Faculty of Resource Science and Technology

Characterization of Soil properties in Relation to Growth Performance of Planted *Shorea macrophylla* After Enrichment Planting Under Sandy Soil at Sabal Forest Reserve, Sarawak, Malaysia

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This thesis submitted

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DECLARATION

I declare that this master project entitles "Characterization of Soil Properties in Relation to Growth Performance of Planted *Shorea macrophylla* after Enrichment Planting Under Sandy Soil at Sabal Forest Reserve, Sarawak, Malaysia" was the result of my personal research except for citations in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

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ABSTRACT

Assessment on the soil condition and growth performance of the planted tree on degraded forest, particularly on the sandy soil, is crucial in providing more information on the current status of the reforestation site. Hence, the aims of this study were to characterize the soil properties in term soil morphological properties and soil physicochemical properties at the reforestation site in comparison with high conservation forest as well as to determine growth performance of planted *Shorea macrophylla* at the reforestation sites under sandy soil. This study were involved two reforestation sites ((Early Estalishment of Reforestation Site (ER) and Late Establishment of Reforestation Site (LR)) and two High Conservation Forests (High Conservation Forest 1 (HCF 1) and High Conservation Forest 2 (HCF 2) as a control. Study plot with the size of 25 m x 25 m were contructed randomly on a reforestation site planted with *S. macrophylla* and High Conservation Forest at Sabal Forest Reserve. For soil morphological properties assessment, soil profile with the soil depth of approximately 100 cm depth was dug at the center of each study sites. As for soil physicochemical properties, soil composites were randomly collected at the soil depth of 0-10 cm and 30-40 cm by using a soil auger. Standard soil analysis for soil physical and chemical properties was performed. Diameter at Breast Height (DBH), total height and survival percentage of the planted *S. macrophylla* in the reforestation site were measured. The results from soil morphological properties showed that the soils in ER and HCF-2 plot were resemble Saratok series under Grey-White Podzolic soils (Ultisols) in which, corresponds to Typic Paleaquults of Soil Taxonomy by USDA Classification. Meanwhile, the soils in LR and HCF-1 plot were classified under Buso series of the Podzols which corresponds to Typic Haplothods of Spodosols under the USDA classification system. As for soil physicochemical properties, soils at study sites were strongly acidic in nature with

pH (H_2O) value less than 5.00 at both surface and subsurface soils. Besides, the sand content in ER and HCF-2 plots were less than 73%, meanwhile the sand content in LR and HCF-1 plots were more than 80% at both surface and subsurface soils. Although the soil in the study sites chacterized as acidic, sandy and low nutrient content, the growth performance of planted *S. macrophylla* still can survive. Based on the survival percentage of planted *S. macrophylla* in the ER and LR plot were 65 % and 56%, respectively. This can be concluded that *S. macrophylla* is suitable indigenous tree species to be planted in reforestation activities in the future especially under sandy soil. Nonetheless, it is recommended that long term monitoring on the soil properties and growth performance of planted *S. macrophylla* are essential in order to continuously provide information on the status of reforestation activity.

Keywords: Grey-White Podzolic soils, Podzols soil, soil physicochemical properties, growth performance, *Shorea macrophylla*

Pencirian Ciri-ciri Tanah Berkaitan dengan Prestasi Tumbesaran Shorea macrophylla yang telah Ditanam Selepas Penanaman Pengayaan di Bawah Tanah Berpasir di Hutan Simpan Sabal, Sarawak, Malaysia

ABSTRAK

*Kajian keadaan tanah dan prestasi pertumbuhan pokok tumbuhan di tapak hutan yang terdegradasi, terutamanya pada tanah berpasir, adalah penting dalam menyediakan lebih banyak maklumat mengenai status tapak penanaman semula hutan. Oleh itu, tujuan kajian ini adalah untuk mencirikan ciri-*ciri *morfologi tanah dan menilai ciri-*ciri *fizikokimia tanah di tapak pemulihan dan Hutan Pemeliharaan Tinggi dan juga untuk menentukan prestasi tumbesaran pokok Shorea macrophylla yang telah ditanam di bawah tanah berpasir. Kajian ini melibatkan dua tapak penanaman semula hutan (Awal Penubuhan Tapak Penanaman Semula Hutan (ER) dan Lewat Penubuhan Tapak Penanaman Semula Hutan (LR)) dan dua Hutan Pemeliharaan Tinggi (Hutan Pemeliharaan Tinggi 1 (HCF-1) dan Hutan Pemeliharaan Tinggi 2 (HCF-2)) sebagai kawalan. Plot kajian dengan saiz 25 m x 25 m dibina secara rawak di atas tapak penanaman semula yang ditanam dengan Shorea macrophylla dan hutan pemeliharaan tinggi di Hutan Simpan Sabal. Untuk menilai ciri-*ciri *morfologi, profil tanah dengan kedalaman tanah kira-kira 100 cm kedalaman digali di tengah bagi setiap tapak kajian. Bagi ciri-*ciri *fizikokimia tanah, komposit tanah dikumpulkan secara rawak pada kedalaman tanah 0-10 cm dan 30-40 cm dengan menggunakan auger tanah. Analisis tanah standard untuk sifat fizikal dan kimia tanah telah dilakukan. Diameter pada Ketinggian Dada (DBH), jumlah ketinggian dan peratusan kelangsungan hidup Shorea macrophylla yang ditanam di tapak penanaman semula diukur. Keputusan ciri-*ciri *morfologi tanah menunjukkan tanah di dalam ER dan HCF-2 plot menyerupai siri Saratok di bawah tanah Kelabu-Putih Podzolic (Ultisols) dimana, berpadanan kepada Typic Paleaquults bagi Taksonomi Tanah oleh Pengelasan*

USDA. Manakala, tanah di dalam plot LR dan HCF-1 dikelaskan di bawah tanah siri Buso, Podzol di mana berpadanan pada Typic Haplothods Spodosols di bawah sistem pengelasan USDA Taksonomi Tanah. Untuk ciri-ciri fizikokimia tanah, tanah ditapak kajian adalah semula jadi sangat kuat berasid dengan nilai pH (H_2O) kurang daripada 5.00 untuk kedua-dua permukaan dan bawah permukaan tanah. Selain itu, kandungan pasir dalam plot ER dan HCF-2 adalah kurang daripada 73%, manakala kandungan pasir dalam plot LR dan HCF-1 adalah lebih daripada 80% pada kedua-dua permukaan dan bawah permukaan tanah. Walaupun tanah dalam tapak kajian dicirikan sebagai berasid, berpasir dan rendah kandungan nutrien, kadar pertumbuhan pokok Shorea macrophylla yang ditanam masih berada pada tahap yang baik. Berdasarkan peratusan kelangsungan hidup Shorea macrophylla yang ditanam di dalam plot ER dan LR berada pada tahap yang memuaskan dengan kadar kelangsungan hidup adalah 65% dan 56%, masing-masing. Kesimpulannya Shorea macrophylla adalah spesies pokok asli untuk ditanam dalam aktiviti penanaman semula pada masa akan datang terutamanya di bawah tanah berpasir. Justeru itu, adalah disyorkan agar pemantauan jangka panjang terhadap sifat tanah dan prestasi pertumbuhan Shorea macrophylla yang ditanam sangat penting agar terus memberi maklumat mengenai status aktiviti penghutanan semula.

Kata kunci: *Tanah Kelabu-Putih Podzolic, Tanah Podzol, ciri-ciri fizikokimia tanah, perkembangan pertumbuhan, Shorea macrophylla.*

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LIST OF ABBREVIATIONS

Al	Aluminium
BD	Bulk Density
C: N	Carbon to Nitrogen ratio
DBH	Diameter at Breast Height
ER	Early Establishment of Reforestation Site
GWP	Grey-White Podzolics
HCF-1	High Conservation Forest-1
HCF-2	High Conservation Forest-2
HCl	Hydrogen Chloride
KCl	Potassium Chloride
LR	Late Establishment of Reforestation Site
MAID	Mean Annual Increment in Diameter at Breast Height
MAIH	Mean Annual Increment in Height
NaOH	Sodium Hydroxide
SFR	Sabal Forest Reserve
TC	Total Carbon
TN	Total Nitrogen

CHAPTER 1

INTRODUCTION

1.1 Study background

Tropical rainforest is well known as one of the most varied and abundant assemblage of complex ecosystems on the earth surface (Arifin et al., 2007). Besides, they were the richest ecosystems in the world in terms of structure and species diversity (Whitmore, 1998). In addition tropical rainforests cover 6% of the earth's land surface yet provide a habitat for more than 50% of the world's living of plant and animal species (Archard et al., 2002; Mayaux et al., 2005). However, despite increasing recognition of the importance of tropical rainforest, around 13 million hectares of forest in the world devastated annually due to deforestation, forest harvesting, shifting cultivation and forest encroachment (ITTO, 2002; Jomo et al., 2004; FAO, 2005). Borneo has experienced some of the highest levels of logging pressure in Southeast Asia, with extraction rate exceeding 100 m^3ha^{-1} (Kenzo et al., 2014). Notwithstanding, more than 50% of Bornean lowlands have been degraded by selection logging, especially in Sabah and Sarawak (Brunig, 1996; Morel et al., 2011). In Sarawak alone, besides forest harvesting, forest encroachment and shifting cultivation is the major cause of land degradation. Lee (2004) reported that 3 million ha (25% of the state) of total land area affected by shifting cultivation in Sarawak, Malaysia.

Therefore, the provision of ecosystem services including carbon storage, timber and food provision, freshwater management and soil protection on these degraded lands is poor compared with non-degraded forests (Appanah & Weinland, 1993). Nonetheless, Montagnini et al. (1997) strongly stated that the conversion of forested area to non-forested lands such as pasture and agriculture have resulted in the permanent reduction of indigenous species including timber species such as dipterocarp spp. from Dipterocarpaceae family. Moreover, when a natural forest is cleared the vegetation is unable to regenerate easily even though it is under humid tropical region with high precipitation because the nutrient stock in the soils is extremely depleted (Sakurai et al., 1998; Ishizuka et al., 2000). Most of soils in tropical region are infertile and once the natural forest has been cleared, nutrients can be rapidly lost consequently leading to longer forest recovery time (Sanchez et al., 2003; Juo & Franzlueebber, 2003). Besides, other researcher also mentioned that, once tropical rainforest was burned and or removed, the soil nutrient cycle change drastically (Jordan, 1985; Kleinman et al., 1995; Malmer et al., 1998; Giardina et al., 2000).

As for the case of heath forests under sandy soils in Sarawak and the common typical heath forest species were *Agathis borneensis* (Araucariaceae) and *Nepenthes* sp. (Nepenthaceae) (Brunig, 1974). In addition, soils in heath forest have low in nutrient retention capacity. Hence, anthropogenic disturbances in this forest may promote further reduction in soil fertility (Hattori et al., 2019). Besides, the destruction of these forest ecosystems would have substantial effects on global carbon emissions (Brunig, 1974, 2016; Miyamoto et al., 2016a, 2016b). Disturbance such as shifting cultivation also can cause severe forest degradation which characterized by soil erosion, loss of soil fertility, decreases in biomass, species richness and expansion of *Imperata grassland* (Kleinman et al., 1995; Lawrence et al., 2005; Bruun et al., 2006; Wasli et al., 2009; Lamb, 2010; Yassir et al., 2010).

Consequently, this has contributed to an increasing interest in creating rehabilitation or restoration techniques by enhancing site quality and productivity on secondary forest to avoid further degradation (McDill & Amateis, 1992; Ramos & Del Amo, 1992; Adjers et al., 1995; Lugo, 1997; Parrotta et al., 1997; Otsamo, 1998; Vincent & Davies, 2003; Ilstedt et al., 2004; Onyekwelu, 2005). In order to reserve such degraded forest land into more productive areas, forest plantation or rehabilitation activities are important countermeasures from a global perspective in terms of wood resources, environment and species conservation worldwide. In Malaysia, mainly in Sarawak, since 1979, Forest Department of Sarawak has made an effort and initiatives to carry out reforestation activities in Sarawak as to enrich and restore the forest areas as well as to return the forest to a stable and productive condition, but not necessarily the original diversity, structure and functions.

In forest rehabilitation, one of promising methods to restore degraded forestland in tropics is by enrichment planting (Ramos & Del Amo, 1992; Adjers et al., 1996; Montagnini et al., 1997). Therefore, enrichment planting has been widely conducted at various regions in Sarawak as an effort to rehabilitate the degraded forest which commonly involves plantation of native and exotic species. Through the enrichment planting, forest stands with uneven distribution of natural regeneration can be stocked as well as increase the soil fertility and productivity and provide benefits such as food and medical products (Schulze et al., 1994; Kuusipalo et al., 1996; Kobayashi, 2004; Lamb et al., 2005; Keefe, 2008). In enrichment planting, dipterocarps trees that have been selected and widely planted in reforestation program in Sarawak such as *Shorea macrophylla* as it has fast growing rate and endemic tree species to Borneo (Ashton, 1998; Chai, 1998; Perumal et al., 2017a, 2017b). Notwithstanding, *S. macrophylla* also listed in the IUCN Red List of Threatened Species. Hence, it is significant to be widely planted in reforestation activities. Besides, according to Chai (1998) the reason for selecting *S. macrophylla* in the state was due to the fact that no other indigenous species in the state can compared with the fruit or illipe nuts it produce. In addition, *S. macrophylla* had been commenced as early as 1982 (Chai, 1998).

1.2 Problem statement

Heath forest is common in Borneo and knows as Kerangas forest by Iban people (Richards, 1957; Proctor et al., 1983). In Sarawak, it only covers minimal in size and are associated with the formation of podzols or bleached sands. Although, the abundance of heath forest is small in Sarawak, it is important to conserve it as it provide habitat for many flora and fauna. Therefore, rehabilitation or reforestation activities by adopting enrichment planting are conducted under sandy soil as to restore degraded vegetation and to foster the recovery of the biodiversity. However, most of the studies focus on the reported on the progress of reforestation activities for the purpose of rehabilitating degraded areas in the tropical region (Nik Muhamad et al., 1994; Suhaili et al., 1998; Norisada et al., 2005; Arifin et al., 2007, 2008a, 2008b; Hattori et al., 2008, 2013; Kenzo et al., 2014; Perumal et al., 2015, 2017a, 2017b). For example in Sabal Forest Reserve, Sarawak, Forest department of Sarawak has been conducted reforestation activities by planting indigenous tree species such as *S. macrophylla* under heath forest. A recent study by Hattori et al. (2019) stated that long term monitoring of soil nutrient and biomass accumulation is rare in degraded tropical rainforest growing on sandy soil despite the known negative effect of forest degradation activities such as shifting cultivation on soil fertility, vegetation and biomass recovery as well as the growth of trees planted to rehabilitate degraded areas. Although still less information is known on the outcome of reforestation practice under sandy soil at degraded forest area via enrichment planting of indigenous tree species especially *S. macrophylla*. Generally, most of the studies were focused on the reforestation practices under Ultisols with less attention was given to the reforestation under Spodosols especially in Sarawak. Therefore, further research to provide baseline information for the forest restoration by planting *S. macrophylla* under sandy soil is required in order to ensure the success of the reforestation activities in the degraded area.

1.3 Objectives of the study

Therefore, the objectives of this study were:

i. To characterize soil morphological properties of sandy soil at the rehabilitation site in comparison with the soil morphological properties from the High Conservation Forest.

ii. To assess the soil physicochemical properties of sandy soil at rehabilitation site in comparison with soil physicochemical properties from the High Conservation Forest.

iii. To determine the growth performance in terms of survival percentage, mean annual increment of height and diameter at breast height of the planted *S. macrophylla* in the reforestation sites under sandy soil.

CHAPTER 2

LITERATURE REVIEW

2.1 *Shorea macrophylla* (de Vriese) P.S. Ashton

2.1.1 Taxonomic classification of *Shorea macrophylla* (de Vriese) P.S. Ashton

Shorea macrophylla (de Vriese) Ashton belongs to the genus *Shorea* in the family of Dipterocarpaceae and is an endemic species of Borneo Islands (Wood & Meijer, 1964; Soerinegara & Lemmens, 1993; Newman et al., 1996). According to Wood and Meijer (1964), the species was first named as *S. gysbertsiana* Burck. However, in the year 1962, Ashton argued that a sterile specimen of *Hopea macrophylla* (de Vriese) belongs to *S. gysbertsiana* (Wood & Meijer, 1964). In the absence of the type specimen of *Hopea macrophylla* at Leiden for confirmation, the name *S. macrophylla* (de Vriese) was adopted as a combination from *S. gysbertsiana* and *H. macrophylla*. The following are the taxonomic classification from kingdom to species of *S. macrophylla* (de Vriese) as shown below:

Kingdom	:	Plantae	**Family**	:	Dipterocarpaceae
Division	:	Magnoliophyta	**Genus**	:	Shorea
Class	:	Magnoliopsida	**Species**	:	*Shorea macrophylla* (de Vriese) P.S.Ashton
Order	:	Malvales			

2.1.2 Vernacular name of *Shorea macrophylla* (de Vriese) P.S.Ashton

The local people called *S. macrophylla* as *Engkabang jantong* in Sarawak. *Engkabang* is an Iban name of tree group consisting of twenty species of genus *Shorea* in Dipterocarpaceae in Sarawak (Smythies, 1958; Anderson, 1980). Besides, it appears to correspond to a local species group known as *Kawang* in Brunei and *Tengkawang* in Indonesia, though some confusion in identification is recognizable between researchers (Hotta, 1992a, 1992b). Kulip (1999) stated that *S. macrophylla* also recognized as *Engkabang ringgit*, *Tengkawang buah* and *Awang katolok*. In English, it was known as Light Red Meranti.

2.1.3 Natural range distribution and habitat

Shorea macrophylla is an endemic species of Borneo (Ashton, 1964). In Sarawak, these species are found in Lundu, Bau and Serian areas in the first division. Along the rivers and tributaries of Batang Lupar river in second division; Oya and Mukah rivers in the third; Balingian, Kemena and Bintulu rivers in the fourth and Rejang river in the seventh division are the common habitats of this species (Sim, 1978). Apart from the natural stands in the forest, small plot varying from a few scattered trees to 0.7 hectare for the production of fruits were established next to longhouses in the rural areas, especially in the central regions of Sarawak (Chai, 1998). According to Wood and Meijer (1964), in Sabah, this species is widely distributed but only locally common and is unaccountably absent in other locations. Anderson (1975) noted that their distribution was predominantly in north and central Borneo, becoming less frequent toward the east (Sabah, Kalimantan Timur).

Besides, *S. macrophylla* is commonly found in lowland tropical rainforest and seldom occur above 600 m in altitude (Ashton, 1964; Wood & Meijer, 1964). Browne (1955) stated that *S. macrophylla* is the most typical large tree of riparian forest in

Sarawak. The preferred habitat of this species is usually along the river, or in areas where the soil has higher water retention ability. It is absent in the dry hilly or mountainous areas. The main production areas of *S. macrophylla* and other minor illipe nuts species in Sarawak are confined to flooded alluvium plains and river banks (Browne, 1955; Wong, 1988; Newman et al., 1996). According to Rasip and Lokmal (1994), this species is confined to damp clay soils near rivers and streams and less favourable growth in hill sides, ridge top or upper slopes. However, it seldom occurs on sandy alluvium and is completely absent from peaty alluvium.

