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REHABILITATION OF DEGRADED PEAT SWAMP FOREST IN RAJA MUSA FOREST RESERVE, SELANGOR, MALAYSIA

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By

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THIS MSC. THESIS IS SPECIALLY DEDICATED TO

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Chairman: Prof. Dato' Nik Muhamad Ab. Majid, Ph.D

Faculty: Forestry

Data from the Third National Forest Inventory shows there are about 0.23 million ha of logged-over peat swamp forests (PSF) in Peninsular Malaysia. It is important to improve the productivity of these areas by planting commercial tree species in order to sustain its role as an important source of high quality timber species. The main objectives of this study are to determine appropriate planting technique and identify suitable timber species to rehabilitate highly degraded PSF. Field planting that represents the core of the study was conducted in Compartment 101, Raja Musa Forest Reserve, Selangor, Malaysia. The area was classified as highly degraded PSF and occupied mostly by weeds especially *Imperata cylindrica*. Four different planting techniques were tested, namely open planting, open planting with mulching, open planting with topsoil and open planting with nurse tree. Six indigenous PSF species were used, namely *Anisoptera marginata*, *Calophyllum ferrugineum*, *Durio carinatus*, *Ganua motleyana*, *Gonystylus bancanus* and *Shorea platycarpa*. Light intensity and foliar analysis were also measured. Light intensity was measured in the nursery to examine the response of the same species used in the field planting to different light intensities. Meanwhile, foliar analysis was conducted to compare the nutrient status of the seedlings among the four different planting techniques.

Open planting was found to be the best technique in rehabilitating highly degraded PSF. The technique produced the highest survival rate of 83.33 percent, lowest planting cost and easiest method. Foliar analysis indicated no significant differences in macronutrient status of seedlings among the different planting techniques. This indicates that the different planting techniques did not affect nutrient uptake by the planted seedlings. Out of six species used in the study, *G. motleyana*, *S. platycarpa*, *A. marginata* and *G. bancanus* with survival rate of 92.19 percent, 79.69 percent, 79.17 percent and 73.44 percent respectively were found to be suitable for rehabilitating degraded PSF. However, based on the availability of seeds and wildings, *G. bancanus* is found to be the best species for rehabilitating the degraded PSF.

Total cost of the field planting in an area of 1.55 ha is about RM 15,929.20. The total costs incurred constitute wages for workers/labours, transportation and materials used for planting and plot maintenance with RM 6,336.00, RM 7,043.20 and RM 2,550.00 or 40 percent, 44 percent and 16

percent out of the total cost, respectively. It is recommended that the Forestry Department carry out rehabilitation program in the degraded PSF. Permanent nursery to raise planting materials of PSF species should be established to support the rehabilitation program. Forest fire can be a major threat to degraded PSF particularly in areas dominated by grass. Therefore, it is also recommended that studies to determine the best prevention and control measures of forest fire in the PSF be conducted.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia bagi memenuhi keperluan untuk ijazah Master Sains.

PEMULIHARAAN HUTAN PAYA GAMBUT TERNYAH-GRED DI HUTAN SIMPAN RAJA MUSA, SELANGOR, MALAYSIA

Oleh

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Data hasil dari Inventori Hutan Kebangsaan Ke-3 menunjukkan terdapat lebih kurang 0.23 juta ha hutan paya gambut (HPG) yang telah dibalak di Semenanjung Malaysia. Adalah amat penting untuk meningkatkan produktiviti kawasan-kawasan hutan tersebut dengan menjalankan penanaman spesis pokok komersial bagi mengekalkan peranannya sebagai sumber untuk mendapatkan kayu-kayan. Objektif utama kajian ini adalah untuk mendapatkan teknik dan mengenalpasti spesis pokok yang sesuai bagi pemuliharaan kawasan-kawasan HPG yang ternyah-gred peringkat paling serius. Tanaman di lapangan yang merupakan komponen terpenting dalam kajian ini telah dijalankan di Kompatmen 101, Hutan Simpan Raja Musa, Selangor, Malaysia. Kawasan berkenaan dikategorikan sebagai HPG ternyah-gred peringkat paling serius dan didominasi oleh rumput-rampai terutamanya *Imperata cylindrica*. Empat teknik tanaman telah diujikaji iaitu tanaman terbuka, tanaman terbuka dengan sungkupan, tanaman terbuka dengan tanah atas dan tanaman terbuka dengan pokok teduhan. Enam

spesis asal HPG telah digunakan iaitu *Anisoptera marginata*, *Calophyllum ferrugineum*, *Durio carinatus*, *Ganua motleyana*, *Gonystylus bancanus* dan *Shorea platycarpa*. Data-data berkenaan intensiti cahaya dan analisa daun juga telah turut diambil. Kajian intensiti cahaya telah dijalankan di tapak semaian bertujuan bagi mengetahui tindakbalas spesis-spesis sama jenis seperti yang digunakan pada tanaman di lapangan kepada intensiti cahaya yang berbeza. Manakala, analisa daun dijalankan bagi membandingkan status pengambilan nutrien oleh anak benih yang ditanam dengan menggunakan teknik-teknik yang berbeza.

Tanaman terbuka telah didapati sebagai teknik terbaik bagi digunakan untuk memulihara HPG ternyah-gred peringkat paling serius. Teknik tanaman terbuka tersebut memberikan keputusan kehidupan anak benih sebanyak 83.33 peratus, kos menanam paling rendah dan merupakan kaedah tanaman yang paling mudah berbanding dengan teknik-teknik yang lain. Tambahan pula, analisa daun menunjukkan tiada perbezaan ketara status pengambilan nutrien-nutrien utama oleh anak benih-anak benih yang ditanam dengan menggunakan teknik-teknik yang berbeza. Ini bermakna, teknik tanaman yang berlainan tidak mempengaruhi pengambilan nutrien oleh anak benih yang ditanam. Manakala itu, daripada enam spesis yang telah digunakan, *G. motleyana*, *S. platycarpa*, *A. marginata* dan *G. bancanus* dengan kehidupan 92.19 peratus, 79.69 peratus, 79.17 peratus dan 73.44 peratus didapati sesuai untuk digunakan bagi program pemuliharaan kawasan HPG ternyah-gred peringkat paling serius. Namun demikian berdasarkan kepada keadaan semasa terutamanya dari segi bekalan anak benih, *G. bancanus* merupakan spesis yang paling sesuai digunakan bagi tujuan penanaman di kawasan HPG ternyah-gred.

Kos keseluruhan bagi tanaman di lapangan yang melibatkan kawasan seluas 1.55 ha adalah lebih kurang RM 15,929.20. Ia melibatkan kos upah, pengangkutan dan bahan tanaman serta penyelenggaraan plot selepas tanaman iaitu lebih kurang sebanyak RM 6,336.00, RM 7,043.20 dan RM 2,550.00 ataupun 40 peratus, 44 peratus dan 16 peratus dari kos keseluruhan tersebut. Adalah disarankan agar pihak jabatan perhutanan menjalankan program pemuliharaan di HPG yang ternyah-gred. Tapak semaian tetap bagi tujuan penyediaan anak benih tanaman spesis HPG harus diujudkan bagi menyokong usaha-usaha pemuliharaan tersebut. Kebakaran hutan boleh menjadi ancaman paling utama kepada HPG ternyah-gred terutamanya kawasan-kawasan yang didominasi oleh *I. cylindrica*. Oleh itu, adalah turut disarankan agar kajian yang mendalam dijalankan untuk mendapatkan kaedah sesuai bagi mencegah dan mengawal kebakaran di HPG.

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I certify that an Examination Committee met on 25th October 2001 to conduct the final examination of Ismail Bin Hj. Parlan on his Master Science thesis entitled "Rehabilitation of Degraded Peat Swamp Forest in Raja Musa Forest Reserve, Selangor, Malaysia" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

ISMAIL BIN HJ. PARLAN

Date: 5 NOV 2001

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LIST OF ABBREVIATIONS

A. marginata	:	*Anisoptera marginata*
a.s.l.	:	Above sea level
ANOVA	:	Analysis of variance
BDI	:	Basal diameter increment
C. ferrugineum	:	*Calophyllum ferrugineum*
D. carinatus	:	*Durio carinatus*
dbh	:	Diameter at breast height
EFB	:	Empty fruit bunches
FR	:	Forest reserve
G. bancanus	:	*Gonystylus bancanus*
G. motleyana	:	*Ganua motleyana*
PSF	:	Peat swamp forests
RLI	:	Relative light intensity
S. platycarpa	:	*Shorea platycarpa*
THI	:	Total height increment

CHAPTER ONE

INTRODUCTION

1.1 Forestry in Peninsular Malaysia

1.1.1 Forest Resources

In general, forest has three main basic roles; providing social-cultural, economic and environmental services. In terms of socio-cultural services, the rural communities living in or near forest area, depend mainly on the forests for their living. The economic contribution of forests is well recognised, as it provides important raw materials to the wood-based industries. Timber products are traded not only in domestic but also in international markets that help to generate income for economic development of the country.

Environmental services of the forest are not easily translated into financial values. Although they are intangibles, the roles of the forests in watershed protection, conservation of soil and water resources, conservation of genetic resources and support for agriculture and other land use have long been recognised (Ministry of Primary Industries Malaysia, 1989).

Peninsular Malaysia is very fortunate because it is well endowed with relatively large tracts of rich and diverse tropical rain forests that have been acknowledged to be amongst the most complex terrestrial ecosystems in the world. Peninsular Malaysia also has one of the richest floras in the world, containing 1,500 genera and more than 7,900 species of flowering plants (Ministry of Primary Industries Malaysia, 1989).

From the Third National Forest Inventory, out of the total land area of about 13.16 million ha, 5.84 million ha or 44.4 percent is still under forest in Peninsular Malaysia (Chin *et al.*, 1997). Of the 5.84 million ha, 4.73 million ha are under the Permanent Forest Estate (PFE) and the remaining is stateland forest, wildlife reserve and others (Table 1). Out of the 4.73 million ha under PFE, 2.83 million ha and 1.90 million ha are classified as production and protection forests, respectively (Chin *et al.*, 1997).

Table 1: Forest resources of Peninsular Malaysia

Forest category	Area (Ha)
Permanent reserve forest	4,730,216
Stateland forest	478,409
Wildlife reserve	611,692
Others	18,543
Total	5,838,860

Source: Chin *et al.* (1997)

1.1.2 Forest Types

Foxworthy (1927) as cited in Wyatt-Smith (1963), classified forest types in Peninsular Malaysia into three broad groups; littoral, lowland and mountain or hill forests where each is further subdivided into a number of sub-groups. These subgroups are as follows:

i) Littoral forests	(a) Beach forests
	(b) Mangrove swamps
ii) Lowland forests	(a) Fresh water swamp forest
	(b) Seasonal swamp forest
	(c) Secondary forest
	(d) High forest (up to 600 m above sea level (a.s.l.))
iii) Hill forests	(a) Mid mountain forests (above 600 a.s.l.)
	(b) High mountain forests
	(c) Ridge forests

A classification of forest types was further refined by Wyatt-Smith (1963) who classified forests in Peninsular Malaysia into six main groups and fifteen subgroups. Among the main groups, Lowland Evergreen Rainforest is the most extensive. According to Wan Razali (1994) as cited in Shamsudin (1997), the Upper, Hill and Lowland Dipterocarp Forests that fall under the group of Lowland Evergreen Rainforests constitute the major subgroups in Peninsular Malaysia as they cover approximately 87 percent of the total forested areas in Peninsular Malaysia. Lowland, Hill and Upper Dipterocarp Forests cover areas with altitudinal limit of <300 m, 300 m - <700 m and ≥700 m - <1,200 m a.s.l., respectively.

Peat swamp forest (PSF), mangrove, freshwater alluvial swamp and riparian forests on the other hand are grouped under Swamp and low-lying Forests. Generally, PSF covers areas at altitudes from sea level to about 50 m a.s.l. (Faizal and Looi, 1999).

1.1.3 Forest Management and Conservation

PFEs are permanent reserves and they will, under existing legislation be managed on a sustainable basis for protection, production, amenity, research and education purposes. These uses must be managed sustainably in accordance with general principles of sustainability that are ecologically viable and commercially feasible. The management of these forests is clearly stated in the National Forestry Policy, which was formulated and approved by National Forestry Council and later endorsed by the National Land Council in 1978.

In Peninsular Malaysia, the productive inland forest under the PFE is managed under the Selective Management System (SMS). Before SMS, the Malayan Uniform System (MUS) was used since 1950's (Wan Mohd. Shukri, 1997). The MUS consists of removing the mature crop in one single felling of all trees down to 45 cm diameter at breast height (dbh) (Wan Mohd. Shukri, 1997).

MUS has been successfully applied to the Lowland Dipterocarp Forest, but later found to be unsuitable in the Hill Dipterocarp Forest (Wyatt-Smith, 1963). Consequently, the SMS which entails the selection of optimum felling regimes based on pre-felling forest inventory data was introduced in 1978 (Wan Mohd. Shukri, 1997). In practice, under the SMS the next cut is expected in 30 years after the first logging with an expected net economic out turn of 30 – 40 m^3 ha^{-1} (Wan Mohd. Shukri, 1997). According to Cedergren and Shamsudin (1999) the SMS is also applicable in managing PSF in Peninsular Malaysia.

Meanwhile the forests which are classified as protection forest are used as water catchment, flood control and conservation purposes. Out of 1.90 million ha allocated as protection forest, approximately 0.74 million ha or 12.7 percent of the total forested land has been designated for the conservation of biological diversity such as national parks, wildlife reserves and bird sanctuaries (Ministry of Primary Industries Malaysia, 1999).

1.2 Justifications of the Study

Many researches on forest rehabilitation have been carried out throughout Peninsular Malaysia (Ang *et al.*, 1992; Abd. Rahman *et al.*, 1992; Paudyal and Nik Muhamad, 1992; Nik Muhamad *et al.,* 1994). Among the degraded areas in logged-over forests where research has been conducted are temporary decking sites, skid trails and road shoulders (Wan Razali and Ang, 1992).

Open and line planting are the most common techniques used in rehabilitating logged-over forests (Ang *et al.*, 1992; Thang and Zulkefli, 1992; Suhaili, 1996; Ismail, 1998). Rehabilitation using open planting technique is normally concentrated in open spaces such as temporary decking sites and road shoulder whereas line planting is used to stock poor secondary forests. Various studies on planting of indigenous timber species in logged-over areas using open and line planting techniques have been reported by Thang and Zulkifli (1992), Ang *et al.* (1992), Abdul Rahman *et al.* (1992) and Suhaili (1996).

Chin *et al.* (1997) estimated that in 1992 there were about 0.23 million ha of logged-over PSF in Peninsular Malaysia. There is no report about how much is considered as degraded areas. However, Woon and Mohd. Parid (1999) reported that more than 30 percent of logged-over PSF in North Selangor is classified as highly degraded areas (Table 2).

Table 2: Degradation classification of PSF in North Selangor

Class	Description	Rehabilitation measures	Ha
I	**Highly disturbed PSF**: cleared land/burnt area - trees are generally cleared and the areas are dominated by grass (especially *Imperata cylindrica* or Lalang) and recently logged-over forest with no big trees and low residual vegetation.	Replanting and enrichment planting	22,213
II	**Moderately disturbed PSF**: some pole-sized trees as well as regeneration, but with very poor distribution and thick under-growth.	Enrichment planting and liberation thinning	23,954
III	**Less disturbed PSF**: unlogged or selectively logged. Good residual stand with regeneration, but poor in commercial species.	Liberation thinning	18,823
IV	**Undisturbed/intact PSF**: unlogged areas.	Virgin forest reserve	7,826
		Total	72,816

Sources:

Shamsudin *et al.* (1997); Anon (1997a); Woon and Mohd. Parid (1999)

The highly disturbed areas are not only poor in stocking but also susceptible to forest fire. Woon and Mohd. Parid (1999) estimated the stumpage value of undisturbed and less disturbed PSF to be at RM 15,765 ha^{-1} and RM 10,510 ha^{-1}, respectively whereas the highly and moderately disturbed PSF have no stumpage value at all. It is important to improve the productivity of these areas by planting with commercial tree species, in order to sustain its role as an important source of high quality timber species as well as protecting the environment. Other wise these areas will be colonised by secondary non-commercial species especially *Macaranga spp.* and *Imperata cylindrica*.

Unfortunately, information on appropriate planting techniques, suitability of species for planting and the supply of planting materials are not available for PSF particularly in Peninsular Malaysia. It was observed that not much work has been done to rehabilitate degraded PSF and even existing reports showed that rehabilitation has never been conducted in this forest type in the past (Wan Yusoff and Abdul Rahman, 1997; Ismail, 1998).

It has never been customary in the past to carry out post-felling treatments including planting in logged-over PSF (Shamsudin and Aziah, 1992). This is mainly due to the fact that most logging activities in PSF was concentrated in areas demarcated for alienation to various agricultural projects and other land uses. After all commercial timber species have been harvested, the area will be cleared and burnt prior to cultivation of agricultural crops such as oil palm and rubber trees. With the current development where many PSF areas under PFE have been logged and the realisation that these areas need to be rehabilitated after logging (Razani and Jalil, 1997), research to examine appropriate planting techniques using suitable commercial tree species in logged-over PSF need to be conducted.

Normal planting techniques applied in rehabilitating inland forests (lowland or hill forests) cannot be adopted directly due to vast differences in environmental conditions between inland forests and PSF. PSF is a unique environment where hydrological parameters are critical in controlling tree growth, besides soil productivity and light conditions. A major difference in planting in these two forest types is the timing of planting.

In inland forests, planting is conducted during the rainy seasons but it is not possible in PSF because generally during this time the PSF is completely flooded. Besides planting techniques, the choice of suitable species for rehabilitating degraded PSF also need to be further investigated. The ability to produce sufficient planting materials through seed and various propagation techniques, for example via stem cutting and tissue culture are regarded as important considerations in selecting suitable timber species for rehabilitating degraded PSF.

1.3 Objectives of the Study

The main objectives of this study are to:-

i) determine appropriate rehabilitation techniques, and

ii) evaluate performance of selected species for rehabilitating degraded PSF.

The main study (field planting) was conducted at Compartment 101, Raja Musa Forest Reserve (FR), Selangor between 1999 to 2000.

CHAPTER TWO

LITERATURE REVIEW

2.1 Peat Swamp Forests in Peninsular Malaysia

2.1.1 Occurrences and Formation

Peat swamp forests (PSF) occur behind the coastal line along both the west and east coasts of Peninsular Malaysia. The PSF on the east and west coasts developed on different sedimentary deposits. The peat along the west coast was formed over clay and it has been protected from strong waves by a strip of mangrove vegetation. In the east coast on the other hand, the peat developed over sand and is exposed directly to the South China Sea (Wyatt-Smith, 1959).

According to Coulter (1950) as cited in Wyatt-Smith (1963), peat is defined as organic soils that are at least a half metre in depth, one hectare in extent and with a mineral matter content not exceeding 35 percent in peat (parent organic material) and 65 percent in muck (organic residues derived from peat acted on by soil forming processes). The high water table in peat areas creates anaerobic conditions, which lead to the accumulation of undecomposed or semi-decomposed organic matter. Morphological characteristics, physical and chemical properties of peat in Peninsular Malaysia have been described by Mutalib *et al.* (1992).

Peatland has a dome shaped structure in which peat layers are greater at the centre than at the edges. According to Coulter *et al.* (1956), the dome-shape may be due to the high acidity that may have accelerated the accumulation of organic matter at the centre. The dome is a less distinct morphological feature for peatland in Peninsular Malaysia (Shamsudin, 1997), but this characteristic is pronounced in Sarawak with peat depth at the centre of about 12 - 13 m (Tie and Esterle, 1992). Zulkifli e*t al.* (1999) reported that the peat in Sungai Karang FR varies in depth between 1.2 m to 7.0 m where the centre was found to be deeper than the edges.

The thickness of peat varies between a few centimetres to more than 10 m and in general the PSF in Peninsular Malaysia is classified as having greater than 5 cm thick (Mutalib *et al*., 1992). In general, peat in its natural state is considered infertile and acidic (pH between 3 – 5) and has poor plant nutrient reserve (Vimala, 1979). It is therefore crucial for any species selected for planting in the PSF to be able to adapt to acidic and low soil fertility conditions.

2.1.2 Characteristics

Wyatt-Smith (1963) classified the profile of PSF as having three-layered vertical structure. The structure varies depending on the depth of the peat and distance from the dry lands. Pioneer species such as *Macaranga spp.* dominates the open area and also areas near to the dry lands (Wyatt-Smith, 1959; Chan, 1990).

Wyatt-Smith (1959) described PSF as having the upper layer as a broken emergent layer that often exceeds 30 m in height and frequently represented by scattered commercial timber species such *as Gonystylus bancanus, Durio carinatus* and *Koompassia malaccensis*. The middle layer reaches a height of about 27 m to 30 m and is frequently very open and discontinuous, while the understorey reaches a height of 9 m to 18 m from the forest floor. The understorey is fairly thick with *Licuala spp.* and *Pandanus spp*. form dense thickets of stemless palms in areas where there are stagnant water.

Generally, species diversity of the PSF is lower than in the lowland dipterocarp forests (Appanah *et al*. 1999). Wyatt-Smith (1963) reported 232 tree species of ≥10 cm dbh in a coastal lowland dipterocarp forest at Sungai Menyala FR, while in a similar study, Appanah *et al*. (1989) found only 84 species of ≥10 cm dbh in the PSF. Generally the majority of the PSF species are endemic to swampy habitat except for *Koompassia malaccensis* which can be found in all forest types (Wyatt-Smith, 1963). There are some differences in the floristic composition between PSF of the east and west coasts of Peninsular Malaysia. *Durio carinatus* is found only in the east coast while *Shorea uliginosa*, *Shorea teysmaniana* and *Palaquium ridleyi* are found only in the west coast (Shamsudin, 1996a). Trees with buttresses, spreading roots, stilt roots, pneumatophores and knee roots are common characteristics in the PSF.

2.1.3 Functions

In Peninsular Malaysia PSF has contributed significantly towards economic development and environmental protection. Economic benefits include the production of valuable timber species which has been estimated to be about 63 m^3ha^{-1} for all trees >40 cm dbh (Shamsudin, 1996a). The most common commercial timber species found in PSF are *Gonystylus bancanus*, *Shorea platycarpa*, *Shorea uliginosa*, *Shorea teysmaniana*, *Kompassia malaccensis*, *Durio carinatus, Ganua motleyana* and *Calophyllum ferrugenium.* Many tree species in PSF that reach >40 cm dbh form potential species for log production.

About 28 percent of the total timber production from primary PSF are represented by species from the medium hardwood group and 72 percent from the light hardwood group (Shamsudin, 1996a). *Gonystylus bancanus*, *Shorea platycarpa* and *Durio carinatus* are the major timber species that constitute approximately 65 percent of the total timber production in the light hardwood group (Shamsudin, 1996a).

PSF produces not only high quality timber species but also a variety of important minor forests produce (Lim *et al.,* 1999). *Eleiodoxa conferta* "Asam kelubi" is a typical minor forest produce that is commercially harvested from PSF and the price of the fruits was about RM 6/kg in 1997 (Lim *et al.,* 1999). Other popular minor forest produce that can be harvested from PSF includes rattan, medicinal plants and honey from wild bees. Five different rattan species have been identified in primary PSF at Pekan, Pahang but they are of inferior quality and not commercially harvested (Shamsudin and Hall, 1992). However, these rattan species provide useful materials for making fish traps and other important household products. Many plants and herbs from PSF are also popular for their medicinal properties (Noor Azlin, 1990).

