbe assumed to apply to another location, but there is some exception 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 *H. odorata*in these three different soil series (Table 6). The regression models were formulated using the independent variable D and a combination of D^2 and height (D^2H).The regression models of the stem biomass and stem volume using the independent variable D^2H had r-square values of 96% and 97%, 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 the 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.

Based on this general analysis, a single allometric equation using the independent variable D was moderately applicable for branch, leaf and root biomass estimates of *H. odorata* in the Baling, Rengam and Kuala Berang soil series. Furthermore, a single allometric equation using the independent variable D^2H was moderately applicable for stem volume and stem biomass of *H. odorata* in the soil Baling, Rengam and Kuala Berang soil series.

Table 6: Single allometric equations to estimate the stem volume and biomass of *H. odorata* for all three locations

Trees Component	Independent variables	a	b	r^2	CF	SEE	Sig.
Stem	D	0.04597	2.54218	0.94205	1.0127	0.160	*
	D^2H	0.04009	0.92519	0.96469	1.0078	0.125	*
Branch	D	0.02697	2.48670	0.81194	1.0469	0.303	*
	D^2H	0.04580	0.80646	0.66024	1.0864	0.407	*
Leaves	D	0.01100	2.34411	0.78538	1.0492	0.310	*
	D^2H	0.01346	0.80439	0.71502	1.0659	0.357	*
Root	D	0.03829	2.53912	0.89712	1.0240	0.217	*
	D^2H	0.04955	0.86546	0.80583	1.0457	0.299	*
Stem volume	D	0.00012	2.40609	0.95437	1.0089	0.133	*
	D^2H	0.00011	0.87633	0.97877	1.0041	0.091	*

*: Significantly different at $p<0.05$; r^2: Coefficient of determination; CF: Correction Factor; SEE: Standard Error of the Estimates; D: Diameter at breast height; D^2H: Square of D and Height

Table 7: Estimated biomass of tree components and stem volume of *H. odorata* stands five years after planting in different soil series

Sites (Soil series)	Stem Volume (m^3ha^{-1})	Stem (a)	Biomass (tons ha^{-1}) Branches (b)	Leaves (c)	Above Ground (a+b+c)	Roots (d)	Total (a+b+c+d)
Baling	33.75± 1.214^a	18.62± 0.66^a	10.22± 0.36^a	3.06± 0.09^a	32.24± 1.12^a	13.87± 0.47^a	46.20± 1.60^a
Rengam	33.66± 1.89^a	18.31± 1.00^a	6.76± 0.34^b	2.17± 0.10^b	27.40± 1.45^{ab}	15.34± 0.83^a	42.90± 2.30^a
K. Berang	21.54± 1.44^b	11.18± 0.77^b	8.37± 0.60^{ab}	2.00± 0.14^b	21.72± 1.52^b	10.61± 0.75^b	32.47± 2.28^b

Note: Note: Means followed by the same letter are not significantly different at $P\leq0.05$ as determined by Least Significant Different (LSD). Values are expressed as mean ± standard error

Productivity of *hopeaodorata* plantation

Table 7 shows the summary of the mean tree component biomass values and stem volumes of the planted *H. odorata* at five years old in three different sites. The results show that there are significant difference between the three soil series ($p<0.05$). Baling soil series produced the highest stem volume (33.75 m^3 ha^{-1}), followed by Rengam (33.66 m^3 ha^{-1}) and Kuala Berang (21.54 m^3 ha^{-1}). While the accumulated aboveground biomass and total biomass in Baling and Rengam were also higher compared with Kuala Berang. In Baling, the accumulated aboveground and the total biomass were 32.24 and 46.20 t/ha, respectively, while in Rengam, the accumulated aboveground and total biomass were 27.40 and 42.90 t/ha respectively. In Rengam, the accumulated aboveground and the total biomass were 21.72 and 32.47 t/ha, respectively.

According to Kusmana et al., (1992), differences in biomass potential at each location can be caused by various environmental factors, such as climate, rainfall and temperature. Other than that, the altitude of sea level and soil fertility also affect the standing stock biomass (Fehse et al. 2002; De Wait and Chave, 2004). In this study, *H. odorata* was planted on the different soil types but in similar environmental conditions, such as rainfall, temperature, humidity and altitude. The differences in biomass accumulation and stem volume of *H. odorata* at five years old in three different soil series in Segamat, Johor were caused differences of soil characteristics.

CONCLUSION

There is a significant response in terms of growth performance and biomass accumulation of five years old *Hopeaodorata* in different sites. In general, the growth performance of the planted *H. odorata* in this study in terms of height and diameter was significantly higher in Baling and Rengam compared tothe Kuala Berang soil series. The developed allometric equation with diameter at breast height (D) as the independent variable was recommended to estimate tree biomass and volume for *Hopeaodorata* in Segamat, Johor. However, a single

allometric equation using the independent variable D was moderately applicable for branch, leaf and root biomass estimates of *H. odorata* in Baling, Rengam and Kuala Berang soil series. Furthermore, a single allometric equation using the independent variable D^2H was moderately applicable for stem volume and stem biomass of *H. odorata* in Baling, Rengam and Kuala Berang soil series. The differences in the growth and biomass accumulation indicated that the productivity of forest was influenced by site conditions. The significantly different in term of growth performance and stem volume between Baling and Renggam compared to Kuala Berang showed that the species was highly adapted to the soil characteristics of the Baling and Rengam soil series. This finding indicates that the soil in Baling and Renggam is more fertile and suitable for the growth of *H. odorata*.

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