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Characterizing Soil Nutrient Status and Growth Performance of Planted Dipterocap and Non-Dipterocarp Species on Degraded Forest Land in Peninsular Malaysia

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Abstract: This study aims to assess the soil nutrient status and growth performance of selected six dipterocarp species namely *Dryobalanops aromatica*, *Hopea nervosa*, *Neobalanocarpus heimii*, *Shorea parvifolia*, *S. assamica* and *S. leprosula* and three non-dipterocarp species of *Azadirachta excelsa*, *Cinnamomum iners* and *Intsia palembanica* were performed six years after planting on degraded forest land in Pasoh Forest Reserve, Negeri Sembilan, Peninsular Malaysia. This assessment consists of determining soil nutrient status based on physico-chemical properties both in rehabilitated and adjacent secondary forests along with measurement of diameter at breast height and height and survival rate. The results showed that rehabilitating degraded forest land with dipterocarp and non-dipterocarp species had improved both soil nutrient status and valuable timber stocks. The soils were acidic with low levels of organic matter and exchangeable bases associated with high level of Al saturation. The negative charges derived from the organic matter and clay minerals play an important role in retaining soil nutrients and probably influence the soil nutrient status. Principal component analysis revealed three most important PC scores which explained 73.8% of total variation. PC1 represents cation retention capacity and soil organic matter. PC2 infers soil acidity, while PC3 related to physical properties of the soils. In the case of growth performance, *A. excelsa* and *C. iners* showed significantly high mean annual increments in diameter and height and survival rate at six years after planting. Irrespective of different ages after planting, the growth performance and survival rate of planted dipterocarp species especially *S. leprosula* and *S. parvifolia* were comparable to similar species grown at other planting trials in Malaysia.

Key words: Degraded forest land, dipterocarp, growth performance, rehabilitation, soil fertility

INTRODUCTION

Tropical rainforests are recognized as the richest ecosystems in the world in terms of structure and species diversity (Whitmore, 1998). On a large scale, tropical rainforests have a prominent role in ameliorating and maintaining global climate change by reducing the accumulation of greenhouse gases (Shukla *et al*., 1990). However, despite the richness and multi-functional roles of tropical rainforests, they are fragile habitats and they are being destroyed at unprecedented rates (Food Agriculture Organization, 2001; Archard *et al*., 2002). One of the most serious problems facing tropical rainforests is deforestation. Deforestation is defined as the conversion of forested areas to non-forest land, which results in the permanent reduction of indigenous species (Montagnini *et al*., 1997; Montagnini and Jordan, 2005). Between 1981 and 1990, the global deforestation rate was estimated to be 180 million ha, which represents an annual loss of 16.9 million ha in tropical regions. Commercial logging, shifting cultivation, urbanization industry and other forms of encroachment are all principal causes of deforestation in tropical regions (ITTO, 2002; Geist and Lambin, 2002).

Conversion of tropical rain forests to other land use types is of great environmental concern worldwide, Malaysia included. Tropical rainforest covers approximately 19.4 million ha or 60% of Malaysia's total

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land area. A large tract of forest areas have been degraded as a consequence of deforestation, excessive forest harvesting and shifting cultivation. As of mid-1980s a total of 4.6 million of forest in Malaysia or 22.8% of the total forest area has been subjected to degradation due to logging activity. In general, the valuable timber trees from dipterocarpaceae family are often heavily logged for commercial timber both local and international, resulting in low density of remaining valuable species. In particular, forest harvesting or logging activities have serious negative environmental impacts on land degradation, including increased soil compaction, erosion and decrease in soil fertility. Once the natural forest has been cleared, the soil nutrients are lost through erosion and leaching resulting in low soil nutrient stocks (Ishizuka *et al*., 2000; Arifin *et al*., 2007). Therefore, if the economic, environmental, social and cultural benefits of the forest are to be continuously enjoyed, the damage has to be repaired by various technical approaches, such as rehabilitation.