PSF also act as an important catchment regulating water supply for rice cultivation. An excellent example is paddy plantation extending about 20,000 ha at Tanjung Karang, Kuala Selangor that receives continuous water supply from adjacent PSF through the Tengi and Dusun Rivers. According to Zulkifli *et al.* (1999) the supply of water to the paddy areas from the PSF started since 1936. The problem of low pH can easily be overcome by diluting with freshwater from the river.

The role of PSF to control floods has also been recognised (Zulkifli *et al.,* 1999). During the monsoon season, excess water from the river is diverted through feeder canals to PSF to minimise the risk of flooding to agricultural or residential areas downstream. The diverted excess water has no adverse effect on the ecosystem (Andriesse, 1988).

PSF also can be used as an eco-tourism attraction but efforts of using the forest for eco-tourism activities have not been fully developed (Woon and Mohd. Parid, 1999). Using PSF for eco-tourism activities will minimize the pressure of managing PSF only for the timber production. Although this ecosystem has great potential for eco-tourism, facilities such as access roads and other infrastructures should be improved in order to attract visitors.

2.2 Extent of Peat Swamp Forest in Malaysia

2.2.1 Peninsular Malaysia

Shamsudin and Ismail (1991) estimated about 673,740 ha of PSF in Peninsular Malaysia in 1981 and the acreage decreased to 336,994 ha in 1991 (Table 3). It was observed that PSF had been converted to other land use such as agricultural, industrial and residential areas. A good example is the development of the Kuala Lumpur International Airport that involved a substantial area of the North Kuala Langat PSF (Appanah, 1997). As a result of rapid rate of conversion to other land use, the extent of PSF in stateland suffered a tremendous reduction from 451,000 ha in 1981 to only 126,000 ha in 1991 (Shamsudin and Ismail, 1991).

The total extent of PSF under permanent forest estate (PFE) was estimated about 222,436 ha and 210,395 ha in 1981 and 1991, respectively. From 1981 to 1991 about 12,041 ha of PSF under PFE were degazetted and developed for non-forestry purposes. From 1981 to 1991, the total conversion rate of PSF including PSF in stateland to other land uses was approximately 33,670 ha $year^{-1}$. This indicates that the total extent of peat soil area under PSF has decreasing over the past ten years (1981 – 1991). The extent of PSF under PFE need to be increased since the total area remaining in 1991 including the stateland area is only about 336,994 ha. It was observed that some degraded stateland PSFs can be reconstituted into

PFE but comprehensive rehabilitation programmes need to be implemented in order to improve their productivity (Shamsudin, 1997).

Table 3: Extent of PSF in Peninsular Malaysia between 1981 - 1991

State	1981		1991	
	PFE	Stateland	PFE	Stateland
Selangor	75,232	33,888	76,134	13,683
Perak	-	47,377	-	-
Johor	35,855	78,745	33,747	20,670
Pahang	86,677	282,870	75,842	89,574
Terengganu	24,672	8,424	24,672	2,672
Total	222,436	451,304	210,395	126,599

Source: Shamsudin and Ismail (1991)

The majority of PSF in Peninsular Malaysia is scattered and occurs mainly in Pahang and Selangor. A Working Group on Malaysian Wetlands (Anon., 1987) identified three major areas of the PSF in Peninsular Malaysia (Figure 1). The areas are:

i) PSF in Northern Selangor (Sungai Karang and Raja Musa FRs also known as North Selangor PSF),

ii) PSF in Southern Selangor (South Kuala Langat and North Kuala Langat FRs), and

iii) continuous block of PSF on the east coast of Peninsular Malaysia extending from Pekan to Endau in Pahang (known as South-East PSF).

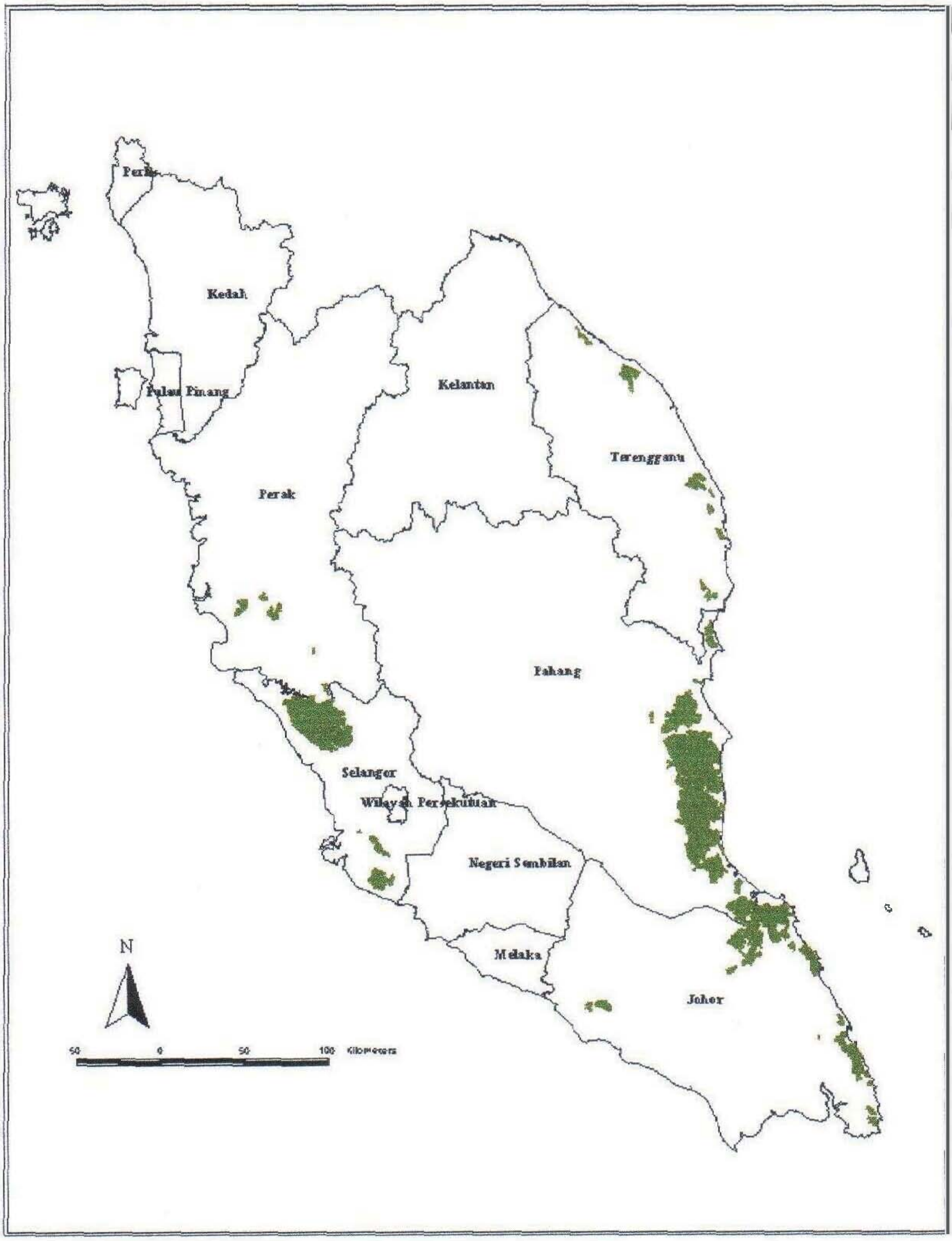

Figure 1: Distribution of PSF in Peninsular Malaysia (Anon., 1987)

2.2.2 Sabah and Sarawak

PSF in Sabah is less extensive and the extent is not known (Shamsudin, 1997). The extent of peat soils in Sabah has been estimated at about 86,000 ha (Figure 2) but not all peat soils are covered by forest as some areas have been cleared and cultivated with agricultural crops (Mutalib *et al.,* 1992). There is no recent estimate of PSF in Sabah but according to Anon. (1981) as cited in Shamsudin (1997) there was about 65,000 ha of PSF in Sabah as of 1980.

However, Sarawak has the largest area of PSF in Malaysia at about 1.7 million ha or 13 percent of the total land area of the state (Abdul Halim, 1994). PSF in Sarawak occupies an extensive area of the lower interfluvial basin, bordered on seaward side by sandy ridges or muddy flats and on the landward side by undulating terrain (Figure 2).

Forestry Department of Sarawak grouped the PSF into five distinct types for management purposes (Francis, 1997). Mixed Swamp Forest occurs on the outer rim followed by Alan Batu Forest, Alan Bunga Forest, Padang Alan Forest and Padang Paya Forest. Mixed Swamp Forest is the most extensive forest subtype and covers approximately 80 percent of the total extent of PSF. From 1970 to 1984, approximately 8,000 ha of Mixed Swamp Forest have been logged annually (Francis, 1997).

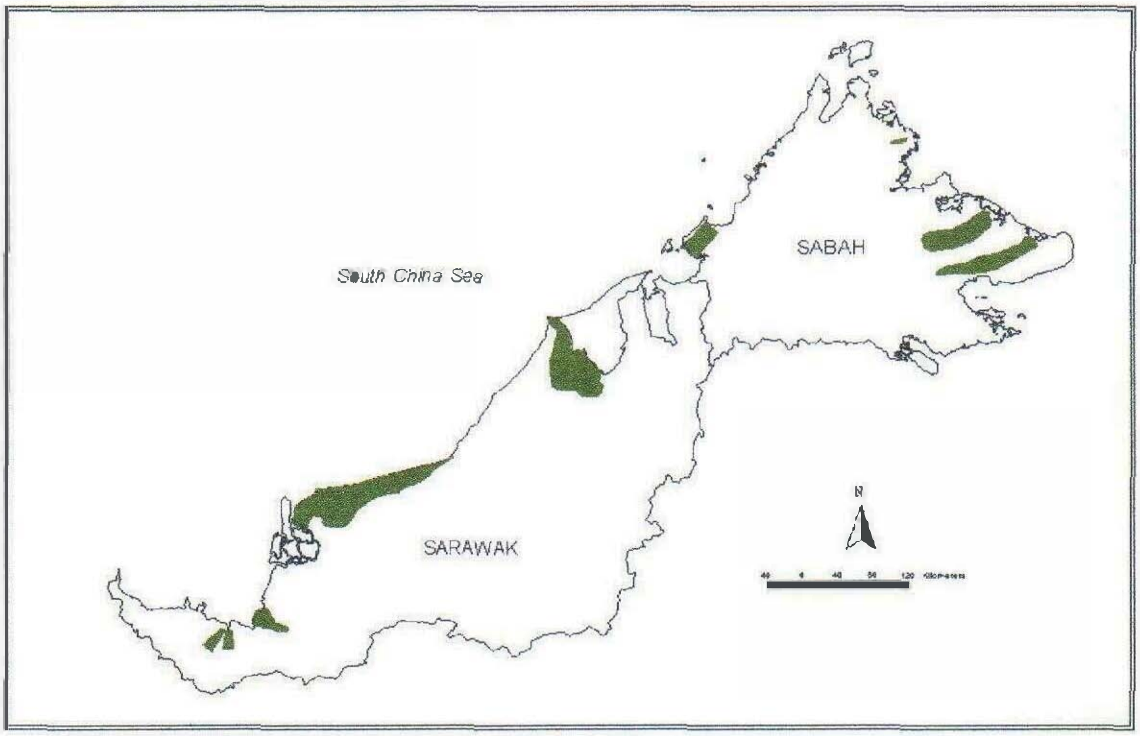

Figure 2: Peat soil in Sabah and Sarawak (Vimala, 1979)

2.3 Peat Swamp Forests in Southeast Asia

Peatland in Southeast Asia has been estimated at about 35 million ha including some 8 million ha that have been converted to agricultural lands and this represent 60 percent of the world's tropical peatland resources (Andriesse, 1988). In Southeast Asia besides Malaysia, PSF also occurs in Southeast Thailand, East Sumatra, Irian Jaya, Kalimantan and Brunei (Faizal and Looi, 1999).

2.3.1 Thailand

The total area of Thailand under PSF is about 64,519 ha or 0.13 percent of the land area in the country or about 0.48 percent of the total forest area. Almost all PSF is distributed in southern and south-eastern part with 63,982 ha and 537 ha, respectively (Nuyim, 1999). About 86 percent or 55,487 ha is under secondary forest while only 9,032 ha or 14 percent is still under primary forest with most of them (about 8,403 ha) is located in the Narathiwat Province (Jirasak *et al*., 1999). PSF in Thailand is considered as shallow peat as the depth is between 1 – 2 m (Jirasak *et al*., 1999).

Chumlong *et al.* (1991) reported that the PSF in Thailand comprises of a total of 124 families and 470 species of plants. Out of this, 109 families and 437 species are flowering plants while 15 families and 33 species are ferns. The 12 dominant tree species in primary PSF are *Syzygium pyrifolium,* *Ganua motleyana, Campnosperma coriaceum, Calophyllum teysmannii, Neesia malayana, Endiandra macrophylla, Syzygium obatum, Sterculia bicolor, Stemonurus secundiflorus, Syzygium muelleri* and *Baccaurea bractaeta* (Nuyim, 1999). Meanwhile, the dominant tree species in secondary PSF are *Melaleuca cajaputi* and *Macaranga pruinosa.*

The PSF in Thailand is managed mainly for conservation. A major step in promoting conservation of PSF was the establishment of Sirindhorn Research and Nature Study Centre located in the Narathiwat Province (Anon., 1997b). A major part of the research centre is located the Toh Dang PSF. Forest fire is the main threat to PSF where it was reported that about 2,374 ha were destroyed by the forest fire in 1998 (Nuyim, 1999).

2.3.2 Indonesia

The largest PSF areas occur in Indonesia with the extent of peatland estimated at about 8.8 million ha (Euroconsult, 1983 as cited in Soetjipto *et al.*, 1996). In fact, more than 85 percent of the peatland areas in Southeast Asia occur in Indonesia (Faizal and Looi, 1999).

The largest area is in Sumatra (4.8 million ha) followed by Kalimantan (3.2 million ha) and Irian Jaya (0.8 million ha). There is a large continuous block of PSF in Eastern Sumatra and scattered blocks in western, southern and central Kalimantan and northern, western and southern parts of Irian

Jaya. Dwiyono and Rachman (1996) reported a total of 1.8 million ha being designated and managed as protected forests in Sumatra and Kalimantan.

In 1996, the Indonesian goverment launched a huge project converting the PSF into agricultural lands in central Kalimantan. This project is popularly known as "one million hectares of mega rice project" where about 1.7 million ha of shallow PSF were reclaimed for rice cultivation (Suwido *et al.,* 1999). Reclamation of PSF areas for cultivating agriculture crops has been identified as one of the management priorities in utilising PSF areas in Indonesia. However, the success of such conversion depends on proper drainage system in maintaining and regulating water supply (Soetjipto *et al*., 1996). Unfortunately, the projects failed due to poor planning and lack of comprehensive research support (Suwido *et al.*, 1999).

2.3.3 Brunei

In Brunei, peat soils cover an area along the coastal and sub-coastal parts of the country (Brunig, 1974). The extent of peat soil in Brunei was estimated at about 183,000 ha or 34.7 percent of the total land area (Shamsudin, 1997), however the extent still under forest cover is not available.

2.4 Forest Degradation

2.4.1 Definition

Rehabilitation is a process of restoring or replacing some form of vegetative cover (usually tree cover) to an area so as to improve its natural productivity, natural environmental and aesthetic values (Lim, 1992). Basically, rehabilitation is a man-facilitated recovery process in contrast to natural regeneration which is a natural process.

Generally, land degradation can be defined as the loss of productive capacity of the land to sustain life (Nik Muhamad and Mohd. Zaki, 1995). In addition, Lamb (1994) defined degraded forest as land that has been severely disturbed and abandoned resulting in poor productivity and low species diversity.

Essentially, forest rehabilitation involves the planting of seedlings of indigenous tree species to supplement the existing natural regeneration in the forests (Rusli *et al.*, 1986; Lamb, 1994). There are numerous advantages of planting indigenous species on degraded lands. For instance, they can adapt to the local environmental conditions and produce good growth performance, provided they are free from insect and fungal attacks and the soil is fertile.

It is therefore advisable not to select exotic species for rehabilitation even though many exotic species are comparable to indigenous species in terms of growth in local environments. There are many uncertainties about their utilisation and resistance to pest and diseases.

2.4.2 Causes of Degradation

Causes of forest degradation can either be natural such as forest fire or man-made such as harvesting, agriculture, mining and shifting cultivation. However, human factors have been recognised as the main catalyst of forest degradation particularly with excessive or uncontrolled harvesting activities (Nik Muhamad and Mohd. Zaki, 1995).

The harvesting activities which include construction of forest roads, felling and skidding operations can change the landscape and environmental conditions of the area. The activities often lead to soil compaction and excessive canopy opening because of high intensity of logging roads, decking sites and skid trails. Due to soil compaction, decking sites, skid trails and road shoulders these area are categorised as degraded logged-over forests (Wan Razali and Ang, 1992). Soil compaction is closely related to poor soil fertility resulting in poor regeneration and growth of commercial tree species over a large area of logged-over forests (Kamaruzaman and Nik Muhamad, 1987). As of 1992, out of 6.12 million ha of forested land in Peninsular Malaysia, about 3.36 million ha or 55 percent of inland forests were logged-over (Chin *et al.*, 1997). Based on this estimation, extensive areas of logged-over inland forests need to be rehabilitated.

The extent of forest degradation through shifting cultivation is relatively small in Peninsular Malaysia. It was reported that until 1992, a total of 151,223 ha or 2.47 percent of the total forested land in the country was encroached through shifting cultivation in Pahang, Perak and Kelantan with an area of 69,184 ha, 45,245 ha and 36,794 ha, respectively (Chin *et al.*, 1997). Normally, aborigines living adjacent to or within the forest areas carry out shifting cultivation. Small patches of forest areas were clear felled and converted to food crop cultivation and settlements.

The activity of shifting cultivation has been considered as a minor threat to forest degradation as the number of aborigines living in the forest has declined over the years. The government at the same time provides permanent settlement for aborigines with proper basic facilities in line with the policy to educate and improve the standard of living of this less privilege minority in the country.

It was also reported that some of the existing logged-over PSF is dominated by *Macaranga spp.* and grasses such as *Imperata cylindrica* which very prone to forest fire. Forest fire is not common in inland forests but it is one of the major threats to logged-over PSF (Wan Mohd. Shukri *et al.*, 1999). It was estimated that approximately 20,000 ha of logged-over PSF in northern Selangor PSF is highly degraded and some parts were burnt (Shamsudin *et al*., 1997; Anon, 1997a; Woon and Mohd. Parid, 1999). Therefore control and mitigation measures in protecting PSF from fires are also very crucial and need to be formulated.

One of the potential solutions to the problem is to replant the area, and as the canopy of planted tree closes, grasses and weeds will be suppressed and indirectly reduce the amount of biomass that can act as excellent fuel for bush fires. Thus successful replanting in degraded PSF will not only improve the productivity of the area but also help in maintaining good environment, besides ensuring continuous water supply for agriculture and other important services.

2.5 Factors for Consideration in Forest Rehabilitation

A number of factors need to be looked at before embarking on rehabilitation projects. Most of these factors highlighted below have been discussed by Ang *et al.* (1992), Abdul Rahman *et al.* (1992), Appanah and Weinland (1993), Nik Muhamad and Mohd. Zaki (1995), Awang Noor *et al.* (1997), Azahar and Masran (1997), Wan Yusoff and Abdul Rahman (1997), Raja Barizan and Shamsudin (1997) and Raja Barizan (1999). The factors discussed below are crucial in determining the success of the project.

2.5.1 Selection of Species

Many factors need to be considered when selecting species for rehabilitation projects. Some of the critical factors are flowering and fruiting behaviour, nursery management, germination rate, pest and diseases. Other important factors are the ability of species to withstand competition between tree species, competition with fast growing pioneer species and capability to produce higher growth rate particularly at the initial growing stage.

Lim (1992) proposed that the choice of species should be based on the ultimate objective of the rehabilitation project. In forestry, species are often selected on the basis of their fast growth rate so that the trees can be harvested within a shorter rotation period. A shorter rotation period is critical to improve economic viability of the rehabilitation project (Awang Noor *et al.*, 1997).

2.5.2 Supply of Planting Materials

A continuous supply of vigorous planting materials is also crucial to ensure the success of rehabilitation projects. Seeds are commonly used as the main source of getting planting materials. A technique of raising planting materials through seed is the easiest and cheapest compared to other methods. However, the supply of seeds is very irregular particularly with indigenous tropical forest species because their flowering and fruiting patterns are unpredictable. The indigenous tropical forest species may flower and fruit between three to six years (Appanah and Weinland, 1993; Mohd. Afendi and Ang, 1994).

A good documentation of phenological information is important in order to understand flowering and fruiting patterns of tropical tree species. On the occurrence of fruiting seasons, attempts must be made to collect as many seeds as possible and store them properly according to standard procedures (Marzalina, 1995; Pukittayacamee *et al.,* 1996; Thai *et al.*, 1996).

Apart from seed as sources for planting materials, seedlings can also be raised through wildings and vegetative propagation either using stem cutting or tissue culture (Aminah, 1991; Aminah *et al.*, 1997). Raising planting materials of PSF species through wildings, stem cutting and tissue culture have already been developed with success (Mohamad Lokmal *et al.*, 1992; Shamsudin and Aziah, 1992; Ismail and Shamsudin, 1999).

2.5.3 Rehabilitation Areas

According to Wan Yusoff and Abdul Rahman (1997), there are in general two critical areas that need rehabilitation. These are poorly stocked stand and open areas. In poorly stocked stand, the major focus of rehabilitation is to increase the number of commercial and high quality indigenous tree species for the production of logs (Abdul Rahman *et al.,* 1992). According to Thang and Chew (1980), in this type of area line planting is normally being used as enrichment planting technique. It was reported that the survival rate was very encouraging in some areas in Selangor and Perak where line planting was employed. A similar post harvest treatment was recommended in other states (Thang and Chew , 1980).

However in open areas such as temporary decking sites, abandoned logging roads and abandoned shifting cultivation areas, the major focus is to rehabilitate with high quality indigenous tree species (Wan Razali and Ang, 1992). It is important to ensure that species planted in the open is light tolerant particularly at the early stage of its development. The problem of planting in compacted soils has been resolved through mechanisation where big planting holes is prepared.

2.5.4 Tending

Tending or post-planting treatments are critical for the successful establishment of planted seedlings. Tending which involves weeding, fertilising, underbrushing and climber cutting is also crucial in order to get better growth and high survival rate and these activities incur a high cost particularly in areas that have poor accessibility. Rusli *et al*. (1986) reported that tending activities represent 39 percent of the total rehabilitation cost at Bukit Tinggi FR, Bentong, Pahang.

It is therefore crucial to focus rehabilitation techniques that help to minimise tending activities which ultimately reduce the rehabilitation cost. Rehabilitation experiment conducted by Raja Barizan (1999) using big planting material is one of the methods to minimise subsequent tending activities.

2.5.5 Financial Support

The viability of rehabilitation program depends not only on appropriate techniques but also sufficient budget allocated over the duration of the program (Rusli *et al*., 1986, Awang Noor *et al*., 1997). The main objective of conducting rehabilitation work is to get better return in terms of timber production and this can easily be attainable if sufficient financial support is given. The cost involved can be considerable depending on the extent of site degradation, location, supply of planting materials and frequency of post-planting treatments. Based on a study done by Rusli *et al.* (1986), a total of RM 942,373.84 was spent to rehabilitate an area of 1,192 ha in 11 compartments in Bukit Tinggi FR, Bentong that took 10 years to be completed.

