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Effects of enrichment planting on the soil physicochemical properties at reforestation sites planted with *Shorea macrophylla* de Vriese in Sampadi Forest Reserve, Sarawak, Malaysia

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Abstract A preliminary assessment on the soils in reforestation sites at Sampadi Forest Reserve, Sarawak was conducted to clarify and compare the effects of enrichment planting on the soil physicochemical properties within the reforested areas and adjacent secondary forest. Reforestation areas which were planted with *Shorea macrophylla* de Vriese by the line planting technique were selected in this study. The study sites were stands reforested in different years (SM96 in 1996; SM97 in 1997; SM98 in 1998; and SM99 in 1999) and an adjacent secondary forest (SF). Undisturbed and composite soil samples were collected at the depth of 0−10 cm (surface soils) and 30−40 cm (subsurface soils) from several random points. We found that the soils at both reforestation sites and secondary forest were strongly acidic, with pH of less than 5.5, with low nutrient status. Soil total carbon in secondary forest was significantly higher than that of the reforestation sites, indicating that a large pool of fresh organic matter was derived from the above vegetation in the surface soil. Notwithstanding, significant differences were observed in soil available phosphorus between the sites in both surface and subsurface soils. In terms of the soil physical properties, the soils observed were relatively of sandy clay loam to sandy clay in texture, and did not vary widely, including their low fertility level, among the studied sites. Based on the current findings of this study, enrichment planting after 15 years might help slightly to restore the productivity of certain soil physicochemical properties at the reforestation sites.

Keywords Reforestation, Sarawak, *Shorea macrophylla*, Soil physicochemical properties, Tropical rainforests

Introduction

The mixed dipterocarp forest of Sarawak, Malaysia is known as having one of the most developed structures with the greatest species diversity of plant and animal life in the world (Whitmore 1984). However, the forest areas in Sarawak have deteriorated at unprecedented rates due to various land use-related activities, such as conversion of forest lands to agricultural lands, forest fragmentation, and degradation by disturbances resulting from the expansion of human activities in agriculture and forestry, including illegal logging (Curran et al. 2004; Hansen 2005; Laurance 2007). Whitmore (1998) and Kobayashi et al. (2001) reported that tropical rainforests of the world are being cleared at the average rate of 16.9 million hectares annually, mainly due to the expansion of agriculture and shifting cultivation, while another 5.6 million hectares are being used for timber production. According to Juo and Franzlueebber (2003), most soils in the tropical regions are infertile, and nutrients can be rapidly lost from the soil once the vegetation above has been cleared. Consequently, it takes considerable time for forests to recover after deforestation.

Enrichment planting is a highly effective technique for the rehabilitation or reforestation of degraded vegetation (Appanah and Weinland 1993; Kenzo et al. 2008). According to Appanah and Weinland (1993), in the enrichment planting scheme tree species that have been lost from the land as a result of human disturbances are reintroduced to restore the degraded vegetation to its original state. Tree planting is also useful for sustaining soil fertility and for producing timber for the future. One of the factors that affects the performance of planted dipterocarp seedlings is soil fertility (Hattori et al. 2009). According to Hattori et al. (2009), soil fertility greatly varies depending on the intensity of disturbances as well as microtopography, even within a small area to be planted. Thus, to obtain better performance of the planted seedlings, one should assess soil conditions such as soil fertility prior to planting and should develop appropriate enrichment planting techniques when the land is seriously degraded. Insam (2001) argued that soil fertility is the most crucial part of environmental management. The success or failure of a particular forest rehabilitation programme might only be identified by evaluating the soil fertility of the land.

Nevertheless, few reports have been published on characterizing soil properties during enrichment planting of more than 15 years in Malaysia. Most of the previous studies on enrichment planting have focused on growth performance of planted species along with the planting technique, and species selection for planting purposes in relation to the growth productivity in degraded forest, with less attention paid to the ecosystem, including the soil fertility status, in reforestation areas (Arifin et al. 2008; Wasli et al. 2014; Perumal et al. 2015). Information on soil properties under degraded vegetation is rather limited, even though several studies on the soil properties of humid tropics in Sarawak, Malaysia have been conducted (Ishizuka et al. 2000). Furthermore, Wasli et al. (2014) pointed out that information on the performance, survivability and soil properties of the planted indigenous tree species under reforestation as implemented by the local authorities in Sarawak is vital, and detail studies have to be carried out.