2.1.4 Botanical description of *Shorea macrophylla* (de Vriese) P.S.Ashton

Shorea macrophylla is a stocky low emergent or main canopy tree and an endemic species in Sarawak, and other parts of Borneo Islands, including Sabah, Brunei and Indonesia. *S. macrophylla* is a tall tree that can grow up to 35 m height, with rather smooth, brownish-green bark when young, becoming cracked and flaky on old trees. Besides, it also has a thick canopy with large crown and simple leaves. In addition, a young leaf of it can exceed 30 cm in length, but on average it is about 20 cm to 25 cm. The width ranges from 7 cm to 10 cm and leaves of seedlings are usually larger than 8 those of the mature trees. The upper surface of the leaf is smooth and slightly leathery on the lower surface. It is elliptic or ovate with a short pointed apex. When the leaf is dry, it is almost black above and reddish brown below. There are about 15 pairs of nerves. The leaf stalk is 2 cm to 3 cm long. Growth rate had been noted to attain 170 cm girth in 23 years and possibly the fastest among the *Shorea* (Browne, 1955). The presences of resin canals in the timber of these species are conspicuous (Browne, 1955). Figure 2.1 shows the view of *S. macrophylla* in reforestation site at Sabal Forest Reserve.

Figure 2.1: **(a)** The planted *S. macrophylla*; **(b)** Bark and stem of *S. macrophylla*; **(c)** Naturally growth sapling of *S. macrophylla*.

On the others hand, *S. macrophylla* is one of the light demanding species as it over the seedling stage. However, it is a shade tolerant species when they are sapling and require partial shade in the early growth for seedling to survive. According to Whitmore (1996), the term shade tolerant has been widely used to describe the ecology of many climax species and there are three distinct intertwined meanings: (1) it can mean the minimum photosynthetic active radiation (PAR) level needed for seedlings survival; (2) it can refer to the length of time for which seedlings can survive at low PAR levels.; and (3) it can refer to the amount of PAR required for release of the seedling from forest floor. Kimmins (1997) argued that shade tolerant species are generally characterised by large leaves and orientated in a none-overlapping plan, with an elongation of branches in a spreading pattern, and having uniquely large seeds as food energy reserved for germination under shade conditions. These characteristics describe well with many *Shorea* species including *S. macrophylla*. During the seedling stage, long exposure to direct sunlight may cause sun scorching on the leaves and subsequently, in severe situations, seedlings will die.

2.1.5 The flowering and fruiting of *Shorea macrophylla* (de Vriese) P.S.Ashton

Shorea macrophylla begins to flower at an age of about 15 to 16 years. Engkabang fruit is synonymous with the Iban community living in the interior part of Sarawak. It has petal or about four to five small wing which acts as the protector of the fruit. The flower of *S. macrophylla* is characterised by its winged fruits with a 5-merous calyx and resembling a badminton shuttlecock (Chai, 1998). It was reported that dipterocarps are pollinated by a wide variety of insects (Appanah & Chan, 1981; Ashton, 1982; Bawa, 1994), including insect such as thrips, stingless bees, beetles and moths. The tree maturity and crown structure influence the amount of fruits a *S. macrophylla* bears.

As mentioned by Sim (1978) that, the flowering of *S. macrophylla* usually occurs in September to October and the fruit ripen in the following January and February. The yield may continue to late March and April in very favourable years. However, Chai (1998) stated that the flowering behaviour of dipterocarp trees is notoriously unpredictable as it always annually flowering. In addition, the amount of flowering and consequent seed production is very small. Once in every few years, many dipterocarp trees flower together to produce a bumper crop of seeds. The phenomenon is called "gregarious" or "general" flowering. In contrast, the flowering of old trees here and there is called "sporadic flowering" (Ng, 1977). Burgess (1972) analysed the phenology data collected from 1927 to 1970, showed that gregarious flowering occurs at interval of 2 to 3 years, with occasional interval up to 5 years. Cockburn (1975) has analysed similar data from Sabah and come to the same agreement. The stimulus triggering for gregarious flowering is not clear, although Burgess (1972) suggested that it is related to periodic water stress and the accumulation of carbohydrates during the dry season in August to October.

2.1.6 The seeds of *Shorea macrophylla* (de Vriese) P.S.Ashton

The seeds of *Shorea macrophylla* are dispersed by wind with the aid of the long calyx, modified into wing-like structures (Chai, 1998). Some of the other dipterocarp species have large fruits like *S. macrophylla*. The seeds of *S. macrophylla* are recalcitrant and have a very short viability period, usually 2 to 3 days (Anderson, 1975; Appanah & Cossalter, 1994; Krishnapillay, 1994). The fruits or seeds of *S. macrophylla* are popularly known as *Engkabang* or *Abang* as in the 1940s to 1950s in Sarawak, while in Sabah, Brunei, and Kalimantan Indonesia they are known as *Tengkawang*. Together with five other *Shorea* spp., the seeds have been known by the foreign traders as illipe nuts. The five other species which produce illipe nuts are Engkabang bintang (*S. splendida* (De Vr.) Ashton), Engkabang rusa (*S. stenoptera* Burck), Engkabang gading (*S. hemsleyana* King ex Foxw), Engkabang terendak or Engkabang tegelam (*S. seminis* (De Vr) V.S.I) and Engkabang asu (*S. palembanica* Miq). All these species are now protected by the Sarawak state government under Sarawak's Wildlife Protection Ordinance (1998), owing to their ethnobotanical utility (Anon., 1994).

Besides, *S. macrophylla* is a protected species as its fruits, known as illipe nut, proves to have commercial importance for the commodity. Other *Shorea* spp. are also the sources of illipe nuts, however, their productions are insignificant. In Borneo, Sarawak (Malaysia) and Kalimantan (Indonesia) are the main producers of illipe nuts (Jantan, 1994). The value of the nuts depends on the size and the oil content of the kernels (Chai, 1998). The seed of *S. macrophylla* has very high oil content (Anderson, 1975; Sim, 1978; Nesaretnam & Au, 1992). It is because of its larger size and about 28 - 42 nuts weight a kilogram with the weight of a single fruit is up to 50 gm (Ahmed & Sim, 1973; Anderson, 1975).

2.1.7 Soil requirement for *Shorea macrophylla* (de Vriese) P.S. Ashton

Shorea macrophylla, growth well under alluvial riverine soils (Meijer, 1969). In Brunei, the tree is confined to damp clay soils on hillsides by rivers and streams, where it is scattered and rare, and on clay riparian alluvium where it is locally abundant (Ashton, 1964). Butt and Chiew (1982) suggested that, deep, most alluvial clays or loams are among the ideal soils for the growth of *S. macrophylla*.

According to Maas et al. (1974), the Sarawak Department of Agriculture listed that the illipe nut is having similar soil requirement to rubber trees. Suitable qualities are among well to imperfectly drained, sandy loam to clay soils at least 50 cm deep on slopes less than 30º. Based on the study by Perumal et al. (2017b) on the Grey-White Podzolic soils of Ultisols at Sampadi Forest Reserve, the planted *S. macrophylla* still can grow well under annually flooding.

2.1.8 Economic significance of *Shorea macrophylla* (de Vriese) P.S.Ashton

The timber quality of *Shorea macrophylla* is remarkable. Unlike most *Shorea* spp., *S. macrophylla* is almost free from heart-rot which is an excellent property for veneers, plywood, hardboard and furniture. Besides, *S. macrophylla* is one of the most important species in Sarawak, and has been selected as one of the indigenous species to be planted in the shifting cultivation area or degraded land in Sarawak.

The reason for selecting this species may be due to the fact that it one of the indigenous species that shows fast growing rate. Ng and Tang (1974) reported that the mean annual increment of *S. macrophylla* was 2.2 cm in DBH. Tan et al. (1987) noted that 3.8% of the 395 *S. macrophylla* in Semengoh forest reserve, Sarawak grew at 2.1 cm per annum from 1967 to 1974. Planting of *S. macrophylla* had commenced as early as 1982.

Besides, *S. macrophylla* also has been listed as vulnerable in the IUCN Red List of Threatened Species. Therefore, conservation can be done by planting *S. macrophylla* in reforestation activities.

In addition, illipe nuts of *S. macrophylla* are an important source of food to the wildlife in the forests including wild boar, woodpeckers, foxes (musang), rodent (rats), freshwater fish (jurawat), squirrel and local reindeer (Wong, 1988). Nonetheless, *S. macrophylla* also has been commercialized in manufacture of chocolate, cosmetics, soaps and candles. The oil produced from the fruit is used as cooking oil or massage oil. The fruit are boiled and eaten with hot rice by local people. Anderson (1975) reported that the kernel of a *S. macrophylla* contains 51.6% of fat, 2.32% of free fatty acid and 1.98% of ash, melting point at 37 °C, and high solvent value. As stated by Yulita (2016), analysis on fatty acid found in seed of *S. macrophylla* has similar characteristics to those found in cocoa seeds. Hence, fat produced by the seed of *S. macrophylla* has often being used as substitute of cocoa fat in food, cosmetic and medical industries. Winarni et al. (2004) reported that in the international market, the seed of *S. macrophylla* extract was known as Borneo tallow or green butter. This Borneo tallow was used as an alternative raw ingredient of cocoa fat was termed cocoa butter equivalent (CBE), cocoa butter substitutes (CBS) and cocoa butter replacer (CBR) (Blicher-Mathiesen, 1994). The term CBE refers to a non-cocoa butter fat by blending other vegetable fats in precise ratio so that it resembles cocoa butter in many physical and chemical properties (Wong, 1988). The fat is blended with cocoa butter for making chocolates and it is also used in the manufacturing of cosmetic products (Jantan, 1994).

2.2 Tropical rainforest in Malaysia

Tropical forest lies within the equatorial zone between the Tropics of Cancer and Tropics of Capricorn and has very high species abundance and species endemism than any other regions of the world. Tropical rainforest is well known for its various and abundant assemble of complex ecosystems on the earth surface (Arifin et al., 2007). They are the richest and most productive of all terrestrial ecosystems in the world in term of structure and species diversity whereby they have the functional role for biodiversity conservation, world climate amelioration and soil conservation (Whitmore, 1998; ITTO, 2002). According to Shukla et al. (1990) on a large regional and global scale, tropical rainforest have an outstanding prominent role and main influence in ameliorating and maintaining global climate change by reducing the accumulation of greenhouse gases.

In addition, tropical rainforest are habitat for over 185,000 species of flowering plants of which around 37,000 species are trees with many more remained undescribed (Prance, 1995; Odegaard, 2000; Ghazoul & Sheil, 2010). Within the tropical forest region, Southeast Asia forms one of the global biodiversity hotspots, home to 20-25% of the world’s plant and animal species (Myers et al., 2000; Mittermeier et al., 2005, 2011; Woodruff, 2010). The Sundaland is one of the four bioregions in Southeast Asia, and contains over 25,000 species of plants including 15,000 endemics, and 1,800 vertebrate species of which 701 are endemics (Myers et al., 2000; Brooks et al., 2002; Mittermeier et al., 2011). Within this bioregion is the island of Borneo, which has the richest tree diversity of between 10,000 to 15,000 species (MacKinnon et al., 1996; Wikramanayake et al., 2001). Borneo Island comprised Sarawak and Sabah (Malaysia) and Kalimantan (Indonesia). Borneo is the distribution centre for the Dipterocarpacea family, comprising 291 species or 75% of the family, and is a dominant and important commercial timber species in Southeast Asia (Soepadmo & Wong, 1995; Ashton, 1982, 2004). The richness of a single tree family such as Dipterocarpaceae, growing in one place is not matched by anywhere else in the world (Whitmore, 1988).

In Sarawak, in order to protect the forest in Sarawak, the forest area have been classified into three main categories namely the Permanent Forest Estate (PFE) which comprises of Gazetted Forest namely Forest Reserve, Communal Forest and Protected Forest: Total Protected Area (TPA) such as National Park, Wildlife Sanctuary and Rehabilitation Centre: State land whereby the forest land not reserved permanently as forest, can be alienated for other land uses as shown in Table 2.1 and other land uses including agriculture land, urban land and native customary land.

Table 2.1: Land classification showing the main categories of forested areas in Sarawak.

Land classification	**Size (ha)**	**Percentage of cover in Sarawak (%)**	**Percentage of cover over forested areas in Sarawak (%)**
Total land area	12,315,600	100	
Other lands	4,462,800	36.24	
Forested area	7,852,800	63.76	100
Forest Classification			
State land	2,824,200	22.93	35.97
Permanent Forest Estates (Forest Reserves, Communal Forests, Protected Forests)	4,507,038	36.60	57.39
Totally Protected Areas (National Park, Nature Reserve)	329,327	2.67	4.19
Protected Areas (Wildlife Sanctuary)	192,235	1.56	2.45

(Source: DOS, 2011)

2.3 Deforestation of tropical rainforest in Malaysia

However, habitat destruction and over exploitation are threatening the biodiversity and subsequently the ecological services provided by tropical rainforest (Sodhi & Brook, 2006). Land cover is changing at very fast rate, whereby natural ecosystems and forests are converted to other land uses such as large scale plantations and small-holder dominated farming areas (Koh & Wilcove, 2008; Wilcove & Koh, 2010); or became degraded due to fire and logging (Archard et al., 2002; Langner et al., 2007; Mittermeier et al., 2011). The lowland rainforests are degraded and being lost at an alarming rate, due to clearing and conversion for timber, agricultural and development uses (Meijaard & Sheil, 2008).

In Southeast Asia, tropical rainforest had experience the highest rate of loss and degradation, resulting in less than half its original forest cover remaining (Archard et al., 2002; Corlett & Primack, 2008). FAO (2011) reported that, in the year 2000, forest cover declined from 51% to 49%, and is projected to reduce to 46% in 2020. In addition, deforestation rates in the lowland rainforest of Southeast Asia have increased significantly, especially over the last 50 years (Hansen & DeFries, 2004; Wright, 2005). As for Malaysia region, forest cover decreased by 8.58% from 22.4 Mha in 1990 to 20.5 Mha in 2010, and is projected to decrease further to 20.0 Mha in 2020, largely due to pressures from conversion to agriculture coupled by the slowness in increasing coverage of permanent forest reserves (FAO, 2011).

Especially in Sarawak, in the year 2010, it was reported that the total forested area in Sarawak was 7.85 Mha or 63.76% of land area (DOS, 2011) and agricultural land was 1.35 Mha (10.96%) (DOA, 2011). However, only a small percentage of forested area which is 6.64% has legal protection status as national parks, nature reserves or wildlife sanctuaries. Jomo et al. (2004) noted that over 90% of forest in Sarawak is available for logging. On the other hand, state land has more extensive coverage, with the least protection status, and can be potentially alienated and converted to other uses, including timber harvesting. Much of the forests outside protected areas are being converted to other agricultural uses or licensed out for logging activities, putting more pressure on existing protected areas.

Besides, DOS (2011) reported that, the gross domestic production of Sarawak in the year 2010 was come from petroleum and gas, followed by oil palm and timber products.

The greatest impact from land conversion in Sarawak is palm oil (*Elaeis guineensis*), accelerated by the exhaustion of land bank in Peninsular Malaysia. Malaysia has been a top palm oil producing country since 1970s, and together with Indonesia, account for more than 85% of the world's production (FAO, 2012). Under the Third National Agriculture Policy (1998-2010), more land in Sarawak was designated for planting oil palm (MOA, 1998) and since then, an average annual increment of 10.5% in planted area was achieved since 2002, the highest for all states in Malaysia. Direct calculation based on yearly increment of palm oil planted area against the total land area, shows a minimum average annual conversion rate of 0.42% since 2002, largely converted from peat swamp forests (Tsuyuki et al., 2011). Deforestation in Sarawak, which occurred at an average rate of 0.64% per year, whereby intact inland forest experienced a loss of about 0.5 Mha within two decades since 1990, was mostly attributed to large scale expansion of palm oil plantations (Tsuyuki et al., 2011).

Logging is not only prevalent in Sarawak, but over the entire Borneo. In the year 1964, rubber was replaced by the timber as the main export for Sarawak. The large scale logging activities in Sarawak begun in the late 1940s and mostly focuses along the coastal peat swamp forest (Aiken & Leigh, 1992). Hence, logging has been blamed for the rapid degradation of forests since large scale commercial forestry started in the 1960s of which in less than two decades from 1980 with the loss was 12% (Aiken & Leigh, 1992; Jomo et al., 2004).

As reported by Wong (1992) that, logging activities in Sarawak were intensified during the 1970, when hill logging technology improved. Notwithstanding, this accelerated the exploitation of interior forests (Aiken & Leigh, 1992). In Sarawak timber harvesting showed an increasing trend from the late 1970's and peak in early 1990's (Chai, 1998). As reported by Blaser et al. (2011) that, up to the late 1970s, 76% of Sarawak was under forest cover, of which 90% was under logging concession, but between 1963 and 1986, an estimated 30% or more of forest area was logged. Log production picked up momentum in the late 1970s, climbing steadily and peaked in 1991 with over 19 Mm^3 harvested before it started to decline. This was reported due to the increasing demand on industrial wood products and fuel wood (Hashim, 2010). In addition, in the year 1988, the timber revenues collected in Sarawak had ranked second after the petroleum industry in Sarawak (Anon., 1988). The mixed dipterocarp forest, which contained large and tall standing species such as *Dryobalanops lanceolata Burck, Shorea superba Symington* and *Dipterocarpus caudiferus Merr.*, were the first to be logged and subsequently converted into agriculture (Ashton, 1995).

2.4 Land degradation in tropical rainforest

Land degradation caused by excessive land use that lead to deforestation (Tanaka et al., 1997; Ayoubi et al., 2011). Deforested area is a highly fragile area and easily irritated by natural disturbance such as drought or flooding that eventually leads to land degradation and desertification. Land degradation was defined as the long-term loss of ecosystem role and productivity caused by disturbances, and that land was unable to improve itself independently. Stocking and Murnaghan (2001) defined land degradation as a temporary or permanent decline in the productive capacity of the land. In addition, deforestation of natural forest leads to soil degradation, which proceeds rapidly under tropical climatic conditions (Liebig et al., 2002; Arifin et al., 2008). Land degradation occurred gradually and cumulatively, and had a long-term force on rural people, making them increasingly vulnerable. About 5 to 7 million hectares of arable land (0.3% to 0.5%) are lost every year through soil degradation. In Malaysia, the expansion of agricultural land has been taking place on marginal soil and steep land that are highly vulnerable to erosion (Lal, 1990).

2.5 Reforestation effort in Malaysia

Rehabilitation activities are important countermeasures from a global perspective in terms of environment and species conservation worldwide to restore degraded forest land into more productive areas. Rehabilitation attempted to restore the forest to a stable and productive condition, but not necessarily the original diversity, structure and functions. Reforestation can be defined as the process of replanting trees in areas where they had been destroyed by over logging, forest fire, disease and others. Adekayode and Akomolafe (2011) defined reforestation as tree planting process carried out to replenish harvested trees from the existing forest land in order to ameliorate the soil fertility that had been degraded from the result of felling trees.

Rehabilitation commonly involved planting the indigenous and exotic species on degraded forest land (Arifin et al., 2007). As discussed by Ashton et al. (2013), exotic tree species are the most favoured species over the indigenous species as exotic species had high adaptability and better tolerant to stress. The main objectives of the reforestation activities were to foster the recovery of biodiversity, to improve and assist the restoration process of the degraded forest area. Besides that, reforestation can be used to restore soil fertility and protecting various species habitat. Several types of research had proven that reforestation is capable of overcoming the problem with degraded land.

