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Assessment on Soil Fertility Status and Growth Performance of Planted Dipterocarp Species in Perak, Peninsular Malaysia

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Abstract: A study was conducted in the rehabilitation of degraded forestland in the Bukit Kinta Forest Reserve, Perak, Peninsular Malaysia with two main objectives: (1) to assess the growth performance of two indigenous dipterocarp species, *Shorea pauciflora* (King) and *S. macroptera* (Dyer) planted under various line planting widths and gap planting openings and (2) to examine soil fertility status and site quality of the study area using two indices; Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF), which are commonly used for estimating soil fertility of secondary forest in humid tropical regions. The survival rate of the two species was not affected by line planting width and gap planting opening. However, its effect on the tree growth was very clear probably due to preference of light intensity under the canopy, which in turn can be controlled by line planting widths and gap planting openings. Principal component analysis categorized the soil properties into three principal components which explained 70% of the total variation. The First Component Score (PC1) was related to cation retention capacity with a high contribution of soil organic matter. The linear regression analysis indicated that there were positive correlations between PC1 score and the proposed SFI and SEF for both soil depths ($p<0.01$). The SFI and SEF were also highly correlated with height, dbh (diameter at breast height) and tree volume, while PC1 score was only correlated with dbh and tree volume for the surface soils. This shows that the SFI and SEF can be used as indices to predict soil fertility and site quality of rehabilitated degraded forestland.

Key words: Enrichment planting, line and gap plantings, forest rehabilitation, site quality, soil fertility

INTRODUCTION

Tropical rain forests are considered as the most productive of all terrestrial ecosystems and they have the functional roles for biodiversity conservation, world climate amelioration and soil conservation (ITTO, 2002). However, indiscriminate exploitation of the natural forest by human activities particularly excessive forest harvesting of wood or non wood products have created large tracts of degraded secondary forest. Between 1950 and 2000, approximately 850 million ha or 60% of the total forest area in the tropics have been degraded which is difficult to regenerate due to physical, chemical and biological barriers (ITTO, 2002). This consequently led the growing interest of developing rehabilitation or restoration techniques on degraded secondary forest (Ramos and Del Amo, 1992; Adjers *et al*., 1995; Otsamo, 1998; Vincent and Davies, 2003; Ilstedt *et al*., 2004) to prevent further degradation (Lugo, 1997; Parotta *et al*., 1997) by means of improving site quality and productivity (McDill and Amateis, 1992; Onyekwelu, 2005).

In the tropics, one of the promising methods used to restore degraded forestland is enrichment planting (Ramos and Del Amo, 1992; Adjers *et al*., 1996; Montagnini *et al*., 1997). Enrichment planting is defined as the introduction of valuable (high quality indigenous) species to poorly stocked logged forests without eliminating the existing valuable individuals (Appanah and Weinland, 1993). It is also done to increase timber volume and the economic value of the secondary forest (Adjers *et al*., 1995; Montagnini *et al*., 1997; Pinard *et al*., 1998; Pena-Claros *et al*., 2002). There are several methods adopted under enrichment planting such as line planting (Adjers *et al*., 1995, 1996; Montagnini *et al*., 1997) and gap/patch planting in secondary forests (Tuomela *et al*., 1996; Numata *et al*., 2006; Romell *et al*., 2007). In general,

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line or gap planting was established on the light requirement since different species may react differently to differing light intensities (Adjers *et al*., 1995, 1996; Ashton, 1995; Bebber *et al*., 2002). Research on the size of both line and gap planting and their effect on survival and growth are limited.

These two types of planting are not widely practiced in Peninsular Malaysia due to the high costs accompanied with regular maintenance of the lines or gaps planting (Appanah and Weinland, 1993). Some researchers have reported that although the growth rate of planted dipterocarp species increased under the enrichment planting program, the seedling survival rates are relatively poor (Pamiotto, 1991; Hashim, 2003). A joint research between Forestry Department Peninsular Malaysia (FDPM) and Japan International Cooperation Agency (JICA) was implemented to enrich a poorly-stocked logged-over forest in the Bukit Kinta, Perak, Peninsular Malaysia. In this project, the indigenous dipterocarp species were planted under various line planting widths and gap planting openings. There was however no information on suitable opening width or size of gap planting for optimum growth neither on soil fertility status even after 10 years the research. Therefore, an assessment of the rehabilitation program in relation to growth performance of planted species and soil fertility status by using soil index could provide key information on species-site preference in order to improve the strategies and effective technique for future rehabilitation efforts.

The aim of this study are therefore to determine the suitable opening of line or gap planting in terms of survival rate and height, diameter and tree volume of two planted dipterocarp species, *Shorea pauciflora* and *S. macroptera*, to examine the soil nutrient status of planted forests in comparison to adjacent natural forest and to test the applicability of a Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF) for estimating the soil fertility and site quality. The SFI (Moran *et al*., 2000) and SEF (Lu *et al*., 2002) are recently recommended methods used for estimating soil fertility and productivity of regenerating secondary forests in humid tropical regions.