2.6 Status of Forest Rehabilitation in Peninsular Malaysia

Historically, forest rehabilitation in Peninsular Malaysia started in the early 1900's through enrichment planting work (Wan Yusoff and Abdul Rahman 1997). During the "gutta-percha era (1900 - 1922)", silvicultural operations were confined to the establishment of *Palaquium gutta* and *Hevea brasiliensis* plantations. Enrichment planting on the other hand used *Neobalanocarpus heimii*, *Palaquium gutta* and *Hevea brasiliensis*, the former were for timber used in construction while the latter for latex.

By 1970, a large scale enrichment planting was carried out in the states of Selangor, Perak and Negeri Sembilan. At the end of 1972, Perak and Selangor had already planted approximately 3,128 and 2,357 ha of poorly stocked areas planted under enrichment program, respectively (Abdul Rahman *et al.,* 1992). It was reported that by the end of 1978, the total area rehabilitated in Peninsular Malaysia amounted to about 12,950 ha (Abdul Rahman *et al.,* 1992).

Despite good results obtained in some areas, it was reported that a systematic survey over line-planted areas in Perak and Selangor in 1972 and 1973 indicated very poor survival (Appanah and Weinland, 1993). The cause of the poor survival is mainly due to ecological and management factors (Abdul Rahman *et al.,* 1992; Appanah and Weinland, 1993). Ecological factors are related to topographical aspects where mortality normally is higher on slope exceeding 60 percent. The management factor is related to planning of planting activities and training of workers to do a proper planting job.

Between 1956 and 1996, a total of 23,060 ha of poor forest areas have been treated with enrichment planting in Peninsular Malaysia. The distribution of enrichment planting in the Malaysia's five-year planning period since 1956 to the Seventh Malaysia Plan (1996 - 2000) is illustrated in Table 4.

Table 4: Total extent of enrichment planting in Peninsular Malaysia between 1966 – 2000

Malaysia Plan Period	Area Planted (Ha)
From 1956 and first Malaysia Plan (1966 - 1970)	5,416
Second Malaysia Plan (1971 – 1975)	5,769
Third Malaysia Plan (1976 - 1980)	3,148
Fourth Malaysia Plan (1981 - 1985)	2,032
Fifth Malaysia Plan (1986 – 1990)	1,755
Sixth Malaysia Plan (1991 - 1995)	3,167
Seventh Malaysia Plan (1996 – 2000)	* 1,773
Total	**23,060**

* Figure of planting area in 1996 only

Source: Wan Yusoff and Abdul Rahman (1997)

Table 5 shows the extent of enrichment planting areas in different states in Peninsular Malaysia between 1956 and 1996. It shows that the largest rehabilitation program was carried out in the state of Perak, followed by Selangor, Kelantan, Pahang and Johore. The species planted were mostly *Shorea leprosula*, *Shorea parvifolia*, *Shorea accuminata*, *Shorea. pauciflora*, *Shorea ovalis*, *Hopea odorata*, *Dipterocarpus cornutus* and *Anisoptera spp.* (Wan Yusoff and Abdul Rahman, 1997).

Table 5: Total area of enrichment planting in different states of Peninsular Malaysia between 1956 – 1996

State	Area Planted	
	Hectare	Percentage (%)
Perak	7,275	31.5
Selangor	4,386	19.0
Kelantan	2,582	11.2
Pahang	2,519	10.9
Johor	2,390	10.4
Kedah	1,606	7.0
Melaka	956	4.2
Terengganu	619	2.7
Negeri Sembilan	602	2.6
Perlis	125	0.5
Total	**23,060**	**100**

Source: Wan Yusoff and Abdul Rahman (1997)

Most of the rehabilitation work in inland forests was conducted in lowland and hill forests and no information was recorded for enrichment planting in PSF. It seems that little attention has been given to rehabilitate logged-over PSF although the area contributes towards the production of valuable timber species (Razani and Jalil, 1997; Shamsudin and Ismail, 1991).

2.7 Rehabilitation in Peat Swamp Forests

The magnitude of damage done to the residual stand in PSF is closely associated with logging methods (Cedegren and Shamsudin, 1999). In the past, logging in PSF was less intensive and only those commercial tree species greater than 45 cm dbh were harvested (Shamsudin and Aziah, 1992). Therefore, damage to seedling or advanced growth after logging is minimal. Observation by Wyatt-Smith (1959) in Kuala Langat South and Telok PSF showed good natural regeneration of commercial species both in primary and logged-over PSF.

Heavy machines were extensively used in PSF in Peninsular Malaysia since the early 1960s (Yap, 1964). Meanwhile, in early 1980s, traxcavator and canal systems were introduced as new logging techniques in PSF (Shamsudin, 1996a). It was found that old extraction tracks by the tramline system were densely colonised by *Pandanus artocarpus* and *Macaranga puncticulata* (Chan, 1990). These two secondary forest tree species are excellent indicators of severity of logging damage done to the residual stand (Chan, 1990). A substantial damage has been observed as logging in PSF became more intensive and mechanized (Cedegren and Shamsudin, 1999).

Damage to the forest stand by traxcavator was severe, particularly along tracks which lead to the extraction routes where logs were dragged on the ground before placing into the canal for final transportation out of the forest (Chan, 1990). A post-logging survey in Sungai Karang PSF indicated a high proportion of non-commercial regenerating species such as *Ilex macrophylla*, *Syzygium cerina*, *Stemonurus malaccensis* and *Acronychia spp.* (Chan, 1990).

The canal system has an important impact on hydrological characteristics of PSF. It was observed that there was gradual seepage and surface runoff of swamp water from the adjacent PSF into the canals. This leads to progressive drying ups of the PSF which is likely to cause adverse effects on regeneration of some commercial tree species and hence hinder the rate of forest recovery. Zulkifli *et al.* (1999) recommended constructing a series of check dams along the canal at appropriate intervals in order to allow water to be retained inside the ecosystem.

2.8 Light Intensity

Light is the most important factor for the survival and development of seedlings in the tropical moist forests (Jeyarai, 1987; Lee *et al.,* 1994). In fact, according to Nicholson (1960), apart from planting and weeding the most critical factor that influences the composition of a regenerating dipterocarp forest is the light conditions within the stand that can be manipulated to favour the growth of certain species according to their light requirements. The observation is supported by Sasaki and Mori (1981) who reported that growth of dipterocarp seedlings depends on light conditions in the forest since different species require different light intensities.

Sasaki and Mori (1981) also reported that usually after heavy fruiting most dipterocarp seeds will germinate on the forest floor but seedlings often disappear within one year after germination due to high mortality. This high mortality of young seedlings is very much related to very low light intensity under the dense canopy of dipterocarp forests.

Plants are generally classified as light demanding or shade tolerant species (Whitmore, 1984). Light demanding plants are also referred to as pioneer species that grow rapidly in height and diameter especially at the early stages (Whitmore, 1984). These characteristics will enable them to be a superior big gap coloniser in the forest where the microclimate in the gap is favourable for development of these species.

However, the pioneer species is short-lived and produce wood with low density (Amir Husni, 1989). Good examples of pioneer species commonly found in all forest types in Peninsular Malaysia are *Macaranga spp*. and *Anthocephalus chinensis* (Cheah, 1995). Some late successional dipterocarps classified as light demanders are *Shorea leprosula, Shorea parviflora* and *Shorea ovalis* (Whitmore, 1984). Among the non-dipterocarps classified as non-pioneer species but light demanding *are Dyera costulata* and *Ixonanthus icosandra* (Whitmore, 1984).

There are many seedlings of tree species that persist under the closed canopy and they are commonly referred to as shade tolerant species (Whitmore, 1984). These species are less capable to colonise big gaps compared to the pioneer species, but they form a group of species that will remain dormant for a longer period of time under shade and are capable to respond positively to favourable growing conditions (Amir Husni, 1989).

Generally, these species have slow growth rate in terms of height and diameter increment and usually produce high quality timber (Amir Husni, 1989). Among the dipterocarp species categorised as shade tolerant are those under the genus *Shorea, Vatica, Hopea* and *Neobalanocarpus* while among the non-dipterocarps include *Pometia pinnata* and *Elateriospermum tapos* (Whitmore, 1984).

2.9 Species Selected

Six indigenous of PSF were used in the study. The selection was based on availability of planting materials and their commercial value (Shamsudin, 1997; Appanah *et al*., 1999). Detailed explanation of the species are given below:

2.9.1 *Anisoptera marginata* Korth.

Vernacular name: Mersawa paya

Family: Dipterocarpaceae

2.9.1.1 Ecological Distribution

The species is distributed in Peninsular Malaysia, Borneo, Bangka and Sumatra (Newman *et al.*, 1996).

2.9.1.2 Growth and Development

A. marginata is a medium to large tree with tall and straight bole exceeding 40 m height (Appanah *et al*., 1999). It has buttresses up to 3 m high, steep, rounded and straight (Newman *et al.*, 1996). The species is less abundant in PSF but it is considered as one of commercial species due to it's superior timber quality (Shamsudin, 1997; Appanah *et al*., 1999).

The species has a basal area of about 0.39 m^2 ha^{-1} and a density of 28 individuals ha^{-1} of above 15 cm dbh (Appanah *et al.*, 1999). The information supports an earlier finding by Feilberg and Sorensen (1999) who reported a total basal area of about 0.30 m^2 ha^{-1} with increment of about 0.01 m^2 ha^{-1} $year^{-1}$ and diameter increment of about 0.8 cm $year^{-1}$. A single tree of *A. marginata* with 40 cm dbh and about 20 m height produced flowers and fruits between June and August 1997 at the Bebar FR in Pekan, Pahang.

2.9.1.3 Utilisation

A. marginata is grouped under light hardwood with a wood density of about 640 kg m^{-3} . The timber is useful for light construction, door and window frames, flooring, ceilings, weather boards, packing cases, crates, boxes and plywood (Anon, 1986).

2.9.2 *Calophyllum ferrugineum* Ridl.

Vernacular name: Bintangor gambut

Family: Guttiferae

2.9.2.1 Ecological Distribution

The species can be found in PSF and freshwater swamp in the east and west coasts of Peninsular Malaysia (Shamsudin and Ng, 2000).

2.9.2.2 Growth and Development

C. ferrugenium is a big-sized tree exceeding 40 m tall and 50 cm dbh. The bole is straight and cylindrical with less prominent buttresses. A survey conducted by Appanah *et al.* (1999) in Compartment 24 and 25 of Raja Musa FR found that the species density was 58 stems ha^{-1} with a total basal area of 73 m^2 ha^{-1}. They also found that *C. ferrugineum* is the 15^{th} most abundant species of the 30 most common species in the area.

2.9.2.3 Utilisation

The timber is categorised as light hardwood with wood density of about 690 kg m^{-3}. The timber is used for light construction, flooring, partitioning, panelling, joinery, furniture, spars and masts of boats, veneer, plywood and wooden pallets (Anon, 1986).

2.9.3 *Durio carinatus* Mast.

Vernacular name: Durian paya

Family: Bombacaceae

2.9.3.1 Ecological Distribution

D. carinatus is found only in PSF in the east coast of Peninsular Malaysia and also in Borneo and Sumatra (Shamsudin and Ng, 2000).

2.9.3.2 Growth and Development

It is a large tree exceeding 30 m tall and 50 cm dbh and usually with no buttress (Kochummen, 1963 as cited in Shamsudin, 1997). It has a cylindrical bole and a massive spreading crown. The species flowers and fruits every year and germination is abundant especially around mother trees following good seed years (Shamsudin and Ng, 2000).

2.9.3.3 Utilisation

The timber is categorised as light hardwood with wood density of about 690 kg m^{-3}. The timber is extensively used for light construction, door and window frames, wooden sandals, flooring, planking, plywood, sliced veneer and furniture (Anon, 1986).

2.9.4 *Ganua motleyana* (De Vr.) Pierre ex Dubard

Vernacular name: Nyatoh ketiau

Family: Sapotaceae

2.9.4.1 Ecological Distribution

The species is commonly found in freshwater swamps and PSF (Shamsudin, 1997). It is widely distributed in Peninsular Malaysia, Borneo, Sumatra, Riau, Bangka, Moluccas and Papua New Guinea (Shamsudin, 1997).

2.9.4.2 Growth and Development

G. motleyana is a medium to large-sized tree exceeding 30 m and 40 cm dbh (Shamsudin, 1997). It has straight and columnar bole without buttresses but produces abundant knee roots (pneumatophores). Appanah *et al*. (1999) listed the species in 29th position in terms of abundant species in Raja Musa FR. The density of individuals ≥ 15 cm dbh was 40 tree ha^{-1} with a total basal area of about 0.36 m^2 ha^{-1}.

2.9.4.3 Utilisation

The timber is categorised as light hardwood with wood density of about 720 kg m^{-3}. Timber of *G. motleyana* is popular for high quality furniture

(Anon, 1986). It is commonly utilised for high-class decorative panelling, cabinet-making, partitioning, moulding, strip, parquet flooring, boat decking, veneer, plywood and pallets. Shamsudin and Ng (2000) reported that oil extracted from the seed of *G. motleyana* can be used for cooking but it is very minor industry in Peninsular Malaysia as compared to India and Africa.

2.9.5 *Gonystylus bancanus* (Miq.) Kurz.

Vernacular name: Ramin melawis

Family: Thymelaeaceae

2.9.5.1 Ecological Distribution

Among the species in the PSF, *G. bancanus* has special attractions and many research work have been done on this species. It is considered the best timber species in the PSF with a good market demand both locally and overseas (Appanah *et al*. 1999). A total of seven species of *Gonystylus* have been recorded in Peninsular Malaysia but *G. bancanus* is the only one found in the PSF (Shamsudin, 1996b). The species distribution is not only in Peninsular Malaysia but also in Borneo, Sumatra, Papua New Guinea and Philippines (Whitmore, 1984).

2.9.5.2 Growth and Development

G. bancanus is fairly large tree, occasionally attaining 89 cm dbh and 45 m tall with a clean straight bole of 21.0 – 30.5 m (Tawan and Ipor, 1992). A study by Appanah *et al.* (1999) shows that the species is the third most abundant species found at the Raja Musa FR with the total basal area of 128 m^2 ha^{-1} and density of 210 stems ha^{-1} for individuals exceeding 15 cm dbh. Young individuals tend to clump together within a small area underneath the mother tree (Shamsudin, 1996b). Regeneration is mostly within a parameter of 10 m radius from the mother tree (Shamsudin, 1996b). The number decreased with increasing distance and no single seedling has been recorded at the distance of 20 m away from the mother tree (Shamsudin, 1996b).

The species is commercially marketed as Ramin both in domestic and overseas market. It represents a major source of Ramin timber compared to other *Gonystylus* timber from dryland forests. The population is highly vulnerable to greater damage under the current method of logging system employed in PSF. Shamsudin (1998) found that the population of *G. bancanus* ≥5 <10 cm dbh reduced to more than half immediately after logging which uses a combination of canals and hydraulic excavator. This may reduce the supply Ramin timber in the future. One of the solutions to a long-term supply of Ramin is through large scale planting.

The species shows a regular flowering and fruiting behaviour with a mass fruiting observed in 1993 (Shamsudin, 1997). It was found that in the Pekan FR on the east coast of Peninsular Malaysia, the species flowers at the beginning of the year and the mature fruits began to drop in March to April. Seeds of *G. bancanus* have a reasonably high percentage of germination (Shamsudin, 1996b).

The species shows a strong rooting through stem cutting (Mohamad Lokmal *et al*., 1992) and has potential to produce plantlets through tissue culture (Shamsudin and Aziah, 1992). Therefore the possibility of getting perpetual supply of planting materials, independent of fruiting seasons is very promising for *G. bancanus*. This important criterion qualifies the species to be considered as one of the potential timber species to be introduced for a large-scale forest plantation (Shamsudin and Ismail, 1999).

In addition, Shamsudin and Ismail (1999) reported that the species shows promising growth performance in planting trial conducted in non-peat swamp area. Results after six years of planting showed survival at about 58 percent while dbh and total height increments were 1 cm $year^{-1}$ and 52 cm $year^{-1}$, respectively.

2.9.5.3 Utilisation

Timber of *G. bancanus* is categorised as light hardwood with wood density of about 655 kg m^{-3}. The timber is widely used as decorative cabinet timber and furniture (Anon, 1986). It is also suitable for general light construction, interior decoration such as panelling, flooring, moulding, and counter-tops (Anon, 1986).

2.9.6 *Shorea platycarpa* Heim.

Vernacular name: Meranti paya

Family: Dipterocarpaceae

2.9.6.1 Ecological Distribution

The species is widely distributed in Peninsular Malaysia, Sumatra, Bangka, Belitung, Sarawak, Brunei, western part of Sabah and Kalimantan (Newman *et al.*, 1996). Although the species can be found both in the east and west coasts of Peninsular Malaysia, it is more common in the east coast (Shamsudin, 1997). In a survey conducted in Compartments 127, 130 and 132 of Sungai Karang FR and Compartments 24 and 25 Raja Musa FR, no *S. platycarpa* was found (Appanah *et al.*, 1999; Feilberg and Sorensen, 1999).

2.9.6.2 Growth and Development

It is a medium-size to large tree exceeding 50 m tall and 50 cm dbh. It has thin, concave, branched and plank-like buttresses that could reach up to 4 m high and to 3.5 m spread. It is a dominant tree species in PSF and has a large crown.

2.9.6.3 Utilisation

The species is categorised under light red meranti group with wood density of about 675 kg m^{-3}. The timber is excellent for veneer production, joinery, furniture, cabinets, office fittings, counter tops and show cases (Anon, 1986; Shamsudin and Ng, 2000).

CHAPTER THREE

METHODOLOGY

3.1 Site Description

3.1.1 Location

The field planting was conducted in Compartment 101, Raja Musa FR, Selangor located at in 03° 26' 08" North and 101° 25' 09" East (Figure 3) with an altitude of approximately 12 m a.s.l. The forest reserve is part of a continuous block of the north Selangor Peat Swamp Forests (NSPSF) between the Bernam and Selangor Rivers. The reserve is separated from the Sungai Karang FR by the Tenggi River.

It is one of the remaining PSF in Peninsular Malaysia. The NSPSF was gazetted as a forest reserve in 1990 (Razani and Jalil, 1997). Prior to that the area was under stateland and hence not subjected to regulations of forest management. This explain why some parts of this area were badly damaged due to intensive harvesting.

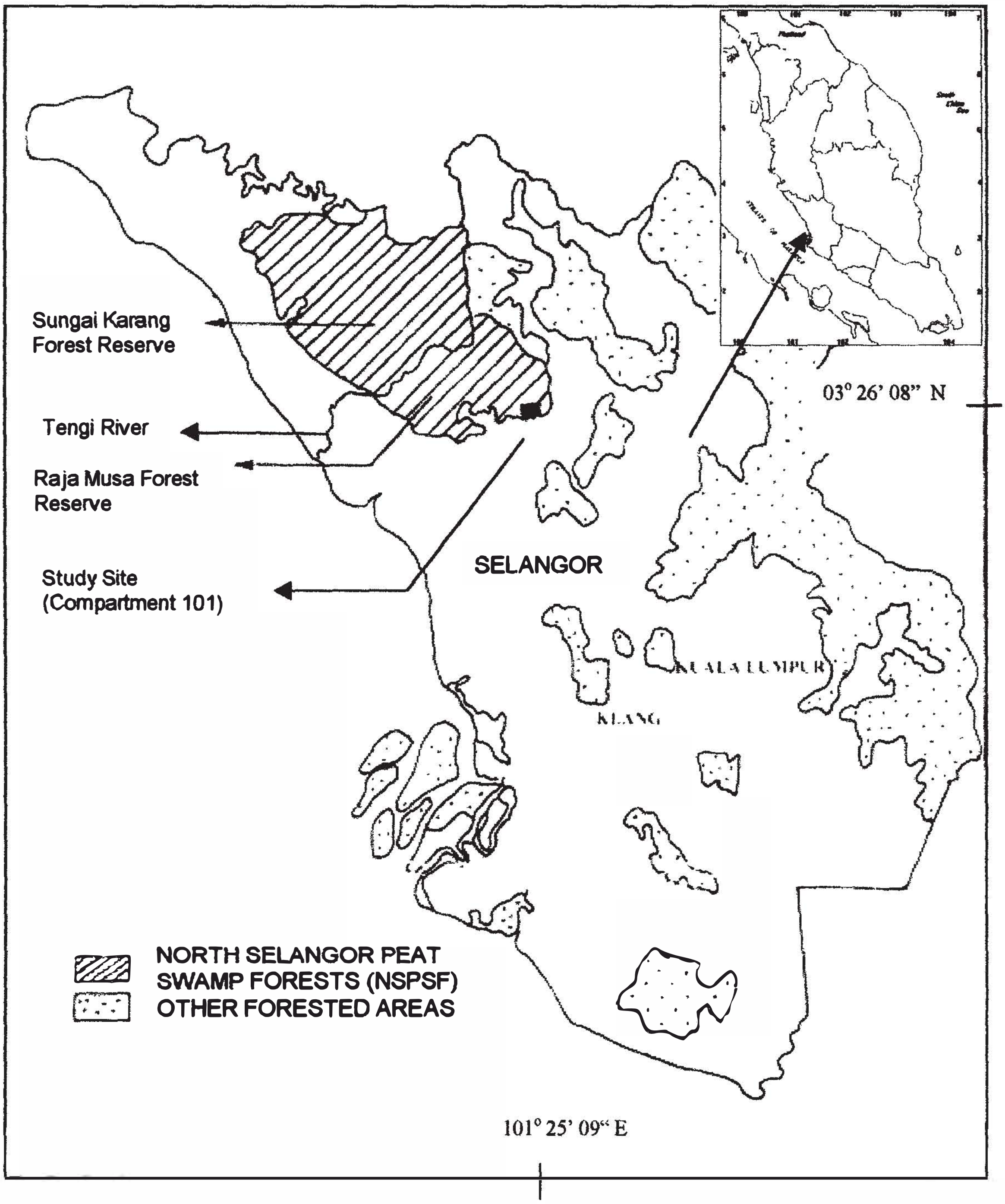

Figure 3: Location of the experimental area

Compartment 101 covers an area of about 416 ha and from the map produced by Shamsudin *et al.* (1997), almost 50 percent of this area is under Class I. The study site (Plate 1) is entirely open and dominated by *Imperata cylindrica* and regularly affected by forest fire. The cause of degradation in this area is probably due to excessive logging.

During the dry seasons the site is very dry and susceptible to forest fire. However, during the raining seasons it is completely flooded and previous records showed that the area can be submerged up to more than three months. Adjacent to the study site is ex-peat and ex-tin mining areas (Plate 2).

Plate 1: *Imperata cylindrica* dominates the study area

Plate 2: Ex-peat and ex-tin mining areas adjacent to the study area

3.1.2 Climate

The meteorological data of the study area was taken from the nearest rainfall station in Tennamaram Estate about three kilometers from the study site. Average annual rainfall at the study site is about 2,232 mm. The average monthly rainfall from 1989 to 1999 in the study area is shown in Figure 4. There are generally two peaks of high precipitation occurring from January to May and October to December.

The dry period starts in June and lasts until September. During this period the water table is about one meter below the soil surface (Figure 5). Zulkifli *et al*. (1999) also found that the water table in Compartment 127, Sungai Karang FR went down below one meter during the dry season. This explains why forest fires occur most frequently in this area between June and August.