Therefore, the objective of this preliminary study was to clarify and compare the effect of enrichment planting on the soil physicochemical properties within the reforested areas and secondary forest in Sampadi Forest Reserve, Sarawak, Malaysia.

Materials and Methods

Brief information on Sampadi Forest Reserve reforestation sites

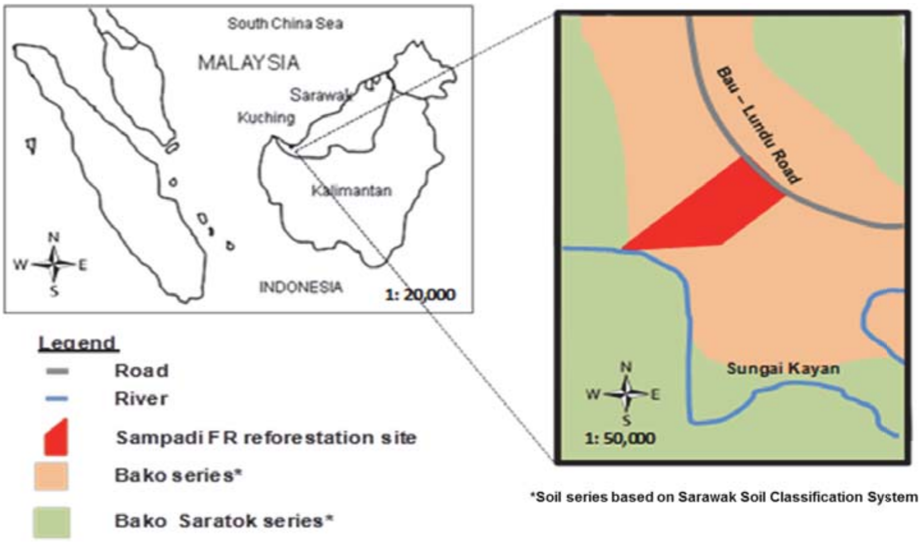

Fig. 1 Location of the study area: Sampadi Forest Reserve.

The Sampadi Forest Reserve reforestation site (01°34'13"N, 109°53'12"E) is located at Lundu, Sarawak, which is approximately 72 km southwest of Kuching City (Fig. 1). It covers about 5,163 hectares and has a humid tropical climate, associated with peaks of seasonal changes of rainfall and temperature. The topography at the study site is of low undulating type, with an average elevation of 87 m above sea level. It has a tropical seasonal climate (no dry season) with all months receiving on average more than 100 mm precipitation, with a subtropical wet forest biozone (Vincent and Davies 2003). The climate condition in the area was classified into AA'r in the Thornthwaite classification system (Thornthwaite 1948). The average annual temperature in the area ranges between 22 °C (72 °F) in the early hours of the morning and rises to around 31 °C (88 °F) during mid-afternoon, with little monthly variation (Andriesse 1972; Meteorological Department 2010).

The soils in the study area consist of mainly the Grey-White Podzolic Soil group, which is derived from a combination of sandstone, coarse-grained, humult ultisols and sandy residual parent material. According to the Sarawak Soil Classification, the morphological properties in the study sites resemble the Bako soil series as a dominant unit in association with Saratok series, which corresponds to the ultisols of Soil Taxonomy by USDA-NRCS Classification (Soil Survey Staff 2014).

Prior to the plantation establishment, the reforestation sites were established under the secondary forests which developed from the previous history of slash and burn activities. All tree seedlings were planted using the line-planting technique with lines cut 5 m apart and trees planted at 5 m intervals along the lines. Preparation and maintenance of planting lines were conducted by manual slashing of the undergrowth with a bush knife along the planting line. Weeding activity in the reforestation area was conducted once annually, in which all herbaceous species and seedlings of pioneer species were slashed with a bush knife. For larger pioneer tree species, the undergrowth was left uncut when preparing the planting lines.

