

Comparing the Fertility of Soils under *Khaya ivorensis* Plantation and Regenerated Degraded Secondary Forests

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Abstract: Problem statement: It is widely accepted that conversion of natural forest to other land use types leads to deterioration of soil fertility and increased soil compaction which consequently become degraded secondary forests. Degraded secondary forest or forestland is indicated by low in soil fertility and organic matter due to imbalance input and output from original vegetation. Forest plantation through planting fast growing exotic species is usually implemented to curtail degradation of secondary forest or forestland and improve the soil fertility through organic matter accumulation. However, fundamental information on degraded forestland being converted to forest plantation using exotic species such as *Khaya ivorensis* is not available. The objectives of this study were: (1) to characterize the properties of three degraded soils under rehabilitation using *K. ivorensis*; and (2) to evaluate their fertility status by Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF). **Approach:** This study was concentrated on three soil series (Rengam, Durian and Padang Besar) found under *K. ivorensis* plantation and at the adjacent secondary forest in Segamat, Johor, Malaysia. To characterize and evaluate the soil fertility status for each soil series, three plots (30 x 40 m) were randomly established on each soil series. Soils for each series were sampled at the depth of 0-10 cm (surface soil) and 20-30 cm (subsurface soil). They were randomly collected at six different points for each replicate. Soil analyses were carried out accordingly. **Results:** The soils both in planted and secondary forests were moderately acidic to slightly acidic with low content of exchangeable bases and available P but high in Al saturation. The Rengam series under *K. ivorensis* plantation contained higher total carbon and clay compared with those of Padang Besar and Durian series. Clay and total carbon contents were highly correlated with the Cation Exchange Capacity (CEC), indicating the potential of negative charge produced by the clay and organic playing an important role in supplying and holding plant nutrients. The SFI result revealed that soil fertility status of Rengam soil was significantly higher than the other two soil series. There was no significant difference observed for SEF. Based on SFI and SEF values, there were no significant differences of fertility status between the planted and secondary forests for both soil depths. **Conclusion:** This study revealed that Rengam soil is more fertile than the other two soils. Using SFI and SEF it can be concluded that fast growing exotic species of *K. ivorensis* has the potential to improve site productivity and soil fertility.

Key words: Exotic species, *Khaya ivorensis*, degraded forestland, secondary forest, soil fertility, soil series, soil organic matter, soil sampling, Soil Fertility Index (SFI), Soil Evaluation Factor (SEF)

INTRODUCTION

Globally, most of tropical forest in the world decline due to deforestation (Montagnini *et al.*, 1997; FAO, (2005). The decrease reaches a rate of 16.9 million hectares annually. In Malaysia, the decrease in forest area is caused by deforestation reaching 1,486,000 hectares annually between 1990 and 2005; this indicates that Malaysian forest cover had lost about 6.64% (FAO, 2005). Deforestation leads to decline in soil fertility, which is indicated by a decrease in soil organic matter due to an imbalance between the input and output of carbon and other nutrients that originate from vegetations. Moreover, most of soils in the tropical forest are infertile (Jordan, 1989), while deforestation can disturb nutrient cycling process, so that nutrient can be rapidly lost.

Forest rehabilitation through plantation forestry is important not only for meeting wood demands, but also as a method that can restore degraded soils resulting from deforestation (Parotta, 1992; Parotta *et al.*, 1997 and Lugo, 1997; Zaidey *et al.*, 2010). Forest plantation is regarded as one of the methods to turn forest into more productive areas by means of reverting the soil fertility and reducing soil erosion. Plantation forest plays an important role in providing and holding nutrients in soils and maintaining their structures. Soils have a role to meet the diverse needs of plant life, such as mechanical support and the establishment of roots, provide air (oxygen) for respiration, provides water and nutrients and as a medium of interaction between the plants with soil.