In order to rehabilitate such a degraded forest land and accelerate recovery of the original ecosystems in Malaysia, high quality indigenous of dipterocarp and non-dipterocarp species as well as fast growing exotic species have to be used (Appanah and Weinland, 1993). In cases of severe forest degradation such as a total loss of forest cover, a more intensive rehabilitative measure, such as enrichment planting can be carried out. Forest rehabilitation or an enrichment planting through introduction of high quality indigenous timber species of dipterocarp (Ang and Maruyama, 1995) and non-dipterocarp (Suhaili *et al*., 1998) have been practiced in degraded forest land or secondary forests. In severe degraded forest land, indigenous species is commonly unsuccessful due the environmental factors such as increased soil compaction and low in fertility associated with acidic nature of the soils. In some cases, non-dipterocarp species such as *Azadirachta excelsa* has also been tested for rehabilitation purpose due to their ability to grow vigorously on degraded forest land. Therefore, an intensive research needs to be done in order clarify the potential of both dipterocarp and non-dipterocarp species in rehabilitating degraded forest land by means of improving site productivity.

A joint research program between Universiti Putra Malaysia (UPM), Center for International Forest Research (CIFOR) and Forestry Department Peninsular Malaysia (FDPM) was conducted to rehabilitate or enrich poorly-stocked logged over forest in Pasoh Forest Reserve, Negeri Sembilan, Peninsular Malaysia. In this project, indigenous dipterocarp and non-dipterocarp species were planted under open planting technique. Numerous researchers have reported that the successes of forest rehabilitation or enrichment planting efforts are mainly concerned on the species selection or species site suitability (Ashton, 1995; Tuomela *et al*., 1996; Norisada *et al*., 2005; Shono *et al*., 2007; Romell *et al*., 2007). There are several studies concerned with growth performance of planted species on degraded forestland, their assessment, but mostly focused on initial stage of less than three years after planting (Ang and Maruyama, 1995; Adjers *et al*., 1996; Vincent and Davies, 2003). Assessment of soil properties under rehabilitation of degraded forest land and growth performance including survival rate of planted dipterocarp and non-dipterocarp species at six years after planting is limited or even lacking (Arifin *et al*., 2008). Assessment of soil nutrient status and growth performance of planted species is important for determination of species site suitability towards an improvement of both strategy and techniques for future rehabilitation efforts. Therefore, this study aimed to examine the soil properties in terms of soil nutrient status both in rehabilitated area and the adjacent secondary forest and to elucidate the most suitable species for future rehabilitation or enrichment planting programs in tropical regions.

MATERIALS AND METHODS

Study area: The study was carried out from June 2007 to August 2008 in Compartment 121, Pasoh Forest Reserve (latitude 3° 15' and longitude 102° 21'), Negeri Sembilan, which is about 140 km South-East of Kuala Lumpur, the business capital city of Malaysia. The Pasoh Forest Reserve covers approximately 2,450 hectares and has a humid tropical climate, associated with weak peaks of seasonal changes of rainfall and temperature. The topography at the study site is undulating with the elevation ranging from 100 to 130 m above sea level. Annual precipitation and temperature are 1349 mm and 27.0°C, respectively for a period of 20 years (1978-1998). There is rainfall throughout the year and nearly half of the annual precipitation falls in April, October and November (Affendy *et al*., 2009). The mean monthly relative humidity of the forest reserve is about 80%. The soils in the study area are derived both from igneous rocks which have undergone considerable clay formation and Paleozoic sedimentary rocks namely limestone, quartzite and shale. The soils in this area classified as Ultisols and Oxisols according to the USDA classification system (Soil Survey

Staff, 1999). These soils are highly weathered, characterized by large amount of low activity clays, acidic reaction and high Al saturation.

The original vegetation is lowland mixed dipterocarp forest (Red Meranti-Keruing) which is predominated by high-quality timber species such as *Dipterocarpus* sp. (Keruing) and *Shorea* sp. (Red Meranti) (Whitmore, 1998). However, in 1984 the high quality commercial tree species were subjected to forest harvesting and clear felled by using crawler tractor and left idle without any further management. As a result, the vegetation of the area was dominated by pioneer species of *Macaranga gigantea*, *Mallotus denticulata*, *M. macrostachys*, *Melastoma* sp., *Trema* sp. and *Vitex pubescens*. The most commonly found herbaceous layers are *Imperata cylindrica*, *Mikania scandens* and other climbers, along with *Musa* sp.