Experimental design, soil sampling and soil physicochemical analyses

In order to clarify the soil properties in greater detail, experimental plots sized 75 m × 50 m in the reforestation areas were constructed within the compartment planted with *Shorea macrophylla* trees at four different-age stands. Abbreviations were applied to represent the studied plots as follows: planted with *Shorea macrophylla* in the year 1996: SM96; 1997: SM97; 1998: SM98; and 1999: SM99. Study plots sized 20 m × 20 m were established for soil sampling at adjacent secondary forest (SF) outside the reforestation areas. For the soil sampling at the reforested areas, soil samples were collected on the planting line at the depth of 0–10 cm (surface soils) and 30–40 cm (subsurface soils) at three random points within each 25 m × 25 m subplot in each study site, and were mixed well to get a composite sample for each soil layer (Wasli et al. 2009; Perumal et al. 2015). Similarly, six random points within the 20 m × 20 m plots located outside the reforested areas (SF) were designated for soil sampling, and soils were collected at the depth of 0–10 cm (surface soils) and 30–40 cm (subsurface soils) and mixed well to get a composite sample for each soil layer. Undisturbed soil samples were collected at the depth of 0–10 cm and 30–40 cm using a 100-cc core sampler for the determination of soil physical properties. Composite soil samples were air-dried, and plant materials such as fine roots, twigs and leaves were carefully removed. Later, the air-dried soil samples were passed through a 2-mm mesh-sieve before use for further analysis. Soil pH was measured in distilled water (soil to solution ratio of 1:5) by the glass electrode method (denoted as pH_w). Total Carbon (T-C) content in soil was determined using the loss on ignition method (McKeague 1976). In addition, the soil Total Nitrogen (T-N) content was determined by Kjeldahl acid digestion. Available Phosphorus content in soil was determined by the Bray II method (Bray and Kurtz 1945; Kuo 1996) with a UV-Vis Spectrophotometer at a wavelength of 710 nm (Jasco V-630). The soil exchangeable bases (Ca, Mg, K and Na) were extracted three times with 1 M ammonium acetate (NH_4-Oac), adjusted to pH 7.0 and 10 % NaCl, and the concentrations of Ca, Mg, K and Na were determined with an atomic absorption spectrophotometer (AAS) (Thermo Scientific, ICE Series 3500). Titration methods were used to determine the cation exchange capacity (CEC) of the soil. The filtrate from the pH (KCl) measurement was used for soil exchangeable Al analysis. All soil physicochemical analyses were conducted at the Laboratory of Environmental Soil Science and the Laboratory of Plant Ecology, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak (UNIMAS).

Statistical analyses

All data of soil were expressed on oven-dry weight basis. In order to compare and determine significant differences between different-age stands of the planted *Shorea macrophylla* in the reforestation areas, all data of soil physicochemical properties at surface and subsurface soils were statistically analyzed using a one-way ANOVA (Tukey's HSD test). All statistical analyses were performed using SPSS version 18.0 for windows (SPSS Inc., 2012).

Results and Discussion

General soil physicochemical properties at reforestation sites and secondary forest of Sampadi Forest Reserve

Table 1 shows the average values of soil physicochemical properties of reforestation sites (SM96, SM97, SM98, SM99) and adjacent secondary forest (SF). In general, the soils of all the study sites in Sampadi Forest Reserve could be characterized as strongly acidic, with pH (H_2O) values of less than 5.50 (ranging from 4.67 to 5.29) at surface layers. The soil texture did not vary widely among all the study sites, where most soils were relatively sandy, ranging from sandy clay loam to sandy

Table 1 Means and standard deviation of surface and subsurface soil physicochemical properties at reforestation sites (SM96, SM97, SM98, SM99) and secondary forest (SF).

