American Journal of Agricultural and Biological Sciences 6 (2): 201-208, 2011
ISSN 1557-4989

Assessing Forest Plantation Productivity of Exotic and Indigenous Species on Degraded Secondary Forests

[1]Yetti Heryati, [1,2]Arifin Abdu, [4]Mohd Noor Mahat, [1,2]Hazandy Abdul-Hamid, [3]Shamshuddin Jusop, [1]Nik Muhamad Majid, [2]Ika Heriansyah and [5]Khairulmazmi Ahmad
[1]Department of Forest Production, Faculty of Forestry,
[2]Laboratory of Sustainable Bioresource Management,
Institute of Tropical Forestry and Forest Products,
[3]Department of Land Management, Faculty of Agriculture,
University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[4]Forest Research Institute Malaysia, 52109 Kepong, Malaysia
[5]Department of Crop Science, Faculty of Agriculture and Food Sciences,
University Putra Malaysia Bintulu Sarawak Campus, 97008 Bintulu, Sarawak

Abstract: Problem statement: There is general agreement that human activities such as deforestation and land use change to other land use types have contributed to degraded secondary forests or forestland and increases the emission of greenhouse gases which ultimately led to global climate change. An establishment of forest plantation in particular is regarded as an important approach for sequestering carbon. However, limited information exists on productivity and potential of fast growth exotic and indigenous tree plantations for sequestering CO_2 from the atmosphere through photosynthesis. This study aimed at assessing the productivity and biomass accumulation along with the potential for sequestering CO_2 of planted exotic and indigenous species on degraded forestland. **Approach:** This study was conducted at *Khaya ivorensis* and *Hopea odorata* plantations, which was planted at the Forest Research Institute Malaysia (FRIM) Research Station in Sega mat Johor, Malaysia five years ago. In order, to evaluate the forest productivity and biomass accumulation of both species, we established plots with a size of 40x30 m in three replications in each stand, followed by measuring all trees in the plots in terms of height and Diameter at Breast Height (DBH). To develop allometric equation, five representative trees at each stand were chosen for destructive sampling. **Results:** The growth performance in terms of mean height, DBH, annual increment of height and diameter and basal area of exotic species (*K. ivorensis*) was significantly higher than that of the indigenous species (*H. odorata*). We used the diameter alone as independent variable to estimate stem volume and biomass production of both species. The stem volume of *K. ivorensis* stand was 43.13 m^3ha^{-1} and was significantly higher than *H. odorata* stands (33.66 m^3 ha^{-1}). The results also showed that the *K. ivorensis* and *H. odorata* stands have the potential to absorb CO_2 from the atmosphere which was stored in aboveground biomass with value 15.90 Mg C ha^{-1} and 13.62 Mg C ha^{-1}, respectively. In addition, the carbon content in root biomass of *H. odorata* stand was higher than that in *K. ivorensis* stand with value 7.67 Mg C ha^{-1} and 4.58 Mg C ha^{-1}, respectively. **Conclusion/Recommendation:** The exotic (*K. ivorensis)* and indigenous (*H. odorata*) species which was planted on degraded forestland exhibited different growth rate, biomass production and ability to absorb CO_2 from the atmosphere in each part of the tree. In general, forest productivity and ability to absorb CO_2 from the atmosphere of exotics species (*K. ivorensis*) was higher than that indigenous species (*H. odorata*). These findings suggest that forest plantation productivity has been affected by species characteristics and suitability of species to site condition. Thus, to sustain high productivity with suitable species selection for carbon sequestration, these factors should be considered for future forest establishment.

Key words: Biomass production carbon content, exotic and indigenous species, *Hopea odorata*, *Khaya ivorensis*, root biomass, carbon sequestration, forest plantation productivity, non-government sectors

Corresponding Author: Arifin Abdu, Department of Forest Production, Faculty of Forestry, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia Tel: +603-89467177 Fax: +603-89432514

INTRODUCTION

Development of plantation forest through forest plantation or afforestation of exotic or indigenous species would bring various benefits such as replacing natural forest in meeting the needs of timber, to restore degraded land due to deforestation (Evans, 1999; Sawyer, 1993) and also providing environmental service as CO_2 sequestration to reduce global warming (Brown, 1999). Moreover, according to Evans (1999), forest rehabilitation through forest plantation establishment serves to sequester large volumes of carbon. However, to achieve multiple benefits of forest plantation in terms of productivity and potential carbon sequestration, an understanding on the suitability of a species planted on degraded forestland is crucial. The suitability of species on the site is a very important factor to be considered, may be a land has a potential for timber plantation, but appropriate species need to be determined (Appanah and Weinland, 1993). The selection of tree species for forest plantation is not only to obtain the optimal timber productivity, but also potentially for increasing carbon stock as well as carbon sink in forest ecosystems.