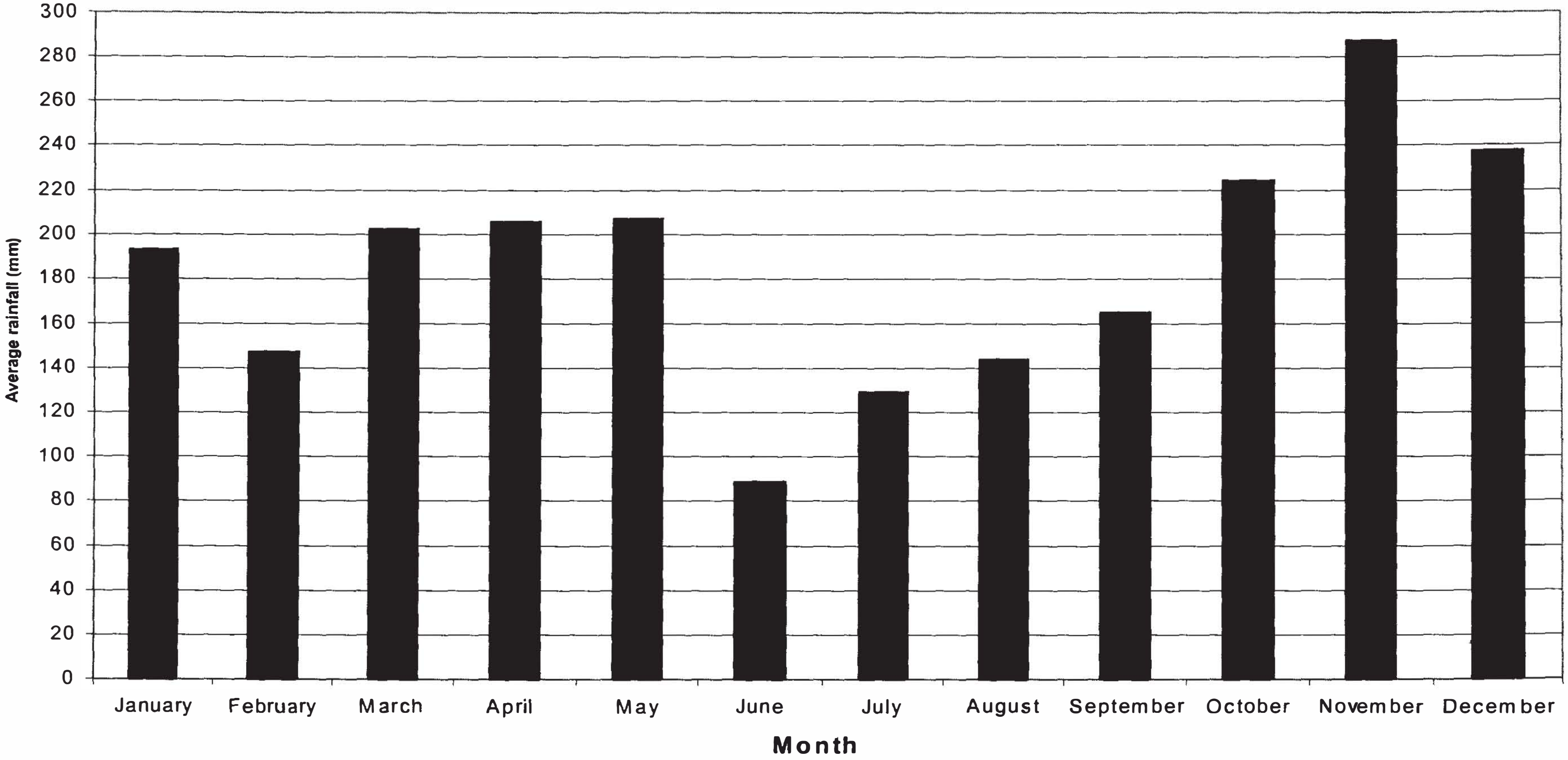

Figure 4: Average monthly rainfall in Compartment 101, Raja Musa Forest Reserve, Selangor from 1989 – 1999 (Meteorology Department Malaysia, 1989 - 1999)

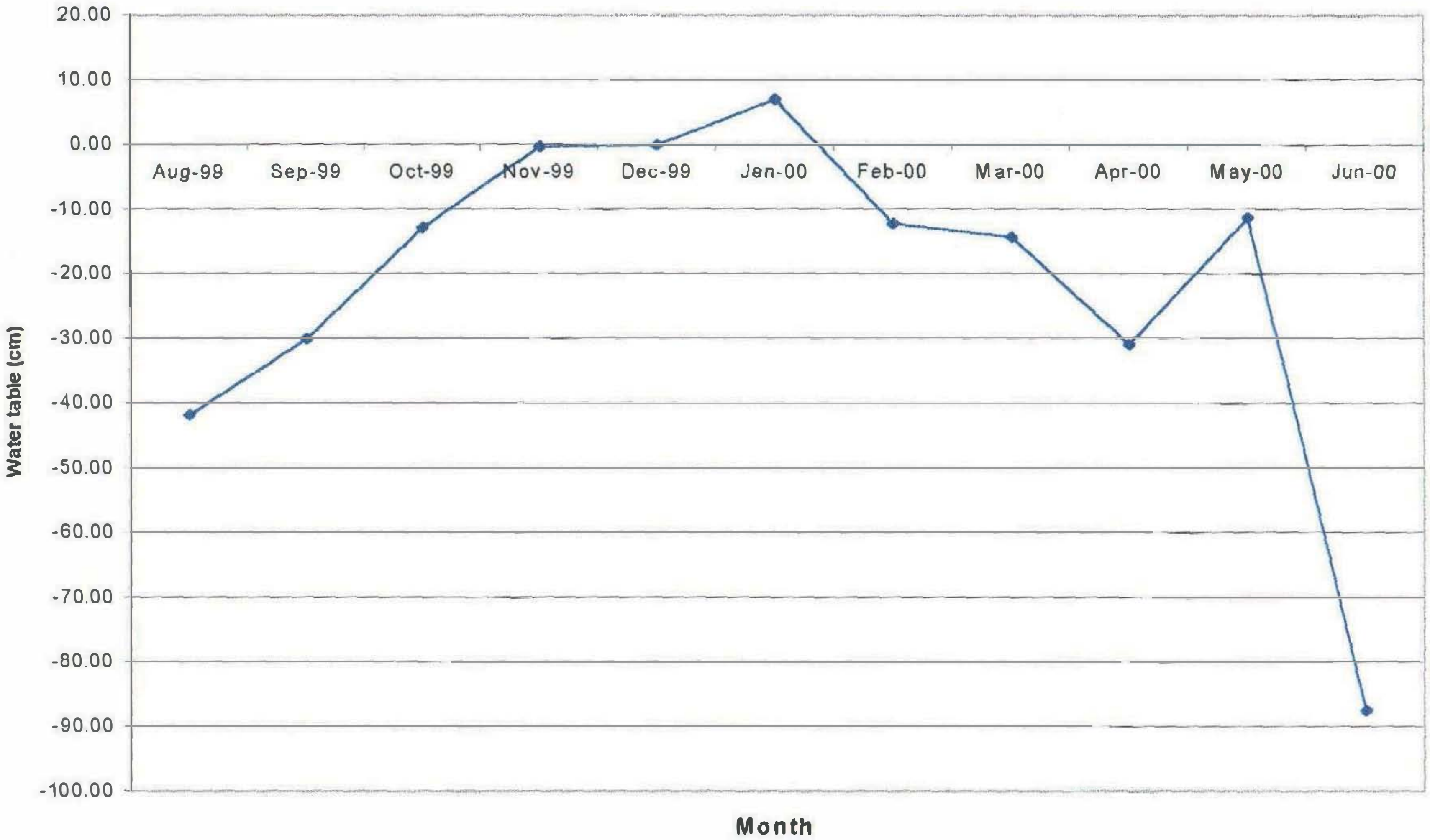

Figure 5: Water table measurements in Compartment 101, Raja Musa Forest Reserve, Selangor

3.2 Production of Planting Materials

Planting materials of PSF species are difficult to obtain because planting in PSF was not included in the rehabilitation programs in the past. Because of low priority given to PSF there was no attempt made to raise planting materials of PSF species. In this study the production of planting materials by using various methods is critical in order to determine the most viable technique. Detailed description on various methods used are given below:

3.2.1 Collection of Wildings

The collection started in early morning (about 7.00 a.m.) in order to minimise moisture stress on seedlings through transpiration loss. Prior to collection, the area was surveyed one day earlier to locate and assess the amount of wildings. Small sized wildings approximately 4 – 12 cm in height and preferably at two-leaf stage were collected by pulling them carefully from the ground. The wildings were then placed in a plastic bag which contain water gel[1] and water at a ratio of 1 : 150 (Plate 3).

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[1] Water gel is water retaining polymer for plant cultivation. It is a synthetic water-imbibing polymer designed to aid water management by improving the water retention properties of all types of growing media. It protects roots and maintains water supply to bare roots while in transit.

Before collecting of wildings, polybags with planting media were prepared in the nursery. The planting media used was a combination of top soil and river sand or paddy husk at a ratio of 3 : 1. When wildings reached the nursery, they were transplanted and watered. Watering was done in the morning and evening.

Weeding and inspection for insect and fungus attack were carried out daily. Insects and fungi infection was controlled by applying suitable insecticide such as Malathion (10 ml per litre of water). A temporary nursery was established in the case where collection of wildings is conducted far from the station (Plate 4).

Plate 3: Wildings placed in a plastic container that contains water gel

Plate 4: Wildings in the temporary nursery

3.2.2 Seeds

The technique of raising planting materials through seeds was done based on procedure established by Aminah *et al*. (1997). Pure river sand with a proportion of approximately 60 percent and 40 percent particles < 2 mm and > 2 mm diameter, respectively were mixed and placed in plastic containers (approximately 60 cm length and 35 cm long). The containers were placed in the germination house with light intensity ranging between 30 – 40 percent.

Only good and mature seeds (physically good and a ripen colour) were selected and used for germination. The seeds were sown at an interval of 2 cm along the row and 4 cm between rows. The narrow or pointed end of the seed was pushed into the sowing media, leaving the blunt end of the seed exposed. After sowing, the seeds were covered with a layer of paddy husk to retain moisture.

Watering was done twice a day usually in the morning and afternoon. This was carried out either manually or using automatic sprinkler system until the seeds germinated. Seeds that had been tested using this technique were *G. bancanus* and *A. marginata* that produced 95 percent and 90 percent germination, respectively. These species were selected because their seeds were available during the study period (Plate 5).

At a about three weeks in seedbeds the seedlings (about 5 cm in height) were transferred into polybags (flat size 24 cm x 16 cm) containing a mixture 3 : 1 of top soil and river sand/paddy husk/peat gro. The seedlings were then placed under the shade with 50 percent light intensity for a period of six to nine months. Conventionally, six-month old seedlings with an average height at about 30 cm are ready for planting in the field (Ang *et al.*, 1992; Aminah *et al.*, 1997). The current practice prefers bigger and taller seedlings of at least two metres tall to reduce costs on post-planting treatments (Raja Barizan, 1999).

Plate 5: *Anisoptera marginata* seedlings in the nursery raised from seeds

3.2.3 Vegetative Propagation via Stem Cutting

Vegetative propagation via cutting is an alternative method commonly used in raising planting materials especially species that has irregular flowering and fruiting, seed storage problems and short viability (Aminah, 1991). The technique offers several advantages by saving time and cost on labour in collecting seeds. Planting stock raised by cuttings will grow and develop uniformly and at the same time helps to maintain purity of the parent stock (Srivastava and Manggil, 1981).

Even though cutting has been tried on many tree species, it has never been used extensively on PSF species. Mohamad Lokmal *et al.* (1992) examined the production of planting materials of *G. bancanus* through cutting and reported promising results.

The method of raising planting materials using stem cutting in this experiment was based on a technique used by Aminah (1991) and Mohamad Lokmal *et al.* (1992). Stem cutting of PSF species was obtained from source plants that were raised in the nursery. The preparation of cutting materials was done in the morning between 8.00 to 11.00 a.m. A commercial rooting hormone, Seradix-3 was applied to improve rooting percentage of the stem cuttings that have a nodal of cutting at least one leaf and approximately 2 - 3 cm in length.

The cutting bed was prepared in a green house with 30 percent light intensity and humidity ranging between 85 – 95 percent (Plate 6). The rooting medium was made up of pure river sand. The stem cuttings and rooting medium were kept moist by an automatic mist sprinkler system operated at hourly intervals with the duration of each spray lasting about one minute. In addition, the cutting bed was covered with clear plastic sheet supported by a wooden frame to maintain high humidity around the cutting.

The rooted stem cuttings were transferred into polybags (flat size 24 cm x 16 cm) containing potting media of 3 : 1 top soil and river sand (Plate 7). They were placed under shade with 50 percent light intensity and watered regularly. One gram of commercial fertiliser nitrophoska blue (12N : 12P : 17K) was applied to each plant at the age of two and five months to boost root and leaf development.

Plate 6: Stem cuttings of *Gonystylus bancanus*

Plate 7: Rooted stem cuttings of *Gonystylus bancanus*

3.3 Field Planting

3.3.1 Experimental Design

Four different planting techniques tested are: 1) Open planting, 2) Open planting with mulching, 3) Open planting with topsoil and 4) Open planting with nurse tree. The six species endemic to PSF used in this study are: 1) *Anisoptera marginata*, 2) *Calophyllum ferrugineum*, 3) *Durio carinatus*, 4) *Ganua motleyana*, 5) *Gonystylus bancanus* and 6) *Shorea platycarpa*.

The experimental design used is a split plot design (128 m x 121 m) with three replicates (36 m x 111 m) as shown in Appendix A. Sixteen seedlings were planted at a spacing of 3 m x 3 m in each subplot.

The total number of seedlings planted is 1,152 (48 seedlings/planting technique/species). The seedlings are about one-year old (Plate 8). Hardening of seedlings was also conducted before they were transplanted to the planting sites. A post planting treatment of clearing 1 m width along the planting line was done at four months interval (Plate 9). The objective is to control weeds and also to facilitate data collection.

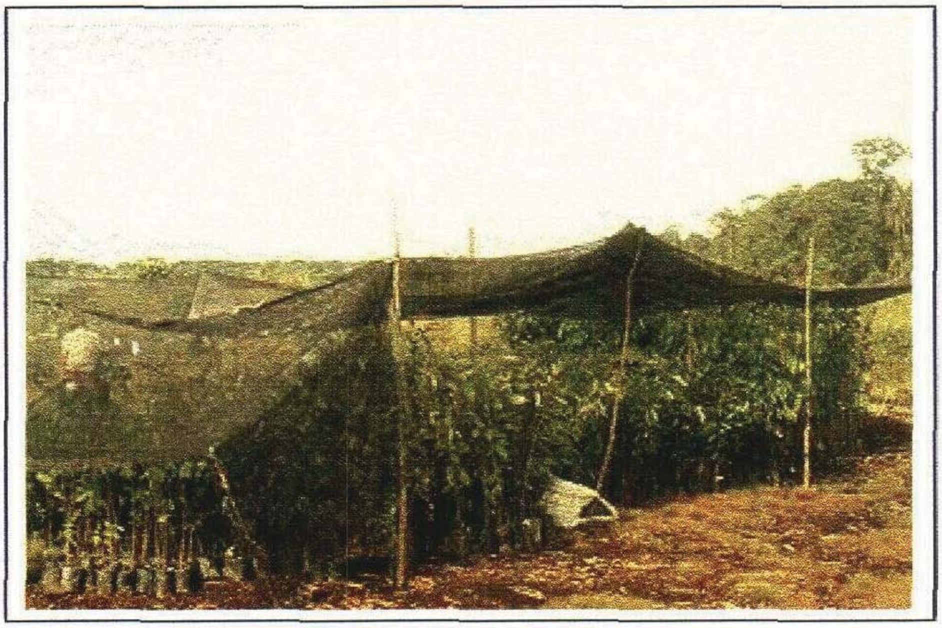


Plate 8: The planting materials for the field planting

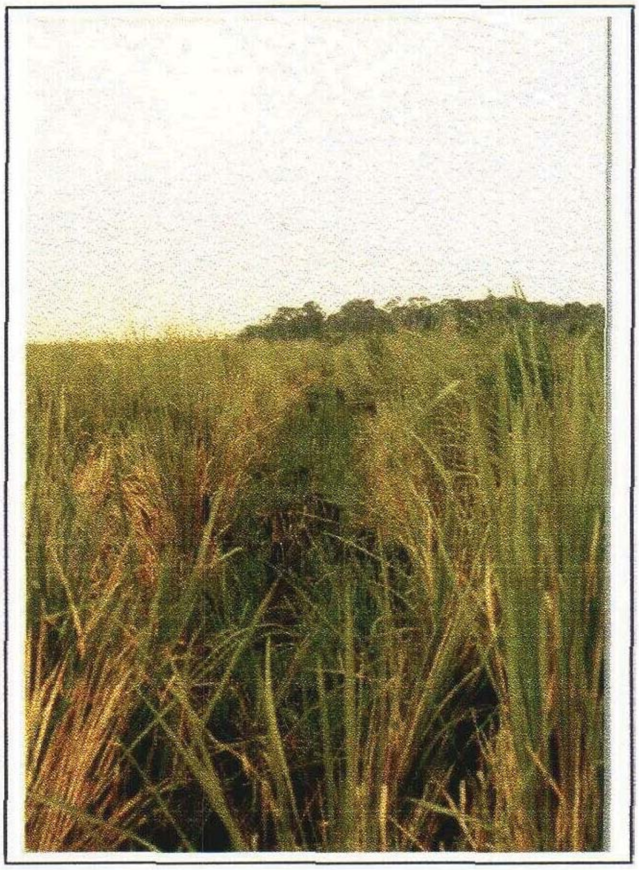


Plate 9: A one-meter width of line clearing

3.3.2 Planting Techniques

Four different planting techniques were tested in order to determine the most suitable technique that can be used to rehabilitate the grassland area in PSF. Details of the planting techniques are presented below:

3.3.2.1 Open Planting

Open planting technique involves complete clearance of existing plants within the study area especially *Imperata cylindrica* to eliminate competition. The clearing was done manually in strips of 1 meter wide.

The strip was spaced at two-meter intervals and grasses along the two meters strips were left uncut to provide protection to newly planted seedlings against direct sunlight (Plate 10). Therefore, the direction of planting strip in open planting technique is south – north, not east – west as commonly used in line planting technique.

A total of 100 gm of Christmas Island Rock Phosphate (CIRP - 15N : 15P : 15K) was applied in the planting hole of 30 cm^3 prior the planting. Excess peat soil was used to cover the planting holes (Plate 11).

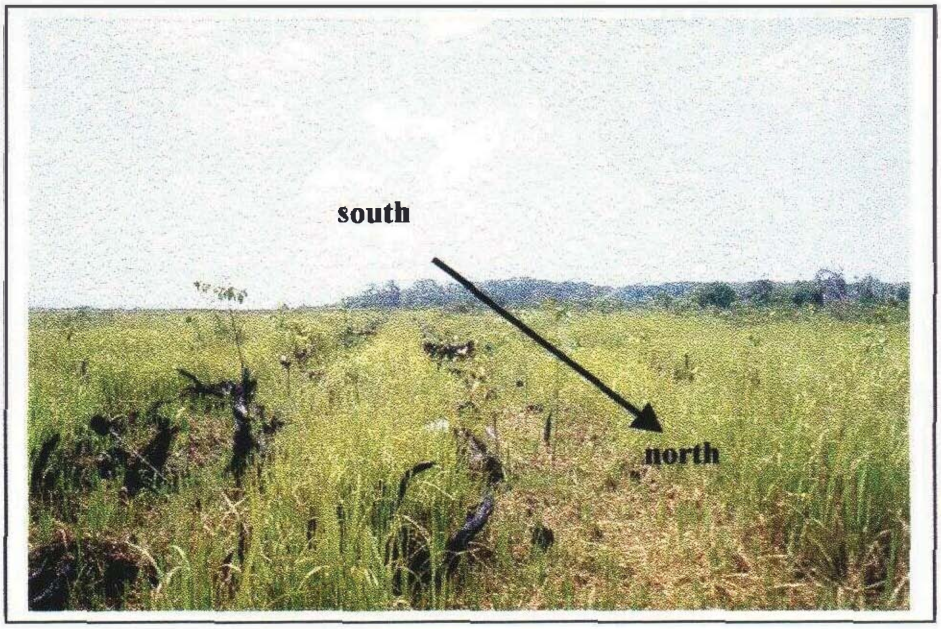


Plate 10: The south - north direction of planting strip

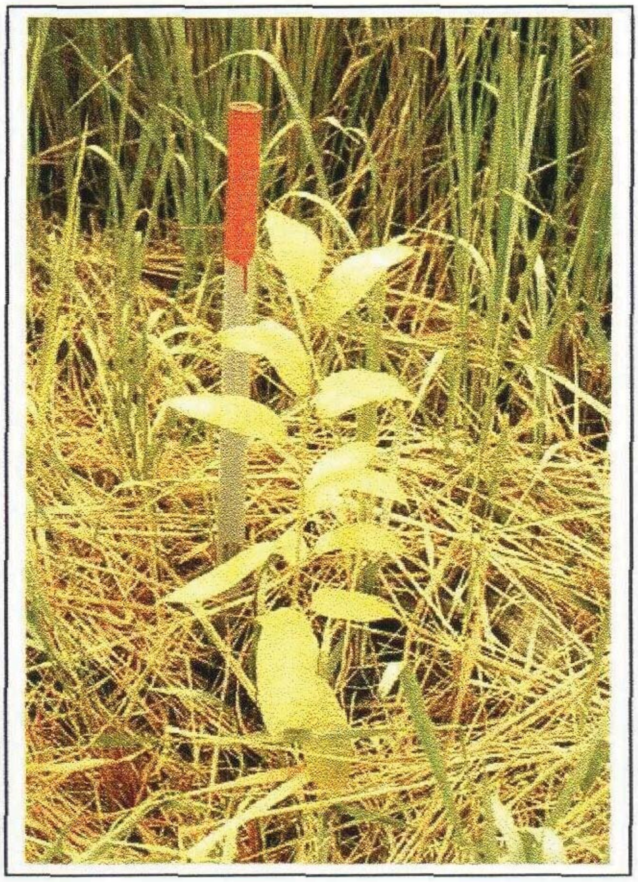


Plate 11: The open planting technique

3.3.2.2 Open Planting with Mulching

In this technique, fresh shredded empty fruit bunches (EFB) of oil palm was used as mulching materials (Plate 12). The fresh EFB provides a good source of organic matter and essential nutrients for plant growth. A detailed composition of EFB is shown in Table 6. It has been calculated that one tonne of EFB (fresh weight) would provide an equivalent of 7.0 kilograms urea, 2.8 kilograms rock phosphate, 19.3 kilograms muriate of potash and 4.4 kilograms kieserite (Gurmit, 1994).