2.6 Reforestation activities in Sarawak

Forest Department Sarawak is the local authority that responsible for the forest area in Sarawak as well as reforestation program conducted throughout Sarawak. Reforestation program in Sarawak started on 1920 at Semengoh Forest Reserve. In early 1980, to curb the practice of shifting cultivation in the permanent forest estate, the Forest Department of Sarawak established a Reforestation Unit. Briefly there are four objectives of this unit which are (1) to restore deforested areas to productive forests; (2) to restore the fertility and the environmental protective functions of the deforested areas; (3) to provide employment to eliminate poverty among the poor population of shifting cultivators and (4) to ensure a future sustainable supply of timber from the areas reforested and rehabilitated both for domestic and industrial use (Anon., 1995).

Besides, in the year 1996, the government of Sarawak had proposed that at least 15% of all the permanent forest estate must be replanted or re-stocked with enrichment planting. The Reforestation Unit of the Forest Department aims to establish 10,000 hectares of forest plantation annually in the permanent forest estate in Sarawak (Anon., 1991). As mentioned by Kendawang (1994) that about 10,000 hectares out of 160,000 hectares of shifting cultivation areas in the permanent forest estate have been planted with both indigenous and exotic species. Besides, as reported by Chai (1998), more than 40% of the area has been planted with *Shorea macrophylla*.

Moreover, Forest Department, Sarawak in cooperation with several international agencies have implemented a reforestation activities by planting indigenous species mainly dipterocarp species for restoration of tropical rainforest at degraded areas (Talip et al., 2011). Therefore, many projects had been organized by Forest Department Sarawak with various agencies to rehabilitate the forest area in Sarawak such as the Long-Term Ecological Research (LTER) Project (1990-1992). This project was established between Forest Department Sarawak, several Japanese universities and Harvard University at Lambir Hill HP. The objective of this study was to study the factors controlling the origin and maintenance of high species diversity.

Besides that, Forest Department Sarawak also worked with few agencies from Japan for the Friendship Forest Projects such as Mitsubishi-Sarawak Friendship Project, Yokohama-Sarawak Friendship Forest Project, Hiroshima-Sarawak Friendship Forest Project and OITA-Sarawak Friendship Forest Project. Among them, the implementation joint tree planting activities under the Friendship Forests Project involving the participation from Japan and Sarawak. This effort was initiated to enable the society, especially the local to appreciate the forests of Sarawak and at the same time, participate in the restoration of tropical rain forest through tree planting activities. Such efforts are especially significant in restoring small areas deforested by various activities such as illegal logging and shifting cultivation within the permanent forest estate and totally protected areas which would not be of economic size for big scale plantation operators. At the same time, such reforestation activity was ecological in nature which aims in restoring the deforested areas through the establishment of vegetative cover while economic returns from the planting were not a major consideration. This project had been conducted in different locations such as Niah Forest Reserve, Kubah Forest Reserve, Sabal Forest Reserve, Gunung Apeng National Park and Sampadi Forest Reserve. Mainly dipterocarps species such as *S. macrophylla, Parashorea macrophylla, Dryobalanops beccarii, S. ovata, S. leprosula* and *S. parvifolia* were planted in this project.

2.7 Enrichment planting technique in reforestation activities

Rehabilitation in degraded forest is a major problem addressed upon on both regional and global states. Hattori et al. (2013) suggested that planting of the indigenous species was an effective rehabilitation method as the trees were able to provide resources such as for food, medicine product and timber. However, few aspects that needed to be considered prior to reforestation included the species of the planted trees, the planting techniques applied on the area. This is because the approach taken on which planting technique used in the degraded area held an important factor which determined the success of reforestation carried out in the area. Besides, different climate with different soil conditions and different types of forest cover required different reforestation technique. The environmental properties such as microclimate, soil qualities and light condition played essential role in the ecosystem of tropical rainforest and it is important in determining the performance of planted seedling in the field (Hattori et al., 2013). Therefore, before planting the seedling, a comprehensive understanding on the effect of environmental factors imposed on planted seedling on each degraded areas is required.

Adapting the appropriate planting technique is important to ensure the success of reforestation activities. Through most of the common planting technique adapted from worldwide is by enrichment planting. Enrichment planting is one of important technique used in forest rehabilitation (Schulze, 2008; Doucet et al., 2009). In addition, enrichment planting was known to be one of the most promising techniques used in restoring degraded forestland in the tropics (Ramos & Del Amo, 1992; Adjers et al., 1996; Montagnini et al., 1997).

Besides, this technique also was known to have the desired potential in rehabilitating logged-over forest areas (LOF) which was deficient in the regeneration of the commercial timber species (Ali, 2006). Enrichment planting of logged-over forest with dipterocarp trees (Dipterocarpaceae), that was predominant with canopy species and acted as important timber sources in Southeast Asian forests, was the primary method used in accelerating regeneration and rehabilitation of degraded forest (Adjers et al., 1995; Appanah & Weinland, 1996; Kenzo et al., 2011).

According to Appanah and Weinland (1993), enrichment planting was defined as introducing high quality indigenous trees species to poor stocked logged forest without eliminating the existing trees. Keefe (2008) defined enrichment planting as a silviculture tool that is capable of adding long-term value to the forests. Enrichment planting was also defined as a method of silviculture management that rehabilitated poorly stocked log-over forest without eliminating existing individual trees species (Arifin et al., 2008a). This method mainly was carried out by planting indigenous species such as *D. aromatica, S. leprosula, S. laevis, Swietenia macrophylla* and *S. macrophylla* (Hattori et al., 2013). The dipterocarps species was widely planted in forest rehabilitation as they had faster growth rate. In addition, they also shade tolerant species when they are sapling (Sasaki & Mori, 1981; Ashton, 1982; Symington, 2004). Most dipterocarp species was recommend to be planted in forest rehabilitation under secondary forest because secondary forest tree may provide optimal shade conditions for the growth of dipterocarp seedlings (Norisada et al., 2005; Kenzo et al., 2008, 2011).

Enrichment planting aimed to improve the forest ecosystem including the poorly stocked logged forest areas to achieve the desired levels while protecting the soil condition and maintaining the surrounding biodiversity (Arifin et al., 2008a; Nelson, 2011). The guideline on enrichment planting currently used by the Forestry Department of Peninsular Malaysia was given under Circular No.2/96 of the Director-General of Forestry, Peninsular Malaysia (Ali, 2006). Under enrichment planting technique, there are several type of planting involved such as line planting method, gap planting method, patch and cluster or nest planting method and island-corridor planting method (Kobayashi, 1988; Adjers et al., 1995, 1996; Tuomela et al., 1996; Montagnini et al., 1997; Sakurai et al., 1999; Ninomiya et al., 2000; Numata et al., 2006; Romell et al., 2007).

Line planting method is the most popular technique to enrich secondary forest in the absence of seedling and sapling on the forest floor. It derives its name from the line clearing and plantation of commercial species (Kobayashi, 1994). According to Lamprecht (1989), the well kwon enrichment planting is line planting which has a number of variants throughout the tropics. Adjers et al. (1995) stated that in a relatively homogenous secondary forests or former shifting cultivation sites, where stratification of canopy layer has not yet been fully developed, line planting is a suitable method of enrichment. Meanwhile, in a high multistory forest, lines are difficult to open up and hence gaps or planting in groups is more suitable for such condition than line planting.

2.8 Role of soil in a forest ecosystem

Soil constitutes a complex mixture of solids, water and gases. Soil is formed partially by the breakdown of rocks and minerals on the surface of the earth through weathering and soil development processes. These processes required a long period to be completed and are influenced by the parent material, time, topography, climate and biota. The soil is made up of three major horizons, started from the surface horizon, followed with subsoil and substratum. The remainder of soil is composed of organic compounds from the decomposition of plants, animals, insects, bacteria, mold and fungi. Water and air are trapped in the spaces between soil particles.

Furthermore, soil plays many roles in the forest ecosystem. These roles include promoting plant productivity, enhancing water relation and recycling carbohydrates and nutrient through mineralization. At the same time, soil is also required to transfer the energy in the detritus food chain and acted as a buffer in the environment (Neher, 1999).

Furthermore, the various types of soil helped determined the type of trees species emerged on the area and eventually followed with the succession of the forest ecosystem.

However, major distruction on the forest ecosystem such as deforestation, would results, decline in soil quality due to an increase in soil erosion and soil compaction. Soil erosion is the most widely recognized and most common form of land degradation. Usually, soil erosion at the deforestation site is usually caused by water from heavy rainfall. The soil particle would be removed by the action of the water. As mentioned by Stocking and Murnaghan (2001) that decline of soil fertility and productivity are induced by soil erosion due to continuous degradation of soil physical, biological and chemical properties. The decline in soil biological activity will reduce soil organic matter while the decline in soil physical properties will affect the soil structure, aeration and water-holding capacity.

Based on a previous study by Alexander (2012) on soil compaction on skid trail after selective logging in the moist evergreen forest of Ghana, mentioned that a soil compaction is a form of damage associated with logging activities which may restrict root growth and reducing natural regeneration. Pressure, vibration, impact and kneading applied to the soil are the factors that cause soil compaction. In this study, soil compaction on 40 years after logging and one year after logging of skid trail was tested at Boin River Forest Reserve. The soil compaction on 40 years after logging and one year after logging has not shown any significant difference. Thus, the rate recovery from soil compaction is slow because of the machinery used to skid the logs in the reserve. The rate of recovery of soil compaction between the 40-year-old abandoned skid trail and the one-year-old skid trail is significantly low even after forty years. Soil compaction generally negatively alter soil structure and hydrology i) by increasing bulk density, soil strength, water runoff and erosion, ii) by breaking down soil aggregation and iii) by decreasing porosity, aeration and infiltration capacity (Jusoff & Majid, 1986,1987; Van der Plas & Bruijnzeel, 1993; Brunig, 1996; Kozlowski, 1999).

Besides, when a natural forest is cleared, the vegetation is unable to regenerate easily even though it is under humid tropical region with high precipitation because the nutrient stock in the soil is extremely depleted (Sakurai et al., 1998; Ishizuka et al., 2000). Sanchez et al. (2003) and Juo and Franzluebbers (2003) also mentioned that most soils in the tropical region are infertile and once the natural forest has been cleared, the nutrient can be rapidly lost consequently leading to longer forest recovery time. According to Akbar et al. (2010) that, soil organic matter would be increased with time. Therefore, there would be a chance for the reforestation site to become likely or similar to High Conservation Forest in the future.

The ecology of the forest including the soil physicochemical properties of the soil is important to determine the succession of the reforestation activities. As the reforestation site on logging activities is history, the soil properties of this site may change compared to natural forest. Jamaluddin et al. (2013) stated that soil fertility index and soil evaluation factor at the rehabilitation site are higher in values as compared to secondary forest. This indicates that forest rehabilitation has improved the soil fertility of degraded land. Besides, this study also shows that after a few years of planting, the physiochemical of the rehabilitation site as also improved. Reforestation activities also have been proven to increase the soil quality at the reforestation site (Ayoubi et al., 2011).

2.9 Heath forest and sandy soil in Sarawak

In Sarawak, there are heath forest which known as "*Kerangas*" forest and a seasonal lowland tropical rain forest that develop in dry land sites with predominantly podzolized, highly acidic, sandy soils (Brunig, 1974; Ghazoul & Sheil, 2010). "*Kerangas*" forest which was named heath forest by Richards (1957) is the particular vegetation of Sarawak. Heath forests in Borneo are known as "*Kerangas*" forests, originating from an Iban word that refers to infertile soils (Brunig, 1974).

"Kerangas" forests are distinctive in their forest structure, physiognomic features, and tree characteristics as compared with the lowland mixed dipterocarp rainforests that are more dominant throughout Borneo (Din et al., 2015). Besides, compared to other forests, heath forest is less vegetation cover, with a partially open canopy, and the woody plants are mostly small and scrubby, with a low species diversity and very distinct floristic composition (Proctor et al., 1983; Whitmore, 1990; Miyamoto et al., 2003). Plants with unusual trophic strategies such as 'ant-plants' that host ant colonies inside themselves, plants with nitrogen (N)-fixing root nodules, and insectivorous plants such as *Nepenthes* sp. are much more common in heath forest (Whitmore, 1990; Proctor, 1999).

On the other hand, "*Kerangas"* trees are typically shorter and unbuttressed and have stilt roots (Brunig, 1974; Whitmore, 1984; Wong et al., 2015). The plants exhibit sclerophylly with leaves that are usually small and thick (Brunig, 1974; Whitmorre, 1984; Becker et al., 1999; Turner et al., 2000) and with low nitrogen content (Peace & Macdonald, 1981). "*Kerangas"* trees are often densely packed, giving the appearance of a pole forest (Brunig, 1974; Whitmore, 1984; MacKinnon et al., 2013).

In addition, various "*Kerangas"* formations have been recorded in Borneo, including dry land "*Kerangas"* formations such as coastal and inland "*Kerangas"* forests and open "*Padang*" forests, as well as wetter "*Kerangas"* formations, known as "*Kerapah*" (Whitmore, 1984; Ghazoul & Sheil, 2010; MacKinnon et al., 2013). In other regions, the best studied equivalent vegetation type appears to be heath forest that also exists in scattered areas in South America, where it is known as caatinga or campina (Moran et al., 2000).

The soil at the heath forest categorized as sandy soil. In Malaysia, sandy textured soils are generally classified into Entisols or Spodosols which covering the soil distribution on beach ridges along the east coast of Peninsular Malaysia as well as the sandstone plateaus and cuesta formation on dip slope in the hilly regions of Sarawak, Sabah and Brunei (Whitmore, 1984). In Sarawak, this type of soil classified as Podzols which are classified under order Spodosols. Podzols soil can be found mainly in humid temperature and humid tropic area, particularly in the area where the parent material is predominantly of quartz or siliceous minerals (Jopony & Tan, 1989). Quartz is low in clay as well as in bases.

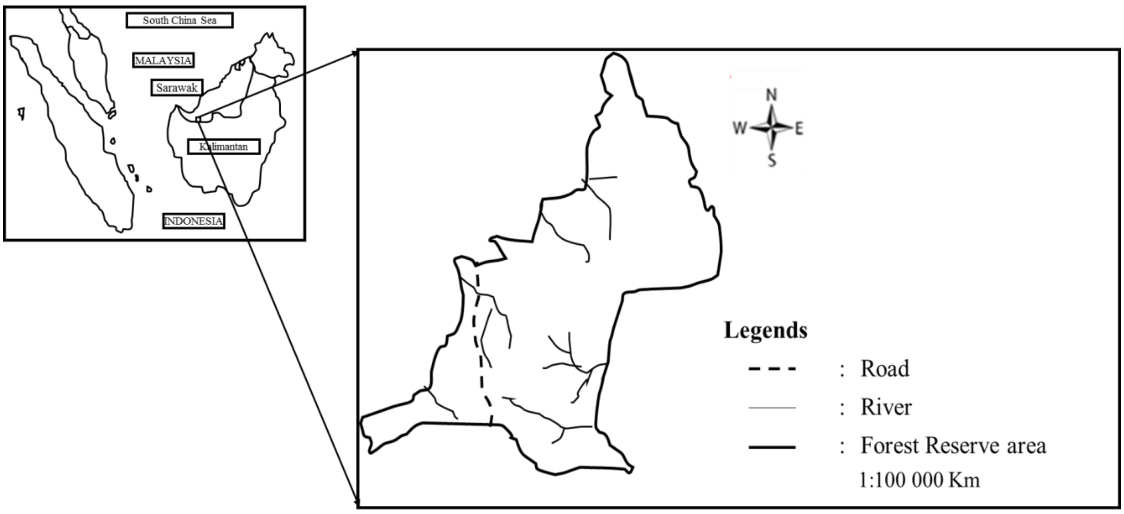
Proctor, (1983) reported that, heath forest occurs on soils derived from siliceous parent materials which are low in bases and coarse-textured. Katagiri et al. (1991) stated that soil of the heath forest was exceedingly moist and strongly acidic. Besides, nitrogen concentrations in soil solution and topsoils, respectively, from "*Kerangas"* forests in Borneo were lower than values recorded from mixed dipterocarp forest soils (Moran et al., 2000; Metali et al., 2015). Similarly, in the Kabili- Sepilok Forest Reserve, Sabah, "*Kerangas"* soils were recorded as least fertile compared to alluvial and sandstone forests (Dent et al. 2006). The free-draining sandy soils allow nutrients to leach readily (Katagiri et al., 1991; MacKinnon et al., 2013). In addition, Jordan, (1985) points out that the nutrient contents are in a critical condition in the tropical rainforest and human impact of rapidly increased cutting and burning has influenced nutrient cycling.

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of the study site

This study was conducted from September 2014 to February 2018 in Sabal Forest Reserve (SFR), Sarawak, Malaysia (Figure 3.1).



(Source: Google Earth, 2018)

Figure 3.1: Map of study sites at Sabal Forest Reserve (SFR)

Generally, Sabal Forest Reserve consists of undulating and low lying lands in the north and steeper hill in the Klingkang range in the south which located 112 km southeast of Kuching and its elevation is about 100 to 150 m above sea level (Chai, 1998; Hashim, 2010). The mean annual rainfall is about 3585 mm while the mean annual temperature is 32.5 °C with little variation throughout the year (Meteorological Department, 2014).

3.2 The history of the Sabal Forest Reserve

The original vegetation in the Sabal Forest Reserve was Mixed Dipterocarp Forest (MDF), Riparian Forest and heath Forest (“*Kerangas”* forest). In addition, based on the personal communication by the Forest Department Officer, the previously Sabal area was implemented as water catchment area located surrounding Sabal Forest Reserve area for more than 50 years by the local people and known as high conservation area (demarcated as HCF-1 and HCF-2). Therefore, it is important to protect the forest area as it used to supplies water around Sabal area and Simunjan area.

Hence, in the year 1927, Sabal Forest Reserve was proclaimed (Chai, 1998). The western boundary for Sabal Forest Reserve was Sg. Sabal Tapang, the eastern boundary was Sg. Sabal Kruin, the junction of these two rivers was the northernmost point and the southern boundary was the border with Kalimantan (Petch, 1986). In the year 1962, about 3188 ha of land lying to the southwest along the Indonesia border was added to the Forest Reserve, presumably because it was still under primary forest.

Although, Sabal Forest Reserve was gazetted in the year 1927, shifting cultivation and logging activities has still widely conducted in the Sabal Forest Reserve. In the year 1953, a block of 401 ha located at the west of Sg. Sabal Kruin and north of the trunk road was excised, because the land had been cleared and cultivated. Chai (1998) stated that timber harvesting of the forest reserve started in 1970 but the local communities had encroached into the reserve and were practicing shifting cultivation as early as 1960. Tractor, truck and heli-logging were used in logging activities to transport the log out of the area. The harvested trees were mainly dipterocarp species such as *Shorea* and *Dryobalanops.* Nonetheless, the shifting cultivation has been done widely and out of necessity for a long time by the local community. In the year 1982, about 2 ha of Sabal Forest Reserve area has been excised by the Angkatan Nahdhatual Islam Bersatu (BINA).