Soil organic matter tends to change continuously by anthropogenic factor such as deforestation. However, Bowyer (2005) stated that with increasing interest worldwide in forest plantations, concerns about the potential environmental impacts of establishing forest plantations on a large scale are increasing as well. Specific concerns focus on potential loss of soil fertility and productivity under short harvest rotations. Therefore, research that can form the basis for selection of stands for planting on a particular environment is needed. This is to anticipate the occurrence of land degradation as a result of planting a particular species and also to determine the necessary actions, thus gaining optimal production (Bowyer, 2005). As we have known, some of species can accelerate soil acidity which tends to lower soil cation exchange capacity and also further accelerate the decline in Ca and Mg content of the soils. However, some tree species such as the family Leguminosae have trait that support towards improving the condition and productivity of the land. Similarly, Hamzah *et al.* (2009) found that

rehabilitating degraded forestland with dipterocarp and non dipterocarp species had improved both soil nutrients and valuable timber stock in Pasoh, Peninsular Malaysia. The related studies Moran *et al.* (2000) in Lu *et al.* (2002) also stated that successional forests play an important role in soil restoration through accumulation of biomass, build-up of litter and organic matter and other beneficial soil/plant interactions. Soil fertility, physical structure and land use history are the most important aspects affecting vegetation growth in the Amazon basin (Lu *et al.* 2002). Therefore, to maintain the soil fertility of degraded forestland, the selection of species must be taken into consideration. This is to avoid the possibility of accelerating acidity and nutrient depletion due to intensive land use. This case might occur in agriculture or in forest, in particular forest plantation.

K. ivorensis is one of exotic species from Africa that have high adaptability on degraded forestland in Malaysia. This species is recommended as forest plantation to meet the needs of timber industry in Malaysia. Several studies of *K. ivorensis* growing on different soil type concerned with growth performance (Appanah and Weinland, 1993; Jeyanny *et al.*, 2009; Yetti *et al.*, 2011), but assessment of soil properties is not done or at most limited. The objectives of this study were: 1) to characterize the properties of three degraded soils under rehabilitation using *K. ivorensis*; and 2) to evaluate their fertility status by soil fertility index (SFI) and soil evaluation factor (SEF). This study is important as a reference for development of forest plantation using *K. ivorensis*.

MATERIALS AND METHODS

Study site description: The study was conducted at the FRIM Research Station in Segamat, Johor, Malaysia. The station located about 250 km from Kuala Lumpur. Generally, the mean annual temperature and humidity are 27°C and 94%, respectively. The mean annual rainfall from 2004-2008 was 2508 mm/year. The topography is flat to undulating. Based on the United States Department of Agriculture soil taxonomy, the three soil series (Rengam, Durian and Padang Besar) at the study site are classified as Ultisols which are the most widespread soil order in Peninsular Malaysia (Paramanathan, 2000). The location of Rengam series is 02° 34' 683 N; 102° 58' 643 E; 82 m above sea level (a.s.l.), the Durian series is 02° 34' 927 N; 102° 58' 678 E; 74 m a.s.l. and the Padang Besar series is 02° 34' 908 N; 102° 58' 725 E; 78 m a.s.l.

Planting history of *K. ivorensis*: *K. ivorensis* is a promising exotic tree species in the forest plantation program in Malaysia (Appanah and Weinland, 1993). The species belongs to the family Meliaceae, which is one type of African mahoganies. It was initially in the States of Kedah and Selangor in Malaysia in the late 1950's and early 1960's and has adapted well to the local climatic conditions. It was selected by the Malaysian Timber Industry Board as one of eight species targeted for large-scale planting in Malaysia in 1992.

The Forest Research Institute Malaysia (FRIM) had established of *K. ivorensis* plantation in Segamat, Johor in 2004 as a sample area for future forest plantation development. The species was planted on different soils such as the Rengam, Durian and Padang Besar series using small scale land clearing and monoculture system (Yetti *et al.*, 2011). The initial planting spacing was 4 m x 3 m. All of the plants were applied with the same dosage of fertilizer from early planting for three years. The treatment during cultivation was fertilizer 200 g of CIRP (Christmas Island Rock Phosphate) fertilizer/tree; after cultivation, 500 g of organic fertilizer/tree was applied every six months until the plant were three years old. Weeding was done once every three months.