Soil physicochemical properties	Reforestation Sites				Secondary Forest
	SM96− (n = 6)	SM97 (n = 6)	SM98 (n = 6)	SM99 (n = 6)	SF (n = 6)
Surface soil, 0−10 cm depth					
pH (H_2O)	4.69 ± 0.12a	4.67 ± 0.09a	4.72 ± 0.08a	5.20 ± 0.06b	5.29 ± 0.26b
T-C[a] (g kg^{-1})	38.5 ± 9.9a	49.6 ± 8.8ab	51.7 ± 12.0ab	49.4 ± 4.8ab	53.9 ± 8.1b
T-N[b] (g kg^{-1})	2.16 ± 0.67ns	2.55 ± 0.38ns	2.99 ± 1.01ns	2.91 ± 0.80ns	3.05 ± 0.50ns
CEC[c] ($cmol_c kg^{-1}$)	11.8 ± 2.8ns	9.7 ± 1.6ns	9.5 ± 1.6ns	8.4 ± 3.0ns	10.2 ± 1.2ns
Exch. Al ($cmol_c kg^{-1}$)	2.54 ± 0.82b	4.03 ± 0.40c	1.35 ± 0.19a	1.56 ± 0.24a	1.40 ± 0.41a
SUM[d] ($cmol_c kg^{-1}$)	1.45 ± 0.23ab	1.35 ± 0.42ab	1.36 ± 0.35ab	0.84 ± 0.32a	1.77 ± 0.62b
ECEC[e] ($cmol_c kg^{-1}$)	3.39 ± 1.01b	5.38 ± 0.40c	2.71 ± 0.51a	2.40 ± 0.44a	3.16 ± 0.65ab
Base sat[f] (%)	12.6 ± 2.3ns	14.3 ± 4.8ns	14.1 ± 1.6ns	11.5 ± 6.4ns	17.2 ± 5.5ns
Al sat[g] (%)	62.9 ± 5.1bc	75.0 ± 6.7c	50.4 ± 4.4ab	65.8 ± 7.6c	44.5 ± 13.6a
Available P (mg P kg^{-1})	14.0 ± 2.1c	13.6 ± 1.5c	6.3 ± 1.0b	2.4 ± 1.1a	5.5 ± 1.2b
Clay (%)	29.0 ± 8.8a	36.9 ± 5.8ab	41.2 ± 7.2c	40.3 ± 6.7c	45.9 ± 1.9c
Silt (%)	21.8 ± 5.9b	33.8 ± 4.2c	5.1 ± 2.7a	6.8 ± 3.3a	6.4 ± 2.1a
Sand (%)	49.1 ± 11.9b	29.3 ± 7.1a	53.7 ± 7.4b	53.0 ± 9.1b	47.7 ± 2.6b
Bulk density (g mL^{-1})	1.08 ± 0.07b	0.92 ± 0.13a	1.01 ± 0.09ab	0.93 ± 0.08ab	0.90 ± 0.04a
Moist. Cont. (%)	3.0 ± 0.9a	4.4 ± 0.5b	3.6 ± 0.5ab	4.0 ± 0.7ab	4.0 ± 0.2ab
Subsurface soil, 30−40 cm depth					
pH (H_2O)	5.01 ± 0.05a	5.04 ± 0.05a	5.35 ± 0.16b	5.29 ± 0.05b	5.38 ± 0.05b
T-C[a] (g kg^{-1})	22.6 ± 5.2a	23.4 ± 4.3a	25.8 ± 4.9a	27.3 ± 4.9ab	34.6 ± 5.1b
T-N[b] (g kg^{-1})	0.95 ± 0.44a	1.06 ± 0.17ab	1.07 ± 0.29ab	1.34 ± 0.30ab	1.61 ± 0.41b
CEC[c] ($cmol_c kg^{-1}$)	7.8 ± 2.3ns	7.3 ± 1.4ns	7.0 ± 1.4ns	7.7 ± 1.7ns	9.3 ± 0.9ns
Exch. Al ($cmol_c kg^{-1}$)	2.72 ± 1.18b	4.30 ± 0.66c	1.30 ± 0.30a	1.56 ± 0.17a	1.81 ± 0.23ab
SUM[d] ($cmol_c kg^{-1}$)	0.65 ± 0.19ab	0.76 ± 0.16b	0.86 ± 0.30b	0.32 ± 0.04a	0.89 ± 0.30b
ECEC[e] ($cmol_c kg^{-1}$)	3.37 ± 1.33b	5.06 ± 0.76c	2.16 ± 0.44ab	1.88 ± 0.16a	2.69 ± 0.38ab
Base sat[f] (%)	8.6 ± 2.4ab	10.4 ± 1.5b	12.6 ± 4.1b	4.3 ± 0.9a	9.5 ± 3.0b
Al sat[g] (%)	79.0 ± 7.6b	85.0 ± 2.3c	60.5 ± 9.4a	82.9 ± 3.0a	67.6 ± 8.9ab
Available P (mg P kg^{-1})	5.9 ± 1.5c	3.7 ± 0.4b	2.6 ± 1.3ab	3.3 ± 1.9b	0.9 ± 0.3a
Clay (%)	31.2 ± 6.9a	37.7 ± 6.4ab	36.1 ± 8.6a	36.5 ± 5.8a	48.1 ± 2.5b
Silt (%)	25.8 ± 5.8b	30.9 ± 2.8b	8.7 ± 7.5a	8.7 ± 3.5a	4.9 ± 1.1a
Sand (%)	43.0 ± 7.0ab	31.4 ± 8.7a	55.2 ± 13.2b	54.9 ± 3.8b	47.0 ± 2.9b
Bulk density (g mL^{-1})	1.32 ± 0.14ab	1.11 ± 0.04a	1.36 ± 0.12b	1.35 ± 0.18ab	1.13 ± 0.19ab
Moist. Cont. (%)	2.6 ± 0.9a	3.7 ± 0.7a	2.8 ± 0.6a	3.3 ± 0.7ab	3.7 ± 0.4b