Besides, in late 1970’s the forest at the foot of the Klingkang Range was logged by Sabal Sawmill Sdn. Bhd. Butt (1983) mentioned that approximately 35 ha of the forest area in Sabal has been burned and cleared. Chai (1998) mentioned that, about 2,277 ha of the reserve have been affected by shifting cultivation.

In order to rehabilitate the degraded forest, Forest Department of Sarawak has implemented the reforestation project in the forest reserve from 1981. In addition, in the year 1984, the shifting cultivation in Sabal was banned although it was widespread all over the area and conflict between the shifting cultivators and foresters arose (Hashim, 2010). After the ban, the reforestation projects had been successful in increasing tree cover in former cultivations areas. Under Sabal reforestation and Agroforestry program, *Acacia mangium* which is exotic Australia timber species was planted in the 1981 and then interplant with the native Bornean species *Shorea macrophylla* in the 1990 (Hisham, 2010). From 1981 to 1994, a total of 2,078 hectares of the land used for shifting cultivation had been rehabilitated (Chai, 1998). The main species planted were *Acacia mangium*, *S. macrophylla*, *Durio zibethinus*, *Swientenia macrophylla*, *Araucaria cunninghamii* and *Paraserianthes falcataria*. Out of the total area planted, *S. macrophylla* alone took up 35% or 720 hectares (Forest Department Sarawak, 1995). Besides, the Forest Department Sarawak along with other non-governmental agencies from Japan has been work together for Sabal Agroforestry Project.

3.3 Plot establishment at the study sites

Two reforestation sites planted with *Shorea macrophylla* with spacing 5 m x 5 m were selected, namely Early Establishment of Reforestation Site (5 years) (ER) and Late Establishment of Reforestation Site (20 years) (LR). Nonetheless, two high conservation forests sites (≥ 50 years) namely High Conservation Forests 1 (HCF-1) and High Conservation Forests 2 (HCF-2) were selected in this study as control. In this study, two controls were used as two soil orders were used in this study which are Ultisols and Spodosols. Before, future analysis, soil texture and soil colour were the first criteria observed during field sampling as to differentiate the soil order at the each study sites. The plot with size of 25 m x 25 m was randomly demarcated within each compartment at the study sites. Table 3.1 and Figure 3.2 show the information of the study plot established in ER, LR, HCF-1 and HCF-2.

Table 3.1: The information on the study sites established in ER, LR, HCF-1 and HCF-2.

Plots	Age stands (Years)	Plot size	GPS locations	Number of plots	Number of planted trees in 25 m x 25 m	Total number of planted trees
ER	5	25 m x 25 m	N01º4’41.57’’, E110º55’50.78’’	6	25	150
LR	20	25 m x 25 m	N01º4’35.37’’, E110º55’35.02’’	4	25	100
HCF-1	≥ 50	25 m x 25 m	N01º5’52.12’’, E110º56’31.19’’	3	-	-
HCF-2	≥ 50	25 m x 25 m	N01º5’54.04’’, E110º56’36.58’’	3	-	-

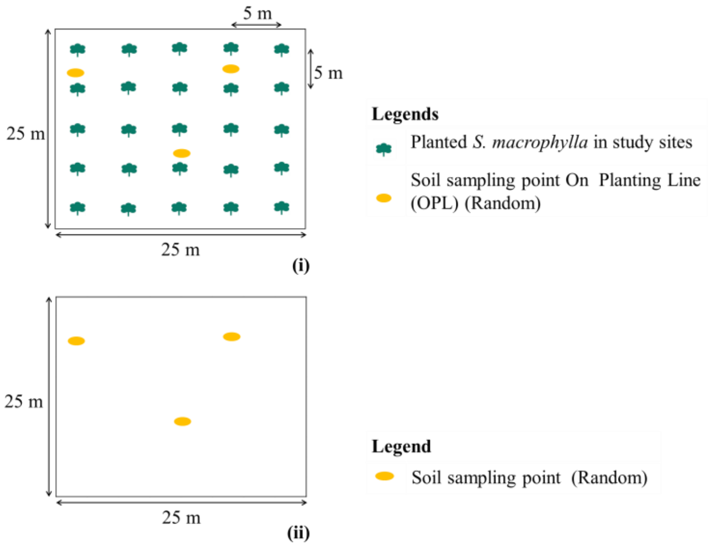


Figure 3.2: **(i)** Study plots for growth performance evaluation and soil sampling located inside reforestation sites, **(ii)** Study plots for soil sampling located inside High Conservation Forest.

3.4 Soil morphological properties assessment

In order to characterize soil morphological properties, soil pit of approximately 100 cm depths were dug at each study sites for soil profile description. Before, soil profiles were dug; a few criteria were required for site selection such as at the middle of the site, avoid compacted area such as trekking area, avoid wet area and avoid big trees area. For the typical soil profile (master horizon), the soil profile was described starting from the top of the profile and the characteristics of the soil moving towards the bottom of the profile was observed. The description was conducted according to the method proposed by National Resources Conservation Service (NRCS) of United States Department of Agriculture (USDA) in Field Book for Describing and Sampling Soils (USDA-NRCS, 2012). The results of morphological characteristics were then recorded in Soil Characteristic Data Sheet. The *in-situ* observation was conducted in order to collect information on soil morphological properties such as colour, texture, consistence, structure, rock fragment, organic matter and roots were distinguished. Soil colour was determined by referring to the

Munsell Soil Colour chart whereas the texture was determined by “feel method”. Additionally, soil hardness was measured and examined at each horizon by using the Yamanaka-type push cone penetrometer.

3.5 Soil physicochemical properties analyses

Soil samples were randomly collected at the depth of 0-10 cm (surface soil) and 30-40 cm (subsurface soil) by using soil auger at three random points and were mixed well to obtain a composite sample. For reforestation sites, the soils were mainly collected on the planting line while in HCF, the soils were collected randomly. The soils then air-dried and crushed to pass through a 2.0 mm and 0.425 mm mesh sieves for soil physicochemical analysis. After that, the soil samples were stored in airtight bag and labelled.

3.5.1 Method for soil physical analyses

Soil particle size analysis was determined through the pipette method to separate the inorganic soil particle into the sand, silt and clay fraction (Gee & Bauder, 1986). This analysis was used to determine the distribution of mineral particle less than 2.0 mm according to size class. The soil texture was determined by using the calculation as below:

Percentage (dry soil base)

Clay1 (%) = $(x_2 - x_1)$ x 100% x 10

x_1: the weight of weighing bottle

x_2: the weight of weighing bottle with soil after oven-dry at 105ºC

Silt 1 (%) = $(y_2 - y_1) - (x_2 - x_1)$ x100% x10

$y_{1:}$ the weight of weighing bottle

y_2: the weight of weighing bottle with soil after oven-dry at 105ºC

Sand 1 (%) = 100- clay (1%) - silt (1%) - organic matter (%) - moisture content (%)

Percentage (mineral particles base)

Clay (%) = Clay 1 (%) ／ (Clay 1 (%) ＋Silt 1 (%) ＋ Sand 1 (%)) × 100%

Silt (%) = Silt 1 (%) ／ (Clay 1 (%) ＋Silt 1 (%) ＋ Sand 1 (%)) × 100%

Sand (%) = Sand 1 (%) ／ (Clay 1 (%) ＋Silt 1 (%) ＋ Sand 1 (%)) × 100%

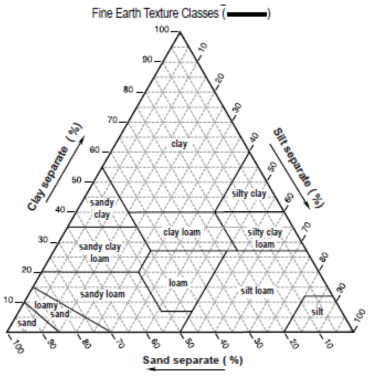


Figure 3.3: Soil textural triangle (USDA-NRCS, 2012).

The soil bulk density was measured on the undisturbed soil sample, collected at the reforestation sites and high conservation forest at the depth 0-10 cm and 30-40 cm using a 100 cc core sampler with the ratio of dry mass of soil to the bulk volume of soil core. This experiment was carried out by drying the undistributed soil sample at 105ºC overnight. The soil bulk density was determined by using the formula as below:

$$\text{Bulk density } (\rho b) = \frac{\text{mass of oven dry soil (g)}}{\text{volume of soil (100cm) (ml)}}$$

Soil organic matter was measured using loss on ignition method by using the formula as shown below (Dean Jr, 1974):

$$\text{Loss and Ignition} = \frac{W1 - W2}{W2} \text{ X } 100\%$$

Where;

W_1: Weight of oven-dry soil sample (g) at 105 °C

W_2: Weight of soil sample (g) after ignition at 500 °C

3.5.2 Methods for soil chemical analyses

Soil pH was measured in distilled water and 1 M KCl in a soil to solution ratio of 1:5 using a glass electrode after reciprocal shaking for 1 hour at 120 rpm⁄ min (Ishizuka et al., 2000). Exchangeable Al and H were determined by using filtrate from pH KCl analysis. The filtrate from pH KCl analysis will undergoes the titration method with 0.01 M NaOH for exchangeable H and content of exchangeable Al with 0.01 M HCl (Akbar et al., 2010). Electrical conductivity (EC) was measured before pH using conductivity meter (Eutech Instrument- Cyberscan Con11) and using the supernatant at the soil to water ratio of 1:5. Total nitrogen (TN) was determined by the Kjeldahl acid-digestion method using concentrated sulphuric acid (Bremner & Mulvaney, 1982). Loss on ignition method was used to measure Total Carbon (TC) in the soil (Dean Jr, 1974). As for the exchangeable bases (Mg, K and Ca) was determined by using Atomic Absorption System. The content of exchangeable bases (Mg, K and Ca) was extracted three times with 1 M ammonium acetate at pH 7.0 and the concentration of Mg, K and Ca were determined with the atomic absorption spectrophotometry (Thermo Scientific, Ice Series 3500). After removing the excessive ammonium, the soil was extracted with 100g L^{-1} NaCl solution and the supernatant was used to determine the Cation Exchange Capacity (CEC) using the titration method. Available Phosphorus was measured using Bray II method (Kuo, 1996) where soil samples were extracted with an extracting solution, mixture of ammonium fluoride (1M

NH_4F) and hydrochloric acid (0.5M HCl), then a colour-developing reagent was added and the available phosphorus was determined by absorbance measurement with a Ultraviolet-visible (UV) spectrophotometer at a wavelength of 710 nm (JASCO V-630) (Bray & Kurtz, 1945). All the analysis of soil physicochemical was performed at the Laboratory of Environmental Soil Science, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, Malaysia.

3.5 Assessment of growth performance of planted *Shorea macrophylla*

In order to study the growth performance of planted *Shorea macrohylla* at the Early Establishment of Reforestation Site (ER) (5 years) and Late Establishment of Reforestation Site (LR) (20 years), the diameter of a stem, tree height and survival percentage were assessed. The diameter tape was used to measure the Diameter at Breast High (DBH) or 1.3 m above ground level. As for sapling, the diameter of trees was taken 0.3 m from the ground level if their height did not reach 1.3 m. The DBH of tree was calculated by using this formula (Wenger, 1984):

$$\mathrm{DBH} = \frac{c}{\pi}$$

Where;

DBH	:	Diameter at Breast High
c	:	Circumference of tree
π	:	3.142

Suunto Clinometer was used to measure the total height of the planted *S. macrophylla*. Trigonometry principle was applied to measure height of the trees and calculation was done by using the formula as shown below (Philip, 1994):

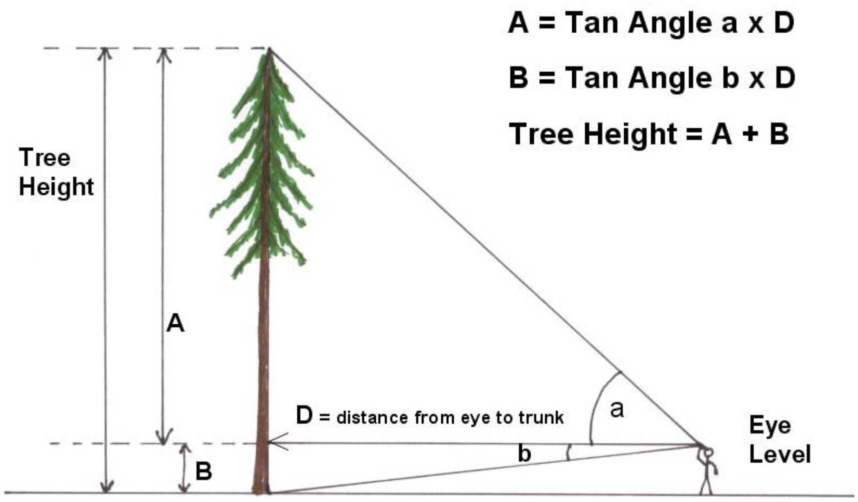


Figure 3.4: Total height of trees estimation using trigonometry principle.

For the mean annual increment in term of tree height (MAIH) and diameter (MAID), both values were estimated using the average values of tree height and stem diameter of assessed trees with the age stand of the study plot (Wasli et al., 2014). The formula to calculate MAIH and MAID of planted *S. macrophylla* were shown as below (Wasli et al., 2014):

$$\text{MAIH}(\text{m/ year}) = \frac{\text{Mean of height } (\bar{y})}{\text{Age of tree (year)}}$$

$$\text{MAID}(\text{cm/ year}) = \frac{\text{Mean of Diameter at Breast Height (DBH)} (\bar{x})}{\text{Age of tree (year)}}$$

As for the survival percentage of the planted *S. macrophylla* was calculated by the using formula as shown below:

$$\mathbf{X} = \frac{\mathbf{Z}}{\mathbf{Y}} \text{ x } 100\%$$

Where:

X= Percentage of survival of *S. macrophylla*

Y= Total number of planted *S. macrophylla*

Z= Total number of planted *S. mcrophylla* that is still survived

(Source: Perumal et al., 2017b).

3.6 Statistical analyses

Independent sample t-test was used to compare the differences between the mean values for selected soil physicochemical properties in reforestation sites and High Conservation Forest. Independent sample t-test was performance using excel. Multiple regression analysis was conducted to determine the dominant properties between soil total C and clay contents in contributing to soil CEC in the study sites.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Morphological properties of soil in the study sites at Sabal Forest Reserve

In-situ observation was performed to collect information on morphological soil properties from the constructed soil profile at each study site (ER, LR, HCF-1 and HCF-2). In the study sites, the soil pit deeper than 60 cm in LR and HCF-2 plots and deeper than 52 cm in HCF-1 plot were unable to dig due to restrictions on manual digging from the existence of the hard subsoil and rock fragments (R horizon) at the bottom of the pit for HCF-1 plot. Figure 4.1 and Table 4.1 showed a detailed overview of the description and interpretation of the soil profile.

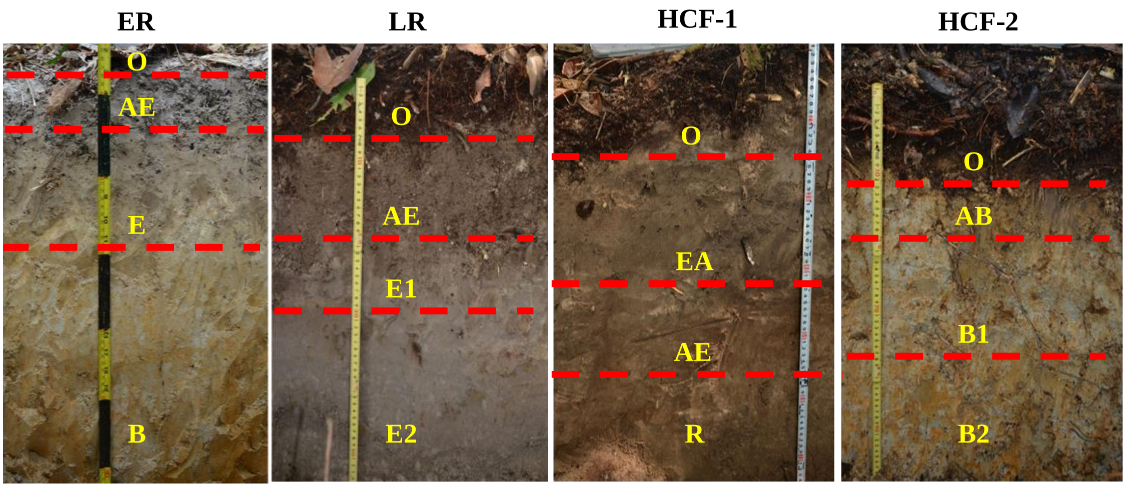


Figure 4.1: Soil profile at Early Establishment of Reforestation Site (ER), Late Establishment of Reforestation Site (LR) and High Conservation Forest (HCF-1 and HCF-2)

Table 4.1: Summary on soil morphological properties at study sites.

Plot	Horizon	Depth (cm)	Colour	Texture[a)]	Structure[b)]	Consistency[c)]	Roots[d)]	Boundary[e)]	Rock[f)]	Motting[g)]	OM[h)]	Hardness (mm)[i)]
ER	(N1º 4' 41.57", E110º 55' 50.78")											
	O	0-3	Root mat and litterfall									
	AE	3-19	10YR5/3	SL	1-2/n/sbk	ss/sp	f-c/ma-fe	cw	n	n	m	18
	E	19-43	10YR7/6	SL	2/n/sbk	ss/sp	vf/vfe	c-gw	n	7.5YR6/6	l	24
	B	43-100	10YR6/8	SCL	2/n/sbk	s-vs/p	n	c-gw	n	7.5YR6/6	l	21
LR	(N1º 4' 35.37", E110º 55' 35.02")											
	O	0-7	Root mat and litterfall									
	AE	7-13	7.5YR3/1	SL	2/n/sbk	ns/np	f-me/fe-ma	ds	n	n	h	12
	E1	13-21	7.5YR5/1	LS	2/n/sbk	ns/np	vf-f/fe	cs	n	n	m	12
	E2	21-60	7.5YR7/1	LS	1/n/sbk	ns/np	n	cs	n	n	l	20
HCF-1	(N1º 5' 54.04", E110º 56' 36.58")											
	O	0-8	Root mat and litterfall									
	EA	8-34	10YR4/3	LS	1/n/sbk	ns/np	f-c/fe-ma	dw	n	n	m	11
	AE	34-52	10YR4/4	LS	2/n/sbk	ns/np	me-c/fe	cir	n	n	m	18
	R	52-100							d/sr/b/slw	n		
HCF-2	(N1º 5' 52.12", E110º 56'31.19")											
	O	0-11	Root mat and litterfall									
	AB	11-26	10YR6/4	SCL	2/n/sbk	s/sp	me-c/fe	cw	n	n	l	17
	B1	26-44	10YR7/4	SL	2-3/n/sbk	s/p	me-c/fe	dw	n	n	l	18
	B2	44-60	10YR6/6	SCL	3/n/sbk	s/p	vf-f/n-fe	dw	n	n	l	14

Abbreviations: a) Field Texture: SL: Sandy Loam, SCL: Sandy Clay Loam, LS: Loamy Sand, b) Soil Structure: 1: weak, 2: medium, 3: strong, Size: n:none, Type: sbk: sub angular blocky, c) Consistency: ns: non-sticky, s: sticky, ss: slightly sticky, vs: very sticky, np: non-plastic, p: plastic, sp: slightly plastic, d) Root size and abundant: vf: very fine, f: fine, me: medium, c: coarse, vfe: very few, fe: few, co: common, ma: many, n: none, e) Boundary: c: clear, g: gradual, d: diffuse, s: smooth, ir: irregular, w: wavy, f) Rock abundant, shape, size and weathering: f: few, d: dominant, sr: sub rounded, b: boulder, slw: slightly weathered, n: none, g) Mottling: n: none, h) Organic matter (OM): l: low, m: medium h: high. i) Hardness (Sources: USDA-NRCS, 2012).