Soil sampling and analyses: Soil samples were collected from three soil series (Rengam, Durian and Padang Besar) which were under five-year-old *K. ivorensis* plantation and the adjacent secondary forest. To evaluate soil fertility in each soil series and adjacent secondary forest, we were collected soil samples at the depths of 0-10 cm (surface soils) and 20-30 cm (subsurface soils) in three replicates for each soil series. For each soil, soil samples from the same soil depth at six points were collected randomly within each replicates, representing 18 samples for both depths at each soil series. The soil samples were air-dried for two to four days and crushed manually and sieves to pass 2 mm mesh sieve. The particle-size distribution was determined by the pipette method. The method consists of preliminary destruction of the organic matter by heating with the hydrogen peroxide. Adsorbed cations were removed by treating the samples with 0.2 M hydrochloric acid and dispersed with calgon. The sand (50-2000 μm) was separated by the sieving process whereas silt (2-50 μm) and clay (< 2 μm) were determined by the pipette method. The USDA system was used for the textural classification. To determine soil bulk density, undisturbed core soil samples taken with core ring of size 76 mm in diameter and 40 mm in height. The samples weight were recorded and put in

the oven at 105°C for 24 hours. Bulk density was expressed in g cm^{-3} on a dry weight basis. The moisture contents were expressed in volumetric (v/v) basis according to the following equation, $\Theta (v/v) = \Theta (w/w) \times \text{bulk density}/\rho_w$, where $\Theta (v/v)$ = % moisture contents on volume basis; $\Theta (w/w)$ = % moisture contents on weight basis; and ρ_w = density of water.

Soil pH was determined in water and 1 M KCl solution with 1: 2.5 ratio of soil to solution. Soil pH in water was measured after shaking for one minute and leaving the suspension to equilibrate overnight. The pH-KCl was measured after 10 minutes of shaking. Total carbon and nitrogen were determined by the CNS 2000. Available phosphorus was determined by The Bray II method. The exchangeable bases (Ca, Mg, K and Na) and CEC were determined by leaching method where ten grams of air dried soil were placed into leaching tube and leached with 100 mL of 1 M NH_4OAc at pH 7.0 by adjusting the interval of drift about 8 to 10 seconds. The leachate was collected and its cation (K, Ca, Mg and Na) determined by Atomic Absorption Spectrometer (AAS). The leached soil sample was washed with 100 mL of 95 % ethanol to remove excess ammonium ions and then leached with 100 mL 0.05 M K_2SO_4 and the leachate was collected for CEC determination using auto-analyzer. Exchangeable aluminum (Al) and hydrogen (H) were determined using the filtrate obtained from pH-KCl suspension pipettes 10 mL of the filtrate into a 100 mL Erlenmeyer flask and added with 3 drops of the Phenolphthalein indicator. The volume of 0.01 M NaOH solution used to titrate until first permanent pink endpoint was recorded as (x). After adding 5 mL of 4 % NaF, it was titrate with 0.01 M HCl and the volume of HCl solution used was recorded.

Data analyses: The data on physico-chemical properties for three soil series were analyzed using one-way ANOVA followed by Tukey's HSD test. The independent student t-test was used to examine any significant difference in soil properties between plantation and secondary forests and/or soil fertility status using SFI and SEF values. A standard multiple regression analysis was used to determine the significant difference among soil properties. All of the data were analyzed using Statistical Packages for Social Packages for Social Science (SPSS) software ver. 17.

Soil index was used to determine the factor that affect the soil fertility by integrating the soil physico-chemical properties. For estimating soil fertility and site quality, two indices were used: 1) Soil Fertility Index

(SFI) (Moran *et al.*, 2000); and 2) Soil Evaluation Factor (SEF) (Lu *et al.* 2002).

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

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

RESULTS AND DISCUSSION

Characteristics of soils under *K. ivorensis* plantation: The soil properties of Rengam, Durian and Padang Besar series are presented in Table 1. There were significant differences in almost all of physico-chemical properties of soils between soil series, particularly for surface soil. The results also showed that the soils under *K. ivorensis* stand were moderately acidic to slightly acidic for subsurface soil (pH ranged from 4.97-5.85), whereas the surface soils were moderately acidic (pH ranged from 5.07-5.42). The pH of Padang Besar series was significantly higher as compared with that of Durian and Rengam series. For Padang Besar soil series, the value was 5.42 for surface soil and 5.85 for subsurface. The lowest pH for Rengam was 5.07 (surface) and 4.97 (subsurface).