Currently, in Malaysia, the development of forest plantation is initiated by the introduction of plantation programmed with planting of high quality indigenous species (Appanah and Weinland, 1993; Heryati *et al*., 2011) and fast growing exotic species (Majid *et al*., 1994). *Khaya ivorensis* (exotic species) and *Hopea odorata* (indigenous species) are among the promising tree species for forest plantation in Malaysia as alternatives to *Acacia mangium* (Appanah and Weinland, 1993). *K. ivorensis* is included in the eight selected species for the National Timber Industrial Policy 2004 formulated by the Malaysian government, through the Malaysian Timber Industrial Board (MTIB).

In this study, we evaluated productivity in terms of growth performance and tree biomass content along with elucidating the potential for sequestering CO_2 of *K. ivorensis* and *H. odorata* plantations planted on similar site condition which was subjected excessive forest harvesting and subsequently regarded as degraded forestland. As we have known that forest vegetation has the potential to absorb CO_2 from the atmosphere during photosynthesis and store it as organic material in forest biomass per unit area and per unit of time. Thus, forest production in this case is forest plantation of *K. ivorensis* and *H. odorata* which has the potential or ability to absorb CO_2 from the atmosphere, calculated based on the content of biomass. Furthermore, the potential of forest plantation biomass to absorb CO_2 from the atmosphere varies according to species, age and stand density. By calculating the accumulation of biomass in a forest stand we can quantify the increment in forest yield, growth or productivity (Kueh and Lim, 1999) and estimates carbon content in forest (Brown and Lugo, 1984; Brown, 1997) and determine the amount of carbon that will be lost due to deforestation or harvesting (Houghton, 2005).

Therefore, assessing the productivity and tree biomass content of planted exotic and indigenous species is important for future forest plantation establishment not only for timber productivity, but also for sequestering CO_2 as greenhouse gas in the atmosphere. Such fundamental information is crucial if the government and non-government sectors intend to turn the unproductive degraded forestland areas into carbon sink through forest plantation.

MATERIALS AND METHODS

Study site: The study was carried out at *K. ivorensis* and *H. odorata* plantations, which was established in 2004 (5-year-old) at the Forest Research Institute Malaysia (FRIM) Research Station in Segamat, Johore, Malaysia. The plantation is located between latitudes 02° 34’ 683 N and longitudes 102° 58’ 643 E, with mean altitude of 82 m above sea level. The mean annual temperature is 27°C and humidity is 94%. The mean annual rainfall from 2004-2008 was 2508 mm/year with the dry season and the wet season varies every year. The area topography is flat to undulating. The soil in the study site is Rengam Series. It is developed over acid igneous rocks, including granite. The soil is deep, strong brown, coarse sandy clay, friable and well drained. Based on USDA soil taxonomy, the soil is classified as Ultisols which is the most widespread soil in Peninsular Malaysia (Paramananthan, 2000). The soils are extremely leached, highly weathered and well drained. Therefore, the soil is dominated by kaolinite and sesquioxides with pH ranging from 4-5. The soils are high in aluminum saturation and low base saturation. The charge on the exchange complex varies with the pH. Before planting, the area was cleared by land clearing. Each species was planted with monoculture system with initial planting spacing of 4×3 m. The seedlings were applied with the same fertilizer for three years. Two hundred g of phosphate rock per tree was applied during cultivation and 500 g of organic fertilizer/tree was applied after cultivation for every six months for three year; weeding was done once in three months.