A few decades ago, shifting cultivation and forest harvesting has been widely done by local people at Sabal Forest Reserve. Those activities left a patchwork of secondary vegetation which can be detected on ER and LR plots. For example, based on the field observation, the reforestation area consisted of existing vegetation which derived after the previous land use were dominated by several woody pioneer species such as *Macaranga* spp., *Ficus* spp., *Dillenia suffructicosa* and abundant of light demanding species such shrub, grass and fern such as *Imperata cylindrica* were observed in ER and LR plots. Besides, charcoals from the effect of forest burning for shifting cultivation were observed during profile description were performed in ER and LR plots.

In term of O layer, compared to ER plot (≤ 3 cm), the O layer at the LR, HCF-1 and HCF-2 plots were the thicker (≥ 3 cm). Conversely, thinner layer of O horizon with 3 cm depth is discovered in ER plot, ascribable due to the availability of raw material since the tree was considered immature (≤ 5 years old) compared with the supply of organic matter from mature vegetation in LR, HCF-1 and HCF-2 plots. In addition, the O layer in High Conservation Forest (HCF-1 and HCF-2) was thicker as compared to reforestation sites (ER and LR plot), even after more than 20 years rehabilitated. The O layer directly comes from accumulation and decomposition of litterfall from planted *Shorea macrophylla* and naturally grown pioneer tree species in the study sites that cover the topsoil. Besides, previously study mentioned that the thicker O horizon was due to the existence and accumulation of a relatively abundant organic matter from mature vegetation in the forest area (Ishizuka et al., 2000; Hattori et al., 2005). In addition, Islam and Weil (2000) also suggested that abundance and thickness of the litter layer on the forest floor promotes high decomposing processes by soil microorganism. Nonetheless, decomposition occurs reflects the decomposer activity that gradually returns nutrient back to the soil.

The surface horizons showed a mixture of eluvial (bleached sand) deposits with A horizon giving rise to EA or AE horizon, with respect to the dominance of A or E features of the pedons, ranged from 3 cm to 52 cm at all study sites except for the case of HCF-2 plot. The existence of distinct spodic horizons with the bleached sandy eluvial layer (E horizon) was noted as a result of the podzolization process (Ho et al., 2019). In ER, LR and HCF-1 plot, E horizon, including E1 and E2 horizon, varies in terms of depth between 13 cm and 60 cm, generally characterized by the sandy loam or loamy sand soil texture.

In addition, dense, well-developed root mat were seen in the plot of ER, LR, HCF-1 and HCF-2 with an abundance of different root sizes, varying from very few to many. However, only root mat in High Conservation Forest (HCF-1 and HCF-2) plot can penetrate up to 50 cm into the subsurface layer. In contrast, root mat development and penetration was rather poor in ER and LR plots, mainly characterized by many to very few and coarse to very fine roots, up to 43 cm and 21 cm and absent towards the deeper soil profile. Based on the field observation, no root mats were found at the depth more than 52 cm at HCF-1 due to the present of rock fragment at the bottom of the soil profile which restrict the further penetration of root in the soil. Besides, the ability of the root to penetrate to deeper soil depth was influenced by the soil hardness. As mentioned by Taylor and Brar (1991) that, soil compaction indirectly affects rooting growth of the root in the soil. This with similar manner with the result of the soil hardness and root mat penetration in HCF-2 plot which soil hardness in HCF-2 plot recorded the decrease as soil depth increased and root in HCF-2 plot could penetrate up to 60 cm soil depth. In addition, soil hardness at the O horizon was lower than subsurface soil in all soil profiles. As mentioned by Hattori et al. (2005), low soil hardness in forest area was presumably due to the presences of relatively thick O horizon and to higher moisture content.

Soil texture class in ER and HCF-2 plots was classified within sandy clay loam to sandy loam and the soil texture in LR and HCF-1 plots fall within the class of sandy loam or loamy sand based on the "feel" method. This indicates that parent materials at the study site mainly consisted of sandstone and sandy shale. In contrast, the soil structure of the soil profile in LR and HCF-1 plots were shown weak to moderate sub-angular blocky and soil profiles in ER and HCF-2 plots were shown moderate to strong sub-angular blocky structure as moving down of the soil profiles. In addition, no consistency in soil was observed in LR and HCF-1 plots as moving down the soil profile as compared to ER and HCF-2 plots. This indicate that the soil in LR and HCF-1 plots were very sandy than in ER and HCF-2 plots.

Based on the *in-situ* observation, the soil profile colour in LR and HCF-1 plots were darker than in ER and HCF-2 plots (Figure 4.1). Based on Figure 4.1 and Table 4.1 the colour of the mixture of EA or AE horizon was usually darker, ranged from dark brown (7.5YR3/1), brown (7.5YR4/4) and yellowish brown (10YR5/3) in ER, LR and HCF-1, respectively. As mentioned by Ho et al. (2019) the colour of the mixture of EA or AE horizon was usually darker because of the continuous supply of fresh organic materials in the form of litterfall contributed to the darker colour of surface and subsurface horizon. Meanwhile, the spodic E horizon is pale in colour, characterized by yellow (10YR7/6), light brownish grey (7.5YR5/1) and light grey (7.5YR7/1) ER, LR and HCF-1 plots. The soil in ER and HCF-2 plots can be classified from yellowish brown (10YR5/3) to brownish yellow (10YR6/6).

The clear differences and similarities of soil morphological properties at the study sites were shown in Table 4.1 and Figure 4.1. Therefore, judging from the soil texture, soil consistency, soil structure, soil colour and the presence of spodic horizon, the soil at the study sites were classified as shown in Table 4.2

Table 4.2: Soil classification for ER, LR, HCF-1 and HCF-2 plots at the study sites.

Plots	Sarawak Soil Classification System (Teng, 2004)		USDA Soil Taxonomy Classification System (Soil Survey Staff, 2014)
	Soil series	**Soil group**	**Soil order**
ER	Saratok	Grey-White Podzolic	Ultisols
LR	Buso	Podzols	Spodosols
HCF-1	Buso	Podzols	Spodosols
HCF-2	Saratok	Grey-White Podzolic	Ultisols

Based on Sarawak Soil Classification System, soil profile in ER and HCF-2 were classified under Saratok series (Table 4.2). In Sabal Forest Reserve, Saratok series was formed mainly on the low undulating hill and strongly dissected erosion surface of the Sabal Forest Reserve. Teng (2004) reported that Saratok series and also known as Grey-White Podzolic soils can be found in sandstone-derived residues. This is supported by the soil texture in ER and HCF-2 which were classified under sandy clay loam to sandy loam. Besides, Grey-White Podzolic soils group in ER and HCF-2 were identified by the existence of contrasting soil texture between 40 cm soil depth. According to Soil Survey Staff (1966), Grey-White Podzolic soils has pale in colour with weak to strong subangular blocky. In this study, the soil colour of the soil profile in ER and HCF-2 were classified from yellowish brown (10YR5/3) to brownish yellow (10YR6/6) with weak to strong subangular blocky. This Grey-White Podzolic soil group corresponds to Typic Paleaquults of Ultisols, according to the USDA Soil Taxonomy (Soil Survey Staff, 2014).

According to Sarawak Soil Classification System, the soil profile in LR and HCF-1 plots were categorized under Buso series of Podzols soil group. The main distinguish feature, of Podzols were the presence weakly cemented to non-cemented of spodic and albic horizon discovered within 100 cm of the surface and the humus pan underlain beneath the E horizon. Other features were soil texture in LR and HCF-1 which ranging from sandy loam to loamy sand with soil colour ranged from light grey (7.5YR7/1) to very dark grey (7.7YR3/1) and dark brown (10YR4/3). Hence, weak to moderate of subangular blocky structure with no consistency of soil were form as the soil was very sandy. The distinct characteristics of sandy soils are the occurrence of spodic horizon (E horizon) (Katagiri et al., 1991). The parent materials of Podzols were derived from alluvial materials on ancient terrace deposits during the Pleistocene period sedentary materials of sandstones or conglomerates of the Tertiary age (Soil Survey Staff, 1966; Andriesse, 1969; Teng, 2004). Podzols soil group under Sarawak soil classification are tentatively correlated with Typic Haplothods of Spodosols under USDA Soil Taxonomy (Teng, 2004; Soil Survey Staff, 2014).

4.2 Soil Physicochemical Properties at the study site

Based on the information from soil profile descriptions, the soil at the study sites were divided into Grey-White Podzolic soils (Ultisols) and Podzols soil (Spodosols).

4.2.1 Soil physicochemical properties of Ultisols at Early Establishment of Reforestation Site (ER) and High Conservation Forest (HCF-2) (Grey-White Podzolic Soils)

Table 4.3 shows the average value of soil physicochemical properties of Early Establishment of the Reforestation Site (ER) and High Conservation Forest-2 (HCF-2) plot under Grey-White Podzolic soils (Ultisols). The soils of the ER and HCF-2 plots were strongly acidic with pH value less than 5 (ranged from 4.19 to 4.78 and 4.56 to 4.88) at both surface and subsurface soil layers, respectively (Table 4.3 and Figure 4.2). The pH value of the HCF-2 plot was lower as compared to ER plot at both surface and subsurface soil layers. Similar results with pH value less than 5 under Ultisols were recorded by others study on the reforestation site (Ishizuka et al., 2000; Arifin et al., 2008).

Table 4.3: Selected soil physicochemical properties under enrichment planting of Early Establishment of the Reforestation Site (ER) and High Conservation Forest 2 (HCF-2) plots under Grey-White Podzolic soils (Ultisols).

Parameters		ER	HCF-2	ER	HCF-2
		n = 6	n = 3	n = 6	n = 3
		Surface soil : 0-10cm		Subsurface soil : 30-40cm	
pH-H_2O		4.44 ± 0.22	4.34 ± 0.19	4.73 ± 0.15	4.65 ± 0.09
EC[a]	μScm^{-1}	29.7 ± 3.0	33.7 ± 6.1	10.6 ± 1.9	13.3 ± 2.8
Total Carbon	gkg^{-1}	26.8 ± 3.2	20.4 ± 8.1	12.7 ± 1.2	12.8 ± 0.6
Total Nitrogen	gkg^{-1}	1.6 ± 0.2	1.1 ± 0.5	0.3 ± 0.1	0.2 ± 0.1**
Carbon: Nitrogen		17.3 ± 0.8	18.8 ± 1.1	39.1 ± 10.3	75.3 ± 23.6
CEC[b]	$cmol_ckg^{-1}$	6.7 ± 2.0	8.3 ± 0.5	5.2 ± 1.8	7.5 ± 0.6**
Exch. Ca	$cmol_ckg^{-1}$	0.31 ± 0.07	0.61 ± 0.03*	0.18 ± 0.02	0.44 ± 0.09**
Exch. K	$cmol_ckg^{-1}$	0.26 ± 0.24	0.18 ± 0.03	0.04 ± 0.03	0.08 ± 0.01
Exch. Mg	$cmol_ckg^{-1}$	0.15 ± 0.05	0.19 ± 0.05	0.09 ± 0.07	0.07 ± 0.02
Exch. Al	$cmol_ckg^{-1}$	1.36 ± 0.79	2.54 ± 0.24*	1.62 ± 0.53	3.09 ± 0.28*
Sum of bases	$cmol_ckg^{-1}$	0.83 ± 0.29	1.17 ± 0.11**	0.36 ± 0.13	0.75 ± 0.10*
ECEC[c]	$cmol_ckg^{-1}$	2.18 ± 1.02	3.70 ± 0.33*	2.14 ± 0.59	3.84 ± 0.24*
Base Saturation	%	12.7 ± 4.2	14.1 ± 0.7	7.4 ± 3.2	10.2 ± 2.2
Available P	$mgkg^{-1}$	8.5 ± 1.7	6.4 ± 1.4	2.8 ± 1.5	3.0 ± 0.7
Al Saturation	%	59.4 ± 10.1	68.5 ± 1.9	81.3 ± 5.7	80.4 ± 3.1
Clay	%	9.3 ± 2.8	21.8 ± 5.2**	16.5 ± 4.7	27.9 ± 0.3*
Silt	%	18.5 ± 3.6	10.7 ± 1.3*	16.7 ± 4.0	14.3 ± 1.7
Sand	%	72.2 ± 4.8	67.5 ± 3.9	66.8 ± 5.2	57.8 ± 1.8*
Bulk density	gmL^{-1}	1.03 ± 0.22	1.21 ± 0.17	1.46 ± 0.12	1.46 ± 0.09

Mean ± standard deviation, n: number of plot, [a]EC: Electrical Conductivity, [b]CEC: Cation Exchange Capacity, [c]ECEC: Effective CEC. The symbol * and ** indicate significant differences at $p<0.05$ and $p<0.01$, respectively (t-test).

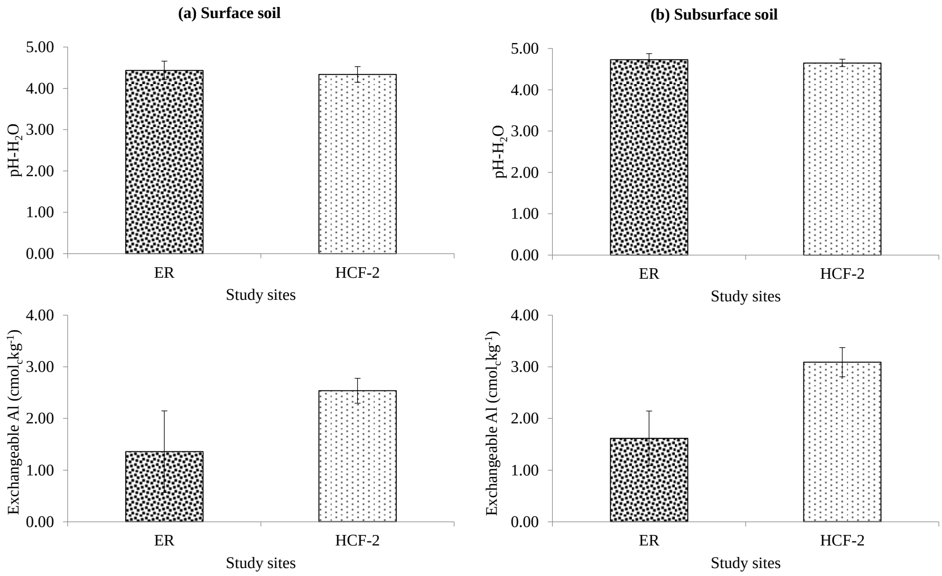


Figure 4.2: Soil pH and Exchangeable Al at the study sites under Grey-White Podzolic soils (ER and HCF-2) at surface and subsurface soil.

Besides, some available nutrients are deficient if the soil pH is below 6.0 (Tan, 2005). Based on the Figure 4.2, pH value for both surface and subsurface soils in the HCF-2 plot were more acidic than those in the ER, which were associated with high exchangeable Al at both surface and subsurface soil. The exchangeable Al at the subsurface soil was significantly higher as compared to surface soil for all study sites. The exchangeable Al at the surface and subsurface soil were ranged from 0.50 $cmol_ckg^{-1}$ to 2.76 $cmol_ckg^{-1}$ and 0.90 $cmol_ckg^{-1}$ to 3.40 $cmol_ckg^{-1}$, respectively. In addition, HCF-2 plot showed significantly higher exchangeable Al at the surface and subsurface soil layer as compared to ER plot. The acidity occurring in the forest soils was due to the presence of Al and H. As reported by Zaidey et al. (2010) that the Al concentrations and organic matter content probably influenced the soil acidity. Moreover, 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. Besides, the acidic nature of the soils, especially in the ER and HCF-1 plots, might due to the loss of exchangeable bases through uptake by plants and leaching in the tropical environment (Juo & Manu, 1996) as well as through volatilization during combustion (Giardina et al., 2000).

Exchangeable Ca at the surface and subsurface soil ranged from 0.24 $cmol_ckg^{-1}$ to 0.63 $cmol_ckg^{-1}$ and 0.15 $cmol_ckg^{-1}$ to 0.54 $cmol_ckg^{-1}$, respectively. Figure 4.3 showed that, exchangeable Ca in plot HCF-2 was significantly higher as compared in ER plot at both surface and subsurface soil. Meanwhile, exchangeable Mg ranged from 0.10 $cmol_ckg^{-1}$ to 0.24 $cmol_ckg^{-1}$ at the surface soil whereas ranged from 0.04 $cmol_ckg^{-1}$ to 0.20 $cmol_ckg^{-1}$ at subsurface soil. The exchangeable Mg in HCF-2 plot was higher as compared to ER plot at the surface soil. However, ER plot showed higher exchangeable Mg as compared to HCF-2 plot at the subsurface soil. The exchangeable K ranged from 0.02 $cmol_ckg^{-1}$ to 0.56 $cmol_ckg^{-1}$ at surface soil and ranged from 0.01 $cmol_ckg^{-1}$ to 0.10 $cmol_ckg^{-1}$ at subsurface soil. The exchangeable K in ER plot recorded the highest at the surface soil and lower at the subsurface soil as compared in HCF-2 plot.

In general surface soil showed the higher exchangeable bases (Ca, Mg and K) as compared to subsurface soil in ER and HCF-2 plots. The study by Perumal et al. (2017a) under Grey-White Podzolic soils (Ultisols) at the reforestation sites also reported the similar result on the exchangeable Ca and Mg at the surface soil was higher as compared to subsurface soil except for exchangeable K. The higher content of exchangeable based in the surface soil is due to the forest litter and dead plant accumulation. The bulk of soil organic matter and nutrients is distributed in a shallow top layer in the humid tropics. In similar manner, plot HCF-2 has thicker O layer that cover with root mat and forest litter as compared in ER plot. Others study also reported that higher content of Ca and Mg in the surface soil was probably associated with biological accumulation from plant and their lower ability in soil (Ohta et al., 1993; Soto & Diazfierros, 1993; Tanaka et al., 1997). Besides, exchangeable K from the decomposition of plant might be dissolved easily and leached out due to soil erosion. In addition, based on Figure 4.3, the soil exchangeable bases in surface and subsurface soils were low compared with the soil exchangeable Al, resulting in a high level of Al saturation both in ER and HCF-2. Soil Al saturation was less than 70% in surface soils and more than 80% in subsurface soils.