Total carbon content in surface soil was significantly different among soil series whereas no significant difference was found subsurface (Table 1). In Rengam series, total carbon in surface soil had the highest value of 16.11 g kg⁻¹, while that for Durian and Padang Besar it was 13.14 g kg⁻¹ and 12.24 g kg⁻¹, respectively. Total N in surface soil was significantly different between soil series. The highest value was 1.29 g kg⁻¹, 0.91 g kg⁻¹ and 0.72 g kg⁻¹, respectively for Padang Besar, Durian and Rengam. In contrast, total N in subsurface soil was not significantly different among soil series, with respective value was in Padang Besar, Rengam and Durian of 1.08, 1.17 and 1.22 g kg⁻¹. Meanwhile, there was a significant difference in the C/N ratio (P<0.05) for surface soil of which Rengam series showed the highest value of 32.24; the highest value for Padang Besar was 16.35 and for Durian series 18.22. This indicates that the content of organic matter for the surface soil of Rengam was higher than that of Padang Besar and Durian series. This explains the decomposition rate of organic matter in Rengam soil was lower than that of Padang Besar or Durian soil. Organic matter affects the CEC of soils. Likewise, the

CEC is affected the type of clay (or amount of clay) present in the soils. Therefore, soils with high organic matter or with high clay content have higher CEC than soils with low organic matter or sandy soils (Hardjowigeno, 2007). This is supported by the study of Abdu *et al.* (2008) who reported that surface soil in natural forest at Bukit Kinta Forest Reserve which have higher organic matter and clay content than that in planted forest has higher CEC compared with that of planted forest.

The availability of soil inorganic phosphate is determined by soil pH. The amount of Fe, Al, Mn, the availability of Ca and the amount and rate of decomposition of organic matter and microorganism activity soil pH. The available phosphorus in surface soil and subsurface soil was similar. Available P in surface soil ranged from 1.85 to 2.13 mg kg⁻¹, while in subsurface soil it ranged from 1.96 to 2.06 mg kg⁻¹. The results showed that there were significant differences of available P between soil series (P<0.05). The available P in Rengam for both surface and subsurface soils was higher (2.13 and 2.05 mg kg⁻¹, respectively) as compared to that of Durian (2.09 and 2.06 mg kg⁻¹, respectively) and Padang Besar series (1.85 and 1.96 mg kg⁻¹, respectively). According to Lal (1997), in tropical and subtropical regions, one of the limiting factors of forest productivity is low phosphorus availability. But every tree species demands phosphorus differently and some have better capacity to extract phosphorus in fixed form from soils.

In all soil series, the exchangeable bases in the surface and subsurface soils were low in comparison to the exchangeable Al, resulting in high level of Al saturation (Arifin *et al.*, 2008; Abdu *et al.*, 2008). The high level of Al saturation could be the reason of low available nutrients in particular P, because the nutrients was fixed by Al, so it could not be used by plants for its growth (Hardjowigeno, 2007). Lu *et al.* (2002) reported that physical structure was related with nutrient accumulation, while chemical properties (Ca, Mg, K and OM) have significant effects on biomass accumulation. Increasing these nutrients induces fast vegetation growth rate, but increasing Al content tends to restrict vegetation growth (Lu *et al.*, 2002). The cation exchange capacity (CEC) and effective cation exchange capacity (ECEC) of the Rengam series for surface and subsurface soils were significantly higher than those in the Durian and Padang Besar soil series. These results indicate that the soil of Rengam series has a greater ability to absorb cations compared with that of Durian and Rengam soil series.

Table 1: Comparison of physico-chemical properties between soil series under *K. ivorensis* plantation