MATERIALS AND METHODS

Study site: The study site is located at Compartment 146 in the Bukit Kinta Forest Reserve (4° 36' N and 101° 44' E), approximately 200 km North of Kuala Lumpur, the business city of Malaysia (Fig. 1). The forest in the Bukit Kinta is classified as a hill dipterocarp forest which consists of steep mountainous region with a slope of 20 to 40° and an elevation ranging from 300 to 600 m above sea level. Between 1981 and 1999, the mean annual precipitation and temperature were 2,417 mm and 24.5°C, respectively. The soils were derived from granite which had undergone considerable clay formation. The soils in this study area are classified as Typic Paleudult and Typic Kandiudult according to the USDA classification system (Soil Survey Staff, 1999). This soil is characterized by

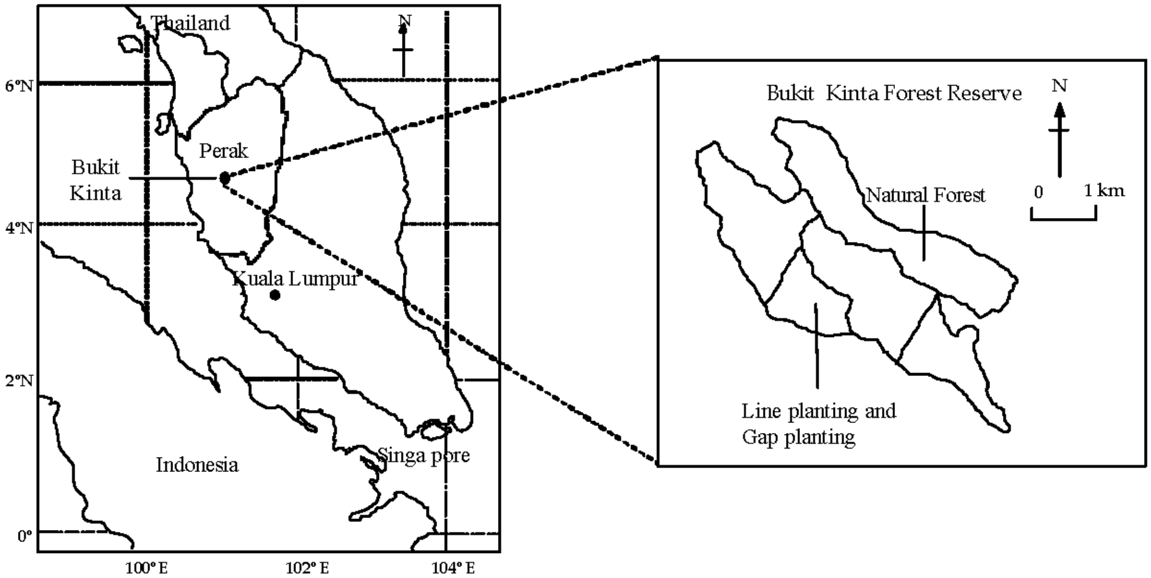

Fig. 1: Location of study site in the Bukit Kinta Forest Reserve, Perak, Peninsular Malaysia

strong weathering with a large amount of low activity clays and also with low base saturation and high Al saturation (Arifin *et al*., 2007).

The commercial tree species at this area was subjected to forest harvesting from April 1990 to November 1993 by using Selective Management System (SMS) method. This is the only record of logging history of the area. The dominant dipterocarp species of the forest before harvesting are mainly *Shorea* spp. and *Dipterocarpus* spp. (Mustafa *et al*., 2002). According to a post-felling inventory carried out on 2 ha plot; the harvesting activities had resulted in poor stocking of dominant dipterocarp species (non-pioneer species from Dipterocarpaceae family). Of the 34 trees ha^{-1} of the commercial species with dbh (diameter at breast height) more than 15 cm surveyed, only four trees of dipterocarp species were present.

Species under study: In January 1995, the secondary forest of hill dipterocarp forest in Bukit Kinta were planted with dipterocarp species, namely *Shorea* spp. through various line planting widths and gap planting openings. In February 2006, the survival rate of planted species, *Shorea pauciflora* and *S. macroptera* was calculated as percentage of individuals present and the height and diameter at breast height (dbh) were measured individually, followed by the calculation of the standing volume. The two species selected in this study are from Dipterocarpaceae family which is important for Malaysian timber industry.

Both species have been widely used for enrichment planting program in Peninsular Malaysia due to their relatively fast growth (Appanah and Weinland, 1993; Ang and Maruyama, 1995). The timber from both species is regarded as light hardwood of the dark red meranti group which is important for general utility, particularly veneer and plywood. These species are moderately to shade tolerant and requires partial shade in early establishment (Appanah and Weinland, 1993; Ang and Maruyama, 1995). In natural conditions, the *S. pauciflora* is commonly found in the lowland and hill dipterocarp forests below than 700 m above sea level (Appanah and Weinland, 1993), while *S. macroptera* normally grows on deep soils of undulating land and hills of less than 600 m above sea level. They are emergent tree species in natural habitat which can reach about 30 to 50 m in height.

Experimental design: The experiment involved two species, three line planting widths (2, 10 and 20 m) and three gap planting openings (10×10, 20×20 and 30×30 m). The seeds of both species were collected from selected mother trees, germinated in the planter's container at the nursery before being transplanted to polythene bags (15×23 cm) with a mixture medium at the ratio of rice husk (5%), river sand (25%) and forest topsoil (70%). All seedlings were kept at the nursery under shade netting which filters about 30 to 50% of full sunlight for a period of six months and moved out to open conditions for hardening (2 to 4 months) before being transported to the field for planting (Mustafa *et al*., 2002).

In January 1995, prior to planting, the planting lines and gaps were opened by slashing all trees, ferns, herbs and bamboos in order to allow overhead light to reach the forest floor. The line planting widths consisted of five replications and the seedlings were planted using a planting space of 3 m. Distance between lines was 10 m. Likewise, there were five replications for gap planting and the seedlings were planted at a spacing of 3×3 m in each planting type. At the time of planting, the average height of the seedlings for both in the line and gap planting was 80 cm.