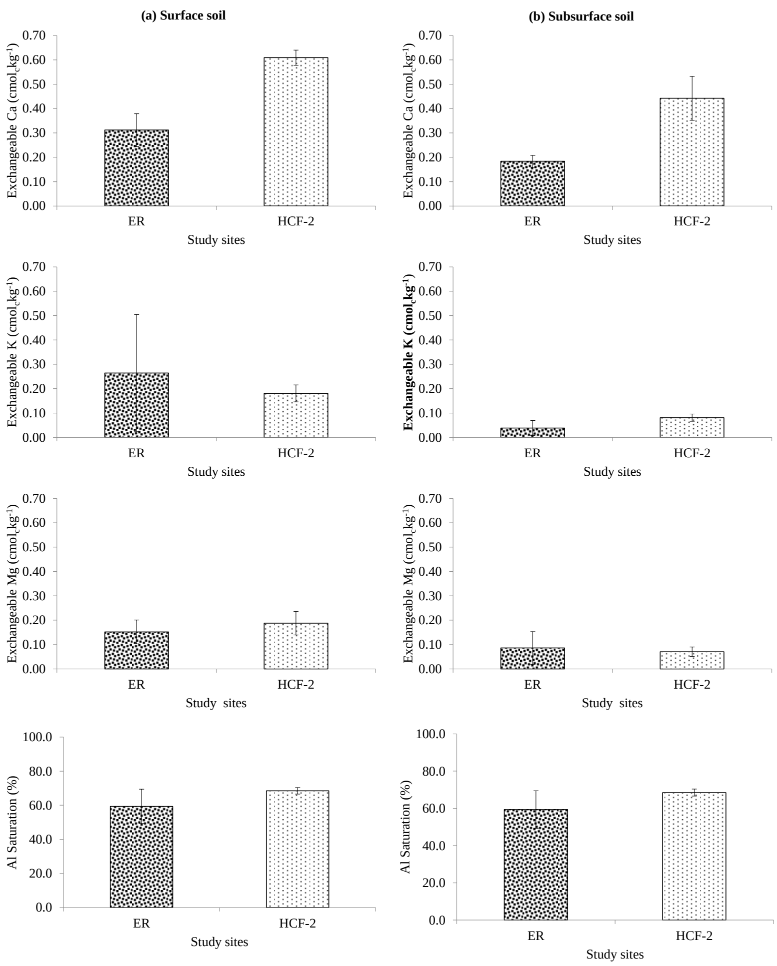


Figure 4.3: Exchangeable bases and Al saturation of the soil at the study sites under Grey-White Podzolic soils (ER and HCF-2) at surface and subsurface soil.

As for the total carbon at the surface soil and subsurface soil were ranged from 13.8 gkg^{-1} to 32.6 gkg^{-1} and 10.7 gkg^{-1} to 13.9 gkg^{-1}, respectively. The total nitrogen at surface soil was ranged from 0.69 gkg^{-1} to 1.94 gkg^{-1} and at the subsurface soil was ranged from 0.1 gkg^{-1} to 0.6 gkg^{-1}. Total carbon and total nitrogen was higher at the surface soil as compared to subsurface soil in the study sites. In addition, total carbon and total nitrogen in ER plot was higher as compared to HCF-2 plot at both surface and subsurface soil (Figure 4.4). The carbon to nitrogen ration at the surface soil was lower as compared to subsurface soil. Generally, soils with high pH usually contain lesser quantities of organic matter because the soil microorganisms become more active as soil acidity decreases (Perumal et al., 2015). In similar manner in this study, soil organic matter in HCF-2 plot was lower and more acidic than soil in ER plot, although the ages of the HCF-2 plot older than ER plot. As mentioned by Carlos et al. (1991) that soil organic matter was restored after 8 years of planting. In addition, Akbar et al. (2010) also reported that organic matter at the early years of planting (before 8 years after planting) has a low accumulation of soil organic matter.

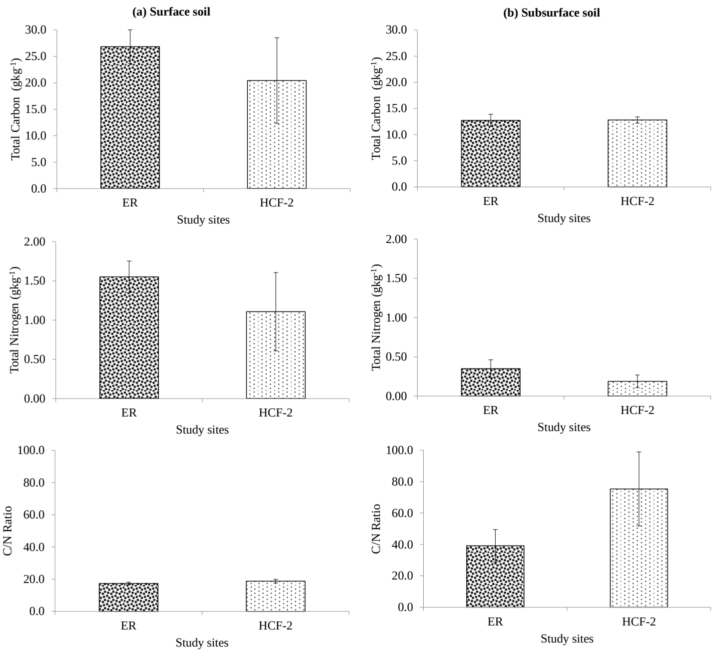


Figure 4.4: Total Carbon (TC), Total Nitrogen (TN), and Carbon:Nitrogen (C:N) ratio of the soil at the study site under Grey-White Podzolic soils (ER and HCF-2) at surface and subsurface soil.

Besides, this was because there was a visible decreased of soil organic matter in the early years and then the pool of soil carbon recovers, reaching the value of typical mature forest (Nadporozhskaya et al., 2006). However, based on Figure 4.4, soil in ER plot (5 years) has higher organic matter as compared to soil in HCF-2 plot.

In term of soil texture, mostly soil at the study sites were relatively sandy ranged from sandy clay loam to loamy sand. The sand content at the both surface and subsurface soil was sandy with more than 55% sand content and followed by clay content was less than 30% and less than 20% for silt content. The sand content in surface and subsurface soil layer in all study sites were 63.1% to 79.9% and 55.9% to 75.2%, respectively, and only subsurface soil showed significant differences for sand content. In addition, the sand content at the surface soil was higher as compared to subsurface soil in the study sites (Figure 4.5). Moreover, the sand content in ER plot was higher than HCF-2 plot at both surface and subsurface soil. Meanwhile, the clay content at the surface and subsurface soil ranged from 5.8% to 27.7% and 7.2% to 28.3%, respectively. The clay content was significantly higher at subsurface soil as compared surface soil in the study sites. Besides, clay content in HCF-2 plot was higher as compared in ER plot at both surface and subsurface soil. According to Soil Survey Staff (1966), soils under Grey-White Podzolic were exhibit increased in clay content with depth. Other study by Hattori et al. (2005) under Ultisols also reported that the clay content in the soil were increased with depth whereas sand content was decreased with increased soil depth. This study was in agreement with the study by Hattori et al. (2005). This could be attributed to the eluviation of clay due to downward movement into the subsurface soil and translocation to the lower part of the slope via rainfall.

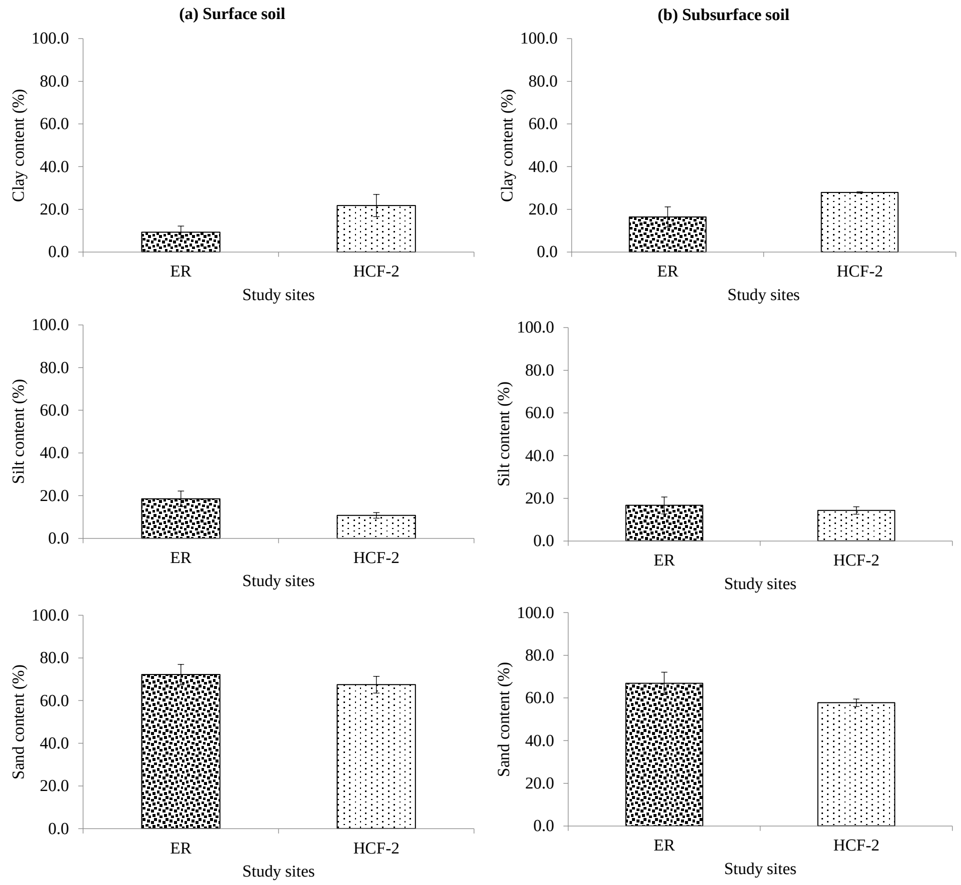


Figure 4.5: Soil texture at the study sites under Grey-White Podzolic soils (ER and HCF-2) at surface and subsurface soil.

Generally, Cation Exchange Capacity (CEC) value was lower for both surface and subsurface soils in ER and HCF-2 plot with value ranged from 4.80 $cmol_ckg^{-1}$ to 9.60 $cmol_ckg^{-1}$ at the surface soil and ranged from 3.00 $cmol_ckg^{-1}$ to 8.00 $cmol_ckg^{-1}$ at subsurface soil. However, the CEC was significantly lower at the subsurface soil as compared to surface soil for both ER and HCF-2 plot. Based on Figure 4.6, CEC in HCF-2 plot were higher as compared in ER plot at both surface and subsurface soil. This could be due to the significant accumulation of clay content at the both surface and subsurface soil of HCF-2 plot as compared to ER plot. Under the naturally acidic soil in tropics, the soil fertility is largely dependent on the negative charge derived from the clay mineral affects the CEC of clayey soils (Ohta et al., 1993; Sakurai et al., 1998; Arifin et al., 2007, 2008; Tanaka et al., 2007, 2009).

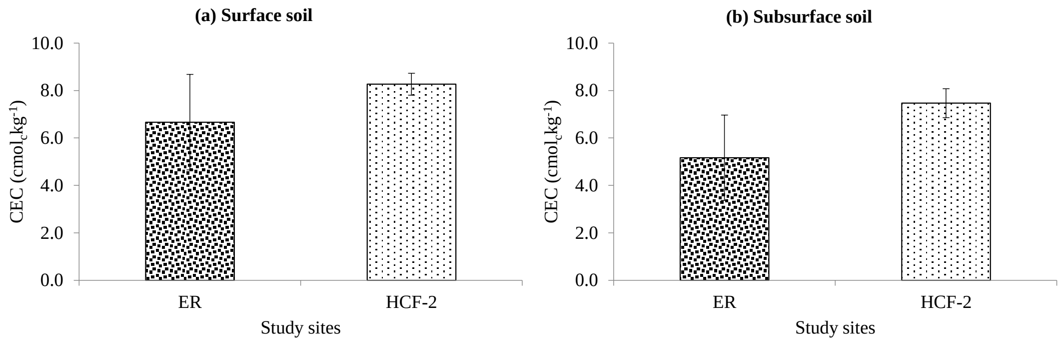


Figure 4.6: CEC value of the soil at the study sites under Grey-White Podzolic soils (ER and HCF-2) at surface and subsurface soil.

In the present study, no correlation was observed between TC and clay contents in both the surface soils and subsurface soils: r = -0.174 and r = -0.054, respectively (data not shown). In addition, based on multiple regression analysis, no correlation between CEC values with either total carbon or clay content (CEC = 0.271 TC + 0.585 Clay, $r^2 = 0.360$) at the surface soil and clay content was found as the dominant contributor of soil CEC with the equation CEC= 0.258 T-C + 0.589 Clay**, $r^2 = 0.782$ at the subsurface soil. 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 ER and HCF-2 plots for total carbon, total nitrogen or clay contents, although the clay content was significantly higher in HCF-2 plot than in ER plot. It is noteworthy that 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). Hattori et al. (2013) mentioned that, due to the relatively high levels of permanent negative charge derived from clay content and inclination that prevent a substantial loss of soil nutrient by leaching.

As for soil bulk density at subsurface soil (ranged from 1.29 gmL^{-1} to 1.58 gmL^{-1}) was higher as compared to surface soil (ranged from 0.71 gmL^{-1} to 1.32 gmL^{-1}) for ER and HCF-2 plot (Figure 4.7). The HCF-2 plot recorded higher soil bulk density at the surface soil as compared to the ER plot (Figure 4.7). As stated by Alexander (1989) that, higher content of organic matter consequently decreased the value of the bulk density of the soil. This is consistent with the ER plot since it had higher content of organic matter than HCF-2 plot.

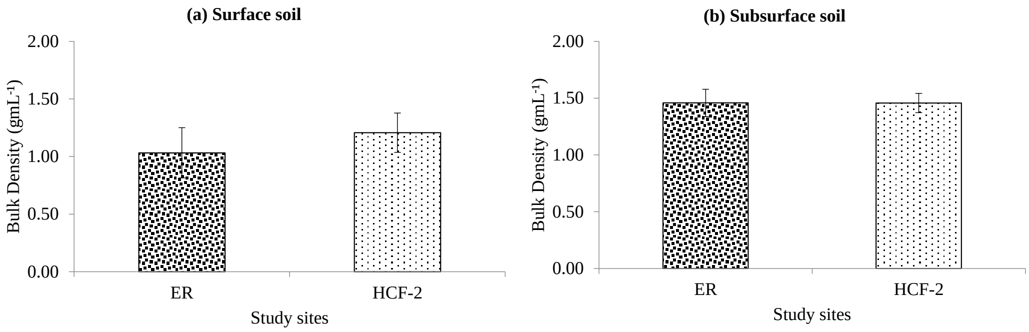


Figure 4.7: Soil bulk density at the study sites under Grey-White Podzolic soils (ER and HCF-2) at surface and subsurface soil.

The value of available phosphorus at surface and subsurface soil ranged from 5.3 $mgkg^{-1}$ to 10.1 $mgkg^{-1}$ and 0.8 $mgkg^{-1}$ to 4.4 $mgkg^{-1}$, respectively. There were no significant difference observed in available phosphorus value at both surface and subsurface soil. Based on the Figure 4.8, showed that available phosphorus was higher at the surface as compared to the subsurface soil in study sites. In addition, as for available phosphorus at the surface soil, HCF-2 plot showed lower available phosphorus as compared in ER plot. However, HCF-2 plot showed higher available phosphorus at the subsurface soil as compared in ER plot. The lower available phosphorus in HCF-2 plot might be due to significant higher accumulation of the clay content in the HCF-2 plot as compared to ER plot. As mentioned by Arifin et al. (2007) that the higher clay content related to a low levels of nutrient especially available phosphorus.

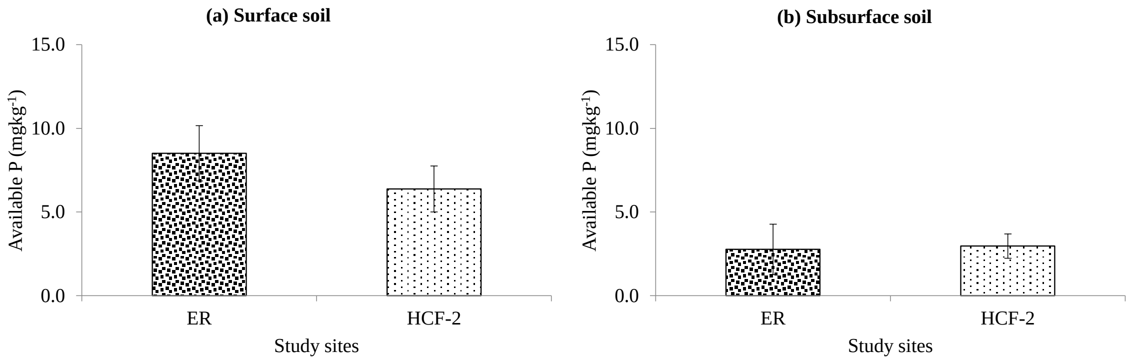


Figure 4.8: Soil available phosphorus at the study sites under Grey-White Podzolic soils (ER and HCF-2) at surface and subsurface soil.

In addition, the concentration of phosphorus in soils also depend on a combination of factors including plant uptake, absorption-desorption and dissolution precipitation of inorganic P, the mineralization of organic P and microbial immobilization and fertilizer addition (Perrot et al., 1990; Frossard et al., 2000). Hence, the composition of forest floor also plays an important role in concentration of phosphorus.

Besides, microbial biomass also plays an important in phosphorus availability. Soil microbes release immobile forms of phosphorus to the soil solution and are responsible for the immobilization of phosphorus (Schachtman et al., 1998). Study conducted by Chen et al. (2003) in improved grassland and 19 years old stand conclude that the recycling of phosphorus was mainly driven by phosphorus demand by plant and sustained by root litter inputs and leaf litter inputs in the forest ecosystems. Besides, seasonal change in environment conditions such as rainfall, soil moisture and temperature also involved in the phosphorus availability. Cross and Schlesinger (1995) found that organic forms are often associated with the availability of soil phosphorus. Tiessen and Coworkers (1984) found that the amount of organic phosphorus determined phosphorus availability in Ultisols. In addition, phosphorus availability in Ultisols soil is often controlled by high absorption capacity of soils minerals and by the tendency of absorbed phosphorus to be occluded in the interior of aluminium (Al) mineral (Sollins et al., 1988; Frossard et al., 1995; Lajtha & Harrison, 1995). Rapid sorption of Phosphorus on the abundant Al mineral in tropical soils precludes its free movement through the soil solution to plant roots (Lawrence & Schlesinger, 2001). 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 Phosphorus is slow, high plant uptake rates create a zone around the root that is depleted of Phosphorus (Schachtman et al., 1998). Based on previous study by Perumal et al. (2017a) under Grey-White Podzolic soils (Ultisols) stated that level of available Phosphorus in the soil influenced the growth performance of planted *S. macrophylla* at the study sites.

4.2.2 Soil physicochemical properties of Spodosols at Late Establishment of Reforestation Site (LR) and High Conservation Forest (HCF-1) (Podzols soil)

The information on the soil physicochemical properties of at Late Establishment of Reforestation Site (LR) and High Conservation Forest (HCF-1) under Podzols soil at 0-10 cm and 30-40 cm soil depth were shown in Table 4.4. Generally, the soils of all study sites were strongly acidic with pH value less than 5 (ranged from 3.96 to 4.62 and 4.23 to 4.77) at both surface and subsurface soil layer, respectively. The value of acidity in the surface soil decreased with depth, resulting higher pH (H_2O) at the subsurface soil. The pH value in LR plot was significantly lower as compared to HCF-1 plot at surface (Figure 4.9). The

Table 4.4: Selected soil physicochemical properties under enrichment planting of Late Establishment of the Reforestation Site (LR) and High Conservation Forest (HCF-1) plots under Podzols soil (Spodosols).