| Soil properties | Soil series | | | | | |
|---|---------------------|----|---------------|----|---------------|----|
| | Padang Besar (n=18) | | Durian (n=18) | | Rengam (n=18) | |
| Surface soil (0-10 cm) | | | | | | |
| pH (H ₂ O) | 5.42 (0.1) | a | 5.22 (0.1) | b | 5.07 (0.1) | b |
| pH (KCl) | 4.30 (0.1) | a | 4.26 (0.1) | a | 3.89 (0.1) | b |
| Total C (g kg ⁻¹) | 12.24 (0.9) | b | 13.14 (1.1) | b | 16.11 (1.2) | a |
| Total N (g kg ⁻¹) | 1.29 (0.43) | a | 0.91 (0.08) | b | 0.72 (0.1) | b |
| C/N ratio | 16.35 (3.25) | c | 18.22 (4.55) | b | 32.24 (7.03) | a |
| CEC (cmol _c kg ⁻¹) | 5.89 (0.2) | c | 6.78 (0.3) | b | 10.93 (0.4) | a |
| Exchangeable Ca (cmol _c kg ⁻¹) | 0.36 (0.03) | b | 0.62 (0.07) | a | 0.59 (0.05) | a |
| Exchangeable Mg (cmol _c kg ⁻¹) | 0.16 (0.01) | b | 0.30 (0.02) | a | 0.20 (0.01) | b |
| Exchangeable K (cmol _c kg ⁻¹) | 0.17 (0.01) | ns | 0.20 (0.01) | ns | 0.20 (0.02) | ns |
| Exchangeable Na (cmol _c kg ⁻¹) | 0.03 (0.003) | b | 0.05 (0.003) | a | 0.05 (0.004) | a |
| Exchangeable Al (cmol _c kg ⁻¹) | 3.51 (0.34) | a | 2.72 (0.17) | b | 3.45 (0.31) | a |
| ECEC (cmol _c kg ⁻¹) | 4.22 (0.34) | a | 3.88 (0.21) | b | 4.48 (0.31) | a |
| Al saturation (%) | 81.83 (1.79) | a | 69.89 (2.13) | b | 74.88 (3.57) | ab |
| Available P (mg P kg ⁻¹) | 1.85 (0.09) | b | 2.09 (0.08) | a | 2.13 (0.11) | a |
| Clay (%) | 16.39 (0.85) | b | 18.99 (3.19) | b | 36.74 (1.22) | a |
| Silt (%) | 17.65 (0.69) | a | 15.26 (0.26) | b | 18.68 (0.62) | a |
| Sand (%) | 65.96 (1.30) | a | 65.75 (2.39) | a | 44.58 (0.89) | b |
| Bulk density (g cm ⁻³) | 1.31 (0.32) | ns | 1.29 (0.28) | ns | 1.19 (0.21) | ns |
| Subsurface soil (20-30 cm) | | | | | | |
| | Padang Besar (n=18) | | Durian (n=18) | | Rengam (n=18) | |
| pH (H ₂ O) | 5.85 (0.12) | a | 5.21 (0.15) | b | 4.97 (0.08) | b |
| pH (KCl) | 4.38 (0.17) | a | 4.35 (0.17) | a | 4.00 (0.19) | b |
| Total C (g kg ⁻¹) | 7.65 (0.41) | ns | 8.67 (1.63) | ns | 9.1 (0.72) | ns |
| Total N (g kg ⁻¹) | 1.08 (0.10) | ns | 1.22 (0.08) | ns | 1.17 (0.06) | ns |
| C/N ratio | 7.52 (0.98) | ns | 7.50 (1.65) | ns | 8.08 (1.15) | ns |
| CEC (cmol _c kg ⁻¹) | 4.98 (0.02) | c | 7.17 (0.43) | b | 9.17 (0.66) | a |
| Exchangeable Ca (cmol _c kg ⁻¹) | 0.25 (0.12) | b | 0.33 (0.02) | a | 0.30 (0.02) | ab |
| Exchangeable Mg (cmol _c kg ⁻¹) | 0.17 (0.01) | ns | 0.22 (0.02) | ns | 0.19 (0.01) | ns |
| Exchangeable K (cmol _c kg ⁻¹) | 0.16 (0.01) | ns | 0.14 (0.001) | ns | 0.13 (0.01) | ns |
| Exchangeable Na (cmol _c kg ⁻¹) | 0.05 (0.001) | ns | 0.04 (0.001) | ns | 0.06 (0.004) | ns |
| Exchangeable Al (cmol _c kg ⁻¹) | 3.12 (0.15) | b | 2.72 (0.11) | b | 3.62 (0.53) | a |
| ECEC (cmol _c kg ⁻¹) | 3.74 (0.16) | b | 3.45 (0.11) | b | 4.30 (0.53) | a |
| Al saturation (%) | 83.22 (1.13) | ns | 78.90 (1.16) | ns | 82.86 (2.45) | ns |
| Available P (mg P kg ⁻¹) | 1.96 (0.13) | b | 2.06 (0.13) | a | 2.05 (0.10) | a |
| Clay (%) | 23.05 (0.75) | b | 24.81 (0.70) | b | 46.53 (0.94) | a |
| Silt (%) | 16.92 (0.98) | a | 14.08 (0.37) | b | 16.72 (0.37) | a |
| Sand (%) | 60.03 (1.13) | a | 61.11 (7.17) | a | 36.75 (0.86) | b |
| Bulk density (g cm ⁻³) | 1.39 (0.35) | ns | 1.34 (0.27) | ns | 1.32 (0.18) | ns |