Species under study: Seeds of indigenous species sown at the nursery were *Azadirachta excelsa* (Jack) Jacobs, *Intsia palembanica* Miq. and *Cinnamomum iners* Reinw. ex Blume of non-dipterocarocarp, while the dipterocarp species were *Neobalanocarpus heimii* King, *Dryobalanops aromatica* Gaertn. f., *Hopea nervosa* Ridl., *Shorea assamica*, *S. leprosula* Miq. and *S. parvifolia* Dyer of dipterocarp. The seeds were germinated for three months before transplanting into plastic pots (15×23 cm) containing a mixture of forest topsoil (70%) and river sand (30%). All seedlings were from dipterocarpaceae except *A. excelsa*, *C. iners* and *I. palembanica* as non-dipterocarp. These dipterocarps species usually form an upper layer of lowland and hill dipterocarp forests. These species were chosen due to their importance for Malaysia's general utility timber such as veneer, plywood, building construction, bridge and electric pole. In general, they have been widely used for an enrichment planting or forest rehabilitation program in Malaysia.

All species were selected based on the following criteria: (1) the species should be found at site; and (2) the species should be found in the vegetation samples (from the phytosociological vegetation studies conducted prior to the study). Moreover, the species should perform well in other rehabilitation trials of degraded forestland (Appanah and Weinland, 1993). The seedlings were selected from the same batch and origin with even age, height and vigor.

Site preparation and experimental design: Site preparation in this trial was relatively difficult due to plenty of pioneer species and herbaceous cover. Prior to planting, the existing vegetation was cleared using small-powered chainsaws and brush cutters. Since, the trial requires mulching in all plots, a simple mulching technique was employed with the use of the debris from the existing vegetation. All branches, small trees and debris were cut and chipped into small pieces and later distributed evenly throughout the plots. These techniques retain soil moisture by reducing direct sunlight reaching soil surface. Planting holes, each with the size of 25 cm (depth) and 20 cm (diameter), were prepared prior to planting. The planting was done in early July 2001, during the seasonal transition period of dry spell to rainy season. During planting, which was done manually, 150 g of rock phosphate fertilizer (Christmas Island Rock Phosphate) were placed at the bottom of the planting hole. The site was left without any weeding after planting, although weeding activity was carried out once a year prior to data collection.

The planting trial employed was open planting technique of Randomized Complete Block Design (RCBD) of 30×150 m with three replications. Each block was divided into 30 subplots, of which each plot (5×10 m) was planted with seedlings from one species. A total of 15 seedlings were planted in each plot, at a planting distance of 2×2 m. As a result, a total of 1350 seedlings were planted. The seedlings were planted using the open planting technique where existing of unwanted vegetation were cleared.

At the age of 6 years after planting, the Diameter at Breast Height (DBH) of 1.3 m above ground level and total height of planted species were measured individually in each plot followed by the calculation of survival rate.

Soil sampling and analysis: Soil samples were collected from the surface layer (0-10 cm) and subsurface layer (20-30 cm) in five points randomly at each planting site. After the roots and dead plant materials were removed, the five samples were mixed well to make one composite sample. In order to evaluate the soil nutrient status at planted sites, five sampling plots 50×50 m with three replications were established in the adjacent secondary forests as a control. The soil samples then were collected both from surface and subsurface layers (one in the center of the plot and 4 points diagonally 25 m apart from the center) and mixed well to get composite samples. The soils were air-dried and crushed to pass through a sieve with 2 mm mesh. Soil pH in deionized water (pH (H_2O)) and 1 M KCl (pH (KCl)) solution were measured by the glass electrode method, at the soil solution ratio of 1:5 after shaking for 1 h. Electrical conductivity (EC) was measured using the glass electrode after the pH (H_2O) measurement. The filtrate from pH (KCl) measurement was used for exchangeable Al, H and NH_4 analysis. Exchangeable Al and H was determined by the titration method with 0.01 M NaOH and the exchangeable Al with 0.01 M HCl. Exchangeable H was calculated as the difference between the values of the exchangeable acidity and exchangeable Al. Exchangeable ammonium (Exch. NH_4-N) was determined using the indophenols blue method (Mulvaney, 1996). Total carbon (T-C) and total nitrogen (T-N) were determined by a NC-analyzer (Sumigraph NC-80; Sumika Chemical Analysis Co., Osaka, Japan). Exchangeable bases (Ca, Mg, K and Na) were extracted three times with 1 M ammonium acetate at pH 7.0 and the concentrations of Ca, Mg and K were determined with the atomic absorption spectrophotometry, whereas Na was determined by flame photometry (AA-6800; Shimadzu Corporation, Kyoto, Japan). The amount of NH_4 absorbed in the residue (replaced by 10% NaCl) was determined using steam distillation. Titration methods were used to determine Cation Exchange Capacity (CEC). Available phosphorus (Av. P) was measured by the Bray II method of which the soil samples were extracted with an extracting solution (1 M NH_4F and 0.5 M HCl). Particle-size distribution was determined using the pipette method (Gee and Bauder, 1986). Bulk density of the soil samples were determined by using undisturbed soil samples.