Parameters		LR	HCF-1	LR	HCF-1
		n = 4	n = 3	n = 4	n = 3
		Surface soil: 0-10 cm		Subsurface soil : 30-40cm	
pH-H_2O		4.07 ± 0.13	4.44 ± 0.17**	4.58 ± 0.24	4.58 ± 0.08
EC[a]	μScm^{-1}	40.2 ± 6.1	31.1 ± 6.6	16.9 ± 4.0	14.2 ± 1.4
Total Carbon	gkg^{-1}	21.7 ± 5.5	17.2 ± 3.4	10.8 ± 4.1	8.2 ± 2.4
Total Nitrogen	gkg^{-1}	0.8 ± 0.3	0.7 ± 0.1	0.3 ± 0.2	0.3 ± 0.1
Carbon: Nitrogen		30.2 ± 13.2	23.6 ± 6.3	49.5 ± 31.2	34.9 ± 17.5
CEC[b]	$cmol_ckg^{-1}$	4.4 ± 0.8	3.8 ± 0.2	1.9 ± 0.5	2.3 ± 0.8
Exch. Ca	$cmol_ckg^{-1}$	0.54 ± 0.13	0.7 ± 0.15	0.60 ± 0.13	0.52 ± 0.03
Exch. K	$cmol_ckg^{-1}$	0.04 ± 0.01	0.06 ± 0.04	0.01 ± 0.01	0.04 ± 0.01**
Exch. Mg	$cmol_ckg^{-1}$	0.17 ± 0.09	0.18 ± 0.08	0.10 ± 0.01	0.07 ± 0.04
Exch. Al	$cmol_ckg^{-1}$	0.46 ± 0.18	0.49 ± 0.26	0.55 ± 0.18	0.60 ± 0.46
Sum of bases	$cmol_ckg^{-1}$	0.85 ± 0.25	1.09 ± 0.28	0.87 ± 0.18	0.80 ± 0.12
ECEC[c]	$cmol_ckg^{-1}$	1.30 ± 0.31	1.59 ± 0.24	1.42 ± 0.05	1.41 ± 0.43
Base Saturation	%	19.4 ± 3.1	28.7 ± 6.1**	49.7 ± 19.4	37.1 ± 11.8
Available P	$mgkg^{-1}$	7.1 ± 0.8	5.4 ± 1.9	3.6 ± 1.9	2.3 ± 1.6
Al Saturation	%	34.6 ± 10.3	30.9 ± 14.2	38.8 ± 13.0	39.5 ± 17.8
Clay	%	7.2 ± 2.7	5.4 ± 1.6	9.4 ± 3.8	8.7 ± 5.0
Silt	%	11.1 ± 0.8	9.9 ± 2.2	9.7 ± 1.9	8.3 ± 2.1
Sand	%	81.6 ± 2.4	84.8 ± 3.5	80.9 ± 3.9	83.0 ± 6.2
Bulk Density	gmL^{-1}	1.31 ± 0.11	1.17 ± 0.16	1.48 ± 0.09	1.47 ± 0.15

Mean ± standard deviation: n: number of plot, [a]EC: Electrical Conductivity, [b]CEC: Cation Exchange Capacity, [c]ECEC: Effective CEC. The symbol * and ** indicate significant differences at p<0.05 and p<0.01, respectively (t-test).

exchangeable Al at the subsurface soil was higher as compared to surface soil for all study sites. The exchangeable Al at the surface and subsurface soil were ranged from 0.28 $cmol_c kg^{-1}$ to 0.79 $cmol_c kg^{-1}$ and 0.30 $cmol_c kg^{-1}$ to 1.10 $cmol_c kg^{-1}$, respectively. In addition, exchangeable Al was higher at surface soil than subsurface soil. Besides, exchangeable Al in HCF-1 plot was higher as compared to LR plot at both surface and subsurface soil. Mackinnon et al. (1996) mentioned that sandy soil mainly Spodosols were very acid and too poor for plant. The range of pH values of this study recorded (3.96 to 4.77) were consistent with those from other Bornean heath forests (Anderson et al., 1983; Proctor et al., 1983; Dent et al., 2006; Haji, 2015; Kerfahi et al., 2019) and Amazonia caatinga (Anderson, 1981: Coomes & Grubb, 1996). The strong acidity in LR plot was due to the slow decomposition in the litter layer (Katagiri et al., 1991). Proctor (1999) stated that extreme pH is more likely to be a major proximal cause of the distinctive white sand in the heath forest ecosystem.

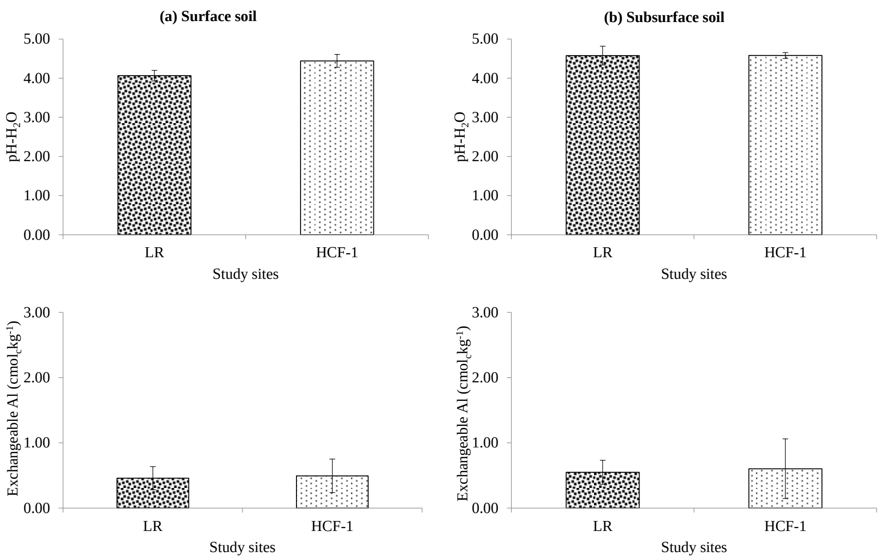


Figure 4.9: Soil pH and Exchangeable Al at the study sites under Podzols soil (LR and HCF-1) at surface and subsurface soil.

In addition, based on Figure 4.10, exchangeable bases (Ca, Mg and K) at the surface soil were higher as compared to the subsurface soil throughout the study sites except for exchangeable Ca in LR plot. At the surface soil, LR plot showed lower exchangeable Ca as compared to the subsurface soil. The exchangeable Ca at the surface and subsurface soil were ranged from 0.42 $cmol_c kg^{-1}$ to 0.87 $cmol_c kg^{-1}$ and 0.48 $cmol_c kg^{-1}$ to 0.67 $cmol_c kg^{-1}$, respectively. The exchangeable Mg was ranged from 0.06 $cmol_c kg^{-1}$ to 0.27 $cmol_c kg^{-1}$ at the surface soil and 0.09 $cmol_c kg^{-1}$ to 0.11 $cmol_c kg^{-1}$ at the subsurface soil. The value of the exchangeable K at the surface and subsurface soil were ranged from 0.04 $cmol_c kg^{-1}$ to 0.47 $cmol_c kg^{-1}$ and up to 0.06 $cmol_c kg^{-1}$. At the surface soil, HCF-1 plot showed higher exchangeable bases as compared to soil exchangeable bases in LR plot. However, at the subsurface, soil in LR plot showed higher exchangeable base as compared to HCF-1, excepted for exchangeable K. The exchangeable K was higher in HCF-1 plot at both surface and subsurface soil than LR plot. These results might be due to higher leaching rates caused by high sand content in the study sites (> 80%).

Recent study by Hattori et al. (2019) documented that the value of CEC and most nutrient contents, including Ca, Mg, and P were decreased between 7 and 14 years after the abandonment of shifting cultivation in a degraded tropical forest on sandy soils. The nutrient supplement provided by the ash was more rapidly leached away from sandy soil than from clayey soil. These concluded that larger quantities of silt and clay are required for nutrient retention (Kendawang et al., 2004, 2005; Tanaka et al., 2004, 2005). The estimated leaching rate of total amount of exchangeable bases that is the sum of exchangeable concentration of Ca, Mg and K, in the sandy soil was twice as large as in clayey soil (Tanaka et al., 2004; Tan, 2010; Hattori et al., 2019). In clay rich soils, decreases in nutrient content are mainly due to uptake by fast growing trees and accumulation in above ground biomass (Sanchez, 1976; Jordan, 1985; Fujiki et al., 2017).

However, in the sandy soil condition, soil nutrient decreased might be due to soil erosion as sandy soil has lower nutrient retention capacity. Most of the exchangeable K added by decomposition of litter fall and ash may leach out during the initial period after the abandonment. In similar manner by the study by Katagiri et al. (1991), the concentration of nutrient element decreased with soil depth, especially those of carbon, nitrogen, exchangeable Ca and Mg. Exchangeable K^+ is a monovalent cations with greater mobility than divalent cations such Mg^{2+} and Ca^{2+} (Christanty, 1986; Andriesse & Schelhaas, 1987; Thomaz et al., 2014). Exchangeable K in study sites was lower than Exchangeable Mg and Ca, which could be ascribed to leaching loss of K due to lower selectivity of the variable negative charges derived from soil organic matter for

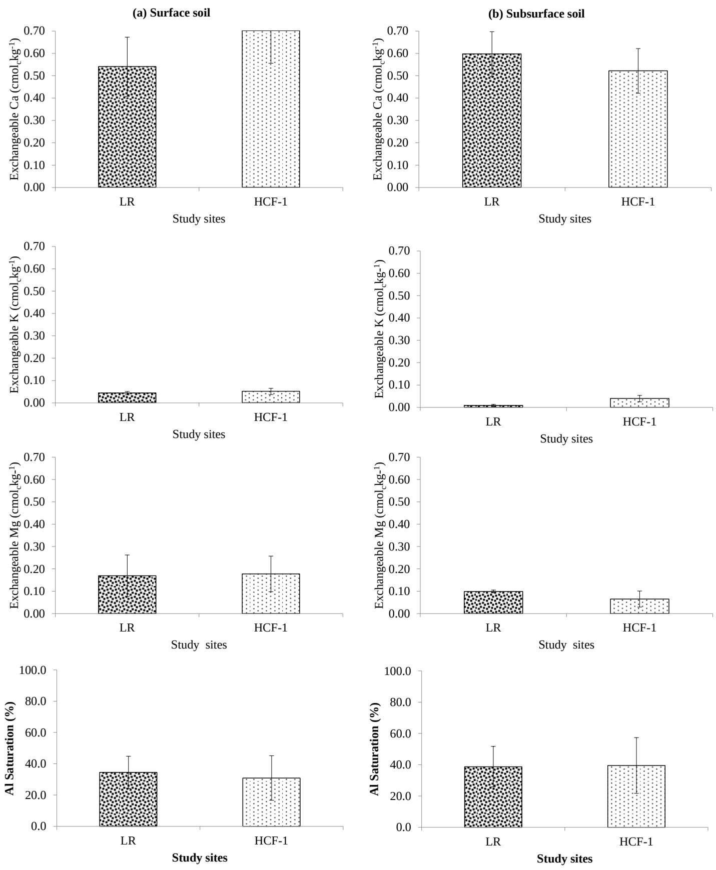


Figure 4.10: Exchangeable bases and Al saturation of the soil at the study sites under Podzols soil (LR and HCF-1) at surface and subsurface soil.

monovalent cations rather than divalent cations as well as less development of the charges under acidic conditions. In turn, relatively high contents of K in the surface soils of the forest might suggest that accumulation of K from leaf litter through a biochemical cycling between plants and soils. At the surface soil, exchangeable bases in the study sites were higher as compared to subsurface soil. Jordan (1985) suggested that the low nutrient in subsurface soil were absorbed by the roots concentrated in the surface soil in the study site. According to Figure 4.10, the soil exchangeable bases in surface and subsurface soils were high compared with the soil exchangeable Al, resulting in a low level of Al saturation both in LR and HCF-1 plots. Soil Al saturation at the study sites were no exceeded 40% at the both surface and subsurface soil.

The total carbon at the surface soil and subsurface soil were ranged from 15.2 gkg^{-1} to 28.6 gkg^{-1} and 6.6 gkg^{-1} to 15.6 gkg^{-1}, respectively. The total nitrogen at the surface soil (ranged from 0.42 gkg^{-1} to 1.11 gkg^{-1}) was higher than subsurface soil (ranged from 0.1 gkg^{-1} to 0.6 gkg^{-1}). In general, total carbon and total nitrogen at the surface soil were higher as compared to subsurface soil at the study sites (Figure 4.11). In addition, total carbon and total nitrogen as well as carbon to nitrogen ratio in LR plot were higher as compared to HCF-1 at both surface and subsurface soil. However, the carbon to nitrogen ration at the surface soil was lower as compared to subsurface soil for both studies site (LR and HCF-1 plot). Total nitrogen in the study sites was lower than total carbon. Low levels of N and P on sandy soil were similarly recorded in another study at Borneo and Amazonia (Anderson, 1981; Proctor et al., 1981; Cueves & Medina, 1988; Marrs et al., 1988; Coomes & Grubb, 1996; Moran et al., 2000; Luizao et al., 2007; Wong et al., 2015).

Besides, this study also on the same agreement with the study by Katagiri et al. (1991) under Spodosols whereby nutrient element especially carbon and nitrogen of the heath forest soils were concentrated in the surface soil. Based on study by the Katagiri et al. (1991), the carbon concentration was proportional with nitrogen concentration and the carbon content of the surface soil was higher than the nitrogen content. This also dependent on the roles of mycorrhiza and tree root which were distributed in the soil. Walter (1971) indicated that the roots act as a filter, absorbing the nutrient from the mineralization of organic matter and allowing humus colloids to pass by in the tropics.

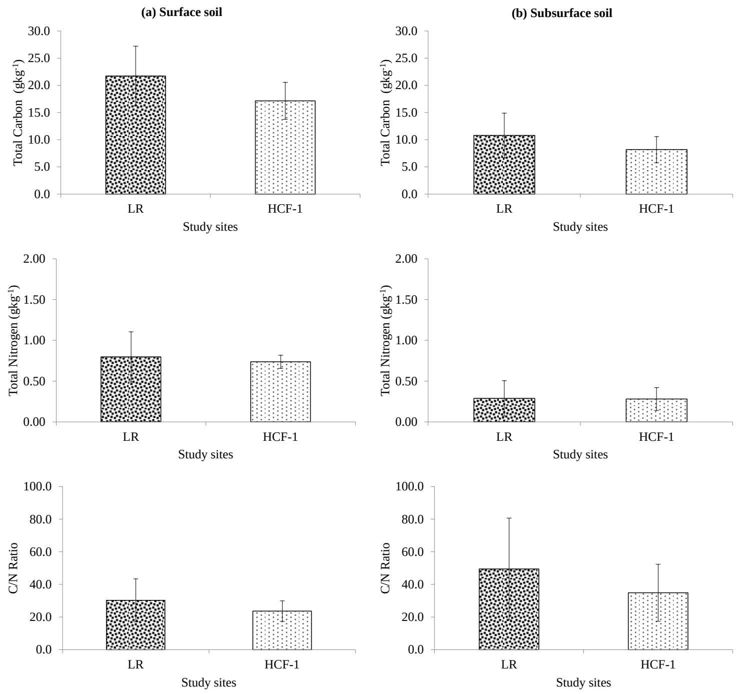


Figure 4.11: Total Carbon (TC), Total Nitrogen (TN), and Carbon:Nitrogen (C:N) ratio of the soil at the study sites under Podzols soil (LR and HCF-1) at surface and subsurface soil.

As for the soil texture, mostly soil at the study sites where relatively sandy with more than 80% sand content (Figure 4.12). The sand content in surface and subsurface soil layer in the study sites were 79.2% to 87.6% and 75.7% to 87.3%, respectively. The sand content for HCF-1 plot was higher as compared to LR plot at both surface and subsurface soil. Meanwhile, the clay content in surface and subsurface soil ranged from 3.6% to 10.7% and 4.1% to 14.5%, respectively. Based on Figure 4.12, clay content in LR plot were higher as compared to HCF-1 plot for both surface and subsurface soil. The value of silt content at surface and subsurface soil ranged from 8.4 % to 12.4% and 6.1% to 12.2%, respectively. The silt content at the surface soil was higher than subsurface soil and LR plot showed the highest silt content for both surface and subsurface soil.

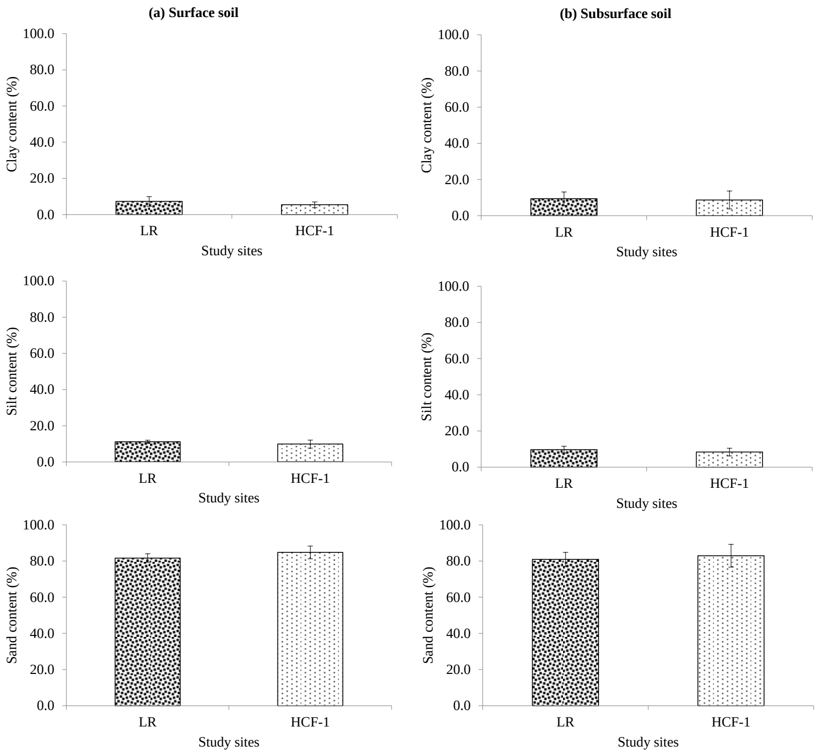


Figure 4.12: Soil texture at the study sites under Podzols soil (LR and HCF-1) at surface and subsurface soil.

Besides, Cation Exchange Capacity (CEC) value was low for both surface and subsurface soils throughout the LR and HCF-1 plot (Figure 4.13). The CEC value of the study sites were ranged from 3.40 $cmol_c kg^{-1}$ to 5.40 $cmol_c kg^{-1}$ at the surface soil and ranged from 1.40 $cmol_c kg^{-1}$ to 3.20 $cmol_c kg^{-1}$ at subsurface soils. The CEC value in LR plot was higher as compared to HCF-1 plot at the surface soil and lower at the subsurface soil.