Description of planted *K. ivorensis* and *H. odorata*: For this study, we chose two fast growing species with different characteristics such as exotic species (*K. ivorensis*) and indigenous species (*H. odorata*). *K. ivorensis* A. Chev (Meliaceae) is an exotic species in Malaysia. It is distributed throughout coastal West Africa, Cote d'Ivoire, Ghana, southern Nigeria and Cameroon. It was first introduced to Malaysia in the late 1950s where it was planted in Kedah and Selangor. The species is deciduous only in drier climates (Appanah and Weinland, 1993) and required biophysical limit to growth at altitude between 0-450 m, mean annual temperature 24-27°C, mean annual rainfall of 1600-2500 mm and it prefers cool land, wet and humid alluvial soils. The trade name of this species is African mahogany. The timber from *K. ivorensis* is light hardwood (Appanah and Weinland, 1993). The wood commands a very high price on the marketplace and can be used for high quality furniture, paneling, cabinet making, molding, turnery, handrails, canoes and other decorative works. The average wood density is 560 kg m^3. The tree is large with height can reach up to 40 m and diameter at breast height reach up to 200 cm.

H. odorata Roxb. (Dipterocarpacea) is an indigenous species in Malaysia. It is distributed in Andaman Islands, Myanmar, Thailand and Indo-China and the northern part of Peninsular Malaysia. In Malaysia it is known as 'Merawan Siput Jantan' and reportedly found in all districts of the Peninsular Malaysia, except Matang, Krian and Lower Perak (Symington *et al*., 2004). It is a medium to large size that can reach up to 45 m height with straight bole, diameter reach up to 1.2 m and branching reach up to 25 m. The habitat of *H. odorata* is riparian and is rarely occur on deep rich soil up to 600 m altitude. It survives on a wide variety of soil types such as on sandy and alluvial soils and Spodosols or/and soil derived from limestone. The species best growth is in areas with annual rainfall more than 1200 mm and means annual temperature of 25-27°C. The timber from *H. odorata* is a strong light to medium-heavy hardwood. The wood density is 620-693 kg m^{-3} at 15% moisture content and the timber is suitable for making rollers in textile industry, piles and bridge construction. It is also cultivated as a shade or ornamental tree in villages especially in Kelantan and Terengganu. The species is also suitable for rehabilitation of degraded lands.

Growth measurement: To assess the growth performance of planted *K. ivorensis* and *H. odorata*, the three plots of 40×30 m/plot were established randomly within each stand. All of the trees within each plot were measured for total height and Diameter at Breast Height (DBH) at 1.3 m above the ground to estimate the tree biomass, carbon sequestration and stem volume of the planted *K. ivorensis* and *H. odorata*. Mean annual increment diameter at breast height, total height and stem volume were calculated from dividing mean diameter or tree height by the plantation age (5 years). Tree height was measured using an ultrasonic hypsometer and DBH was measured using diameter tape. The number of trees at each plot was recorded.

Destructive sampling of *K. ivorensis* and *H. odorata*: Five sample trees for destructive sampling in each stands were chosen. We chose the representative trees by sorting the DBH and tree height data in each stands from the lowest to the highest. Thereafter, 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. The tree samples were chosen to destructive sampling that has diameters in the range of 9-20 cm for *K. ivorensis* and 7-17 cm for *H. odorata*. The method for destructive sampling was done by digging roots out and fell the tree. After falling, the total height of the tree was measured and then the stems were separated into component logs, for example, 0-30 cm, 30-130 cm, 130-330 cm and every 2 m to the top (Heriansyah *et al*., 2007). The destroyed trees were divided into four components as follows: stems, leaves, branches and twigs (branches) and roots. About 5 cm disc stem samples were taken from each part of component log. The samples disc stem were taken from the base of the component log. The diameter of each stem disc was measured with the diameter tape. The samples disc stem 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.

Data analysis: The samples of tree components 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). The dry weight/fresh weight ratios were used to estimate the dry weights of the biomass components for the individual trees. The total dry weight of individual trees was calculated by the whole weight of the components. 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.

The allometric equation was used to estimate the biomass of the tree components and stem volume was established using the independent variable D and combination of D square and Height. The relationship between the independent variable and the biomass of components and stem volume was described by a power function $Wi = a(D)^b$ and $Wi = a(D^2H)^b$, where a and b are the regression constants, D is the tree diameter at breast height (cm), H is total height and Wi is the dry biomass (kg) of a tree component i (stem, branches, leaves and roots) or stem volume (m^3).

The aboveground biomass was determined by calculating the sum of the biomasses of the stems, branches and leaves. The total tree 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. Thus, we had estimated carbon sequestration assuming that carbon content in dry weight of biomass is approximately 50% (Brown and Lugo, 1982; Brown, 1997). The tree biomass, stem volume and carbon sequestration were converted into hectares. The regression analysis was conducted between tree growth parameters with tree component biomass and stem volume values. The power functions were include from the linear regression on log-transformed data using the model $\log(Y) = \log(a) + b[\log(X)]$. All the data were analyzed using the Statistical Analysis System (SAS) software ver. 9.1.