Table 6: Composition of empty fruit bunches

Parameter	Dry Matter Basis		Fresh Weight Basis (moisture contents: 60-65%)
	Range	Mean	(mean)
Ash (%)	4.8 - 8.7	6.3	2.52
Oil (%)	8.1 – 9.4	8.9	3.56
C (%)	42.0 – 43.0	42.8	17.12
N (%)	0.65 – 0.94	0.80	0.32
P_2O_5 (%)	0.18 – 0.27	0.22	0.09
K_2O (%)	2.0 – 3.9	2.90	1.16
MgO (%)	0.25 – 0.40	0.30	0.12
CaO (%)	0.15 – 0.48	0.25	0.10
B (ppm)	9 – 11	10	4
Cu (ppm)	22 – 25	23	9
Zn (ppm)	49 – 55	51	20
Fe (ppm)	310 – 595	473	189
Mn (ppm)	26 – 71	48	19
C/N ratio	-	54	54

Source: Gurmit (1994)

In general, peat has low fertility particularly the micronutrients (Vimala, 1979). Therefore, it was expected that the application of mulching materials would enhance the supply of nutrients necessary for plant growth.

Based on observation by Gurmit (1994) in oil palm plantation, the application of mulching materials from EFB not only helped to improve the physical, chemical and biological properties of the soil but also contribute directly to better vegetative growth and increase the level of nutrients in leaves and fruit bunches. In this planting technique, the mulching material was applied only on the upper surface after the planting hole was covered with the peat (Plate 13).

Plate 12: Freshly shredded oil palm empty fruit bunches (EFB)

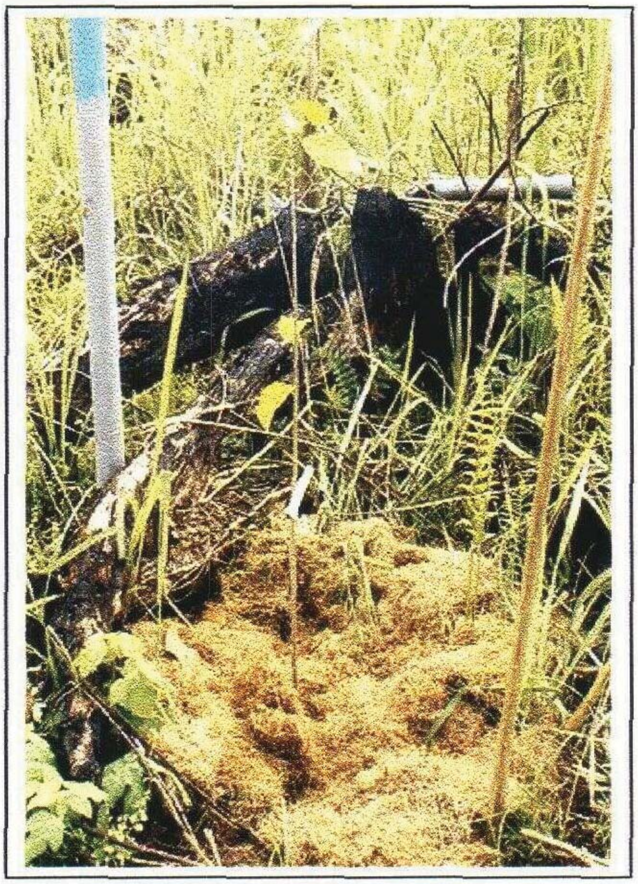


Plate 13: Open planting with mulching

3.3.2.3 Open Planting with Topsoil

In this planting technique, topsoil that is commonly used in the nursery as planting media was filled up in the planting hole. Physical and chemical properties of the topsoil are shown in Tables 7 and 8, respectively. The seedling was planted at the middle of the planting hole (Plate 14). The rationale of using topsoil was to assist young seedlings to continue growing under the same conditions of planting media provided in the polybag.

Usually the planting media in the polybag consists of a mixture of topsoil and sand. By using the same planting media in the planting holes, seedlings is expected to experience less planting shock and will be able to recover rapidly with the production of more roots.

Table 7: Physical properties of topsoil

pH	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
4.8	46.0	12.5	10.5	31.0

Table 8: Composition of macronutrients of topsoil

C (%)	N (%)	P (ug/g)	K (ug/g)	Ca (ug/g)	Mg (ug/g)
1.1	0.1	20	0.08	0.7	0.07

3.3.2.4 Open Planting with Nurse Tree

Hopea odorata with the average size of about 2 m height were planted as nurse trees prior to planting of commercial trees species (Plate 15). The nurse trees were expected to provide shade to young seedlings and create a competition that promotes better height growth of planted commercial species. Even though, *H. odorata* is not a PSF species, it prefers sites with moving ground water (Appanah and Weinland, 1993).

Plate 14: Open planting with topsoil

Plate 15: Open planting with nurse tree

It is very difficult to get suitable nurse trees of PSF species in the study area. Attempts have been made to use *Macaranga pruinosa*, the pioneer species commonly found in logged-over PSF as nurse trees. Wildings of *M. pruinosa* were collected and raised in the nursery. However, wildings of *M. pruinosa* showed greater mortality in the nursery.

H. odorata is light demanding species and reports have shown good survival and growth performance of this species when planted in an open area (Ab. Rasip *et al.,* 1991; Ang *et al*., 1992; Appanah and Weinland, 1993; Raja Barizan, 1994). The species has never been planted in the PSF before, however, trial planting conducted prior the planting experiment showed positive indications that the species can be planted in the degraded PSF. Currently, the species is the most popular species used in rehabilitating degraded areas and urban landscaping.

3.3.3 Data Collection

The establishment of plots was completed in August 1999. The field planting was initially planned to collect 12 months data for analysis. Unfortunately, due to forest fires in April 2000 approximately eight months after the establishment, data collection in the plot was disrupted. Therefore, the experiment only used data collected over a period of eight months. The following parameters were monitored:

3.3.3.1 Survival

The survival of seedlings planted were monitored and recorded every month. Factors affecting survival of the seedlings were also noted.

3.3.3.2 Basal Diameter and Total Height Measurements

The basal diameter (BD) and total height (TH) were measured and recorded every month. BD was measured at 5 cm above the ground by using a digital diameter calliper. To ensure each measurement is taken at the same point, the individual plant was marked at 5 cm above the ground.

Measurement for BD was recorded in millimetre (mm). Meanwhile, TH measurement was recorded by using a long stick with graduation in centimetre (cm). Measurements were recorded to the nearest one decimal point.

3.3.4 Project Limitations

The establishment of plots started in early June 1999 and was completed in August. It took a long time to establish the plots because the site was affected by fire. The main limitation of the study was to identify the suitable time for planting. The area is subjected to flooding during the rainy season and fire during the dry season.

Proper planning is very crucial to initiate planting where the impact of flooding and fire is minimal. From the demonstration plot established prior to the field planting, the best time for planting in the PSF is one or two months before the raining season. The seedlings were already stable and able to survive the flooding conditions two months after planting. It was also found that most of the planted seedlings in the demonstration plot survived as long as they are not totally submerged even though the area was flooded for more than three months.

3.4 Light Intensity Study

In the light intensity study, three different relative light intensities (RLI) were used; 100 percent, 70 percent and 30 percent. Two shade chambers of 3 m height, 4 m wide and 12 m long were constructed and the chambers were fully covered with sarlon net that represent 70 percent and 30 percent RLI, respectively (Plates 16 and 17). 20 seedlings of each species aged about one-year old were placed in the shade chambers as well as in the open area. All seedlings, either in the shade chambers or open areas were given similar treatments with respect to watering, fertiliser application and weeding.

Data on survival, basal diameter and total height increments were collected in this study at two weeks interval for a period of three months. Only three months data are available for this thesis because the light intensity study started late as compared to the field planting due to lack of planting materials. Additional planting materials of the same six species were raised specifically for the light intensity study. Data on basal diameter measured in mm (at 5 cm above the soil surface) and total height in cm.

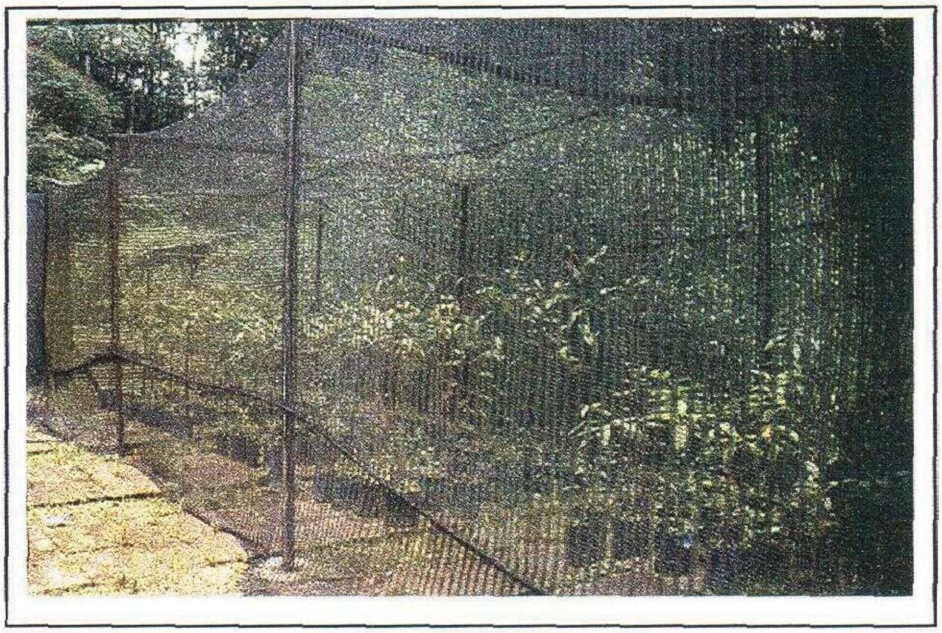


Plate 16: Shade chamber of 70 percent RLI

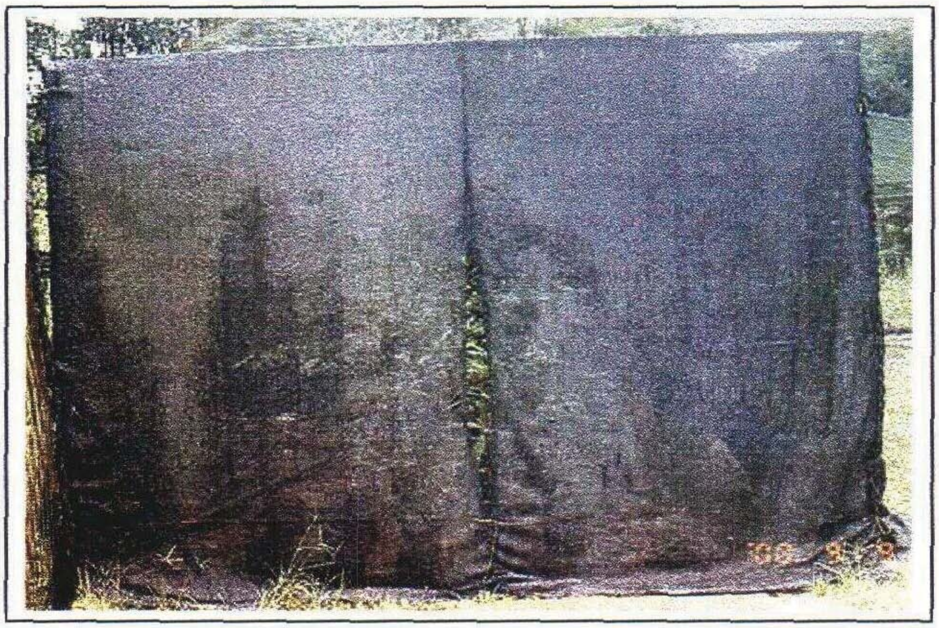


Plate 17: Shade chamber of 30 percent RLI

3.5 Soil and Foliar Analysis

Leaf samples, chemical and physical properties of soil at the study site were analysed in this study. Physical properties of peat were analysed for texture by using method as used by Wan Rasidah *et al.* (1989) and (1990). Chemical properties were analysed for pH and nutrient content by using method as also used by Wan Rasidah *et al.* (1989) and (1990). The peat samples were collected randomly inside the study site at different depths; 1 – 10 cm, 10 – 20 cm and 20 – 30 cm.

Foliar analysis was conducted at three different stages; before planting (in nursery), three months after planting, and six months after planting. Foliar analysis before planting is to determine the status of nutrients under favourable nursery conditions. The seedlings were fertilised with 1 gram of nitrophoska blue (12N : 12P : 17K) every month throughout 12-month duration in the nursery.

Meanwhile, foliar analysis of planted seedlings is to determine the uptake of nutrients by seedlings of the same species for the different planting techniques at three and six months after planting. Leaves from the same species and same planting technique were collected and pooled as one sample. The leaves were collected from the middle part of the tree between old and young leaves (Amir Husni, 1989). A total of 24 samples were collected in each sampling exercise. At least 20 gram of wet weight or about 15 leaves were required for laboratory analysis.

In the laboratory, leaves samples were initially cleaned by dipping into distilled water and then left in the open to completely air dry. The leaf petiole was then removed and the sample dried in the oven for 24 hours at the temperature of 60^{o} C by which time the foliage had become brown and brittle. After cooling, they are ground in a clean leaf grinder with a sieve of 0.5 mm. The fine-grounded leaf is then stored in a labelled bottle ready for analysis.

Procedures of foliar analysis to determine the nutrients were the same as used by Wan Rasidah *et al.* (1989) and (1990). Nitrogen (N) was determined by using Kjedahl method while other macronutrient elements were determined by using dry ashing technique. Micronutrient elements were determined by using wet ashing technique.

3.6 Data Analysis

The data collected was analysed by using MS EXCEL spreadsheet and S-PLUS software. The results are presented in form of tables, figures and graphs. Analysis of variance (ANOVA) was conducted to test the significance ($p < 0.05$) difference between treatments. In the field planting, survival results are in the range on 30 – 100 percent. According to Gomez and Gomez (1984), Fredericksen and Mostacedo (1999), data in the range (30 – 100 percent) must be transformed by using Arc Sine.

Transformation before conducting ANOVA in order to stabilise variances. Therefore, data of survival from the planting experiment were transformed by using Arc Sine Transformation before conducting the ANOVA. Meanwhile for the BD and TH, data of cumulative monthly increment were used in the analysis.

3.7 Project Costs

Costs of conducting the field planting were also assessed. Information about the costs is important as it provides useful guidelines to plan future planting activities. It is based on actual costs including wages, transportation, materials and field maintenance.

CHAPTER FOUR

RESULTS

4.1 Field Planting

4.1.1 Survival

The survival rate of seedlings eight months after planting is shown in Figure 6. The results showed that seedling survival varies among planting techniques and species. It was found that survival below 50 percent occurred only in the open planting with mulching technique for all species except *S. platycarpa* and *G. motleyana* that has slightly better survival (60 – 70 percent). Meanwhile, other planting techniques showed survival exceeding 80 percent for all species.

Results of Analysis of variance are presented in Table 9. There were significant differences in survival between different planting techniques and species. A multiple comparison test was conducted to compare mean of survival (Table 10). It shows that only open planting with mulching produced significantly different survival rate as compared to the other planting techniques. There was no significant difference in of survival among the other three planting techniques. Open planting with mulching produced poor survival with only 49.65 percent (Table 11). The most promising planting technique, which has the highest survival rate is open planting followed by open planting with topsoil and open planting with nurse tree with 83.33 percent, 82.98 percent and 81.94 percent, respectively.

A multiple comparison of means of survival rate of different species is shown in Table 10. There was a significant difference in survival eight months after planting for some of the species. C. *ferrugineum* and *D. carinatus* had the lowest survival rate. The ranking of survival from the highest to the lowest is as follows; *G. motleyana, S. platycarpa, A. marginata, G. bancanus, D. carinatus* and C. *ferrugineum* with 92.19 percent, 79.69 percent, 79.17 percent, 73.44 percent, 66.15 percent and 56.25 percent, respectively (Table 11).

Table 9: Analysis of variance of survival rate for the different planting techniques and species

Source of variation	df	Survival		
		SS	MS	F value
Planting technique	3	7185.11	2395.04	16.50 *
Species	5	6753.39	1350.68	9.30 *
Planting technique x Species	15	1853.36	123.56	0.85^{ns}
Residuals	48	6969.34	145.19	

Note:

* = significant at $p < 0.05$
^{ns} = not significant at $p < 0.05$

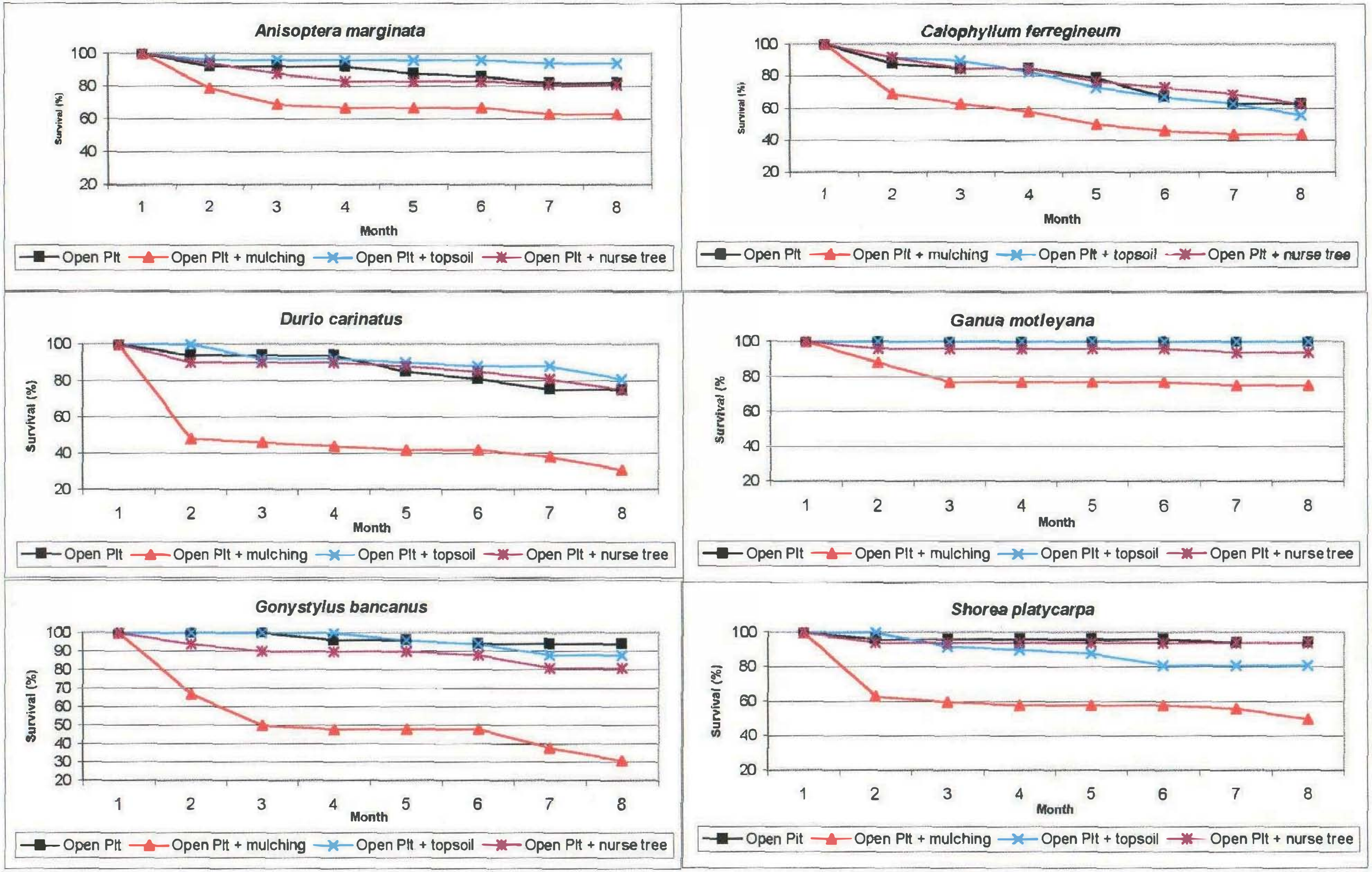


Figure 6: Average survival rate in different planting techniques

Table 10: Multiple comparison of mean of survival using Tukey method

Source of variation	
Planting technique	**Species**
A – B****	AM – CF****
A – C	AM – DC
A – D	AM – GM
B – C****	AM – GB
B – D****	AM – SP
C – D	CF – DC
	CF – GM****
	CF – GB
	CF – SP****
	DC – GM****
	DC – GB
	DC – SP
	GM – GB****
	GM – SP
	GB – SP

Note:

**** = significant at $p < 0.05$

Planting technique:

A = Open planting
B = Open planting with mulching
C = Open planting with topsoil
D = Open planting with nurse tree

Species:

AM = *Anisoptera marginata*
CF = *Calophyllum ferrugineum*
DC = *Durio carinatus*
GM = *Ganua motleyana*
GB = *Gonystylus bancanus*
SP = *Shorea platycarpa*

Table 11: Ranking order of planting technique and species based on mean of survival

Planting technique	Means	Rank	Species	Means	Rank
Open planting	83.33 (± 18.19)	1	*A. marginata*	79.17 (± 19.82)	3
Open planting + mulching	49.65 (± 25.32)	4	*C. ferrugineum*	56.25 (± 16.64)	6
Open planting + topsoil	82.98 (± 15.72)	2	*D. carinatus*	66.15 (± 24.49)	5
Open planting + nurse tree	81.94 (± 14.84)	3	*G. motleyana*	92.19 (± 14.63)	1
			G. bancanus	73.44 (± 26.13)	4
			S. platycarpa	79.69 (± 23.86)	2

4.1.2 Basal Diameter Increment

Results of cumulative basal diameter increment (BDI) for the field planting by species is shown in Figure 7. The results showed that each species in general has similar BDI for different planting techniques particularly for *S. platycarpa* where the BDI is very similar among the different planting techniques. The pattern was confirmed by ANOVA, which shows that BDI is not significantly different between different planting techniques and species (Table 12).