Statistical analysis: All data of soil physico-chemical properties in planted and secondary forests were statistically compared using an independent student's t-test. The mean annual increment of diameter and height and survival rate were statistically analyzed by using a one-way Analysis of Variance (ANOVA) and the Tukey's HSD were chosen as post hoc tests. Standard multiple regression analysis was performed to identify the most significant soil properties that affect the cation exchange capacity. Principal Component Analysis (PCA) was performed to find the important factor that affects the soil fertility by integrating the soil physico-chemical properties. All statistical tests were performed using SPSS version 10.0 for windows.

Table 1: Physicochemical properties between planted and non planted (secondary) forests

Soil properties	Rehabilitation (n = 60)	Secondary (n = 25)
Surface soil (0-10 cm)		
pH (H_2O)	4.30±0.03ns	4.80±0.05ns
pH (Kcl)	3.70±0.05ns	4.20±0.06ns
Total C (g kg^{-1})	12.40±2.5b	15.60±2.7a
Total N (g kg^{-1})	1.10±0.35b	1.50±0.49b
C/N ratio	11.30±2.14ns	10.40±2.27ns
CEC ($cmol_c$ kg^{-1})	7.20±0.43b	9.30±0.54a
Exchangeable Ca ($cmol_c$ kg^{-1})	0.23±0.09ns	0.29±0.12ns
Exchangeable Mg ($cmol_c$ kg^{-1})	0.11±0.08ns	0.12±0.08ns
Exchangeable K ($cmol_c$ kg^{-1})	0.08±0.01ns	0.07±0.01ns
Exchangeable Na ($cmol_c$ kg^{-1})	0.06±0.0ns	0.05±0.0ns
Exchangeable NH_4-N ($cmol_c$ kg^{-1})	0.18±0.04ns	0.19±0.03ns
Exchangeable Al ($cmol_c$ kg^{-1})	3.50±0.1a	3.00±0.1b
Sum of exchangeable bases ($cmol_c$ kg^{-1})	0.48±0.12ns	0.53±0.15ns
ECEC ($cmol_c$ kg^{-1})	3.98±0.23ns	3.53±0.20ns
Available P (mg P kg^{-1})	9.50±0.94ns	10.70±1.12ns
Al saturation (%)	87.90±2.82ns	84.90±2.76ns
Clay (%)	35.30±1.1ns	34.70±1.3ns
Silt (%)	20.00±0.9ns	22.30±1.0ns
Sand (%)	44.70±1.3ns	43.00±1.7ns
Bulk density (g cm^{-3})	1.39±0.5ns	1.35±0.8ns
Subsurface soil (20-30 cm)		
pH (H_2O)	4.50±0.05ns	4.90±0.08ns
pH (KCl)	3.90±0.06ns	3.90±0.07ns
Total C (g kg^{-1})	9.40±0.15ns	10.30±0.85ns
Total N (g kg^{-1})	0.90±0.09ns	0.80±0.15ns
C/N ratio	10.40±1.52ns	12.90±3.15ns
CEC ($cmol_c$ kg^{-1})	5.30±0.24b	6.90±0.39a
Exchangeable Ca ($cmol_c$ kg^{-1})	0.18±0.05ns	0.19±0.01ns
Exchangeable Mg ($cmol_c$ kg^{-1})	0.07±0.01ns	0.09±0.01ns
Exchangeable K ($cmol_c$ kg^{-1})	0.05±0.0ns	0.06±0.0ns
Exchangeable Na ($cmol_c$ kg^{-1})	0.04±0.0ns	0.03±0.0ns
Exchangeable NH_4-N ($cmol_c$ kg^{-1})	0.10±0.01ns	0.12±0.04ns
Exchangeable Al ($cmol_c$ kg^{-1})	2.70±0.12ns	2.40±0.09ns
Sum of exchangeable bases ($cmol_c$ kg^{-1})	0.34±0.02ns	0.37±0.04ns
ECEC ($cmol_c$ kg^{-1})	3.04±0.34a	2.77±0.32b
Available P (mg P kg^{-1})	7.10±1.23ns	8.90±1.13ns
Al saturation (%)	88.80±2.78ns	86.60±2.95ns
Clay (%)	32.40±1.8ns	31.80±2.0ns
Silt (%)	20.20±0.9ns	21.20±1.1ns
Sand (%)	48.40±2.6ns	47.00±2.9ns
Bulk density (g cm^{-3})	1.24±0.4ns	1.29±0.6ns