RESULTS AND DISCUSSION

Growth performance of *K. ivorensis* and *H. odorata*: Table 1 shows the growth performances of *K. ivorensis* stand in terms of mean DBH, mean total height, mean annual increment of DBH and total height and basal area which tended to be higher compared with *H. odorata* stand. However, when compared with growth rate at several sites, growth performance of *K. ivorensis* plantation in the present study indicates slower growth. For example, *K. ivorensis* was planted on Rengam soil at Bukit Lagong Forest Reserve can achieve an average diameter of 12.3 cm after 4 years of planting, while in Mata Ayer, Perlis, 4-year-old *K. ivorensis* planted on Penambangan soil had average 2.28 cm and 1.63 m for mean annual increment of diameter and height, respectively (Krishnapillay, 2002). In Cote d'Ivoire, 4-year-old *K. ivorensis* attained 2.3 m in mean annual increment of height and 2.5 cm in mean annual increment of diameter. However, the growth performance of *H. odorata* in this study was higher compared with that of the previous study. 5-year-old *H. odorata* planted on slime in Bidor, Perak, Malaysia had average of 0.90 m yr^{-1} for mean annual increment of height and 1.11 cm yr^{-1} for mean annual increment of DBH.

The amount of basal area in *K. ivorensis* stand was 9.65 m^2ha^{-1}, which was higher compared with that of *H. odorata* stand (8.00 m^2ha^{-1}). It means that stand density showed a relationship with the amount of basal area, where the high stand density planting produces a high basal area. Stand density in the *K. ivorensis* stand was 808 trees/ha, while in the *H. odorata* stand it was 783 trees/ha.

The results showed that *K. ivorensis* planted on Rengam soil in this study grew slower than that planted on the same soil at other places. This shows that beside soil characteristic, growth is affected by other factors such as altitude, climate and silviculture treatment. Although the growth performance of 5-year-old *H. odorata* in this study was lower than the growth performance of *K. ivorensis* stand, it is better than that of the previous study. This indicates that *H. odorata* is suitable to be planted in the condition prevailing in this study area. Besides that, according to Evans (1992), indigenous trees have some other advantages such as resistance to pests and diseases. Based on the observation in the field, *H. odorata* stands seems to be more healthy compared with *K. ivorensis* stands, while *K. ivorensis* stands was beginning to be attacked by shoot borers, *Hypsiphylla robusta*. The pest attack will inhibit further growth of *K. ivorensis*.

Biomass storage of *K. ivorensis* and *H. odorata*: The proportion of each tree component biomass of planted *K. ivorensis* and *H. odorata* are shown in Table 2. The proportion of stem biomass was highest among the tree components. It was appropriately stated by West (2009) that in the stem of tree there was large proportion of biomass. The contribution of tree component biomass to total biomass was in the order of stems > roots > branches > leaves. The contributions of stems, roots, branches and leaves of *K. ivorensis* plantation was 44.35, 21.66, 19.01 and 14.69%, respectively, while for the *H. odorata* stand it was 42.84, 36.18, 16.08 and 4.90%, respectively (Table 2). According to Evans (1992), the high proportion of root biomass for both plantations was caused by years after planting.

Table 1: Growth performance of the *K. ivorensis* and *H. odorata* plantations at five years after planting

Species	Planting spacing	Stand density (trees/ha)	Diameter at breast height (DBH) (cm)	MAI DBH (cm/year)	Total height (m)	MAI Total height (cm/year)	Basal area
Khaya ivorensis	4×3 m	808	11.60±0.31a	2. 32±0.06a	7.85±0.50a	1.57±0.10a	9.65a
Hopea odorata	4× 3 m	783	10.64±0.40b	1.93±0.07b	6.84±0.38b	1.24±0.07b	8.00b

Note: Means followed by the same letter in the same column are not significantly different at P<0.05 by Least Significant Different (LSD). Values are expressed as mean ± standard deviation for three replicates plots; MAI: Mean annual increment

Table 2: The proportion of tree component biomass of planted *K. ivorensis* and *H. odorata*

Species	Stems (%)	Branches (%)	Leaves (%)	Roots (%)
Khaya ivorensis	44.35±2.86a	19.01±1.84a	14.98±1.54a	21.66±2.43b
Hopea odorata	42.84±2.35b	16.08±1.60b	4.90±0.78b	36.98±2.72a