Table 12: Analysis of variance of basal diameter increment (BDI) for different planting techniques and species

Source of variation	df	Basal diameter increment		
		SS	MS	F value
Planting technique	3	8.7510	2.9170	2.0338 ^{ns}
Species	5	11.9928	2.3985	1.6723 ^{ns}
Planting technique x Species	15	8.9607	0.5974	0.4165 ^{ns}
Residuals	48	68.8425	1.4342	

Note:

^{ns} = not significant at $p < 0.05$

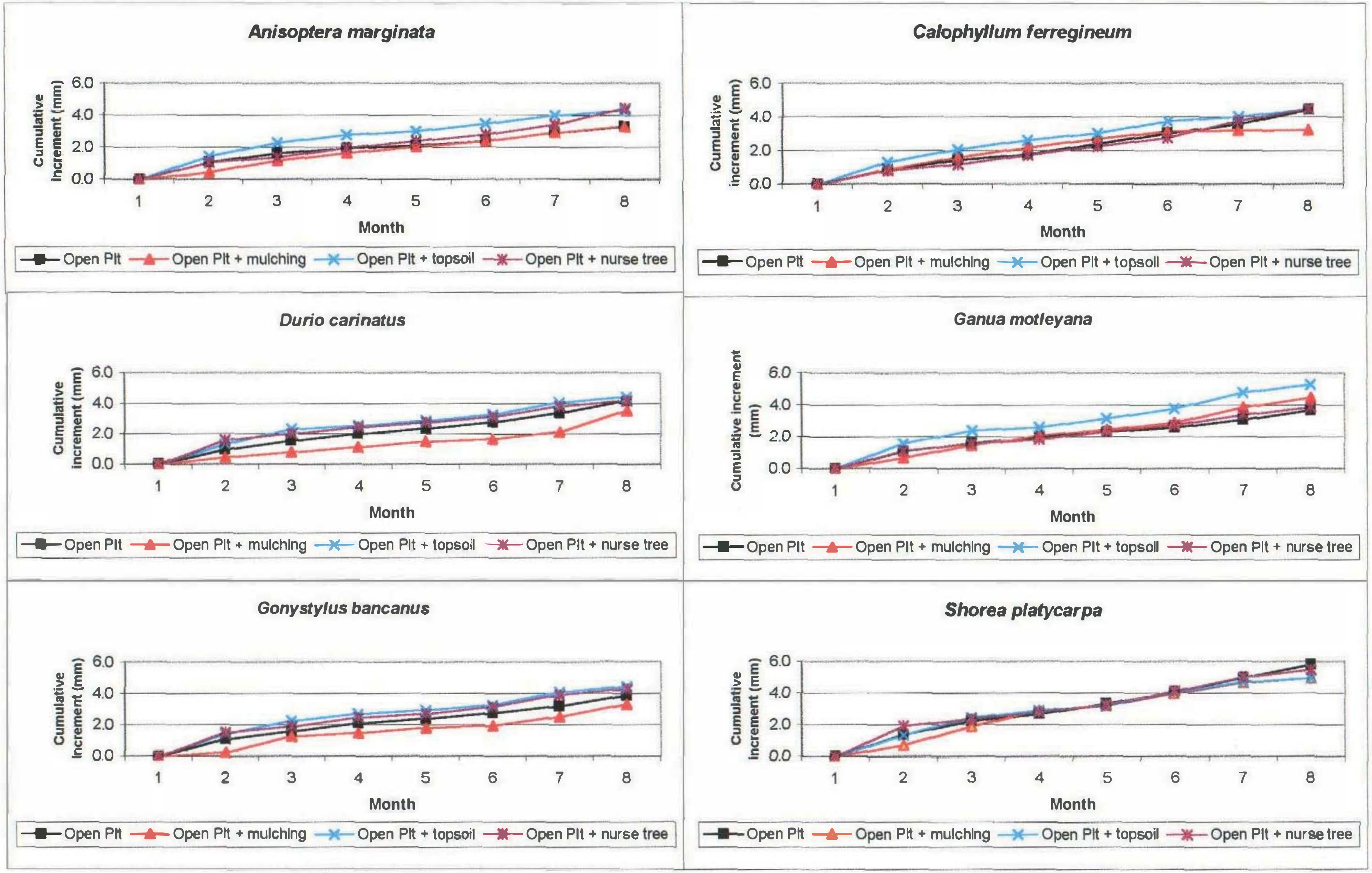


Figure 7: Average cumulative values of basal diameter increment (BDI) for the different planting techniques

4.1.3 Total Height Increment

Results of cumulative total height increment (THI) are shown in Figure 8. It was found that generally THI is also quite similar for the different planting techniques and species particularly for *A. marginata* and *S. platycarpa*. Analysis of variance showed no significant difference in THI between the planting techniques and species (Table 13).

Table 13: Analysis of variance of total height increment (THI) for the different planting techniques and species

Source of variation	df	Total height increment		
		SS	MS	F value
Planting technique	3	24.1150	8.0384	0.2507 ns
Species	5	123.9720	24.7943	0.7734 ns
Planting technique x Species	15	1168.4400	77.8960	2.4299 *
Residuals	48	1538.7480	32.0572	

Note:

* = significant at $p < 0.05$
ns = not significant at $p < 0.05$

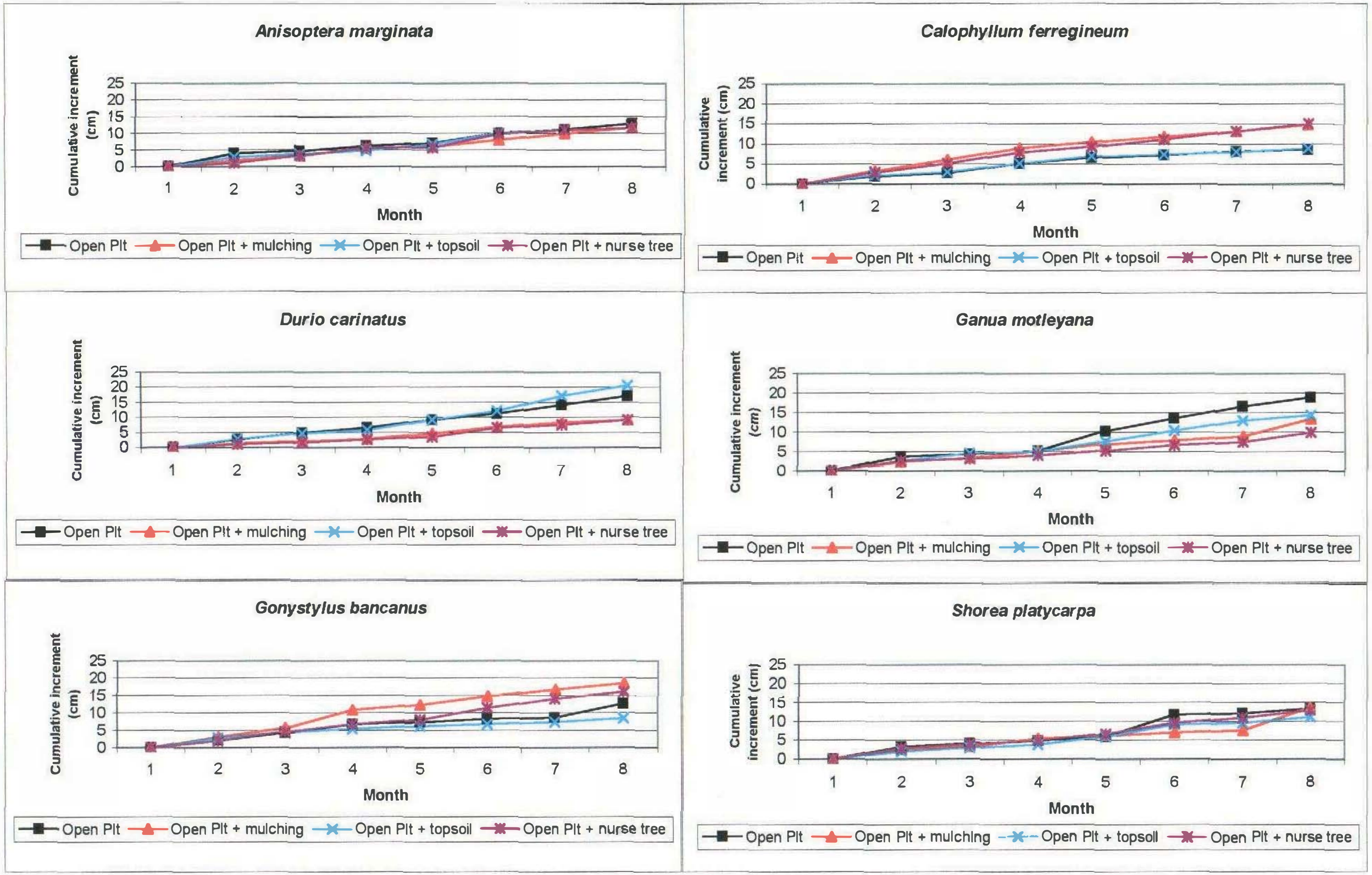


Figure 8: Average cumulative values of total height increment (THI) for the different planting techniques

4.2 Light Intensity Study

4.2.1 Survival

All seedlings either in the shade chamber or in the open area survived after three months. Even though all the seedlings under all different light regimes are survived the vigour, shoot development and leaf size varied quite significantly. For example, *D. carinatus* and *C. ferrugenium* showed good vigour (whole tree physically in good conditions) at 30 percent RLI but poor at 100 percent RLI while the other species showed moderate physical conditions. Marzalina (1992) reported similar observation on others forest species where seedlings of *Dryobalanops aromatica* were found to perform best in early stages of growth if they are placed under 20 percent RLI while *Shorea leprosula* can be grown under 100 percent RLI.

Shoot development of all species is generally similar but *G. motleyana* showed the most active producing new shoots under all light intensities. The obvious difference is leaf size where it was observed that, generally seedlings in the open area have the smallest leaf size compared to seedlings inside the chamber with the seedlings under 30 percent RLI having the biggest leaf size. Similar finding was reported by Aminuddin (1982) who found *Dyera costulata* under 33 percent RLI had biggest leaf size. Both findings are in line with Sasaki and Mori (1981) who concluded that seedling grown at low light intensity generally have large and thin leaves, but in extremely low light intensities, leaf size becomes small again.

4.2.2 Basal Diameter Increment

Results of cumulative basal diameter increment (BDI) are shown in Figure 9. The figure shows that *A. marginata, G. bancanus*, *C. ferrugineum* and *S. platycarpa* performed better at 100 percent RLI while *D. carinatus* showed better BDI at 70 percent RLI. Meanwhile, BDI for *G. motleyana* is less sensitive to 100 percent RLI but began to show a good response after the sixth week.

However, BDI of *G. motleyana* remained below 30 percent and 70 percent RLI at the twelfth week. Results of Analysis of variance showed that there was significant difference of BDI of the different RLI and species (Table 14).

Table 14: Analysis of variance of basal diameter increment (BDI) for light intensity study

Source of variation	df	Basal diameter increment		
		SS	MS	F value
RLI	2	5.3515	2.6757	6.8367 *
Species	5	7.8511	1.5702	4.0120 *
RLI x Species	10	6.7177	0.6717	1.7164 ns
Residuals	296	115.8463	0.3913	

Note:

* = significant at $p < 0.05$
ns = not significant at $p < 0.05$
RLI = relative light intensity

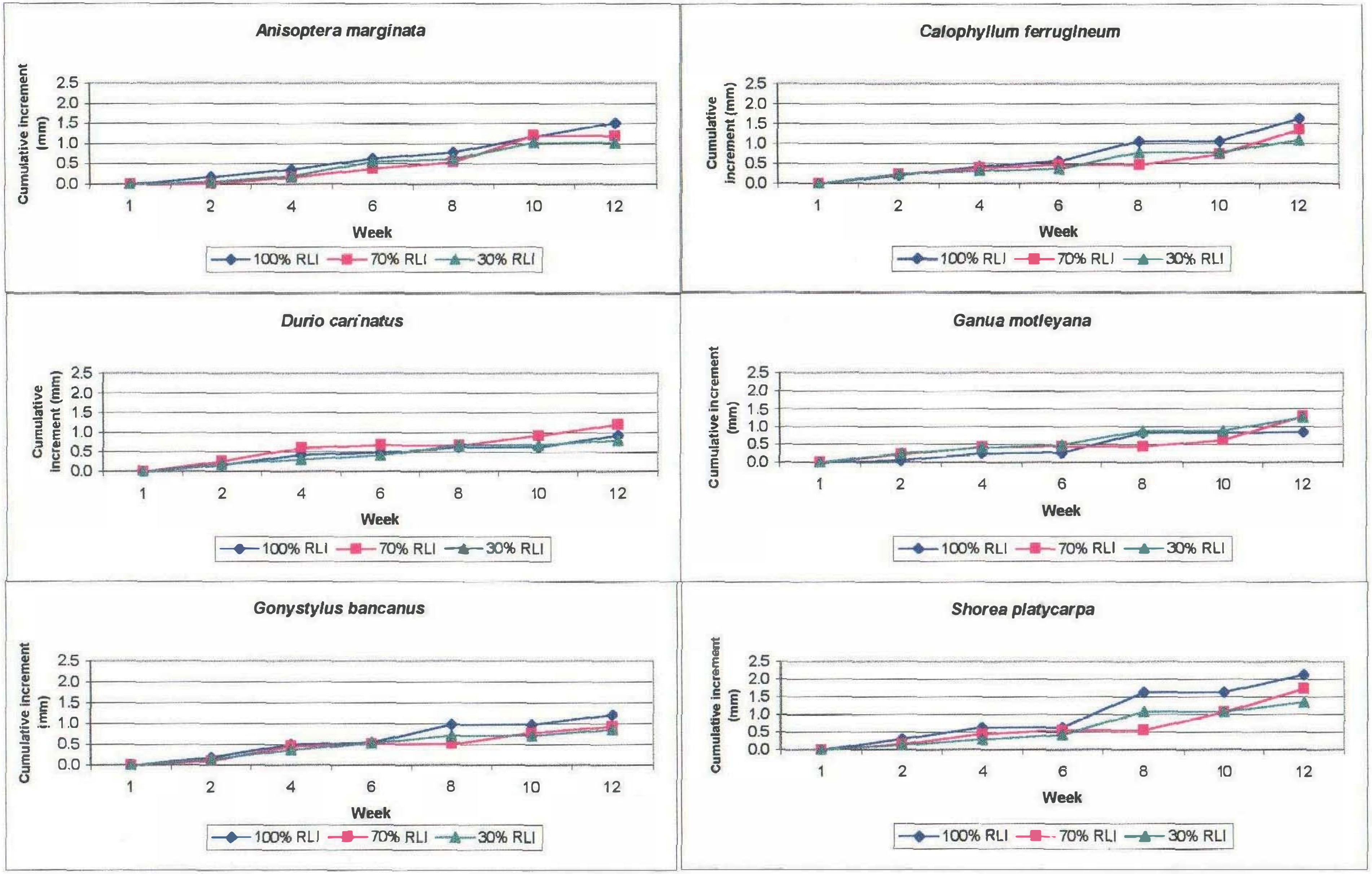


Figure 9: Average cumulative of basal diameter increment (BDI) at different relative light intensities (RLI)

4.2.3 Total Height Increment

Results of cumulative total height increment (THI) are shown in Figure 10. The figure shows that 100 percent RLI produced a consistently low THI for *D. carinatus*, *G. motleyana* and *S. platycarpa*. However, *A. marginata and C. ferrugineum* showed better THI at 100 percent RLI. *G. bancanus* showed no consistent pattern of THI at different RLI but began to show a better THI at the sixth to twelfth week of the experiment. David *et al.* (1996) had categorised *G. bancanus* as light demanding species which growing most rapidly in partial sunlight.

D. carinatus and *G. motleyana* showed an encouraging THI at 30 percent RLI and the pattern of higher THI was consistently maintained throughout the experiment. A summary of Analysis of variance results in Table 15 shows that there was significant difference in THI under the different RLI and species.

Table 15: Analysis of variance of total height increment (THI) for light intensity study

Source of variation	df	Total height increment		
		SS	MS	F value
RLI	2	131.8140	65.9072	4.1385 *
Species	5	1028.1310	205.6263	12.9120 *
RLI x Species	10	541.8010	54.1801	3.4021 *
Residuals	283	4506.8040	15.9251	

Note:

* = significant at $p < 0.05$
ns = not significant at $p < 0.05$
RLI = relative light intensity

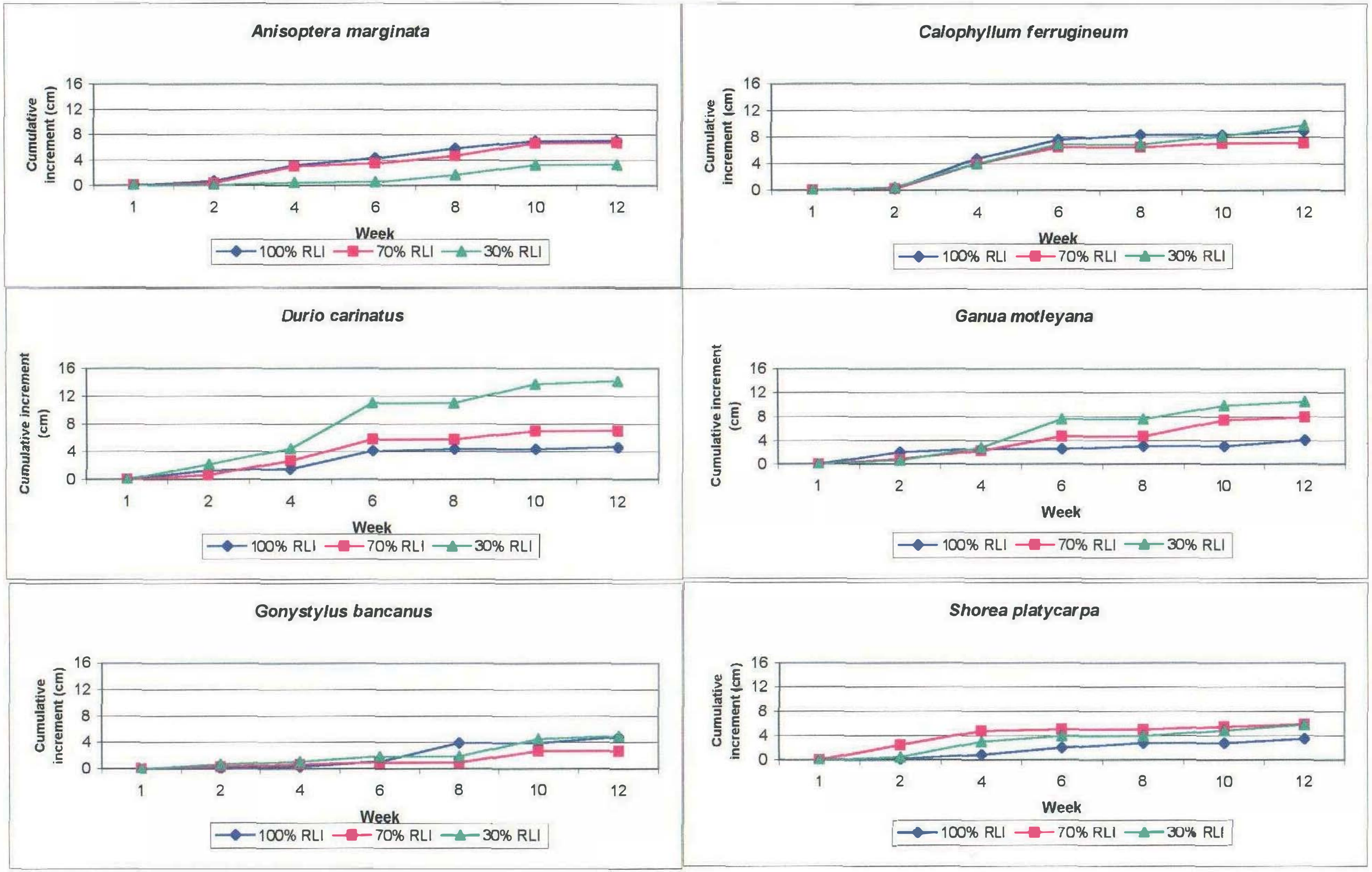


Figure 10: Average cumulative of total height increment (THI) at different relative light intensities (RLI)

4.3 Soil and Foliar Analysis

4.3.1 Chemical and Physical Properties of Peat

Results of the physical and chemical properties of the peat soil samples collected from the study site are given in Tables 16, 17 and 18. The pH in this area is about 4.2 and the average peat depth is about 3.7 m. Vimala (1979) reported that generally pH in peat areas is in the range of 3 – 5. The peat depth in the area is considered moderate as it had been reported that peat depth in NSPSF is between 1.3 m to 7.0 m (Zulkifli *et al.,* 1999).

The sand content in the study site until 30 cm depth is very minimal. It was found that, the silt content decreased while clay increased with increasing depth. According to Wyatt-Smith (1959) peat along west coast of Peninsular Malaysia is formed over the clay.

The highest element content in the peat was organic carbon (C) with more than 40 percent and followed by nitrogen (N), calcium (Ca), phosphorus (P), potassium (K) and magnesium (Mg) for macronutrients. Iron (Fe), aluminium (Al), sodium (Na), manganese (Mn) and zinc (Zn) for the micronutrients. Parbery and Venkatachalam (1964) reported that peat soil in Pekan Nanas, Johore had also high organic C at 42 percent.

Table 16: Some physical properties of peat

Peat depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
0 – 10	Trace	Trace	31	69
10 – 20	1.00	Trace	16	82
20 – 30	Trace	Trace	12	88

Table 17: Macronutrient concentrations of peat in the study site

Peat depth (cm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
0 – 10	0.91	0.09	0.05	0.15	0.03
10 – 20	0.86	0.04	0.04	0.15	0.02
20 – 30	0.68	0.03	0.06	0.14	0.02

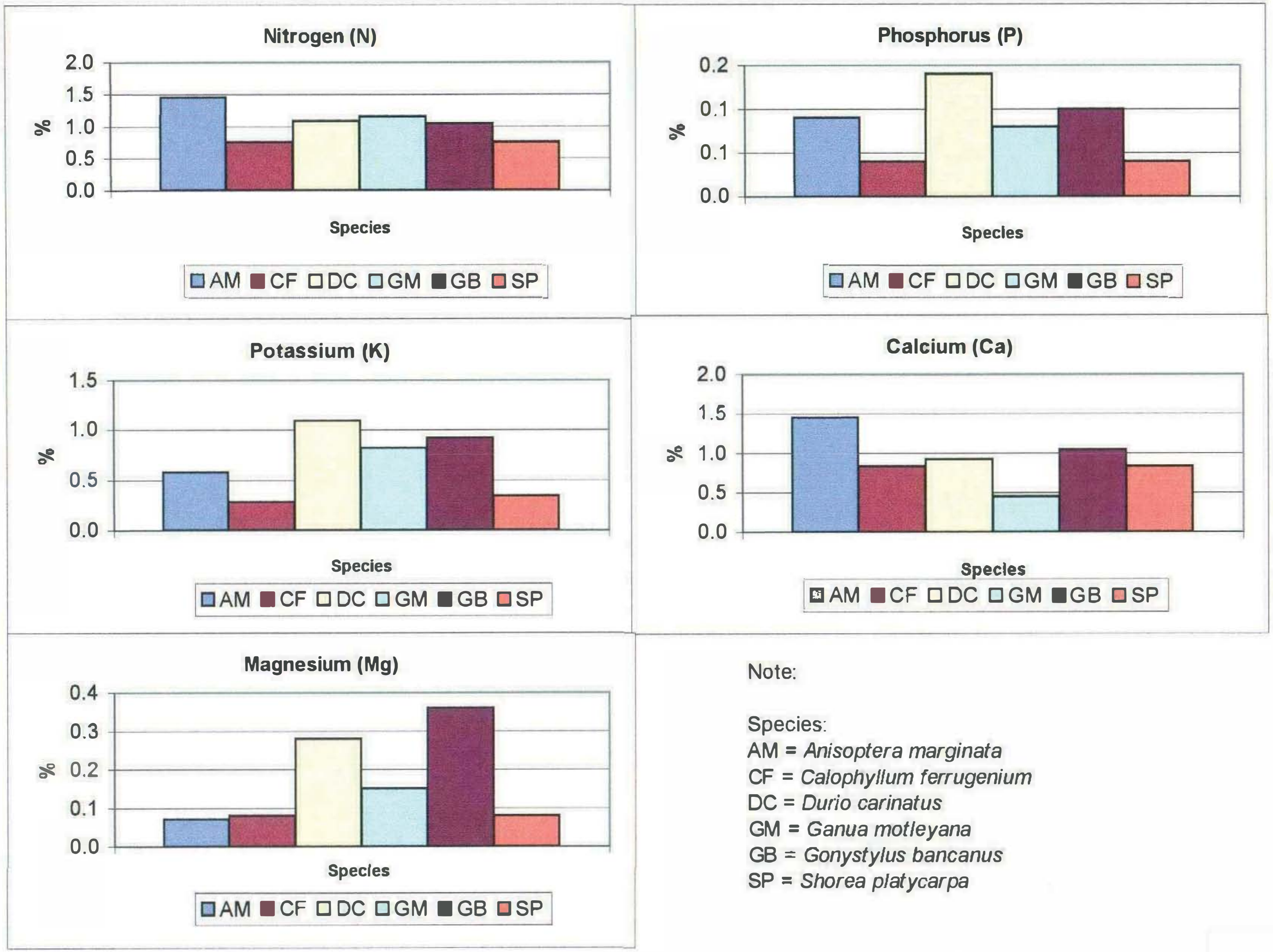
Table 18: Carbon and micronutrient concentrations of peat in the study site

Peat depth (cm)	C (%)	Fe (%)	Al (%)	Na (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	B (ppm)
0 – 10	50.8	3.73	0.5	23.2	9.9	46.9	38.6	Trace
10 – 20	42.5	0.92	0.6	24.1	6.3	27.5	24.2	Trace
20 – 30	49.8	0.58	1.3	23.6	48.5	28.3	75.0	Trace

4.3.2 Foliar Analysis of Seedlings in the Nursery

Results of foliar analysis of seedlings in the nursery are presented in Figures 11 and 12. The results showed some differences in foliar macronutrients of different species at the nursery stage. *D. carinatus* showed a higher concentration of K, Mg, and P, whereas *A. marginata* showed a relatively high concentration of Ca and N, while *G. bancanus* has a relatively high concentration of K and Mg.