Note: Parentheses indicate standard error; different letters in the same row indicate significant differences among sites at 5% using Tukey's HSD test; ns, no significant difference; ECEC, Exch. Ca + Mg + K + Na + Al; Al saturation, (Exch. Al/ECEC) × 100

There were significant differences in the particle-size distribution between soil series. In the case of sand, Padang Besar and Durian soils have higher value compared with Rengam soil for both surface and subsurface soils. For clay content, the highest value in Rengam soil was 36.74% for surface soil and 46.53% for subsurface soil. The lowest value of clay content in Padang Besar soil was 16.39% in surface soil and 23.05% in subsurface soil. In the case of silt, the highest value was recorded in Rengam soil with value of 18.68% in surface soil and 16.72% in subsurface soil. The lowest value of silt content was in Durian soil with value of 15.26% in surface soil and 14.08% in subsurface soil. According to Lu *et al.* (2002), physical structure is related to nutrient content retention in the soil layers. Higher clay content associated with lower

coarse sand content can hold more nutrients in the soil. Conversely, low clay content associated with high coarse sand content results in low nutrient retention in the soil. Multiple regression analysis showed that clay content and total carbon in Rengam series were highly and positively correlated with CEC at P<0.01 (data not shown). These results indicate that negative charge derived from clay and organic matter play an important role in retaining soil cation nutrients.

Comparison of soil properties between planted and secondary forests: Table 2 shows the influence of planting of *K. ivorensis* (planted forest) on its soil properties conditions compared with the soil properties at adjacent secondary forests. The soil properties of planted forest are mean of soil properties within three soil series.

Table 2: Comparison of physico-chemical properties in surface and subsurface soils between planted and secondary forests

| Soil properties | Sites | | | | | |
|---|----------------|------------------|--------|-----------------|------------------|--------|
| | Surface soil | | | Subsurface soil | | |
| | Planted forest | Secondary forest | t-test | Planted forest | Secondary forest | t-test |
| pH (H ₂ O) | 5.23 (0.11) | 4.43 (0.13) | ns | 5.34 (0.12) | 5.72 (0.11) | ns |
| pH (KCl) | 4.15 (0.10) | 4.06 (0.09) | ns | 4.24 (0.11) | 3.99 (0.08) | ns |
| Total C (g kg ⁻¹) | 13.78 (0.92) | 16.03 (1.17) | ns | 8.47 (0.98) | 9.19 (0.98) | ns |
| Total N (g kg ⁻¹) | 0.97 (0.07) | 0.58 (0.07) | ns | 1.36 (0.12) | 0.80 (0.06) | ns |
| C/N ratio | 22.27 (3.22) | 49.38 (5.36) | * | 7.69 (1.13) | 15.81 (1.56) | * |
| CEC (cmol _c kg ⁻¹) | 7.86 (0.23) | 5.81 (0.18) | ns | 7.10 (0.21) | 5.90 (0.27) | ns |
| Exchangeable Ca (cmol _c kg ⁻¹) | 0.51 (0.09) | 0.50 (0.10) | ns | 0.29 (0.08) | 0.25 (0.07) | ns |
| Exchangeable Mg (cmol _c kg ⁻¹) | 0.21 (0.02) | 0.19 (0.03) | ns | 0.19 (0.03) | 0.14 (0.02) | ns |
| Exchangeable K (cmol _c kg ⁻¹) | 0.18 (0.01) | 0.17 (0.01) | ns | 0.14 (0.01) | 0.21 (0.02) | * |
| Exchangeable Na (cmol _c kg ⁻¹) | 0.04 (0.003) | 0.05 (0.004) | ns | 0.04 (0.002) | 0.07 (0.003) | * |
| Exchangeable Al (cmol _c kg ⁻¹) | 3.22 (0.24) | 3.42 (0.35) | ns | 3.15 (0.21) | 4.06 (0.25) | ns |
| ECEC (cmol _c kg ⁻¹) | 4.19 (0.15) | 4.35 (0.15) | ns | 3.83 (0.18) | 4.64 (0.19) | ns |
| Al saturation (%) | 75.53 (1.98) | 77.50 (2.18) | ns | 81.65 (2.54) | 87.11 (3.25) | ns |
| Available P (mg P kg ⁻¹) | 2.02 (0.11) | 1.96 (0.35) | * | 2.05 (0.19) | 2.00 (0.16) | ns |
| Clay (%) | 24.04 (0.87) | 12.47 (0.54) | * | 31.45 (0.67) | 16.40 (0.39) | * |
| Silt (%) | 17.16 (0.87) | 19.11 (0.65) | ns | 15.90 (0.49) | 19.33 (0.78) | ns |
| Sand (%) | 58.73 (2.39) | 68.30 (3.24) | ns | 52.61 (2.87) | 64.20 (4.58) | ns |