Note: Means followed by the same letter in the same column are not significantly different at P<0.05 by Least Significant Different (LSD). Values are expressed as mean ± standard deviation for three replicates plots

Table 3: Alllometric equation used to estimate the biomass of *K. ivorensis* and *H. odorata* plantations using independent variable D and combination of D square and height

No.	Trees component	Independent variable	*Khaya ivorenis* (5- year-old) a	b	r^2	Sig	*Hopea odorata* (5- year-old) A	b	r^2	Sig
1	Stem	D	0.07315	2.30400	0.98	**	0.07230	2.390170	0.99	**
		D^2H	0.08596	0.79971	0.99	**	0.06067	0.865830	0.99	**
2	Branch	D	0.01079	2.65330	0.78	*	0.04428	2.187640	0.95	**
		D^2H	0.01316	0.91917	0.79	*	0.03843	0.078975	0.94	**
3	Leaf	D	0.01266	2.49264	0.76	*	0.02098	2.030420	0.86	*
		D^2H	0.01776	0.84276	0.73	ns	0.01685	0.074562	0.88	*
4	Root	D	0.03004	2.36025	0.92	**	0.06274	2.376280	0.95	**
		D^2H	0.03599	0.81710	0.93	**	0.05565	0.853020	0.93	**
5	Stem volume	D	0.00014	2.36435	0.99	**	0.00010	2.503750	0.99	**
		D^2H	0.00017	0.81925	0.99	**	0.00008	0.908410	0.99	**

Note: r^2 means coefficient of determination; * and ** indicate significant difference at levels of P<0.05 and P<0.01, respectively; ns, no significant difference

(Evans, 1992) found that root biomass of *Shorea robusta* constitutes 33.55% of the total biomass when tree are young, 15.7% at the age 15 years and 14% at 26 years. Meanwhile, Onyekwelu, (2007) reported that *Pinus caribaea* in Nigeria have the proportion root biomass about 20% of the total. Besides age factor, changes in root biomass among tropical forest depend on climate and soil characteristics (Brown and Lugo, 1982).

According to the regression analysis, using D as independent variable, the stem, branch, root and stem volume of *H. odorata* as well as that of the stem, root and stem volume of *K. ivorensis* were significantly higher than 90% at the level P<0.01. This means that the biomass of these parts proportionately increased with the increase in D (Diameter). However, the leaf and branch biomass of *K. ivorensis* was significantly less than 80% at the level P<0.05. Meanwhile, leaf biomass of *H. odorata* was significantly higher than 80% at the level P<0.05 and branch biomass was significantly higher than 90% at the level P<0.01. Allometric equation was developed based on relationship between combination of D squared and height (D^2H) with tree component biomass to estimate tree biomass. Stem volume of *K. ivorensis* and *H. odorata* plantation has a slightly different in r-square value compared with allometric equation using D as independent variable (Table 3). Therefore, we considered using allometric equation with D as independent variable for estimating the tree component biomass and stem volume in the sample plot. Besides, the equation is statistically was right, using diameter only as independent variable will be easier to work in the field in estimating a forest stand (Zianis, 2008; Pilli *et al*., 2006; Segura, 2005; Hashimoto *et al*., 2004; Aboal *et al*., 2005). In addition, the developed allometric equation that incorporate diameter alone would be practical, simple and economical (Onyekwelu, 2007).

Table 4: Biomass of tree component and stem volume of stands of *K. ivorensis* and *Hopea odorata* at five years after planting

Species	Stem Volume (m^3 ha^{-1})	Stem biomass (Mg ha^{-1})	Branch biomass (Mg ha^{-1})	Leaf biomass (Mg ha^{-1})	Aboveground biomass (Mg ha^{-1})	Root biomass (Mg ha^{-1})	T/R ratio *(t t^{-1})	Total biomass (Mg ha^{-1})
Khaya ivorensis	43.13±3.72a	19.25±1.61a	7.10±0.71a	5.46±0.50a	31.80±2.93a	9.16±0.79b	3.47±0.02a	40.96±3.73a
Hopea odorata	33.66±3.27b	18.31±1.72a	6.79±0.59a	2.17±0.18b	27.39±2.51b	15.34±1.43a	1.78±0.00b	42.90±3.97a