In the first two years, the plots were weeded every three months where all climbers were removed and ferns, shrubs and grasses were slashed at two meter width along the line planting and one meter circle surrounding planted seedlings in the gap planting (Mustafa *et al*., 2002). In the following year, the plots were weeded twice a year up to 5 years.

Soil sampling and analyses: In evaluating the forest rehabilitation program in relation to soil fertility comprehensively, soil samples at the depths of 0-5 cm (surface soils) and 20-25 cm (subsurface soils) were collected in five replications within each planting type in February, 2006. The soils were mixed well to obtain one composite sample after the roots and coarse plant debris were removed. In order to evaluate the soil fertility status in the planted forests after 11 years of forest rehabilitation, five sampling plots of 40×40 m were established in the adjacent natural forest as a control. In each sampling plot, soil samples were also collected at 0-5 and 20-25 cm in five replications (one in the center of the plot and 4 points diagonally 20 m apart from the center). The soil samples from the same soil depth at five points were mixed well to get composite sample. Prior to soil analysis, the soils were air-dried and crushed to pass through a 2 mm mesh sieve. Particle-size distribution was determined using the pipette method. Electrical Conductivity (EC) was measured using the EC meter CCM-K1P, TDA DKK). Soil pH was determined in water or 1 M KCl (designated as pH (H_2O) and pH (KCl), respectively) in a soil to solution ratio of 1:5 using the glass electrode method. Total C and N contents (T-C, 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 concentration of Ca, Mg and K were determined by 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 which was replaced by 10% NaCl and was determined using steam distillation and titration methods was regarded as Cation Exchange Capacity (CEC). The filtrate from pH (KCl) measurement was used for exchangeable Al, H and NH_4 analysis. Exchangeable acidity (Al+H) was determined by the titration method with 0.01 M NaOH and the exchangeable Al with 0.01 M HCl. The exchangeable H was calculated as the difference between the values of the exchangeable acidity and exchangeable Al. The exchangeable ammonium (Exch. NH_4-N) was determined using the indophenols blue method (Mulvaney, 1996). Available phosphorus was determined by the Bray II method (Kuo, 1996), of which the soil samples were extracted with an extracting solution (1 M NH_4F and 0.5M HCl). Then, a color developing reagent was added and determined the available phosphorus by absorbance measurement with spectrophotometer at a wavelength of 710 nm (Shimadzu, UV-140-02, Kyoto, Japan).

Data analysis: This study mainly focused on the growth performance of planted dipterocarp species, soil fertility and the applicability of SFI and SEF to estimate soil fertility and site quality. We performed an independent t-test to analyze the significant differences on the survival rate and height, dbh and volume increments of planted species between line planting and gap planting. A one-way Analysis of Variance (ANOVA) was also performed to find significant differences on the survival rate, height, dbh and volume among the planting types. Differences among the planting types were evaluated with a *post-hoc* test (Tukey's HSD). The soil physico-chemical properties were also statistically analyzed by using a one-way ANOVA followed by Tukey's HSD test to detect significant differences between line planting, gap planting and adjacent natural forest. Multivariate analysis was used to detect the key factor that affects the soil fertility status, by integrating Principal Component Analysis (PCA) with selected soil physico-chemical properties. Integrating PCA score with a soil index that represent a soil fertility status is important for estimating the soil fertility and productivity in humid tropical forests. However, an effective method to evaluate soil fertility status is still scarce or even lacking. In this study two soil indices were used for estimating soil fertility and site quality. The Soil Fertility Index (SFI) (Moran *et al*., 2000) and Soil Evaluation Factor (SEF) (Lu *et al*., 2002) are applicable for estimating soil fertility and exert predicts of the increase in biomass in the Amazonian humid tropical forests under a succession secondary forest. However, the SFI is dependent largely on pH and pH is not an independent value but dependent on the relative amount of Ca, Mg and exchangeable Al in the soil. In order to improve this latent drawback, a new index, SEF, was developed by Lu *et al*. (2002). The equations for both indices are as follows:

$$\text{SFI} = \text{pH} + \text{organic matter (\%, dry soil basis)} + \text{Available P (mg kg}^{-1}\text{, dry soil)} + \text{exchangeable Ca (cmol}_c\text{ kg}^{-1}\text{ dry soil)} + \text{exchangeable Mg (cmol}_c\text{ kg}^{-1}\text{ dry soil)} + \text{exchangeable K (cmol}_c\text{ kg}^{-1}\text{ dry soil)} - \text{exchangeable Al (cmol}_c\text{ kg}^{-1}\text{ dry soil)} \quad (1)$$

$$\text{SEF} = [\text{exchangeable Ca (cmol}_c\text{ kg}^{-1}\text{ dry soil)} + \text{exchangeable Mg (cmol}_c\text{ kg}^{-1}\text{ dry soil)} + \text{exchangeable K (cmol}_c\text{ kg}^{-1}\text{ dry soil)} - \log(1 + \text{exchangeable Al (cmol}_c\text{ kg}^{-1}\text{ dry soil)})] \times \text{organic matter (\%, dry soil basis)} + 5 \quad (2)$$

To detect if the proposed indices could be an effective method to evaluate the soil fertility status in this study, a linear regression analysis between the PC score and SFI and SEF was conducted. In order to emphasize the most appropriate index for estimating the soil fertility and site quality as well as growth performance, we performed a linear regression analysis between PC score, SFI and SEF and tree growth parameters (height, dbh and volume). All statistical tests were performed in SPSS version 10.0 for windows (SPSS Inc., 1989).