Values are expressed as Mean±SE. Different letters in the same row indicate significant differences among sites at 0.05 using studendt's t-test; ns: No significant difference; Sum of exch. Bases, Exch. Ca + Mg + K + Na; ECEC, Exch. Ca+Mg + K + Na + Al: Al saturation (Exch. Al/ECEC)×100

RESULTS AND DISCUSSION

Characterization of soil properties: Table 1 shows the average value of physico-chemical properties of soils both in planted and secondary forests. There were no significant differences in physico-chemical properties among planting sites or blocks (data not shown). Irrespective of different species, the result clearly showed that no significant influence of species on soil properties at the age of six years after planting on degraded forest land. Soils at both planted forest and secondary forests were slightly acidic with the pH (water) ranging from 4.3 to 4.8 and 4.5 to 4.9 in the surface and subsurface soils, respectively. The acidic nature of the soils might be due to the loss of exchangeable bases through uptake by plants and leaching under tropical environment. The sand content both in surface and subsurface soils was less than 50%, while that of clay content was more than 30%. Total carbon in surface and subsurface soils ranged from 12.4 to 15.6 and 9.4 to 10.3 g kg^{-1}, respectively. Total nitrogen ranged from 1.1 to 1.5 and 0.8 to 0.9 g kg^{-1} in surface and subsurface soils, respectively. The exchangeable bases in surface and subsurface soils were low compared with that of exchangeable Al, resulting in a high level of Al saturation both in the planted and secondary forests. Al saturation was more than 70% for both surface and subsurface soils. Exchangeable Al and NH_4-N were higher in the surface soils as compared to those of the subsurface soils at both sites. The level of CEC was regarded as low which ranged from 7.2 to 9.3 $cmol_c\ kg^{-1}$ at the surface and 5.3 to 6.9 $cmol_c\ kg^{-1}$ at the subsurface soils.

The clay contents in surface and subsurface soils were 34.7 to 35.3% and 31.8 to 32.4%, respectively (Table 1). Under the acidic nature of the tropical soils, the soil fertility is largely dependent on the negative charges derived from organic matter and clay content (Arifin *et al*., 2007; Tanaka *et al*., 2007, 2009). In the present study, there were high correlations between total carbon and clay contents in both surface ($r = 0.65^{**}$, $p<0.05$) and subsurface ($r = 0.54^{**}$, $p<0.05$) soils (Table not shown). This could be ascribed by the contribution of organic matter stabilization of soils by formation of organo-mineral complexes (Tanaka *et al*., 2007). The results of standard multiple regression analysis showed that the CEC value was highly correlated both with total carbon and clay contents in surface ($CEC = 0.926 \times \text{total carbon}^{**} + 0.659 \times \text{clay}^{**}$ ($r = 0.69^{**}$, $p<0.01$)) and subsurface soils ($CEC = 0.989 \times \text{total carbon}^{**} + 0.849 \times \text{clay}^{**}$ ($r = 0.78^{**}$, $p<0.01$)) .The present result suggests that a larger fraction of negative charges is derived both from organic matter and clay minerals. The CEC values were higher than the effective CEC (ECEC), indicating the presence of some negative charges in the soils (Boonyanuphap *et al*., 2007; Tanaka *et al*., 2009). There was no large variation among sites and in secondary forests for total carbon, total nitrogen and clay contents, although the content of total carbon was significantly high secondary forests than planted forest. It is noteworthy to note that the negative charge derived from organic matter and clay contents is regarded as an important factor for nutrient retention capacity and is probably influencing the fertility status of the soils.