Values in the same row followed by different letters indicate significant differences among sites at $P < 0.05$ using Tukey's HSD test; ns: no significant differences. [a] T-C; Total Carbon, [b] T-N; Total Nitrogen; [c] CEC; Cation Exchange Capacity, [d] SUM; Sum of Exchangeable Bases (Ca, Mg, K, Na), [e] ECEC; Effective CEC, Sum of exchangeable bases and exchangeable Al, [f] Base sat; Base saturation, Sum of exchangeable bases in percent of CEC, [g] Al sat; Al saturation, ratio of exchangeable Al to ECEC.

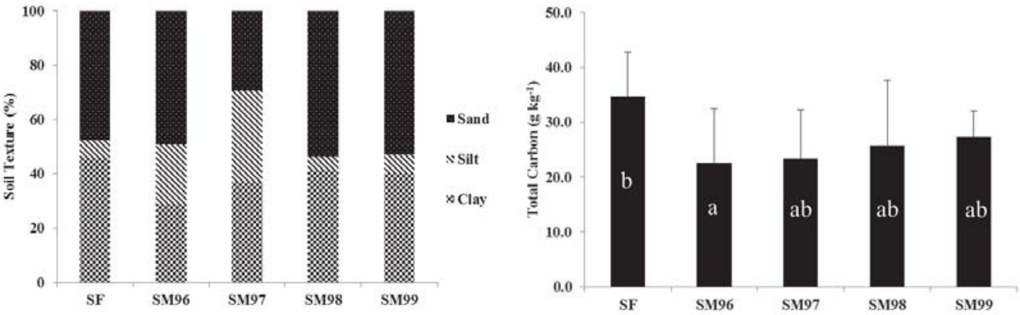

Fig. 2 Soil properties for all study sites at surface soils; a) Soil texture and b) Total carbon.
*Different letters indicate significant differences among study sites at $P < 0.05$ using Tukey's HSD test.

clay in texture. The soil exchangeable bases were low as compared to the exchangeable Al, which resulted in high Al saturation for all study sites. In terms of soil total carbon (T-C) and total nitrogen (T-N), the soils in this study had higher values in surface soils (0–10 cm depth) than in subsurface soils (30–40 cm depth). The T-C value for surface soil ranged from 38.5 to 53.9 g kg^{-1} and that for subsurface soil ranged from 22.6 to 34.6 g kg^{-1}. At the depth of 0–10 cm, the T-N level of soil ranged from 2.16 to 3.05 g kg^{-1}, whereas at the depth of 30–40 cm, it ranged from 0.95 to 1.61 g kg^{-1}. The soil cation exchange capacity (CEC) value was generally low for both the surface and subsurface soils throughout the reforestation sites and secondary forest. The CEC value ranged from 8.4 to 11.8 $cmol_c kg^{-1}$ in surface soils and ranged from 7.0 to 9.3 $cmol_c kg^{-1}$ in subsurface soils. The values of soil available P in surface and subsurface soils ranged from 2.4 to 14.0 mg kg^{-1} and 0.9 to 5.9 mg kg^{-1}, respectively. Regarding soil bulk density, the average bulk density of subsurface soils was higher than that of surface soils. The bulk density at the depth of 0–10 cm ranged from 0.90 to 1.08 g mL^{-1} whereas at the depth of 30–40 cm ranged from 1.11 to 1.36 g mL^{-1}. Further elaboration of selected soil physicochemical properties will be presented in the next section of this report.