RESULTS AND DISCUSSION

Survival rate and growth performance of line planting and gap planting: The results showed that the average survival rate of *S. macroptera* (54%) in the gap planting was significantly higher than in the line planting (47%). In contrast, no significant difference was detected for *S. pauciflora* between line planting (34%) and gap planting (36%). The survival rate for both planted species in this study was relatively lower than other similar species planted on degraded forestland in this tropical region (Table 1). For example, Romell *et al.* (2007) reported the survival rate for *S. pauciflora* of 86% 30 months after planting under artificial canopy gaps planting dominated by *Macaranga* spp. in Sabah; while Ang and Maruyama (1995) reported a survival rate for

Table 1: Comparison of survival rate and mean annual increment in height (MAIH), diameter (MAID) and volume (MAIV) of planted species between line planting and gap planting

Species	Treatment	Survival rate (%)	MAIH (m year^{-1})	MAID (cm year^{-1})	MAIV (m^3 ha^{-1} year^{-1})
Shorea pauciflora	Line planting	34.3±2.71^{ns}	7.39±1.12^{ns}	8.14±1.08^{b}	0.71±0.1^{b}
	Gap planting	35.7±4.28^{ns}	8.49±1.31^{ns}	11.87±1.21^{a}	3.34±0.8^{a}
Shorea macroptera	Line planting	47.3±3.14^{b}	6.82±0.87^{ns}	7.10±1.05^{b}	1.04±0.1^{b}
	Gap planting	54.2±6.54^{a}	7.73±1.03^{ns}	8.68±0.97^{a}	2.99±0.2^{a}

Different superscripts letter(s) in the same column indicate significant differences between planting types at 5% using Turkey's HSD test, ns: Non significant

S. macroptera of 64% 25 months after planting on degraded forest in Peninsular Malaysia. Irrespective of the difference in species and age after planting, the survival rate of the two planted species in this study was slightly lower to those reported from line planting of dipterocarp species in Kalimantan, Indonesia (Adjers *et al*., 1995) and gap planting in Peninsular Malaysia (Suhaili *et al*., 1998).

There were no significant differences in the mean annual increments of the height for both species between line and gap plantings. On the contrary, mean annual dbh increment of both species was significantly higher in the gap than line planting ($p<0.05$). In general, the trees measured in the present study were comparable in height to the similar species planted on degraded forestland in this region (Ang and Maruyama, 1995; Romell *et al*., 2007; Shono *et al*., 2007). In the case of mean annual dbh increment, results showed it was greater than the annual increment in dbh of naturally growing *S. pauciflora* (0.38 cm year^{-1}) and *S. macroptera* (0.42 cm year^{-1}) in Peninsular Malaysia after 26 years and 30 years of monitoring, respectively (Manokaran and Kochummen, 1992). However, the dbh increment of *S. macroptera* in this study was lower than the annual dbh of *S. macroptera* (1.38 cm year^{-1}) 42 years after planting on a degraded land in Peninsular Malaysia (Appanah and Weinland, 1993).

The mean annual volume increment of both planted species was significantly higher in the gap planting than line planting ($p<0.05$). In the gap planting, the mean annual volume increment of *S. pauciflora* was 3.4 m^3 ha^{-1} and *S. macroptera* was 3.0 m^3 ha^{-1}, while that of the line planting the values were 0.7 and 1.0 m^3 ha^{-1}, respectively. These results were relatively lower compared to the annual volume of different planted dipterocarp species in Peninsular Malaysia. For example, Appanah and Weinland (1993) reported the annual volume of plantation for *S. leprosula* of 7.7 m^3 ha^{-1} and *S. parvifolia* of 7.9 m^3 ha^{-1} at 35 years after planting under enrichment planting program on a degraded forestland in Peninsular Malaysia.

Taking into account the mean survival rate and mean annual increments in height, diameter and volume of both planted species in the line planting and gap planting, it is seemed that the gap planting was more appropriated method in rehabilitating such degraded hill dipterocarp forest such as in Bukit Kinta. Adjers *et al*. (1995) stated that in a relatively homogenous secondary forests or former shifting cultivation sites, where stratification of canopy layers has not yet been fully developed, line planting is a suitable method of enrichment, whereas in a high multistory forest, lines are difficult to open up and hence gaps or planting in groups is more suitable for such conditions than line planting.

Survival rate and growth performance among the planting types: There is an increasing need to assess the appropriate line or gap planting techniques to promote high survival and growth rates towards the successful implementation of rehabilitation program. In the line planting, the survival rates of *S. pauciflora* were slightly higher in the narrower planting types of L_1 (36%) and L_2 (39%) as compared to type L_3 of less than 30%, although no statistically significant differences were found among the planting types (Table 2). Likewise the survival rate of *S. macroptera* was also not significantly different among the planting types which range from 46 to 48%. In the gap planting, the survival rates for both species were higher in type G_1 as compared to types G_2 and G_3. Although, high survival rate of both planted species in the narrower opening in types L_1 and G_1, these two planting types require addition canopy opening of adjacent vegetation and this consequently would increase the cost of management and also opening up the canopy after the establishment can damage the under-planted species.