Rehabilitating degraded forest land through the plantation of forest with dipterocarp and non-dipterocarp species could increase the soil fertility through the turn over of fallen leaves of litter layer in the surface soils. The soil properties at subsurface did not show any significant difference with those at surface soils, though the differences in the magnitude of values was unknown. The surface soil was more directly affected by the contribution of organic matter after the establishment of forest rehabilitation. Principal Component Analysis (PCA), a multivariate data set of soil physico-chemical properties, was carried out to reduce the original dimensionality and to figure out the important variables that influence surface soil fertility status. The PCA was performed using selected physico-chemical properties of surface soils (Table 2). The PCA results exhibited the three most significant PC scores and explained about 73.8% of the total variation. The PC1 showed positive contribution of factor loadings to cation exchange capacity, total carbon, clay, total nitrogen, pH and exchangeable Al. Therefore, the PC1 contribute to the cation retention capacity and organic matter. The PC2 was correlated positively with exchangeable Ca and Mg and to a lesser extent with exchangeable NH_4, but Al saturation was correlated negatively which concomitantly related to soil acidity. On the other hand, PC3 showed a high positive factor loading for bulk density and C/N ratio, to a lesser degree, of silt content which is inferred as physical properties. The PCA results showed that soil nutrient status was mainly derived from the input of organic matter through litter fall and associated with clay minerals in the soils. In addition, previous studies have reported that the negative charge derived from organic matter and clay minerals of the soils play an important role in determining the soil nutrient or fertility status of acidic nature of tropical soils (Tanaka *et al*., 2009; Arifin *et al*., 2007; Boonyanuphap *et al*., 2007).

Growth performance of planted species: The results for mean annual increment in terms of diameter at breast height and height of planted dipterocarp and non-dipterocarp species are shown in Table 3. There were significant differences ($p<0.05$) of the mean annual increments in diameter and height among species after six years after planting. Moreover, the results showed that non- dipterocarp species attained significantly higher mean increment of diameter for *A. excelsa* (1.40 cm $year^{-1}$)

Table 2: Results of the principle component analysis derived from selected soil properties

Variables properties	Value	PC1	PC2	PC3
Variables with a high positive factor loading (>0.7)	+	CEC, T-C, Clay, T-N, pH and Exch. Al	Exch. Ca, Mg and Exch. NH_4-N	Bulk density, C/N ratio and silt
Variables with a high negative factor loading (>0.7)	-	-	Al saturation	-
Contribution name of PC axis (73.8%)		48.3% cation retention capacity and organic matter	20.5% acidity	5.0% physical properties

Variables analyzed: pH (KCl), EC, T-C, T-N, C/N, CEC, ECEC, Exch. Ca, Exch. Mg, Exch. K, Exch. NH_4-N, Exch. Al, available P, Al saturation, Bulk density, clay, silt and sand contents

Table 3: Mean annual increment in diameter at breast height (MAID) and height (MAIH) and survival rate of dipterocarp and non-dipterocarp species six years after planting

Species	MAID (cm year^{-1})	MAIH (m year^{-1})	Survival rate (%)
Dipterocarp species			
Shorea leprosula	1.10±0.13b	1.08±0.13b	21.5±7.5cd
Shorea parvifolia	1.00±0.11b	1.01±0.17b	29.6±5.6c
Shorea assamica	0.73±0.08bc	0.65±0.11c	8.1±1.7e
Drayobalanops aromatica	0.41±0.09c	0.43±0.10cd	8.1±1.2e
Neobalanocarpus heimii	0.61±0.10cd	0.57±0.12cd	17.5±8.6d
Hopea nervosa	0.82±0.14bc	0.73±0.22c	38.5±9.9bc
Non-dipterocarp species			
Azadirachta excelsa	1.40±0.12a	1.41±0.16a	73.3±20.5a
Cinnamomum iners	1.35±0.15a	1.12±0.13ab	77.5±19.4a
Intsia palembanica	0.51±0.10cd	0.53±0.09b	47.4±15.6b
p-value	<0.004	<0.001	<0.001

Values are expressed as Mean±SD. Different letters in the same column indicate significant differences among planting types at 5% using Tukey's HSD test

and *C. iners* (1.35 cm year^{-1}) followed by dipterocarp species of *S. leprosula* (1.10 cm year^{-1}), *S. parvifolia* (1.0 cm year^{-1}), *H. nervosa* (0.82 cm year^{-1}), *S. assamica* (0.73 cm year^{-1}), *N. heimii* (0.61 cm year^{-1}), *I. palembanica* (0.51 cm year^{-1}) and *D. aromatica* (0.41 cm year^{-1}).