Note: Parentheses indicate standard error; significant difference between sites at 5% using Tukey's HSD test; ns, no significant difference; *, significant difference; ECEC, Exch. Ca + Mg + K + Na + Al; Al saturation, (Exch. Al/ECEC) × 100

The pH value in surface soil of planted forest is higher than in secondary forest, while pH value for subsurface soil in secondary forest was higher than that in planted forest. The soils in planted forest were moderately acidic, with pH (H₂O) of less than 5.5. The soil in secondary forest for surface soil was moderately acidic, while in subsurface soil was slightly acidic, with pH (H₂O) more than 5.5 (Amacher *et al.*, 2007). The results indicate that planting of *K. ivorensis* seems to have the potential in shifted the pH value into higher value than as was found in secondary forests.

The results also exhibited that for the surface soils, there were no significant differences between planted and secondary forests in almost all of the soil properties except C/N ratio, available P and content clay content. For the subsurface soil there was significant difference for C/N ratio, exchangeable K, exchangeable Na and clay content. The C/N ratio of soils in planted forest for both surface and subsurface soils was lower than that in secondary forests (Table 2). This indicates that the decomposition rate of organic matter in planted forest is faster than that in secondary forest. The rate of decomposition can be seen from the total value of N, if the total N small, the rate of decomposition will be low, resulting in inhibition of plant growth.

The available P in the surface soils of planted forest (2.02 mg kg⁻¹) for surface soil was higher and significantly different compared with that of the secondary forests (1.96 mg kg⁻¹), while for subsurface soil, there was no significant difference between

planted (2.05 mg kg⁻¹) and secondary forests (2.0 mg kg⁻¹). Meanwhile, the exchangeable K and Na in the subsurface soil were significantly different between planted and secondary forests, but there was no significant difference was found for surface soil. In addition, no significant difference was observed for exchangeable Ca and Mg between planted and secondary forests for both the surface and subsurface soils. Overall, the exchangeable bases of soils in the planted forest were higher than that in the secondary forest. This indicates that *K. ivorensis* was planted at 5 years old did not reduce nutrients in the soil. These results differ from studies by Abdu *et al.* (2008) who worked on 11-year-old dipterocarp species (*Shorea Pauciflora* and *S. Macroptera*) in Perak, Malaysia. In this study, it was found soils in the planted contained less Ca, Mg and K and available P compared with the adjacent natural forest. This tendency shows that the vegetations and stand age have a very important role in changing soil conditions.

The CEC of surface and subsurface soils in the planted forest was higher than that in secondary forests. This indicates that the planted forest is more fertile than that of the secondary forest. The clay content of soils in the planted forest is higher than that of the secondary forest. It means that soils in the planted forest can hold more nutrients. Zaidey *et al.* (2010) reported that for sandy soils the negative charges from clay minerals play important roles in retaining and releasing soil nutrients.

Table 3: Comparison of soil fertility between soil series under *K. ivorensis* plantation using SFI and SEF indices

| Soil series | SFI | | SEF | |
|--------------|----------------------------|----------------------------|---------------------------|---------------------------|
| | Surface | Subsurface | Surface | Subsurface |
| Padang Besar | 25.27 (1.67) ^b | 18.46 (0.70) ^{ns} | 5.94 (1.12) ^b | 4.50 (0.58) ^{ns} |
| Durian | 28.35 (1.83) ^{ab} | 20.29 (2.70) ^{ns} | 16.96 (2.29) ^a | 6.43 (0.65) ^{ns} |
| Rengam | 32.51 (2.38) ^a | 19.70 (1.73) ^{ns} | 16.40 (3.48) ^a | 4.87 (0.92) ^{ns} |