In contrast to survival rate, mean annual increments in the height and dbh of two species were significantly different among the planting types in both line planting and gap planting ($p<0.05$). These differences were probably due to the species characteristics as difference in shade tolerant and growth rates (Appanah and Weindland, 1993). In the line planting, mean annual increments in terms of height and dbh for both species were significantly higher at wider widths in types L_2 and

Table 2: Survival rate and mean annual increment in height (MAIH), diameter (MAID) and volume (MAIV) of planted species in the line planting (L_1-L_3) and gap planting (G_1-G_3)

Species	Treatment	Survival rate	MAIH (m year^{-1})	MAID (cm year^{-1})	MAIV (m^3 ha^{-1} year^{-1})
Shorea pauciflora	**Line planting**				
	L_1	36.3 ± 4.2^{ns}	0.47 ± 0.05^{b}	0.46 ± 0.03^{b}	0.7 ± 0.1^{ns}
	L_2	38.6 ± 0.6^{ns}	0.81 ± 0.06^{a}	0.96 ± 0.06^{a}	0.9 ± 0.3^{ns}
	L_3	28.1 ± 1.2^{ns}	0.74 ± 0.09^{a}	0.81 ± 0.10^{a}	0.5 ± 0.1^{ns}
	Gap planting				
	G_1	46.7 ± 9.6^{ns}	0.65 ± 0.01^{b}	0.87 ± 0.09^{b}	1.7 ± 0.3^{b}
	G_2	42.1 ± 2.1^{ns}	0.87 ± 0.04^{a}	1.31 ± 0.16^{ab}	5.9 ± 1.6^{a}
	G_3	29.4 ± 7.1^{ns}	0.79 ± 0.05^{a}	1.06 ± 0.11^{a}	2.4 ± 1.1^{b}
Shorea macroptera	**Line planting**				
	L_1	48.7 ± 5.1^{ns}	0.45 ± 0.05^{b}	0.49 ± 0.04^{b}	1.1 ± 0.1^{ab}
	L_2	46.0 ± 7.9^{ns}	0.72 ± 0.01^{a}	0.75 ± 0.03^{a}	1.6 ± 0.4^{a}
	L_3	47.3 ± 3.9^{ns}	0.66 ± 0.04^{a}	0.77 ± 0.09^{a}	0.4 ± 0.1^{b}
	Gap planting				
	G_1	65.5 ± 3.5^{ns}	0.52 ± 0.09^{b}	0.47 ± 0.18^{b}	1.8 ± 1.4^{b}
	G_2	52.2 ± 9.1^{ns}	0.87 ± 0.03^{a}	1.09 ± 0.11^{a}	4.7 ± 1.9^{a}
	G_3	45.0 ± 9.7^{ns}	0.83 ± 0.05^{a}	1.01 ± 0.09^{a}	2.5 ± 0.8^{ab}

Different superscripts letter(s) in the same column indicate significant differences among planting types at 5% using Tukey's HSD test; ns: Non significant

L_3 as compared to the narrower width in type L_1. Similarly, the height and dbh of both species were also significantly higher at wider opening gaps in types G_2 and G_3 than the smaller gap opening of type G_1.

This result shows that the two planted species seems to have different light requirements under various lines spacing and gaps opening. Earlier works have shown that the success of planted dipterocarp species in the field trials was related to species selection, specific planting techniques and light requirements (Adjers *et al*., 1996; Ang and Maruyama, 1995; Bebber *et al*., 2002; Norisada *et al*., 2005). In the study conducted by Adjers *et al*. (1995), planted *Shorea parvifolia* and *S. leprosula* for a period of 26 months the seedlings exhibited better height and basal diameter in the 2 and 3 m line planting widths compared to 1 m, reflecting sufficient amount of overhead light. Therefore, opening of the adjacent vegetation canopy should be matched with species-specific light requirement to promote higher survival and growth rates of the planted species.

In the case of the mean annual volume increment, there was no significant difference among the line planting for *S. pauciflora* ($p<0.05$). In the gap planting, both planted species exhibited significantly higher annual volume in type G_2 than the other two types of G_1 and G_3. Judging from the survival rate and growth performance in terms of height and dbh as well as volume for both species, planting types of L_2 and G_2 can be recommended for the establishment of rehabilitation program through enrichment planting in the future. However, further studies on silvicultural treatments and species-specific requirements of different dipterocarp species under various planting types are needed to verify the effects on survival rate, growth performance and tree volume of under-planted species. Such research is important if the recent efforts by forest department and other related agencies to rehabilitate degraded logged-over forests are to be successful.

Soil fertility status in the planted forests and natural forest: Although an attempt to create artificial line and gap plantings could promote plant growth by means of increasing above ground biomass and soil fertility level, no statistical significant differences were observed in the soil physico-chemical properties among the planting types. Table 3 shows the physico-chemical properties of the surface and subsurface soils in the line planting, gap planting and adjacent natural forest. The clay contents in all sites ranged from 24 to 32%, while that of sand content varied from 58 to 64%. The soils were moderately acidic, with pH in water of less than 5. However, the soils for both surface and subsurface soils in adjacent natural forest were significantly more acidic than those in the planted forests, which were associated with high concentration of exchangeable Al resulting in high Al saturation.

The content of T-C in the surface soils of natural forest was almost double than that in the planted forests; whereas there was no significant difference in the subsurface soils. This was presumably due to a large contribution of fresh organic matter from the permanent vegetation in the former than the latter. Soil organic matter is regarded as the single most important indicator of soil fertility and a major component in the assessment of soil quality in the tropical regions (Paniagua *et al*., 1999). The content of T-N in the line and gap planting was

Table 3: Physicochemical properties between planted forests at secondary forest and adjacent natural forest