Note: Means followed by the same letter in the same column are not significantly different at P<0.05 by Least Significant Different (LSD). Values are expressed as mean ± standard deviation for three replicates plots; * T/R ratio: ratio of aboveground biomass to root biomass

Table 5: Carbon content of *K. ivorensis* and *H. odorata* plantations at five years after planting

Species	Stems (Mg C ha^{-1})	Branches (Mg C ha^{-1})	Leaves (Mg C ha^{-1})	Aboveground (Mg C ha^{-1})	Roots (Mg C ha^{-1})	Total (Mg C ha^{-1})
Khaya ivorensis	9.62±0.80a	3.55±0.35a	2.73±0.25a	15.90±1.41a	4.58±0.39b	20.48±1.80a
Hopea odorata	9.15±0.86a	3.38±0.30a	1.08±0.09b	13.62±1.24b	7.67±0.72a	21.29±1.96a

Note: Means followed by the same letter in the same column are not significantly different at P<0.05 by Least Significant Different (LSD). Values are expressed as mean ± standard deviation for three replicates plots

Forest productivity of *K. ivorensis* and *H. odorata*: The productivity of biomass of each component of individual stand of *K. ivorensis* and *H. odorata* in the sample plot were calculated using allometric equation with diameter alone as independent variable. The aboveground biomass of individual stand was estimated by summing up the stem, branch and leaf, while the total tree biomass was calculated by summing up the aboveground biomass and root biomass. The total biomass in each stand was calculated from the summed biomass of all trees in the plot.

The biomass accumulations of each species are shown in Table 4. The mean aboveground biomass of *K. ivorensis* was 31.80 Mg ha^{-1} which is significantly higher compared with *H. odorata* (27.39 Mg ha^{-1}). The stem biomass of *K. ivorensis* stand was 19.25 Mg ha^{-1} higher than in *H. odorata* stand (18.31 Mg ha^{-1}) leaves biomass was higher in *K. ivorensis* plantation (7.10 Mg ha^{-1} and 5.46 Mg ha^{-1}, respectively) than in *H. odorata* plantation (6.79 Mg ha^{-1} and 2.17 Mg ha^{-1}, respectively). Conversely, the total tree biomass of *H. odorata* stand was 42.90 Mg ha^{-1}, which was higher than that in *K. ivorensis* stand (40.96 Mg ha^{-1}). This could be due to high root biomass in *H. odorata* stand (15.34 Mg ha^{-1}) as compared to *K. ivorensis* stand (9.16 Mg ha^{-1}).

The total ratio of aboveground biomass to root biomass (T/R ratio) is a standard to estimate the biomass allocation pattern to the underground part of the plant (Komiyama *et al*., 2000). In the temperate forest, T/R ratio ranges from 2.68-3.70 (Yamada and Shidei, 1972; Komiyama *et al*., 2000). However, the T/R ratio of *K. ivorensis* stand was 3.47 higher than that in *H. odorata* stand (1.78). The result our study are similar to those reported by Kamo *et al*. (2008) where the T/R ratio of exotic species (*Acacia* species) was higher (5.2-6.1) compared with slow growing of indigenous species (*Pterocarpus macrocarpus* and *Xylia xylocarpa*) which were T/R ratio 2.8-2.9, respectively. The low T/R ratio indicates that the amount of tree biomass was accumulated at below-ground root biomass, as studied by Komiyama *et al*., (2000) on *Ceriops tagal* that have a T/R ratio of 1.05, where the root biomass was higher than that above-ground biomass. This indicates that the estimate of root accumulation of the tree species is needed to understand the overall carbon stock process in the tropical forest areas.

Based on biomass production in each tree component and assuming that carbon content is approximately 50%, of tree biomass, the carbon content in the tree component biomass of *K. ivorensis* stand and *H. odorata* stand five years after planting were calculated (Table 5). The carbon content in stem biomass of both species was higher compared with other tree component in each stand. The carbon content of stem in *K. ivorensis* and *H. odorata* were 9.62 Mg C ha^{-1} and 9.15 Mg C ha^{-1}, respectively, followed by root which was 4.58 Mg C ha^{-1} and 7.67 Mg C ha^{-1}, respectively. The carbon content of leaves of both species is smallest with values of 2.73 Mg C ha^{-1} and 1.09 Mg C ha^{-1} for *K. ivorensis* and *H. odorata*, respectively, while the carbon content of branches of *K. ivorensis* and *H. odorata* stands were 3.55 Mg C ha^{-1} and 3.38 Mg C ha^{-1}, respectively. Thus, 5-year-old *K. ivorensis* stand has the ability to absorb CO_2 from the atmosphere and stored in aboveground biomass as much as 15.90 Mg C ha^{-1}, while the aboveground biomass of *H. odorata* stand has the ability to absorb 13.62 Mg C ha^{-1} CO_2 which was lower compared with that of *K. ivorensis* stand (Table 5).