Similar trends were found for mean annual increment in height of which non- dipterocarp species attained the highest height as compared to other remaining dipterocarp species. *A. excelsa* showed the highest height (1.41 m year^{-1}) followed by *C. iners* (1.12 m year^{-1}), *S. leprosula* (1.08 m year^{-1}), *S. parvifolia* (1.01 m year^{-1}), *H. nervosa* (0.73 m year^{-1}), *S. assamica* (0.65 m year^{-1}), *N. heimii* (0.57 cm year^{-1}), *I. palembanica* (0.53 m year^{-1}) and *D. aromatica* (0.43 m year^{-1}). The exceptionally high mean annual increment in diameter and height for *A. excelsa* might be attributed to its ability to adapt well to the harsh environment especially high soil compaction and low in soil nutrients. According to Andrew *et al*. (2004), *Azadirachta* sp. is found to grow well in dry sites which receive more than 300 mm of annual rainfall, whereas in the present study it is more than 1000 mm. This indicates the ability of these species to grow well in a wide range of dry to humid conditions. The growth performance of planted *A. excelsa* on degraded forest land in Peninsular in terms of diameter and height was reported by several researchers. For example, Ong *et al*. (2002) reported that three years after planting of *A. excelsa* exhibited mean annual diameter and height increments of 3.5 mm year^{-1} and 1.6 cm year^{-1}, respectively. In addition, Ahmad and Weinland (1995) reported that at the age of 41 years, the mean diameter and height by the species attained 34.9 cm and 26.0 m, respectively.

The growth increments of the light and medium hardwood dipterocarp species such as *S. leprosula*, *S. parvifolia, H. nervosa* and *S. assamica* were not significantly different from those of the heavy hardwood of *D. aromatica*, although the former species exhibited slightly better growth increment than the latter. This could be due to the characteristics of former species group was regarded as light demanders and hence adapted well with the open light environment (Appanah and Weinland, 1993). In general, these species utilized full sunlight to increase their photosynthetic activities and hence their growth. Ang and Maruyama (1995) found that those species with high rate of photosynthesis generally have higher chlorophyll content in the same unit area of leaf and this eventually contribute to higher capacity for photosynthesis. Unfortunately, no measurement of photosynthetic activities was performed in the present study. Therefore, an alternative measures for clarifying the effects of photosynthetic rate on growth performance are needed.

On the other hand, both *S. leprosula* and *S. parvifolia* are commonly found in low-lying areas of moderately fertile soils with abundant soil water, which is characterized by the presence of moderate to shade tolerant species. In the present study, the diameter increment of *S. leprosula* and *S. parvifolia* were slightly lower than the result reported by Arifin *et al*. (2008) at 12 years after planting on a degraded forest land in Perak, Peninsular Malaysia, but slightly higher compared to the annual increment of naturally growing of *S. leprosula* (0.8 cm year^{-1}) and *S. parvifolia* (0.6 cm year^{-1}) in the Pasoh Forest Reserve, at 13 years after monitoring, Peninsular Malaysia (Manokaran and Swaine, 1994). On the other hand, the mean annual increment of the height of *S. leprosula* in this study was comparable to the result of Azman *et al*. (1990) at 15 years after planting on a degraded secondary forest in Peninsular Malaysia, whereas lower as compared to the results reported by Arifin *et al*. (2008). In the case of *H. nervosa* and *S. assamica*, the present results showed that their annual diameter and height increments were slightly lower than the planted similar species on a degraded forest land in Peninsular Malaysia (Ang and Maruyama, 1995).

Intsia palembanica, a heavy hardwood, was found to be the slowest growing in terms of diameter and height among planted species. *I. palembanica* is preferred list of forest regeneration and of high planting potential, but it is reputed to be slower growing (Appanah and Weinland, 1993). According to Lee *et al*. (2002), the species growing in sample plots recorded that the diameter and height increments were 0.6 cm year^{-1} and 0.7 m year^{-1}, respectively which was comparable to the results of the present study. On the other hand, the growth rate of planted *D. aromatica* in terms of diameter and height increments was slightly lower compared to that reported by Vincent and Davies (2003) at 22 months after planting on a degraded forest land in Sarawak, Malaysia. Although, the heavy hardwood species is relatively slow in growth, it was found by other researchers to be adapted well to full sunlight when planted on degraded forest land elsewhere in South-East Asia region (Appanah and Weinland, 1993; Adjers *et al*., 1996; Vincent and Davies, 2003). In general, there are many environmental factors affecting the growth performance of indigenous dipterocarp and non-dipterocarp species particularly when planted on a degraded forest land in tropical regions. According to Evans (1992), environmental factors such as drought season, diseases, planting technique and weed competition contribute to the growth performance and survival of planted species.