Note: Different superscripts letter (s) in the same column indicate significant difference between soil series at the 5%, ns, no significant difference; SFI, soil fertility index; SEF, soil evaluation factor

Table 4: Comparison of soil fertility between planted and secondary forests under *K. ivorensis* plantation using SFI and SEF indices

| Sites | SFI | | SEF | |
|------------------|----------------------------|----------------------------|----------------------------|---------------------------|
| | Surface | Subsurface | Surface | Subsurface |
| Planted area | 28.71 (1.22) ^{ns} | 19.48 (1.05) ^{ns} | 13.10 (1.68) ^{ns} | 5.27 (0.72) ^{ns} |
| Secondary forest | 32.50 (2.35) ^{ns} | 20.02 (3.54) ^{ns} | 12.84 (3.11) ^{ns} | 4.26 (1.74) ^{ns} |

Note: Significant difference between sites at the 5% using Tukey's HSD test; ns, no significant difference; SFI, soil fertility index; SEF, soil evaluation factor

In order to achieve sustainable production with minimal soil degradation, land-use planning and soil management must be taken into account because planting trees could reduce soil erosion and increase soil nutrients through organic matter accumulation (Lavelle, 1987). In this study, it seems that planting fast growing *K. ivorensis* have increased organic matter and plant nutrients as compared to secondary forest. This result indicates that the potential of fast growing species for rehabilitating degraded forestland by means of improving site productivity and soil fertility. Similarly, Evans (1999) and Sawyer (1993) stated that forest plantation have great potential for restoring degraded sites in the tropics. Bowyer (2005) reported the negative impacts of forestation can be avoided by proper matching of species to site. Therefore, for degraded secondary forest or forestland such as in the present study, the selection of species and site suitability need to be taken into consideration, if the government and private agencies intend to establish future forest plantation towards increasing site productivity.

Assessing soil fertility status using SFI and SEF: The complexity of soil properties make it difficult to find an appropriate method to evaluate soil condition in the humid tropical (Lu, *et al.*, 2002). Therefore, for estimating soil fertility and site quality, Moran *et al.* (2000) and Lu *et al.* (2002) developed methods called Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF), respectively. The methods were used to estimate soil fertility and site productivity under different succession stage of secondary forest in the tropical Amazon forest. Both SFI and SEF are applicable for estimating soil fertility and site quality under dipterocarp plantation in rehabilitated degraded

forestland in Perak, Malaysia (Abdu *et al.*, 2008; Zaidey *et al.*, 2010). In the current study, we used both SFI and SEF for estimating soil fertility and site quality of three soil series under five-year-old *K. ivorensis* (Table 3). The results show that there was no significant difference of SFI and SEF values among soil series. The highest SFI was for the surface soils of Rengam soil, followed by Durian and Padang Besar soils. The value of SEF showed that the Durian soil series exhibited the highest, followed by Rengam and Padang Besar.

In addition, we also used SFI dan SEF indices for estimating soil fertility and site quality in adjacent secondary forest in order to compare the values obtained with those of the planted forest. Although the value of SFI at surface and subsurface soils in secondary forest was higher than planted forest, but no significant difference was found (Table 4). Similarly, there were no significant differences in SEF of the surface and subsurface soils for planted and secondary forests.

CONCLUSION

This study showed that Rengam soil is more fertile as compared with Durian and Padang Besar soils. The Rengam soil contained higher organic matter and clay, resulting in higher value of CEC than the other two soils. It seems that the soil under 5-year-old *K. ivorensis* stand did not have much different from that of the secondary forest. The SFI revealed that soil fertility status under Padang Besar was significantly higher than other soil series, whereas no significant difference was observed for SEF. The results also showed that, no significant difference was observed between planted and secondary forest by using SFI and SEF. These results suggest that plantation of fast growing exotic

species such as *K. ivorensis* could increase the fertility of soils. The SFI and SEF indices are suitable as an index for estimating both soil fertility and site quality of different soil series under *K. ivorensis* plantation. However, further studies on soil conditions under *K. ivorensis* plantation after more than ten years need to be identified in order to clarify the role of forest plantation in terms of site productivity and carbon sequestration.

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