According to West (2009), the principal commercial product of forest is wood. In this study, stem wood of both species were estimated by using allometric equation which is presented in Table 2. The result shows that the stem volume of *K. ivorensis* stand was 43.13 m^3 ha^{-1}, which was higher than that in *H. odorata* stand (33.66 m^3 ha^{-1}) Table 3. Therefore, the Mean Annual Increment (MAI) of stem volume for *K. ivorensis* stand was higher compared with *H. odorata*. The mean annual increment of stem volume for *K. ivorensis* and *H. odorata* were 8.63 m^3 $ha^{-1}yr^{-1}$ and 6.73 m^3 $ha^{-1}yr^{-1}$, respectively. Compared with previous studies, the mean annual increment of stem volume of *K. ivorensis* was higher. Based on the study, the mean annual increment of stem volume of 40-year-old *K. ivorensis* stand was 7.64 m^3 ha^{-1} yr^{-1}, it was lower than that of MAI volume of *K. ivorenis* in this study. This is due to the younger stand age of *K. ivorensis* (5 years), where in general, the tree growth tend to be faster when the tree is still young. Meanwhile, the lower value of stem volume of *H. odorata* stand than *K. ivorensis* stand showed that the growth of indigenous species is slower than exotics species. This indicates that the exotic species have high adaptability to site conditions at the degraded forest land in Johor.

CONCLUSION

The exotic and indigenous species which were planted on degraded forest land exhibited different growth rate. In general, growth performance of exotic species (*K. ivorensis*) was higher than that indigenous species (*H. odorata*) in terms of mean total height, mean diameter, mean annual increment of height, mean annual increment of diameter and basal area. However, compared with the previous studies at other site, growth of *K. ivorensis* was slower.

K. ivorensis produced significantly higher stem volume and aboveground biomass than that of *H. odorata*, while the root biomass was higher in *H. odorata* stand than that in *K. ivorensis* stand. Thus, *K. ivorensis* stand has higher ability to absorb CO_2 from the atmosphere and stored in aboveground biomass compared to *H. odorat*; however, carbon content which was stored in root biomass was higher in *H. odorata* stand than in *K. ivorensis* stand. In general, exotics species have higher productivity than that of indigenous species. These findings suggest that forest plantation productivity seems to be affected by species characteristics and suitability of species to site condition. Thus, to ensure sustainability in producing high productivity, these factors should be considered for future forest plantation establishment.

ACKNOWLEDGEMENT

Funding for this research was received from Forest Research Institute and Fundamental Research Grant Scheme from the Ministry of Higher Education of Malaysia (MOHE) through Universiti Putra Malaysia, Malaysia. We also appreciate the FRIM staff who helped us with the fieldwork. We would like to acknowledge two anonymous reviewers for their kind editorial suggestions and comments. Thanks to Ms. Zarina Abdul Rahman, Ms. Debora, Ms. Norisah, Mr. Leslie, Mr. Arwel and Mr. Hafizuddin for their laboratory and field assistant.

REFERENCES

Aboal, J.R., J.R. Arevalo and A. Fernandez, 2005. Allometric relationships of different tree species and stand above ground biomass in the Gomera laurel forest (canary Islands). Flora-Morphol., Dist., Func. Ecol. Plants, 200: 264-274. DOI: 10.1016/j.flora.2004.11.001

Appanah, S. and G. Weinland, 1993. Planting quality timber trees in Peninsular Malaysia: A Review. 1st Edn., Forest Research Institute Malaysia, Malaysia, ISBN-10: 9839592181, pp: 221.

Brown, S. and A.E. Lugo, 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. Biotropika, 14: 161-187.

Brown, S. and A.E. Lugo, 1984. Biomass of tropical forests: A new estimate based on forest volumes. Science, 223: 1290-1293. DOI: 10.1126/science.223.4642.1290

Brown, S., 1997. Estimating biomass and biomass change of tropical forest. 1st Edn., Food and Agriculture Organization of the United Nations, USA., ISBN-10: 9251039550, pp: 55.