Soil properties	Line planting (n = 15)	Gap planting (n = 15)	Natural forest (n = 5)
Surface soil (0-5 cm)			
pH (H_2O)	4.50 ± 0.04^{a}	4.40 ± 0.03^{a}	4.10 ± 0.06^{b}
pH (KCl)	4.10 ± 0.05^{a}	4.00 ± 0.03^{a}	3.50 ± 0.08^{b}
Total C (g kg^{-1})	20.50 ± 1.10^{b}	21.90 ± 1.30^{b}	42.90 ± 5.10^{a}
Total N (g kg^{-1})	2.20 ± 0.10^{b}	2.50 ± 0.20^{b}	3.90 ± 0.40^{a}
C/N ratio	9.30 ± 1.00^{ns}	8.80 ± 0.70^{ns}	11.10 ± 0.60^{ns}
CEC (cmol$_c$ kg^{-1})	5.70 ± 0.30^{b}	5.80 ± 0.40^{b}	12.20 ± 1.00^{a}
Exchangeable Ca (cmol$_c$ kg^{-1})	0.42 ± 0.03^{b}	0.57 ± 0.03^{b}	0.84 ± 0.20^{a}
Exchangeable Mg (cmol$_c$ kg^{-1})	0.17 ± 0.03^{ns}	0.20 ± 0.02^{ns}	0.28 ± 0.05^{ns}
Exchangeable K (cmol$_c$ kg^{-1})	0.13 ± 0.01^{b}	0.14 ± 0.01^{b}	0.20 ± 0.01^{a}
Exchangeable Na (cmol$_c$ kg^{-1})	0.04 ± 0.00^{ns}	0.05 ± 0.00^{ns}	0.05 ± 0.00^{ns}
Exchangeable NH_4-N (cmol$_c$ kg^{-1})	0.15 ± 0.02^{ns}	0.17 ± 0.03^{ns}	0.21 ± 0.02^{ns}
Exchangeable Al (cmol$_c$ kg^{-1})	2.20 ± 0.10^{b}	2.20 ± 0.10^{b}	4.80 ± 0.70^{a}
Sum of exchangeable bases (cmol$_c$ kg^{-1})	0.76 ± 0.07^{b}	0.96 ± 0.07^{b}	1.35 ± 0.25^{a}
ECEC (cmol$_c$ kg^{-1})	3.00 ± 0.1^{b}	3.20 ± 0.1^{b}	6.20 ± 0.6^{a}
Available P (mg P kg^{-1})	12.50 ± 1.4^{ns}	12.40 ± 1.1^{ns}	15.10 ± 2.5^{ns}
Al saturation (%)	74.80 ± 1.5^{ns}	69.90 ± 1.6^{ns}	77.20 ± 4.5^{ns}
Clay (%)	26.10 ± 1.5^{a}	23.70 ± 1.3^{b}	31.60 ± 0.8^{a}
Silt (%)	10.30 ± 0.7^{b}	12.50 ± 0.7^{b}	8.40 ± 1.9^{c}
Sand (%)	63.60 ± 0.6^{a}	63.70 ± 0.7^{a}	59.90 ± 1.6^{b}
Subsurface soil (20-25 cm)			
pH (H_2O)	4.60 ± 0.04^{ab}	4.70 ± 0.03^{a}	4.50 ± 0.12^{b}
pH (KCl)	4.10 ± 0.03^{a}	4.20 ± 0.03^{a}	3.90 ± 0.05^{b}
Total C (g kg^{-1})	13.20 ± 0.40^{ns}	15.60 ± 1.10^{ns}	16.80 ± 1.10^{ns}
Total N (g kg^{-1})	1.20 ± 0.10^{b}	1.40 ± 0.10^{ab}	1.70 ± 0.10^{a}
C/N ratio	11.10 ± 1.20^{ns}	11.40 ± 2.00^{ns}	9.80 ± 0.90^{ns}
CEC (cmol$_c$ kg^{-1})	4.80 ± 0.20^{b}	5.00 ± 0.20^{b}	6.30 ± 0.30^{a}
Exchangeable Ca (cmol$_c$ kg^{-1})	0.28 ± 0.03^{b}	0.39 ± 0.01^{ab}	0.50 ± 0.05^{a}
Exchangeable Mg (cmol$_c$ kg^{-1})	0.14 ± 0.01^{ns}	0.17 ± 0.01^{ns}	0.20 ± 0.03^{ns}
Exchangeable K (cmol$_c$ kg^{-1})	0.10 ± 0.00^{ns}	0.10 ± 0.00^{ns}	0.06 ± 0.00^{ns}
Exchangeable Na (cmol$_c$ kg^{-1})	0.03 ± 0.00^{ns}	0.04 ± 0.00^{ns}	0.05 ± 0.00^{ns}
Exchangeable NH_4-N (cmol$_c$ kg^{-1})	0.12 ± 0.01^{ns}	0.13 ± 0.02^{ns}	0.12 ± 0.02^{ns}
Exchangeable Al (cmol$_c$ kg^{-1})	1.90 ± 0.10^{b}	2.10 ± 0.10^{b}	3.40 ± 0.20^{a}
Sum of exchangeable bases (cmol$_c$ kg^{-1})	0.56 ± 0.04^{b}	0.71 ± 0.03^{ab}	0.81 ± 0.07^{a}
ECEC (cmol$_c$ kg^{-1})	2.70 ± 0.1^{b}	2.80 ± 0.1^{b}	4.10 ± 0.2^{a}
Available P (mg P kg^{-1})	11.40 ± 1.3^{ns}	10.70 ± 1.5^{ns}	9.30 ± 1.3^{ns}
Al saturation (%)	78.60 ± 2.2^{ns}	73.50 ± 1.8^{ns}	80.80 ± 1.5^{ns}
Clay (%)	30.40 ± 1.3^{ns}	30.80 ± 1.1^{ns}	31.20 ± 1.8^{ns}
Silt (%)	11.20 ± 0.6^{ns}	11.00 ± 0.6^{ns}	11.10 ± 0.8^{ns}
Sand (%)	58.40 ± 0.8^{ns}	58.20 ± 1.0^{ns}	57.70 ± 1.6^{ns}

Different superscripts letter(s) in the same row indicate significant differences among sites at 5% using Tukey's HSD test; ns, Non significant; Sum of exch. Bases, Exch. Ca + Mg + K + Na; ECEC, Exch. Ca + Mg + K + Na + Al; Al saturation, (Exch. Al/ECEC) ×100

significantly lower than the natural forest. In spite of high total carbon and nitrogen contents in the natural forest, no significant difference was observed for C/N ratio both in the planted forests and natural forest.