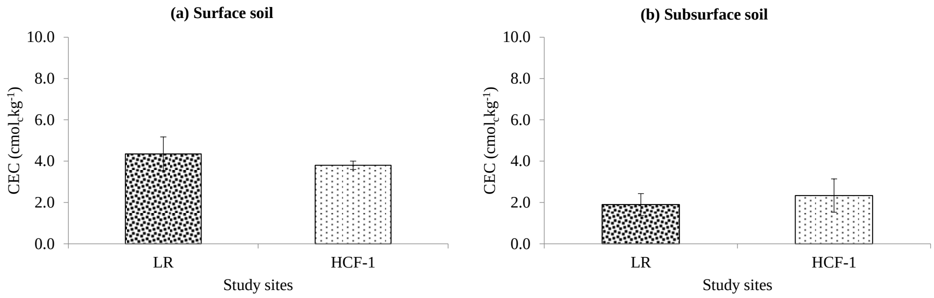


Figure 4.13: CEC value of the soil at the study sites under Podzols soil (LR and HCF-1) at surface and subsurface soil.

In the present study, no correlation was observed between TC and clay contents in the surface soils r = -0.421, respectively (data not shown). However, correlation was observed between TC and clay contents in the subsurface soils r = 0.681* ($p > 0.05$), respectively (data not shown). They are ascribable to organic matter stabilization of soils by formation of stable organo-mineral complexes (Ohta et al., 2000; Tanaka et al., 2007). However, based on multiple regression analysis result, no correlation between CEC value with both clay content and total carbon in the surface soil (CEC = 0.594 TC + 0.066 Clay (r^2 = 0.420)) and in the subsurface soil (CEC= -0.479 TC + 1.009 Clay (r^2 = 0.443)). These indicate that the soil in the study sites were extremely sandy and lower cation retention capacity. As stated by Katagiri et al. (1991), sandstone parent material and low clay content influenced the poor nutrient retention in sandy-textured soils as nutrient were easily leached from all layer of the soil. Katagiri et al. (1991) also reported that the amount of nutrients was very low under sandy soils of heath forests resulted from the low supply of organic matter returned by litterfall and the rapid decomposition caused by high temperature. Thus, the dissolved nutrients were stored within the thick litterfall (O horizon) and root mat layer before the nutrients were leached into the spodic E horizon (Kendawang et al., 2004). Such a condition, therefore, explained the low availability of nutrients and acidic properties of soils under LR and HCF-1 plots.

According to Syuhada et al. (2014), the accumulated thick layer of litterfall contributed to the formation of organic acids through microbial decomposition. Moreover, the presence of organic acids is likely to enhance the weathering of silicates and minerals to release cations (Syuhada et al., 2014) for the uptake of the standing vegetation. Hattori et al. (2019) further reported that the removal and destruction of the thick layer of litterfall and root mat may accelerate the leaching process of nutrients and limiting the recovery of the secondary forest under sandy-textured soils. Under LR plot, the previous forest disturbance influence the development of the root mats and slightly thin O horizon as compared to HCF-1 plot. In LR plot, root mat accumulate at the surface soil and only penetrate up to 21 cm soil depth as compared to root mat in HCF-1 plot that could penetrate up to 52 cm. The past disturbance such as fire that occurs at the start of shifting cultivation destroy the surface litter layer and root mat and take time to recover, which accelerates nutrient loss and in turn limits the tree growth in degraded forests on sandy soil (Brunig, 2016).

Total C and Total N are typically higher in unburned "*Kerangas"* forest (Kendawang et al., 2004) because thick root mats cover the infertile sandy soil and help to retain nutrient. However, in this study, total carbon and total nitrogen in HCF-1 plot was lower as compared to LR plot. This might be due to the organic leached out or absorbed by existing tree species in the study site. In general, thick root mats in tropical forests growing on infertile sandy soils can sequester 99% of the dissolved nutrient available in the soil before they leach down to the mineral layer (Stark & Jordan, 1978). Therefore, the destruction of those soil layer by fire may accelerate nutrient leaching, further limiting the recovery of secondary forest trees in the site. Browne (1952) reported a very high regrowth rate of trees even after forest disturbance by clear cutting without soil surface disturbance in *Kerangas* forest on sandy soil in Sarawak.

The bulk density at subsurface soil (ranged from 1.40 gmL^{-1} to 1.57 gmL^{-1}) was higher as compared to surface soil (ranged from 0.99 gmL^{-1} to 1.45 gmL^{-1}) in LR and HCF-1 plots. In general soil bulk density at both surface and subsurface soil for LR plot was higher as compared to HCF-1 plot (Figure 4.14). However, LR plot has higher soil bulk density although it has slightly low sand content than HCF-1 since the reforestation site has a fewer plant with less root. As stated by Akbar et al. (2010) that root elongation increase soil porosity. Besides, the pore in the soils develops due to the penetration of roots, worms and other forms of soil life.

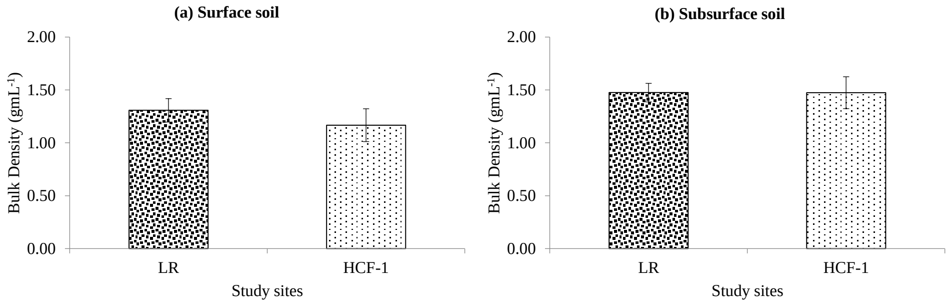


Figure 4.14: Soil bulk density at the study sites under Podzols soil (LR and HCF-1) at surface and subsurface soil.

The available phosphorus value was presented in Table 4.4 and Figure 4.15 at both surface and subsurface soil. The value of available P in surface soil and subsurface soil were ranged from 4.1 $mgkg^{-1}$ to 7.7 $mgkg^{-1}$ and 1.0 $mgkg^{-1}$ to 6.4 $mgkg^{-1}$, respectively. There were no significant differences observed in available phosphorus value at both surface and subsurface soil in LR and HCF-1 plots. However, soil in LR plot showed higher value of available phosphorus as compared to HCF-1 plot at both surface and subsurface soil. Hattori et al. (2019) documented that available phosphorus in the soil decreased significantly over time after 14 years land abandonment due to higher leaching rates caused by high sand content (approximately 71%), relatively steep slopes (approximately 23º) and large amount of precipitation (approximately 2900 mm $year^{-1}$). The decreased of available phosphorus also might be due to the lower CEC in the soil to retain nutrient such as available phosphorus. In addition, nutrient supplement from the decompose litterfall also more rapidly leached away from sandy soil than from clayey soil.

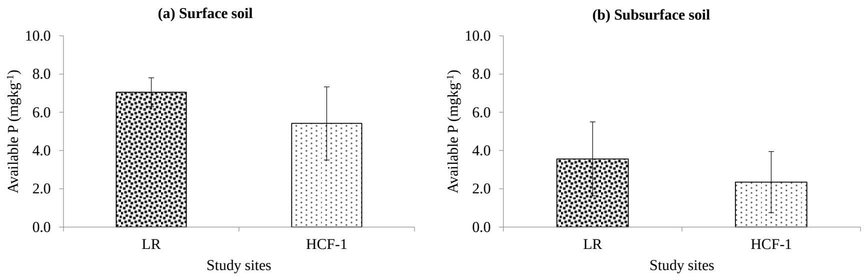


Figure 4.15: Soil available phosphorus at the study sites under Podzols soil (LR and HCF-1) at surface and subsurface soil.

4.3 Suitability, adaptability and growth performance of planted *Shorea macrophylla* under sandy textured at the reforestation sites

The preliminary assessment on the growth performance of the planted dipterocarp species, especially *Shorea macrophylla* under sandy textured of the degraded forest is important information and required the recommendation for the future reforestation activities especially planted on sandy soil. Therefore, it is important to clarify and find out the information on the suitability of planted *S. macrophylla* under sandy textured soil as one of the appropriate species for the future reforestation and rehabilitation purpose in Sarawak. In the present study, finding on this studies with previous studies in Malaysia on experimental reforestation efforts to rehabilitate degraded lands by using indigenous dipterocarp tree species under enrichment planting techniques were compared as shown in Table 4.5.

In the current study, the survival percentage of the planted *S. macrophylla* in ER plot under Ultisols was 65% with the 0.48 $myear^{-1}$ of mean annual increment of height (MAIH) and 0.35 $cmyear^{-1}$ of mean annual increment of diameter at breast height (MAID). Meanwhile, the survival percentage of the planted *S. macrophylla* in LR plot under Spodosols was 56% with 0.50 $myear^{-1}$ of MAIH and 0.82 $cmyear^{-1}$ of MAID. In addition, study by Perumal et al. (2017b) documented that the survival percentage of planted *S. macrophylla* were ranged from 57% to 88% with 0.51 myear^{-1} to 0.65 myear^{-1} of MAIH and 0.44 cmyear^{-1} to 0.82 cmyear^{-1} of MAID. Both studies were conducted under limitation condition such as sandy soil (Sabal Forest Reserve) and sandy soil and annually flooding (Sampadi Forest Reserve). Although these studies were conducted under sandy soil, the planted *S. macrophylla* still survive under such condition.

Table 4.5: The growth rate of planted *S. macrophylla* in the present studies and previous study at reforestation site in Malaysia.

Species	Plot	Age stands (Years)	Planting technique	Survival (%)	MAIH (myear^{-1})	MAID (cmyear^{-1})	Soil order	Sources
S. macrophylla	ER	5	LP	65	0.48	0.35	Ultisols	Present study
S. macrophylla	LR	20	LP	56	0.50	0.82	Spodosols	Present study
S. macrophylla	SM99	15	LP	57	0.58	0.44	Ultisols	Perumal et al. 2017
S. macrophylla	SM98	16	LP	82	0.52	0.44	Ultisols	Perumal et al. 2017
S. macrophylla	SM97	17	LP	80	0.51	0.55	Ultisols	Perumal et al. 2017
S. macrophylla	SM96	18	LP	88	0.65	0.82	Ultisols	Perumal et al. 2017

Abbreviations; SM99: *S. macrophylla* planted in the year 1999 at Sampadi Forest Reserve, SM98: *S. macrophylla* planted in the year 1998 at Sampadi Forest Reserve, SM97: *S. macrophylla* planted in the year 1997 at Sampadi Forest Reserve, SM96: *S. macrophylla* planted in the year 1996 at Sampadi Forest Reserve, *Planting technique: LP, Line Planting.

Based on the results of this study, sandy soil showed low cation retention capacity due to low clay content especially soil under Spodosols. In addition, a previous study by Turner et al. (2000) found that a high sand content and low water retention capacity in the forest soils led to brief periods of severe soil-water deficit, which in turn limited plant growth. Johnson et al. (2000) also reported that moisture holding capacity (represent by soil texture) was the principle independent factor influencing above ground biomass accumulation in most post-disturbance secondary forests worldwide. The study conducted by Tanaka et al. (2014) at Sabal Forest Reserve reported that infertile sandy soil in Sabal influence the shortness of trees. The severe disturbance by fire that occurs at the start of shifting cultivation destroys the surface litter layer and root mat, which accelerates nutrient loss and in turn limit trees regrowth in degraded forests on sandy soil (Brunig, 2016).

However, based on the survival percentage result of planted *S. macrophylla* at the reforestation sites which were more than 50% for the soil under Ultisols and Spodosols, it can be conclude that *S. macrophylla* were suitable dipterocarp species to be planted under sandy soil. Although Vincent and Davies (2003) reported that in most studies, planting of dipterocarp tree species in logged and degraded forests has recorded significantly higher mortality In addition, based on the previous study by Perumal et al. (2017b) under Grey-White Podzolic soils of Ultisols soil, the planted *S. macrophylla* in plot SM99 still can withstand in poor soil conditions (over 50% sand content) and annual flooding with 57% survival percentage in SM99 plot after 15 years rehabilitated.

Besides sandy soil, competition between the existing pioneer species, light intensity, soil fertility, mineral nutrients and water holding capacity as well as topographical feature also contributed to the growth performance of the planted *S. macrophylla* at the study sites. According to Perumal et al. (2017b), the high density of pioneer species in plot SM99 could be assumed to be another reason why most of the growth performance of planted of *S. macrophylla* in SM99 was poor. Based on the *in-situ* observation, study sites were surrounded by varies type of pioneer tree species that growing between the planting line. In the ER plot, several existing pioneer species were higher than planted *S. macrophylla*. Therefore, the planted *S. macrophylla* in ER plot may have acclimated to compete with the existing pioneer trees species for light, minerals and water. However, those pioneer species can provided the shade for the planted *S. macrophylla* in the ER plot as *S. macrophylla* is well known as shade tolerant species at seedling stage.

As stated by Perumal et al. (2017b) that competition between *S. macrophylla* and pioneer tree species in the SM99 plot for sunlight significantly affected the mortality rates in which, had a large impact on the growth performance of planted *S. macrophylla*. However, dipterocarp species shows relatively slow growth rate but it is adapting well to sufficient amount of sunlight when planted in the land with poor soil properties (Appanah & Weinland, 1993; Adjers et al., 1996; Vincent & Davies, 2003). Based on the previous study by Hattori et al. (2013), it has been reported that high light intensity reduced seedling survival for both 0-24 months and 24-81 months of planted dipterocarp forest species. Moreover, other study also mentioned that, effect of the extreme heat, strong winds and overexposure of the light to the planted seedling caused scorching of the leaves, resulting in a low percentage of survival According to (Suhaili et al., 1998; Arifin et al., 2008; Hamzah et al., 2009). The light conditions are determined by the complex spatial structure and dynamics of the multi-layer canopy (Bebber et al., 2002; Bunyavejchewin et al., 2003; Okuda et al., 2003). Therefore, planting line technique that has been practice in the planting of *S. macrophylla* in the study was suitable practice as enables undisturbed pioneer species which has grown naturally before establishment of planting lines to provide shades for the planted seedlings to reduce over exposure to sunlight. Adjers et al. (1995) reported that line planting technique is suitable to be adapted for reforestation activities under homogenous secondary forests or fallow forests after shifting cultivation where stratification of canopy layers has not been fully developed. In addition, enrichment planting using sapling of primary forest trees is generally deemed effective for the rehabilitation of degraded secondary forests (Hattori et al., 2009; Atondo-Bueno et al., 2018). It is because, primary forest trees are usually intolerant of strong sunlight and achieved limited growth on infertile soils (Irino et al., 2004, 2005; Yoneda et al., 2005; Kenzo et al., 2007, 2011; Lamb, 2010).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In conclusion, based on the assessment and information on the soil texture, soil colour, soil structure, soil consistency and the presence of spodic horizon, soil morphological properties at the study sites were distinguished. The findings of this study indicated that soils in the Early Establishment of Reforestation site (ER) and High Conservation Forest-2 (HCF-2) were classified under Grey-White Podzolic soils which derived from the combination of sandstone, coarse-grained, humult ultisols and sandy residual parent material. According to the Sarawak Soil Classification, the morphological properties in the ER and HCF-2 plots resemble of Saratok series in which, corresponds to Typic Paleaquults of Ultisols soil of Soil Taxonomy by USDA Soil Taxonomy. The soils in ER and HCF-2 were characterized under Saratok series whereby the soil colour ranged from yellowish brown (10YR5/3) to brownish yellow (10YR6/6). The existence of contrasting soil texture between 40 cm soil depth (sandy loam to sandy clay loam) with weak to strong sub-angular blocky was found on the soil profiles. As for the soil at Late Establishment of the reforestation Site (LR) and High Conservation Forest (HCF-1) were classified under Buso series which corresponds to Podzols soil according to Sarawak Soil Classification System. Podzols group under Sarawak Soil Classification are tentatively correlated with Typic Haplothods of Spodosols under USDA Soil Taxonomy. The main characteristic that categorized the soil in LR and HCF-1 plot under Spodosols were due to the presence of the spodic horizon as well as the soil texture which ranged from sandy loam to loamy sand with very dark in soil colour. In addition, the structure of the soil were grouped from weak to moderate of sub-angular blocky structure with no consistency as the soil was extremely sandy.

In terms of the soil physicochemical properties, generally the soils at both reforestation sites (ER and LR) and High Conservation Forest (HCF-1 and HCF-2) in Sabal Forest Reserve were strongly acidic in nature with pH (H_2O) value less than 5.00 at both surface and subsurface soils. In the present study, the soils under Grey-White Podzolic was sandy with less than 73% of sand content at both surface and subsurface soils. Meanwhile, soil under Podzols was extremely sandy with more than 80% of sand content at both surface and subsurface soils. Besides, soil under Grey-White Podzolic and Podzols have poor cation retention capacity due to the low clay content.

In spite of the soil at the reforestation sites (ER and LR) being strongly acidic with more than 55 % sand content and poor cation retention capacity due to low clay contents, the planted *S. macrophylla* still able to tolerate well under such condition with a higher percentage of the survival in the reforestation sites. In this study, the survival percentage of the planted *S. macrophylla* in ER and LR plots were 65% and 56%, respectively. Based on the survival percentage of planted *S. macrophylla* in this study, it can be concluded that the reforestation activity by planting *S. macrophylla* under sandy soils was a success although under certain limitations with poor nutrient content in the soil. Besides, other factors such as planting techniques also might influence the success of the planted *S. macrophylla* in the reforestation sites. It is known that *S. macrophylla* are shade tolerant species and therefore extreme sunlight exposure can cause scorching of leaves and further damage of the planted *S. macrophylla* during the initial seedling stage. Silvicultural treatment such as weeding on the planting lines are also important especially during the initial seedling stage as to decrease the competitions between the existing pioneer species with the planted trees.

However, further detailed assessment and studies were required to implement the reforestation activities under the sandy soil texture in the future. Therefore, based on this study, it is suggested that further study on the vegetation survey especially under reforestation sites should be performed as to get detail information on the species distribution on the reforestation site and the high conservation forest under the same soil condition. Nonetheless, long-term monitoring on the soil as well as growth performance of the planted *S. macrophylla* in the planting site are required as to draw up a dipterocarp planting scheme for rehabilitation purpose.

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APPENDIX

List of Indexed Proceedings:

1. Che Adanan, I., Wasli, M.W., Perumal, M., & Ho, S.Y. (2016). Soil under Enrichment Planting Assessing Soil Properties at Reforestation Sites of Sabal Forest Reserve. In: Jusoh, I., Ipor, I., Puad, A.S.A. & Hassan, R. (eds.), *Proceedings of Regional Taxonomy and Ecology Conference*, 1-2 December 2015. Faculty of Resources Science and Technology, Universiti Malaysia Sarawak, Sarawak, Malaysia, (pp. 411-419).
2. Che Adanan, I., Wasli, M.W., Perumal, M., Ho, S.Y., & Sahat, M.S. (2016). Characterizing soil morphological properties at forest rehabilitation sites in Sabal Forest Reserve, Sarawak. In: Arshad, A.M., Haruna, A.O., Abdullah, R., Ishak, C.F., Sung, C.T.B., Vijayanathan, J., & Sembok, W.Z.W. (eds.), *Proceeding of Soil Science Conference of Malaysia: Soil Improvement for Sustainable Crop Production*, 5-7 April 2016. Malaysian Society of Soil Science and Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, (pp. 321-325).

List of Journal:

1. Che Adanan, I., Wasli, M.E., Perumal, M. & Ho, S.Y. (2020). Characterization of soil properties in relation to Shorea macrophylla growth performance under sandy soils at Sabal Forest Reserve, Sarawak, Malaysia. *Biodiversitas Journal of Biological Diversity, 21*, 1004.