Soil Texture and Organic Matter-related Properties

In the present study, a high correlation was observed between T-C and clay contents in both the surface soils and subsurface soils: r = 0.832** and r = 0.880**, respectively (data not shown). This indicated that they are ascribable to organic matter stabilization of soils by formation of stable organo-mineral (Ohta et al. 2000; Tanaka et al. 2007). However, the results of standardized multiple regression analysis showed no correlation between CEC values and either T-C or clay contents in either surface or subsurface soils. The fact that the CEC was higher as compared to the Effective Cation Exchange Capacity (ECEC) suggested the possible occurrence of some variable negative charges (Boonyanuphap et al. 2007; Tanaka et al. 2009). Since the ECEC values were much lower than the CEC values, permanent negative charges of clay minerals were predominant under acidic conditions. Judging from the small difference between soil CEC and ECEC, the contribution of negative charges from soil organic matter to the cation retention capacity might be small (Arifin et al. 2008). There was no large variation among reforestation sites and secondary forest for total carbon, total nitrogen or clay contents, although the content of total carbon was significantly higher in secondary forest than in reforestation sites (Fig. 2a, b). It is noteworthy that

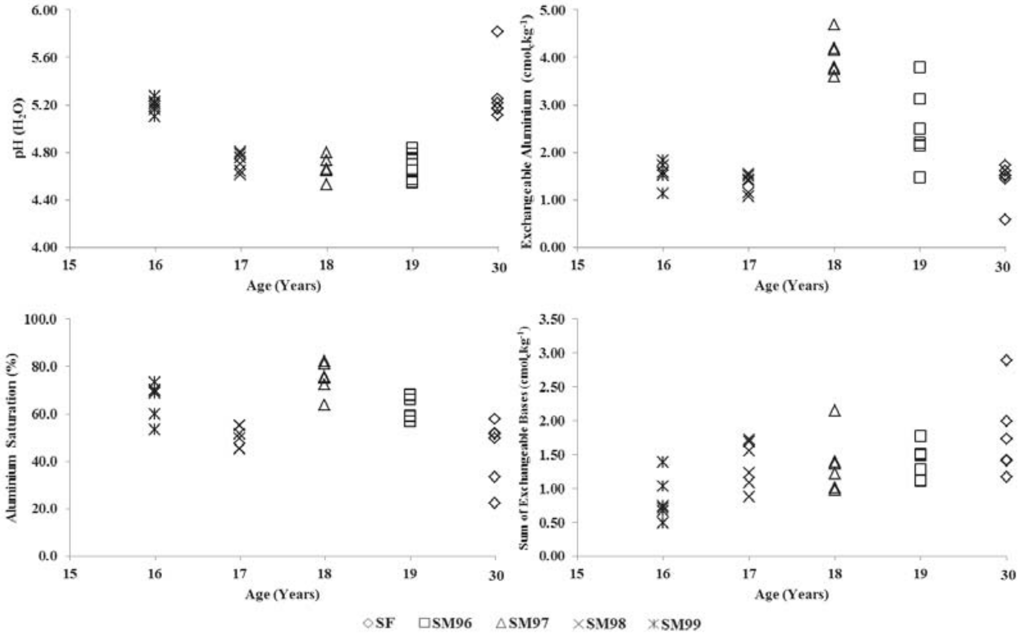

Fig. 3 Soil properties in surface soils of all study sites; a) Soil pH (H_2O), b) Exchangeable Al, c) Aluminium saturation, and d) Sum of exchangeable.

the negative charge derived from organic matter and clay contents is regarded as an important factor for nutrient retention capacity and probably influences the fertility status of the soils to a certain extent (Hamzah et al. 2009). In addition, the T-C, T-N and CEC values are also likely to be affected by the input-output balance of soil organic matter after the period of establishment of the reforestation sites, and in the fallow period of the secondary forest, through inputs of litterfall and output by decomposition. The higher content of T-C especially in secondary forest was presumably due to a large contribution of fresh organic matter and its greater accumulation in soils from the permanent vegetation in the former than the latter (Fig. 2b).

Soil Acidity and Exchangeable Bases-related Properties

The acidic nature of the soils, especially in the reforestation sites, might have been due to the loss of exchangeable bases through uptake by plants and leaching in the tropical environment (Juo and Manu 1996) as well as through volatilization during combustion (Giardina et al. 2000). Tan (2005) reported that some available nutrients are deficient if the soil pH is below 6.0. In addition, Aiza et al. (2013) reported that many soil properties and processes are affected by pH, including the formation of clay minerals and microbial activity. The pHs for both surface and subsurface soils in the reforestation sites were more acidic than those in the secondary forest, which were associated with high exchangeable Al, especially in SM96 and SM97 sites. The acidity occurring in the forest soils was due to the presence of Al and H. Zaidey et al. (2010) reported that the Al concentrations and organic matter content probably influenced the soil acidity. On the other hand, Akbar et al. (2010) mentioned that acidity may be caused by water deficiency due to drought. Development of root mats and accumulation of forest litter on the surface layer of soil may result in high carbon content, which may indirectly affect the acidity of soil. According to Table 1, the soil exchangeable bases in surface and subsurface soils were low compared with the soil exchangeable