The Cation Exchange Capacity (CEC) value was generally low both for the surface and subsurface soils throughout the line planting, gap planting and natural forest. However, the CEC was higher compared with that of the Effective Cation Exchange Capacity (ECEC), suggesting the occurrence of some variable negative charges (Tanaka *et al*., 2007). Judging from a small difference between CEC and ECEC, the contribution of negative charges from soil organic matter to the cation retention capacity might be small. Exchangeable bases especially Ca and K were also high in the natural forest to that in the line and gap planting, while no significant differences was observed for exchangeable Mg and Na. It should be noted that available P is generally low both in the surface and subsurface soils of both planted forests and natural forest.

For the surface soil physico-chemical properties, principal component analysis generated three most significant components (Table 4). These three components (PC1, PC2 and PC3) explained about 70% of the total variability and each component represents a series of variables which simplifies the analysis and interpretation. The first component score (PC1) was defined as cation retention capacity as the CEC, total C and effective CEC, total N, clay content, exchangeable K and Mg and electrical conductivity exhibited high positive factor loadings and pH to a lesser degree. PC2 was related to soil acidity as Al saturation showed high positive factor loadings, whereas the third component score (PC3) reflects to organic matter quality as C/N ratio showed high positive factor loadings. It should be noted that this factor analysis provides statistical evidence of the ability of the three principal component scores to integrate soil physico-chemical properties within the components.

Table 4: Soil parameters used for PCA and results of PCA of the surface soils

	Variables analyzed			
	pH (KCl), EC, T-C, T-N, C/N, CEC, ECEC, Exch. Ca, Exch. Mg, Exch. K, Exch. NH4-N, Exch. Al, Available P, Al saturation, Clay and Sand contents			
	Value	PC1	PC2	PC3
Variables with a high positive factor loading (>0.7)	+	CEC, T-C, ECEC, T-N, Clay, Exch. K, Exch. Mg and EC	Al saturation	C/N ratio
Variables with a high negative factor loading (>0.7)	-	pH	ND	ND
Contribution name of PC axis		44.8% Cation retention capacity	15.9% Acidity	9.3% Organic matter quality

+: Factor loading with a positive value, -: Factor loading with a negative value, ND: Not Determined

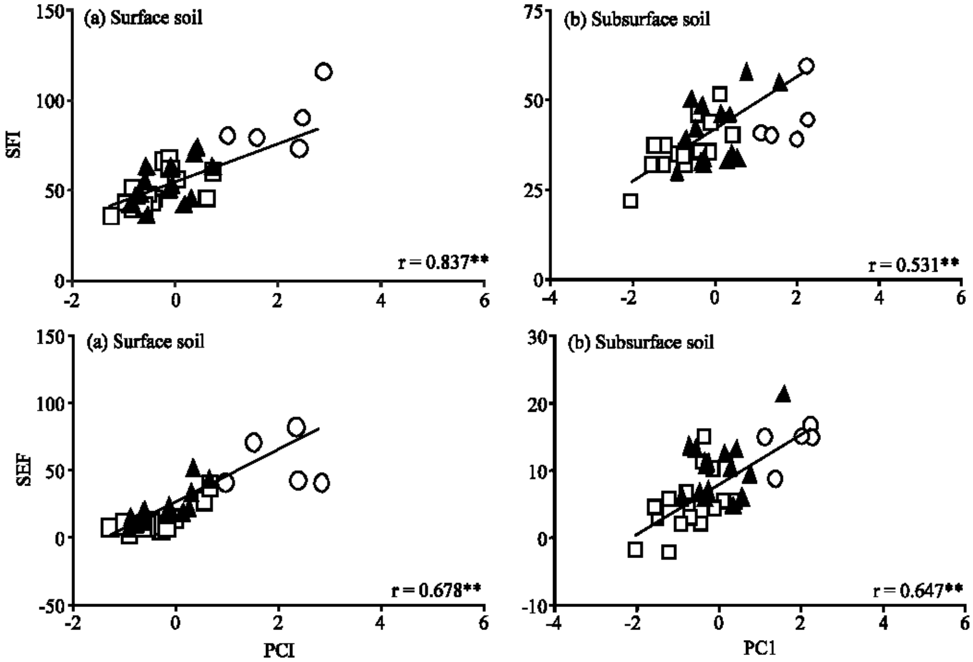

Fig. 2: Relationship between PC1 score derived from PCA analysis and the calculated Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF) for surface and subsurface soils: (▲) gap planting, (☐) line planting and (○) natural forest, **Significant differences at 1% using Pearson correlation

Identification of suitable index for estimating soil fertility status and site quality: There is an increasing need for simple soil indices for assessment of soil fertility and site quality. The assessment of soil fertility and site quality is important in forest management because it reflects to the productive capacity of the forest area to support plant growth. In the tropical Amazon forest, soil fertility index (Moran *et al*., 2000) and soil evaluation factor (Lu *et al*., 2002) were used to estimate soil fertility and site productivity under different succession stage of secondary forest. Previous studies have provided evidence that SFI and SEF were applicable to estimate the soil quality and productivity under various land degradation gradient in Northern Thailand (Doi and Sakurai, 2004). However, there is no study conducted to test the applicability of the soil indices derived from factor analysis, SFI and SEF for estimating the soil fertility and site quality under dipterocarp plantation in rehabilitated degraded forestland.