Survival rate of planted species: The assessment of sufficient number of species survival of various dipterocarp and non-dipterocarp species when planted on a degraded forest land under rehabilitation or plantation programs is required towards better recommendation of species selection in future. The mean average survival rate for the planted species at six years after planting is shown in Table 3. The results showed that the average survival rate of planted non-dipterocarp species ranged from (47.4 to 77.5%), while those for dipterocarp species ranged from (8.1 to 38.5%). The highest survival rate was *C. iners* (77.5%), followed by *A. excelsa* (73.3%), *I. palembanica* (47.4%), *H. nervosa* (38.5%), *S. parvifolia* (29.6%), *S. leprosula* (21.5%), *N. heimii* (17.5%) and the lowest was *S. assamica* and *D. aromatica* which attained 8.1%, respectively. These results clearly showed that planted dipterocarp species on degraded secondary forest with open planting technique resulted in low survival rate. According to Evans (1992), the two major factors that influence the seedlings survival are light intensity and the amount of available moisture especially during the initial stage of stand establishment. Seedlings in these trials were planted in the open and exposed to extreme heat and strong winds. The full sunlight received by the seedlings has caused scorching of leaves, resulting in low survival (Suhaili *et al*., 1998). This phenomenon was especially true for *D. aromatica* and *S. assamica* which recorded the lowest survival amongst planted species in this study.

The non-dipterocarp species of *C. iners* and *A. excelsa* which are considered as light hardwood and light demanding species seems to be readily adapted to poor sites because of their natural habitats that are the open secondary forest. It is interesting to note that *I. palembanica*, a heavy hardwood species, attained a higher survival rate (47.4%) than many of the light hardwood dipterocarp species. In natural forests, the species is found to be widespread and scattered in all inland lowland forests up to 1000 m, usually along river valleys (Appanah and Weinland, 1993). In the case of planted dipterocarp species, several researchers have also reported similar trend of low survival rate when involving planting dipterocarp species on degraded secondary forest. For example, Azman *et al*. (1990) reported that a survival rate for planted *S. leprosula* and *S. parvifolia* of 30 and 20%, respectively at 15 years after planting. Adjers *et al*. (1996) reported the survival rate of planted ten dipterocarp species varied widely from 5.9 to 77.8% three years after planting in degraded secondary forest subjected to shifting cultivation in Kalimantan, Indonesia. On the other hand, Arifin *et al*. (2008) and Abdu *et al*. (2008) registered that the survival rate of planted *Shorea* sp. species was significantly higher under narrow than wider opening of both line and gap planting techniques in Peninsular Malaysia. Similar results were also reported by Adjers *et al*. (1996) and Romell *et al*. (2007) where they found that dipterocarp seedlings survived better at shaded sites as compared to open sites.

CONCLUSIONS

Rehabilitating degraded forest land with indigenous dipterocarp and non-dipterocarp species offer a potential to improve site productivity and increase valuable timber stocks. An important finding of this study is the soil nutrient stock or fertility status in rehabilitated area was almost identical with those in secondary forests, indicating a replenishment of soil fertility through rehabilitation project. It is noteworthy to state that the retention of soil nutrient in this study was mainly controlled by negative charges derived from soil organic matter and clay minerals shown by high correlation between CEC and total carbon as well as clay contents. Another important finding is that the exceptionally high survival rate and growth performance of planted non-dipterocarp species of *A. excelsa* and *C. iners*, to a lesser extent of two dipterocarp species of *S. leprosula* and *S. parvifolia*. Hence, the present study concludes that some non-dipterocarp and dipterocarp species can be adapted to degraded forest land conditions. The potential of *A. excelsa*, *C. iners*, *S. leprosula* and *S. parvifolia* as an introduced species in future rehabilitation projects is enormous, not only because of its high growth but also because of its adaptability to harsh environment as the case in this study. Therefore, exceptionally better growth rates in terms of diameter and height associated with high survival rate of species planted in this study might be due to the species-site suitability which is able to tolerate well with harsh environment such as soil compaction, water stress and other unfavorable site conditions. These characteristics combine with its high value of timber and its abundant storable seeds make the species suitable for future rehabilitation projects in tropical regions. Further studies in identifying the effects of silvicultural treatments, planting types and net photosynthetic rate on the growth performance and survival rate along with determination the role of soil properties particularly physico-chemical, clay minerals and charge characteristics which limit the growth of planted species should be conducted. Such an assessment is important if the current efforts by Universiti Putra Malaysia, Forestry Department Peninsular Malaysia and other international agencies in tropical regions to expand the area of forest rehabilitation or plantation forest.

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