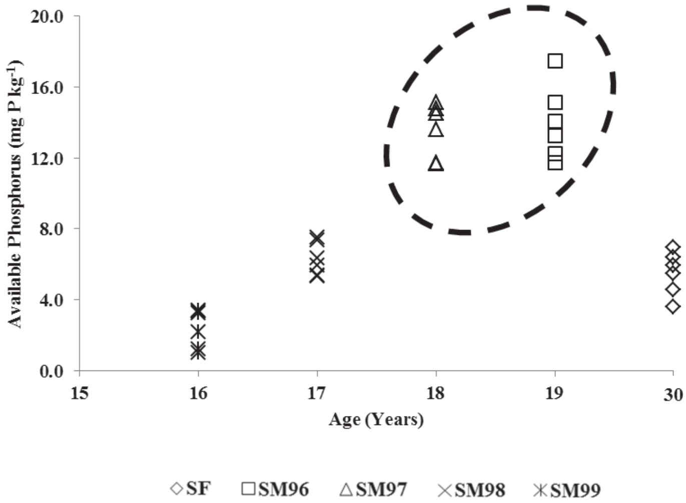

Fig. 4 Soil available phosphorus for surface soils at all study sites.

Al, resulting in a high level of Al saturation both in reforestation sites and secondary forest. Soil Al saturation was more than 40 % in surface soils and more than 60 % in subsurface soils (Fig. 3c).

Soil phosphorus-availability-related property

According to Table 1, significant differences were observed in soil available P values between the study sites in both surface and subsurface soils.

SM96 and SM97 sites showed significant differences in available phosphorus from SM98, SM99 and secondary forest (SF) sites at the depth of 0–10 cm. On the other hand, at the depth of 30–40 cm, no significant differences were observed in soil available phosphorus between SM97, SM98 and SM99 sites, but significant differences were observed between SM96 and secondary forest (SF). Meanwhile, SM98 site had no significant difference in soil available phosphorus from secondary forest (SF) sites at subsurface soil. Figure 4 shows that the P availability in SM96 and SM97 sites was higher than that in the secondary forest. Based on our previous study (Perumal et al. 2014), the high content of available phosphorus in soils was related to an increase in the growth of *S. macrophylla* in SM96 and SM97, whereas the low content of available phosphorus was related to a decrease in the growth of the planted trees in the SM98 and SM99 sites.

One possible reason for the poor growth rate of the planted *S. macrophylla* (data not shown) especially in study sites SM98 and SM99 was probably the low availability of soil phosphorus pools in the form of organic and inorganic phosphorus in the bulk soil, which would limit the plant uptake. Soluble minerals such as potassium move through the soil via bulk flow and diffusion, whereas phosphorus is moved mainly by diffusion. Since the rate of diffusion of P is slow, high plant uptake rates create a zone around the root that is depleted of P (Schachtman et al. 1998). Several studies reported that the available P content in soils depends on a combination of factors including plant uptake, adsorption-desorption and dissolution-precipitation of inorganic P, the mineralization of organic P and microbial immobilization and fertilizer addition (Perrott et al. 1990; Frossard et al. 2000). Soil microbes release immobile forms of P to the soil solution and are responsible for the immobilization of P (Schachtman et al. 1998). According to the study of Arifin et al. (2007) at Kinta, Perak, Malaysia, higher clay content and exchangeable Al are related to a low level of nutrients, especially available phosphorus. Moreover, a study conducted by Chen et al. (2003), in an unimproved grassland and 19-year-old stand concluded that the recycling of P was mainly driven by plant P demand and sustained by root and leaf litter inputs in forest ecosystems. Environmental factors such as rainfall, soil moisture and temperature may also affect the P availability.

Conclusion

In general, reforestation activity through establishment of enrichment planting at Sampadi Forest Reserve, Sarawak resulted in slightly better soil physicochemical properties in reforestation sites, especially in SM96 and SM97, as compared to adjacent secondary forest. Based on the current progress reported in this study, it can be deduced that the effect of enrichment planting on soil physicochemical properties in the SM96 and SM97 reforestation sites slightly improved soil productivity in terms of soil available phosphorus.

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