Table 5: Relationship between PC1 score, SFI and SEF and tree growth parameters

Growth data	PC1		SFI		SEF	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
Height	0.26	0.24	0.35*	0.33*	0.41*	0.47**
DBH	0.31*	0.33	0.22*	0.38*	0.42*	0.46**
Volume	0.39*	0.35	0.31*	0.50**	0.48**	0.51**

*, **Significant differences at 5 and 1% levels, respectively using Pearson correlation

The applicability of SFI and SEF to other sites though to be valuable, because only a few number of variables soil chemical properties is required. However, it is uncertain whether both indexes could be applicable for evaluating soil fertility status and site quality in the present study because the SEF consists of constant number to avoid the negative value in contrast to SFI. Figure 2 shows the positive and high correlation between the PC1 score and SFI for both surface ($r = 0.837$, $p<0.01$) and subsurface soils ($r = 0.531$, $p<0.01$) and high correlations between PC1 score and SEF at both surface and subsurface soils ($r = 0.678$, $p<0.01$ and $r = 0.647$, $p<0.01$, respectively). This result indicates that both SFI and SEF can be used to estimate soil fertility in a rehabilitated degraded hill forest such as the present study.

In order to determine the most suitable index for the soils in the present study, the values of PC score and SFI and SEF at both soil depths were correlated with tree growth parameters mainly of height, dbh and volume. The results showed that the values of both indexes at surface and subsurface soils were positively correlated with the height, dbh and volume, while the PC1 score was only correlated with dbh and volume for surface soils (Table 5). These results revealed that the SFI and SEF are suitable indices for estimating soil fertility levels and site quality

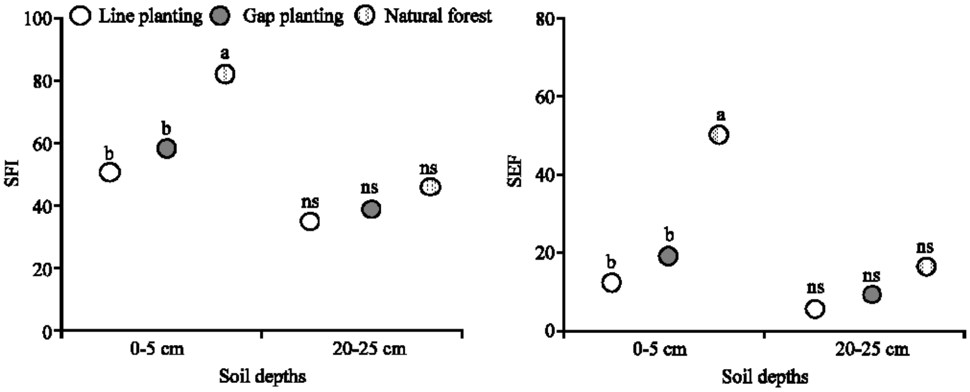

Fig. 3: Comparison of soil fertility status between the line planting, gap planting and natural forest based on the Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF). Different letter(s) in same soil depths indicate significant differences at 5% using Tukey's HSD test

and to a lesser extent the PC1 score. The use of soil indices derived from physico-chemical properties by using factor analysis to estimate the site quality and productivity has been described by several researchers (Vanclay, 1992; Paniagua *et al*., 1999; Doi and Sakurai, 2004). It should be noted that SEF (Lu *et al*., 2002) was applicable for evaluating the soil fertility on the soils of the humid tropics (Ultisols) such as in this study, in contrast to sandy soils in the previous study reported by Arifin *et al.* (2008) in press. For practical purposes, the two indices revealed that the soil fertility status in the surface soils were significantly higher for natural forest than either in the line planting or gap planting, whereas there was no clear significant difference was observed in the subsurface soils (Fig. 3). Based on this result, 11 years after rehabilitation of degraded forestland by the planting indigenous dipterocarp species under line and gap plantings are still insufficient to restore the soil fertility level similar to that of the natural forest.

CONCLUSIONS

Rehabilitation of poorly stocked logged-over forest through enrichment planting of dipterocarps species using line planting and gap planting methods offers a potential to increase valuable timber stock and site productivity. Line planting width and gap planting opening seemed to have no effect on survival rate, but its affect on the tree growth probably due to preference of light intensity under the canopy. A moderate planting width of 10 m in the line planting and 20×20 m in gap planting resulted in the most favorable growth in terms of height, dbh and tree volume of two species studied which may reflect to the specific amount of light intensity. The *S. pauciflora* and *S. macroptera* should not be planted without opening the canopy as it would suppress their growth. A linear regression analysis indicated that the PC1 score was significantly correlated with the proposed SFI and SEF. Moreover, the SFI and SEF were positively and highly correlated with tree growth parameters, indicating the applicability of both indices for estimating the soil fertility and site quality. This positive relationship between SFI and SEF with tree growth parameters means that as the trees grow the soil fertility increases. It can be further illustrate that, the SFI and SEF could be appropriate indices to evaluate the growth performance of planted trees due to the variability and heterogeneity of soil fertility levels within a site. In addition to specific planting spacing and preference of light intensity, soil fertility levels should be taken into consideration when attempting to rehabilitate degraded logged-over forest. Further studies are recommended to identify the effects of silvicultural treatment on the growth and survival rates as well as tree volume of other indigenous high quality timber trees and to examine how specific soil physical, chemical and biological factors limit the growth of planted species under rehabilitation of degraded forestland in tropical regions.

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