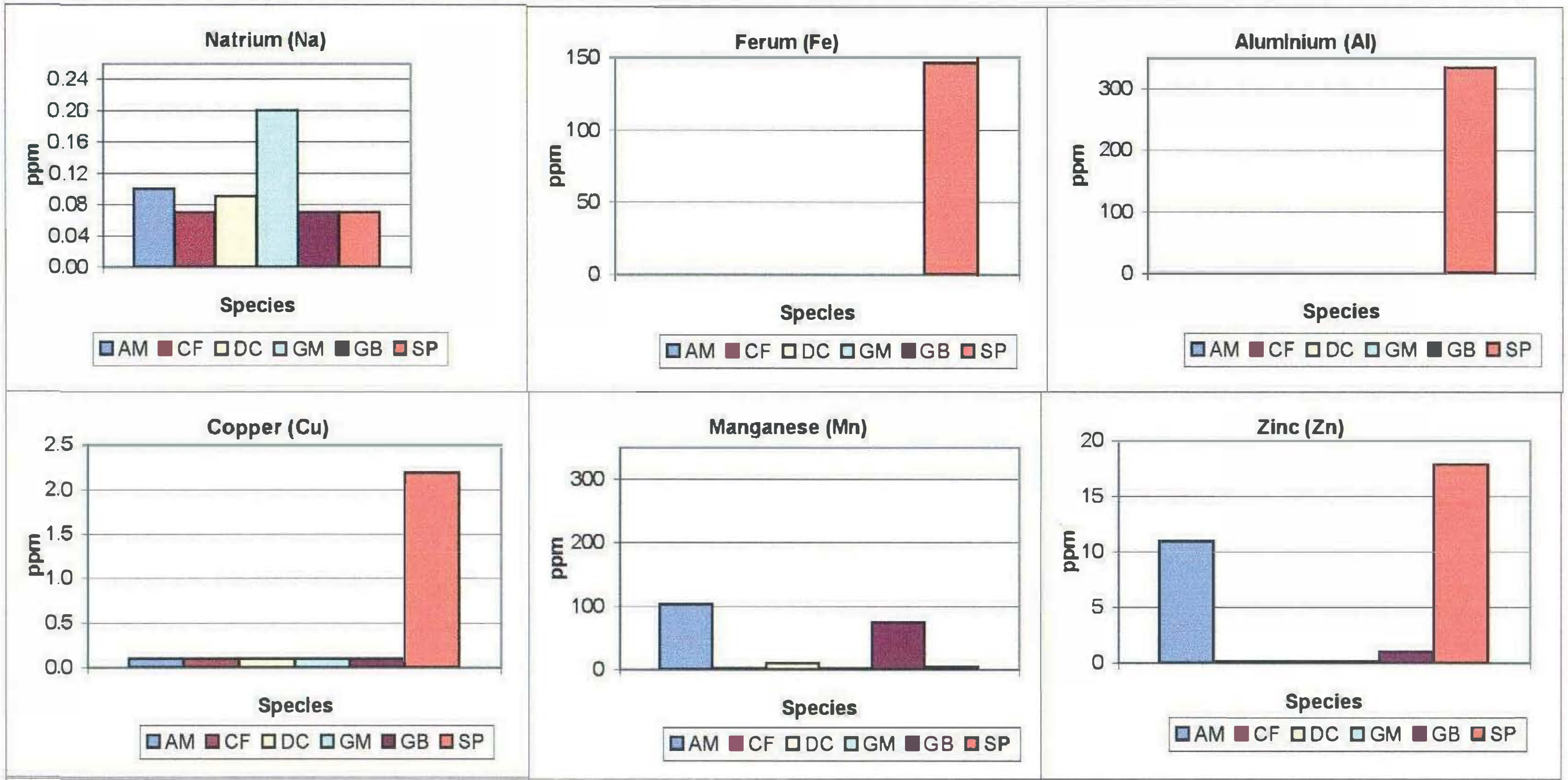
However, the concentration of micronutrients is highly variable between species with *S. platycarpa* has prominently higher concentrations of Cu, Fe, Al and Zn in the leaves. *G. motleyana* and *A. marginata* on the other hand contained higher concentrations of Na and Zn, respectively. Ghazali (1996) in his nursery study found that *Tectona grandis* had higher concentrations of P and K but lower Ca and Mg. It shows that even in the favourable conditions with continuos supply of nutrients, each species has their own preferences of nutrient.

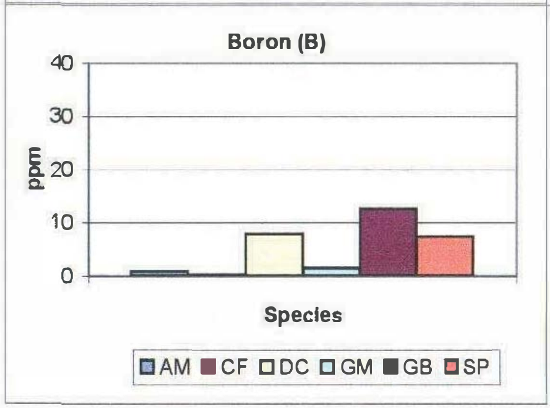


Note:

Species:
AM = *Anisoptera marginata*
CF = *Calophyllum ferrugenium*
DC = *Durio carinatus*
GM = *Ganua motleyana*
GB = *Gonystylus bancanus*
SP = *Shorea platycarpa*

Figure 11: Macronutrient concentrations in the seedlings at nursery stage





Note:

Species:
AM = *Anisoptera marginata*
CF = *Calophyllum ferrugenium*
DC = *Durio carinatus*
GM = *Ganua motleyana*
GB = *Gonystylus bancanus*
SP = *Shorea platycarpa*

Figure 12: Micronutrient concentrations in the seedlings at nursery stage

4.3.3 Foliar Analysis of Seedlings in the Field Planting

i) *Anisoptera marginata*

The status of macronutrient of *A. marginata* three and six months after planting is shown in Figure 13. Generally, status of the macronutrient elements was different between three and six months after planting for all planting techniques except for P that remained consistently the same at three and six month after planting. May be the species is still using P in minimal amount as compared to other elements.

ii) *Calophyllum ferrugineum*

The status of macronutrients for *C. ferrugineum* is shown in Figure 14. The concentrations of macronutrients increased from three and six months after planting for all planting techniques. The concentration of Ca was prominently greater in open planting with mulching, open planting with topsoil and open planting with nurse tree six months after planting. The concentration of P in leaves of *C. ferrugineum* is consistently low even after six months of planting. In general, it shows that the species is increasingly use available nutrients to support it growths.

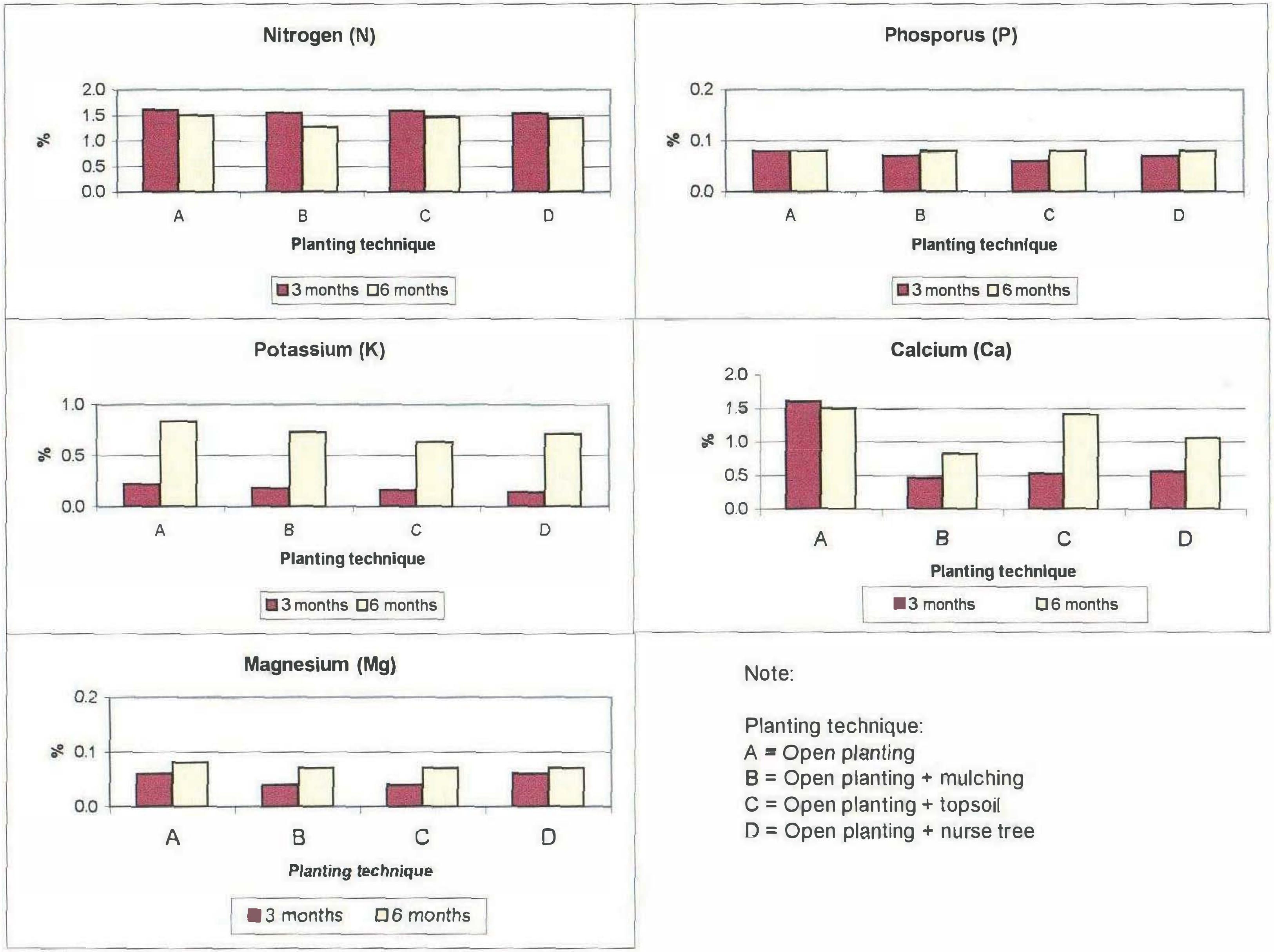


Figure 13: Macronutrient status of *Anisoptera marginata* three and six months after planting

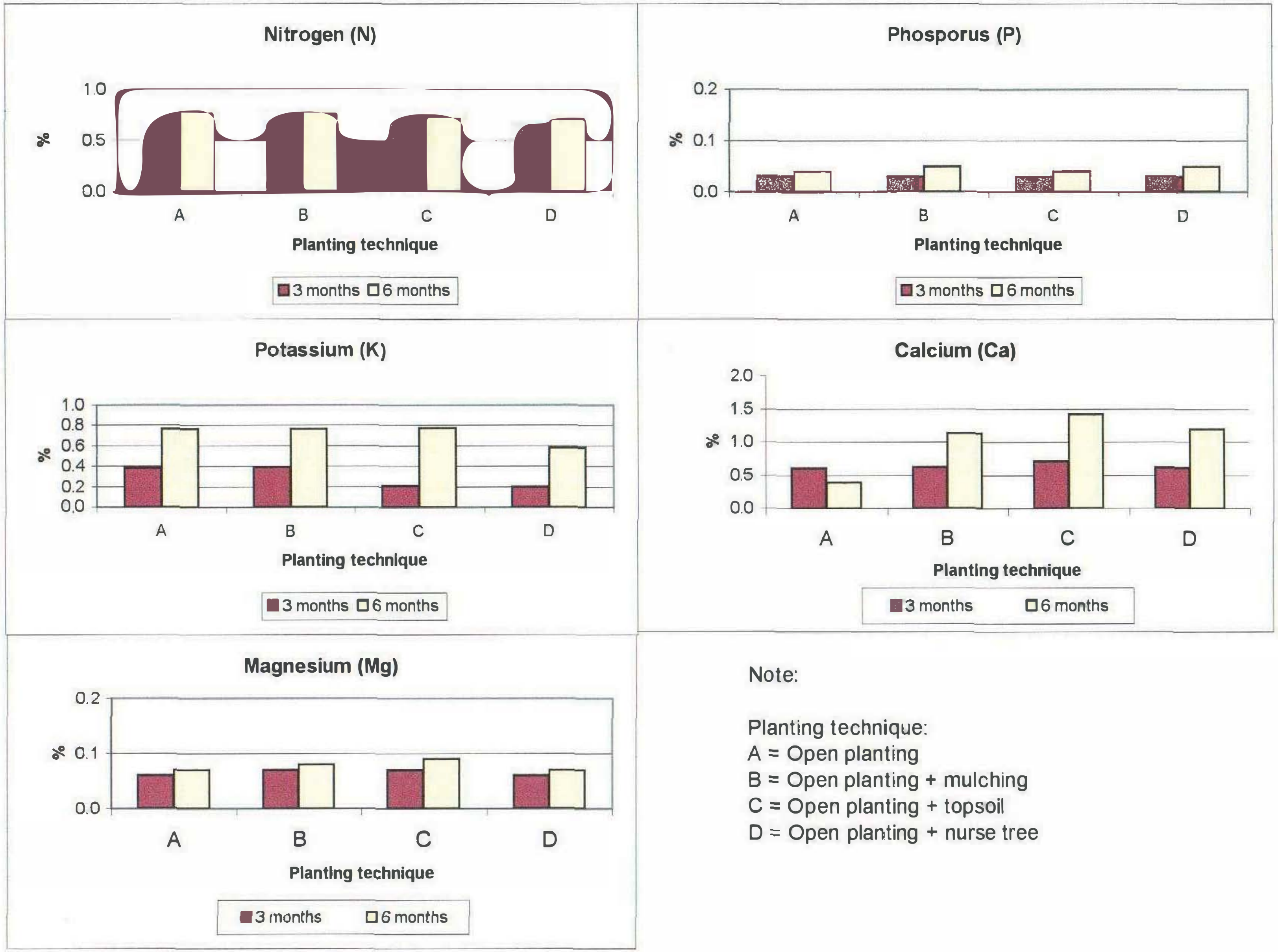


Figure 14: Macronutrient status of *Calophyllum ferrugineum* three and six months after planting

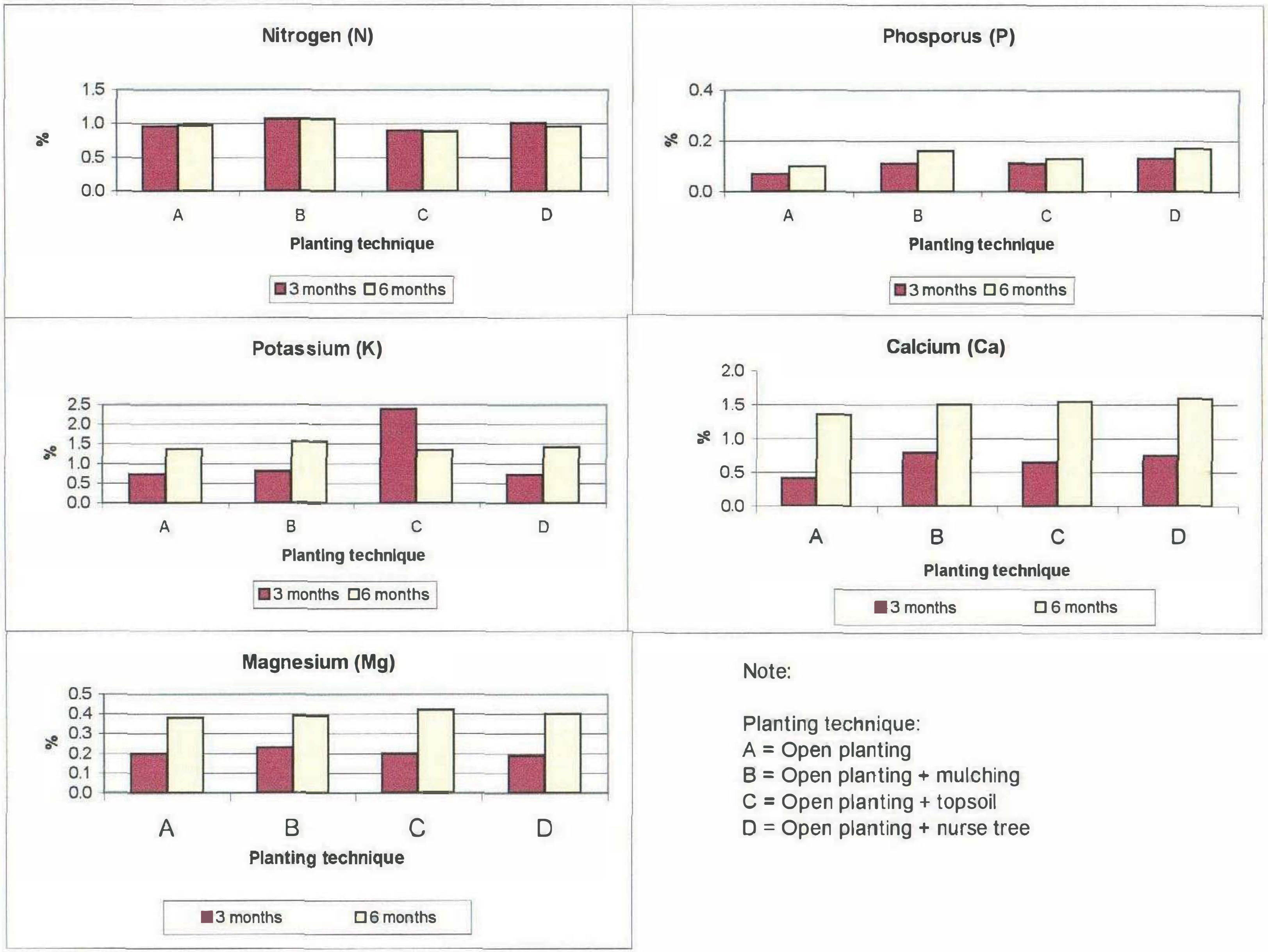
iii) *Durio carinatus*

The status of macronutrients at three and six months after planting for *D. carinatus* is shown in Figure 15. *D. carinatus* showed a temporal increase in the concentration of macronutrient elements for all planting techniques. A temporal increase is particularly prominent for Ca for all the planting techniques. May be the species is starting to use available Ca six months after planting as in the nursery stage it took more K, Mg and P.

The concentration of N is high only in the open planting with mulching with less temporal variations between three and six months after planting. The concentration of N in *D. carinatus* leaves is negligible in other planting techniques.

iv) *Ganua motleyana*

The status of the macronutrients in leaves of *G. motleyana* for the different planting techniques is shown in Figure 16. The temporal variation showed an increase in the concentrations of N, K, Mg and Ca three to six months after planting for all planting techniques. However, the concentration of Ca in open planting technique dropped at the sixth month. The concentration of P is consistently low for all planting techniques, but showed an upward trend with increase in time after planting. May be the species increasingly utilise available P to support it growths.