Brown, S., 1999. Opportunities for mitigating carbon emission through forestry activities. Winrock International, Airlington, V.A., USA. http://www.winrock.org/ecosystems/files/Opportun_for_mitigating_carbon.pdf

Evans, J., 1992. Plantation Forestry in The Tropics: Tree Planting for Industrial, Social, Environmental and Agroforestry Purposes. 2nd Edn., Oxford University Press, USA., ISBN-10: 0198542577, pp: 424.

Evans, J., 1999. Planted forests of the wet and dry tropics: their variety, nature and significance. New Forests, 17: 25-36. DOI: 10.1023/A:1006572826263

Hashimoto, T., T. Tange, M. Masumori, H. Yagi, S. Sasaki and K. Kojima, 2004. Allometric equations for pioneer tree species and estimation of the aboveground biomass of a tropical secondary forest in East Kalimantan. Tropics. 14: 123-130.

Heriansyah, I., K. Miyakuni, T. Kato, Y. Kiyono and Y. Kanazawa, 2007. Growth characteristics and biomass accumulations of *Acacia mangium* under different management practices in Indonesia. J. Tropical Forest Sci., 19: 226-235.

Heryati, Y., D. Belawan, A. Abdu, M.N. Mahat and H. Abdul-Hamid *et al*., 2011. Growth performance and biomass accumulation of a *khaya ivorensis* plantation in three soil series of ultisols. Am. J. Agric. Biol. Sci., 6: 33-44. DOI: 10.3844/ajabssp.2011.33.44

Houghton, R.A., 20005. Aboveground forest biomass and the global carbon balance. Global Change Biol., 11: 945-958. DOI: 10.1111/j.1365-2486.2005.00955.x

Komiyama, A., S. Havanond, W. Srisawatt, Y. Mochida and K. Fujimoto *et al*., 2000. Top/root biomass ratio of a secondary mangrove (*Ceriops tagal* (Perr.) C.B. Rob.) Forest Ecol. Manage., 139: 127-134. DOI: 10.1016/S0378-1127(99)00339-4

Krishnapillay, B., 2002. A Manual for forest plantation establishment in Malaysia. 1st Edn., Forest Research Institute Malaysia, Malaysia, ISBN-10: 9832181283, pp: 286.

Kueh, R.J.H. and M.T. Lim, 1999. An estimate of forest biomass in ayer hitam forest reserve. Pertanika J. Trap. Agric. Sci., 22: 117-123.

Majid, N.M., A. Hashim and I. Abdol, 1994. Rehabilitation of ex-tin mining land by agroforestry practice. J. Trop. For. Sci., 7: 113-127.

Onyekwelu, J.C., 2007. Growth, biomass yield and biomass functions for plantation-grown Nauclea diderrichii (de wild) in the humid tropical rainforest zone of south-western Nigeria. Biores. Technol., 98: 2679-2687. DOI: 10.1016/J.BIORTECH.2006.09.023

Paramananthan, S., 2000. Soil of Malaysia: their characteristics and identification. 1st Edn., Academy of Sciences Malaysia, Malaysia, ISBN-10: 9839445065

Pilli, P., T. Anfodillo and M. Carrer, 2006. Towards a functional and simplified allometry for estimating forest biomass. Forest Ecology Manage. 237:583-593. DOI:10.1016/J.FORECO.2006.10.004

Sawyer, J. 1993. Plantations in the tropics: environmental concerns. 1st Edn., World Conservation Union, U.K., ISBN-10: 2831701392, pp: 96.

Segura, M. and M. Kanninen, 2005. Allometric models for tree volume and total aboveground biomass in a tropical humid forest in Costa Rica. Biotropika, 37: 2-8. DOI:10.1111/j.1744-7429.2005.02027.x

Symington, C.F., P.S. Ashton and S. Appanah, 2004. Forester's manual of dipterocarps. 2nd Edn., Forest Research Institute Malaysia, Malaysia, pp: 519.

West, P.W. 2009. Tree and forest measurement. 2nd Edn., Springer, USA., ISBN-13: 978354095965-3, pp: 190.

Zianis, D., 2008. Predicting mean aboveground forest biomass and its associated variance. Forest Ecol. Manage., 256: 1400-1407. DOI: 10.1016/j.foreco.2008.07.002