Note:

Planting technique:
A = Open planting
B = Open planting + mulching
C = Open planting + topsoil
D = Open planting + nurse tree

Figure 15: Macronutrient status of *Durio carinatus* three and six months after planting

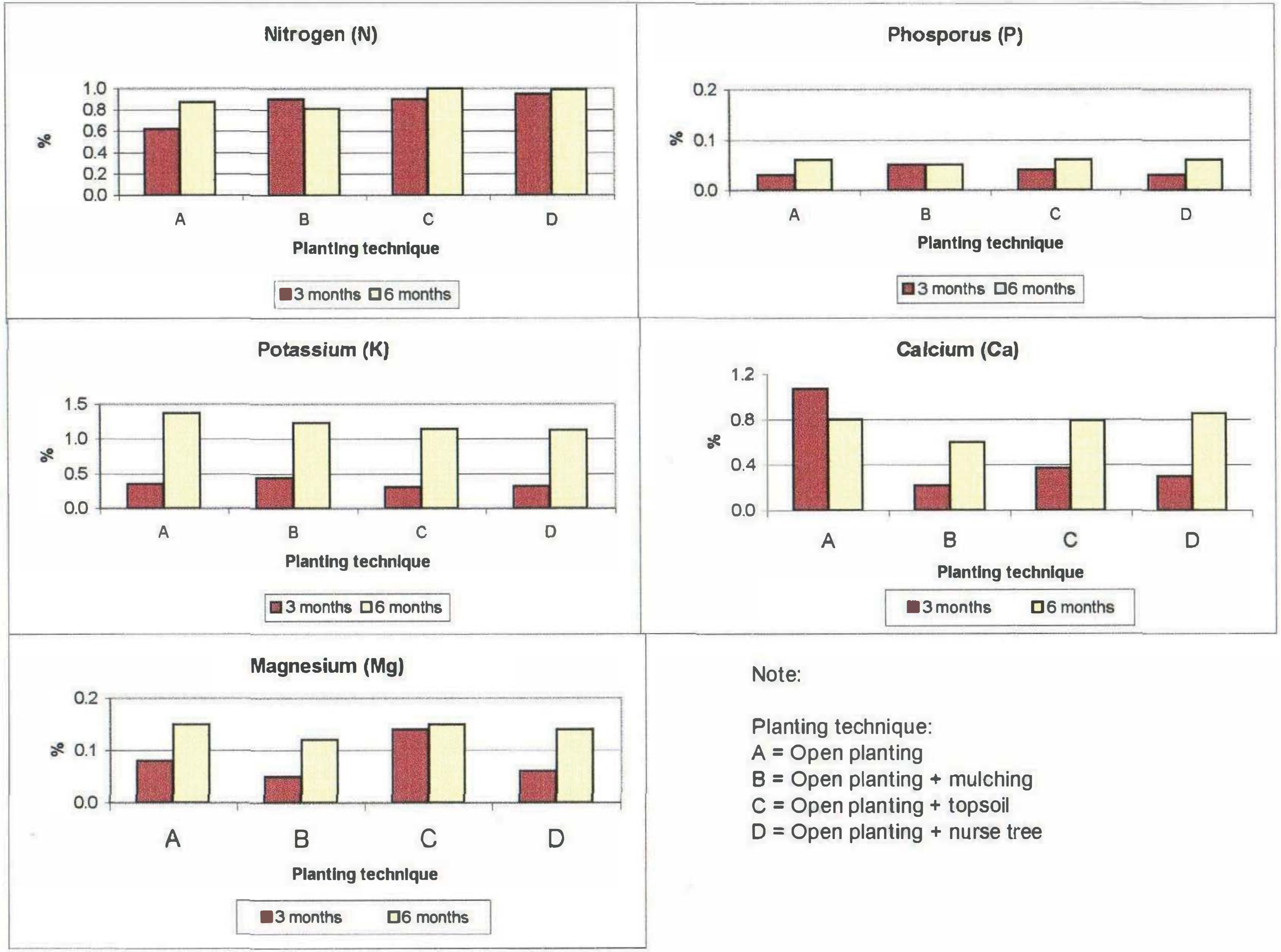


Figure 16: Macronutrient status of *Ganua motleyana* three and six months after planting

v) *Gonystylus bancanus*

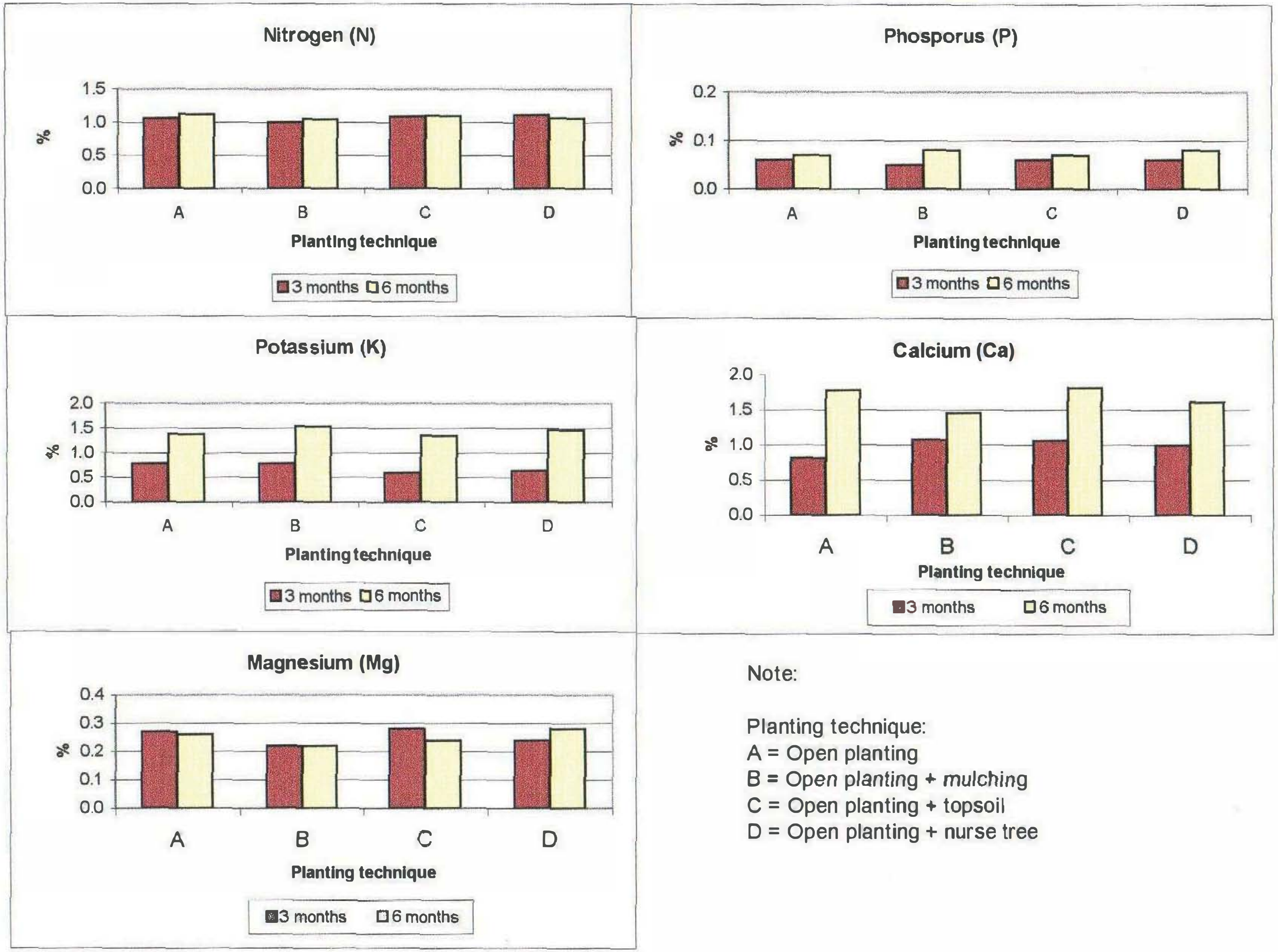
The status of the macronutrients in the leaves of *G. bancanus* after planting is shown in Figure 17. The uptake of major elements by *G. bancanus* is almost the same for all planting techniques with an increase in the concentration on the sixth month after planting.

With the exception of N where the concentration dropped almost to halve six months after planting in the open planting with nurse tree. The concentration of P is relatively low compared to the other major elements for all planting techniques but the level increased with time. In general, it shows that the species is increasingly used available nutrients for their growths.

vi) *Shorea platycarpa*

The status of macronutrients in the leaves of for *S. platycarpa* three and six months after planting is shown in Figure 18. The concentrations of K and Ca increased from three to six months after planting for all planting techniques. However, for N and Mg, the trend is reversed with the concentration decreased at sixth month after planting.

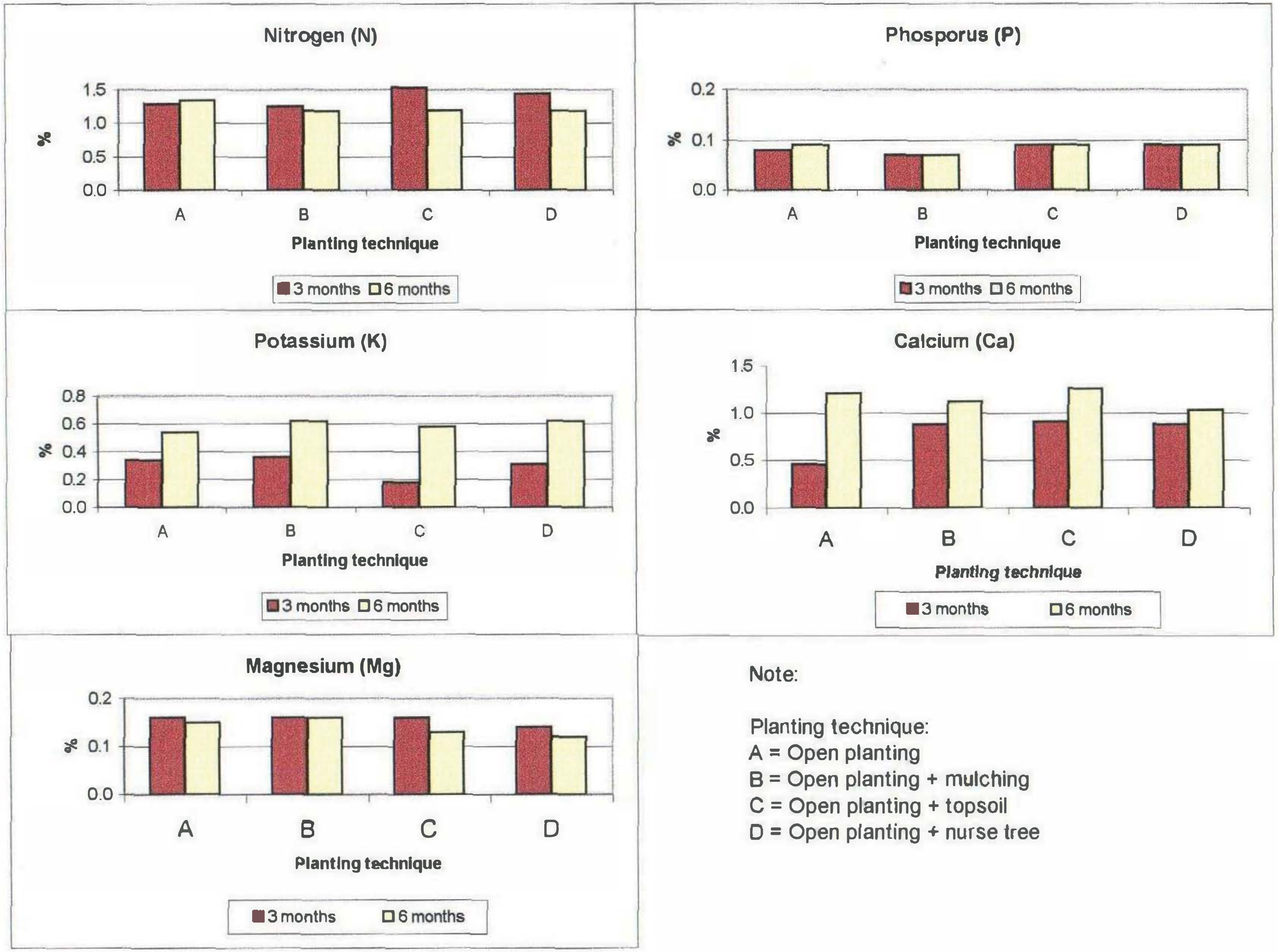
A downward trend in the concentration of N was prominent for open planting with mulching, open planting with topsoil and open planting with nurse tree. Whereas, in case of the Mg, a decline in concentration was observed for the open planting with topsoil and open planting with nurse tree. Meanwhile, the concentration of P remained low at three and six months after planting for all planting techniques. In this case, may be the species is still using P in minimal amount as compared to other elements.



Note:

Planting technique:
A = Open planting
B = Open planting + mulching
C = Open planting + topsoil
D = Open planting + nurse tree

Figure 17: Macronutrient status of *Gonystylus bancanus* three and six months after planting



Note:

Planting technique:
A = Open planting
B = Open planting + mulching
C = Open planting + topsoil
D = Open planting + nurse tree

Figure 18: Macronutrient status of *Shorea platycarpa* three and six months after planting

4.4 Cost Assessments

4.4.1 Total Planting Costs

Estimation of costs for the field planting is illustrated in Table 19. The total cost of the field planting in an area of 1.55 ha is about RM 15,929.20. The total costs incurred constitute wages for workers/labours, transportation and materials used for planting and plot maintenance with RM 6,336.00, RM 7,043.20 and RM 2,550.00 or 40 percent, 44 percent and 16 percent out of the total costs, respectively.

It is important to point that the cost for research work is expected to be higher due to additional materials needed during the establishment and monitoring of research plots. The cost is expected to be much lower if any of the planting technique is recommended for implementation on commercial scale.

Table 19: Estimation costs of the field planting

No.	Items	RM
1.	Wages for workers (labours)	6,336.00
2.	Transportation and materials used:	
	▪ Transportation	790.00
	▪ Planting materials (RM 3.30/seedling)	3,801.60
	▪ Mulching materials (RM 1.20/seedling)	345.60
	▪ Topsoil (RM 1.00/seedling)	288.00
	▪ Nurse tree (RM 6.00/sapling)	1,728.00
	▪ Fertiliser	90.00
	Sub-total	7,043.20
3.	Maintenance (RM 850.00 x 3 times/year)	2,550.00
	Total	**15,929.20**

4.4.2 Cost of Planting per Seedling

Comparison of planting cost per seedling for each planting technique is shown in Table 20. The comparison is used to determine the cost incurred by different planting techniques. The cost of planting techniques varies from the lowest to highest in the following order; open planting, open planting with mulching, open planting with topsoil and open planting with nurse tree. The additional cost of open planting compared to other planting techniques is 20 percent, 25 percent and 124 percent, respectively.

Table 20: Estimation costs per seedling based on planting technique

Planting Technique	Cost of planting/seedling					
	Seedling + transportation (RM)	Fertiliser (RM)	Labour (RM)	Additional materials (RM)	Total (RM)	Additional (%)
Open planting	4.00	0.08	4.00	-	8.08	-
Open planting + mulching	4.00	0.08	4.40	1.20	9.68	20
Open planting + topsoil	4.00	0.08	5.00	1.00	10.08	25
Open planting + nurse tree	4.00	0.08	8.00	6.00	18.08	124

CHAPTER FIVE

DISCUSSION

The study shows that raising planting materials of PSF species could be done using normal procedures as applied to other inland forest species. Besides collection of seed which is a common practice, collection of wildings and vegetative propagation via stem cuttings are also possible options to be used to raise planting materials. The management aspects of PSF species in the nursery are also similar as practised with other inland forest species.

The methods used by Aminah (1991), Mohamad Lokmal *et al*. (1992) and Aminah *et al.* (1997) to raise planting materials of inland forest species is applicable to the PSF species. The findings from the study indicated that the lack of planting materials to rehabilitate degraded PSF could easily be overcome.

The field planting showed that open planting has the highest survival rate compared to other planting techniques. Besides open planting with topsoil and open planting with nurse tree that also has high survival rate, open planting with mulching was found to produce the lowest seedling survival. The survival for the open planting with mulching is significantly different from the other planting techniques. This shows that open planting with mulching is not suitable to be used as a planting technique in rehabilitating degraded PSF.

The low survival in the open planting with mulching technique could be due to two main reasons. The first and probably the most important reason is that fresh empty fruit bunches (EFB) of oil palm used as mulching materials are found to be very attractive to wild boar. The animal digs the peat under the mulching materials in search of food. This damaged the planted seedlings. It was observed that only the seedlings planted by this planting technique attracted the wild boar. The fried-oil smell emitted by the fresh EFB could probably be a strong factor that attracts the animal.

Another reason is that the fresh EFB produced hot vapour during the decaying process. The hot vapour caused leaves of the seedlings to dry and often lead to mortality of planted seedlings. Therefore, fresh EFB of oil palm is not suitable to be used as a mulching material in PSF. However, dried EFB mulching mat has a potential as a replacement. Wan Asma and Wan Rasidah (1998) reported that dried EFB mulching mat is suitable to be used as mulching materials for seedlings of *Tectona grandis* (Teak). However, their study was conducted in non-peat swamp area. Further studies need to be conducted to test the suitability of the dried mulching mat in the peat swamp area.

Although the results of using mulching are not encouraging in this planting experiment, mulching was reported as a good treatment to be used in rehabilitating degraded areas. Applegate and Robson (1994) reported that using bagasse as mulching was the best planting technique to rehabilitate degraded lands in coastal lowlands of Northern Australia. Nik Muhamad *et al.* (1994) also used living mulching (peanut and *Setaria* grass) to rehabilitate ex-tin mining land by agroforestry practise in Semenyih, Selangor. Mulching material is also used in 'Miyawaki's forest rehabilitation technique' that reported gave good growth results (Ismail and Othman, 1992). It shows that mulching could contribute to better tree growth in degraded lands, but using appropriate mulching materials at different sites is a very important factor to be considered.

Based on foliar analysis, it was found that there are no differences in the status of macronutrient concentration in leaves of planted seedlings among the different planting techniques. This means that the different planting techniques do not affect the nutrient intake by planted seedlings at least for a period of six months after planting. Maybe in early stage of establishment, the planted seedlings is still using nutrient available in their potting media. Analysis of peat samples collected from the study site also found that the concentrations of N, P, K and Ca were the most abundant. Nevertheless, the amount of nutrient intake was different among the species. For example, *A. marginata* has higher concentration of Ca compared to *C. ferrugenium* that has more N. This is probably the best strategy for PSF tree species to minimise competition from the limited nutrient reserve for optimising their growth.

Among the four planting techniques, open planting was found to be the lowest in terms of planting cost, whereas open planting with nurse tree incurred the highest cost with additional 124 percent compared to the open planting. The cost of open planting with nurse tree was very high because the nurse trees are expensive (*Hopea odorata* with at least 2 m height cost about RM 6.00/sapling). Moreover, the cost of labour is also higher because more seedlings need to be planted for this technique.

Nurse trees were reported to give high survival results in rehabilitating highly degraded areas (Wan Yusoff and Abd. Rahman, 1997; Mohd. Basri, 2001). However, the technique used in this experiment is totally different with that used by Mohd. Basri (2001) or reported by Wan Yusoff and Abd. Rahman (1997). Mohd. Basri (2001) used *Acacia mangium*, a fast-growing species as a nurse tree that was planted two years earlier before planting seedlings of indigenous species. Wan Yusoff and Abd. Rahman (1997) reported that indigenous timber species was successfully grow when planted under existing *A. mangium* plantation.

Besides that, existing areas that are dominated by secondary forest species especially *Macaranga spp.* can also be used as a nurse tree. Awang Sham and Garcia (2001) reported an average of 87 percent survival of dipterocarps and non-dipterocarps species three months after planting under *Macaranga spp*. infested area in Kalabakan FR, Sabah.

Meanwhile, the open planting technique with topsoil did not promote better growth of seedlings as compared to the other planting techniques for at least eight months after planting. Logically, the topsoil will assist newly planted seedlings to continue growing under the same conditions of planting media provided in the polybag and reduce planting shock under harsh environment. Eight months of observation is probably not sufficient for the root system to fully develop and occupy the whole planting hole. It is expected that the topsoil may be useful in assisting the seedlings to grow better in the long run.

Although open planting with topsoil and nurse tree produced high survival, they incurred a higher cost of planting. Therefore, the best planting technique for rehabilitating highly degraded PSF is the open planting. Furthermore, the open planting technique is practically the easiest method to be implemented. Suhaili (1986) also found that the open planting technique is practically the easiest and suitable method for rehabilitating degraded forests especially using light demanding species.

Results from light intensity study conducted in the nursery showed that all seedlings had good survival both in the shade chambers and open area. This indicates that in early establishment the species could grow in the light condition ranging between 30 – 100 percent relative light intensity (RLI). However, basal diameter increment (BDI) and total height increment (THI) of all species were significantly affected by different light intensities. It shows that in order to have better growth performance, tree species have their own preference and some could tolerate wider range of light intensity.

In the field planting where the area received 100 percent RLI, *G. motleyana* was found to have the highest survival with 92.19 percent eight months after planting. Based on the results of the light intensity study, it was found that *G. motleyana* prefers an area with light conditions of 70 – 100 percent RLI (moderate to open area) for both BDI and THI. The second best performance in terms of survival was *S. platycarpa* with 79.69 percent and the species was also found to adapt very well under a wide range of light intensity.

A. marginata was third place with a survival of 79.17 percent and also grows well in light conditions of 70 – 100 percent RLI. A study by Otsamo *et al.* (1996) in a planting trial on grassland area also found that *A. marginata* was the best among dipterocarps species with 80 percent survival two years after planting. This is a clear indication that *A. marginata* is suitable for planting in open areas.

One more species that showed good survival performance was *G. bancanus* with 73.44 percent and the species could adapt well in an open area or light conditions of 100 percent RLI. This finding is in line with results of the planting experiment by Shamsudin and Ismail (1999) who found 58 percent of *G. bancanus* survived six years after planting in an open area with an average growth of dbh increment at 0.8 cm year^{-1} and the total height increment of 52 cm year^{-1}.

However, the two species; *D. carinatus* and C. *ferrugineum* had low survival with only 66.15 percent and 56.25 percent, respectively eight months after planting. Furthermore, both species prefer low to moderate light conditions of 30 – 70 percent RLI. Both species could be considered as shade tolerant species. This indicates that *D. carinatus* and C. *ferrugineum* are not suitable for planting in open areas such as the highly degraded PSF. Nevertheless, both species are expected to grow better in moderate degradation class areas (Shamsudin *et al.*, 1997; Anon, 1997a; Woon and Mohd. Parid, 1999).

The other two parameters measured, that is BDI and THI are not significantly different both for different planting techniques and species. It shows that BDI and THI for all species planted were not affected by the different planting techniques eight months after planting. These two parameters may produce significant results over long term monitoring.

Therefore, based on the results of the four species used in the field planting; *G. motleyana, S. platycarpa, A. marginata* and *G. bancanus* are found suitable for rehabilitating highly degraded PSF. All four species could be considered as light demanding species because they survived well in open areas. However, the issue of supply of planting material of the species needs to be considered before the species can be used for large-scale rehabilitation program.

With the current state of knowledge, only *G. bancanus* was reported to flower and fruit more regularly in the primary PSF (Shamsudin and Ng, 1995; Shamsudin, 1996b). Basically, seeds and wildings of *G. bancanus* can be collected every year particularly in the east coast of Peninsular Malaysia. Besides *G. bancanus*, none of the other three species was observed to flower or fruit regularly except *A. marginata* that was reported to produce fruits in July/August 1997 at the Bebar FR (Ismail and Shamsudin, 1999).

The current supply of *G. motleyana, S. platycarpa* and *A. marginata* planting materials depends entirely on wildings. Therefore sufficient collection of wildings depends on regular flowering and fruiting of a particular species. It is therefore crucial to know flowering and fruiting behaviours of the species to ascertain the most appropriate time to collect seeds and wildings. Appanah and Weinland (1993); Mohd. Afendi and Ang (1994) observed that indigenous tropical forest species may flower and fruit at an interval of three to six years. Therefore, based on present situation, the best species to be used for rehabilitating degraded PSF is *G. bancanus*.

Nevertheless, besides appropriate planting technique and suitable species, accessibility to logged-over PSF in order to conduct forest rehabilitation is also crucial. In fact according to Shamsudin and Aziah (1992), problem of accessibility in PSF needs to be resolved first before embarking rehabilitation programs. In the past, it has not become customary to carry out any silvicultural treatments including rehabilitation in logged-over PSF. The main reason is probably due to inaccessibility of the area after logging because these areas are mostly located in the interior parts of PSF.

The construction and maintenance of either railways or canals as the main transportation routes into these areas depend entirely on loggers. So far no attempts have been made to maintain either canals or railways for the purpose of carrying out the post-felling silvicultural treatments (Shamsudin and Aziah, 1992). Loggers will either remove railway lines as they moved to new logging areas or they are required to fill back canals with earth after logging is completed.

It is suggested that railways and canals should be maintained by forestry department to be used for the post-felling silvicultural treatments. Post-felling inventory should also be conducted as soon as possible after logging operations completed so that the silvicultural treatments can be carried out early to avoid colonisation by pioneer species especially in the transportation routes.

CHAPTER SIX

CONCLUSIONS

Conclusions made from the studies are as follows:

1. It was found that the planting materials of PSF species could be raised through seeds, wildings and vegetative propagation via stem cutting using normal procedures applied to other inland forests species.

2. Management aspects of PSF species in the nursery are also similar to other inland forest species.

3. Open planting was found to be the best planting technique for rehabilitating the degraded PSF (degradation Class I).

4. Four indigenous species of PSF suitable to be used for rehabilitating the highly degraded PSF are *Ganua motleyana, Shorea platycarpa, Anisoptera marginata* and *Gonystylus bancanus*. However, under the current situation, the best species to be used for rehabilitating degraded PSF is *G. bancanus*.

5. Forest fire was found to be the main threat to degraded PSF especially in areas dominated by grassland.

The following recommendations can be made from this study:

1. Large-scale rehabilitation of logged-over PSF can be practised because planting materials of valuable timber species can be raised easily through seeds, wildings and vegetative propagation via stem cuttings.

2. Nursery for raising planting materials should be established. The nursery will ensure continuous supply and help to reduce the cost of planting materials for rehabilitation programs.

3. The planting experiment in moderate degraded PSF areas also need to be conducted in order to have a more detailed and complete information on suitable techniques for rehabilitating moderately degraded PSF.

4. The planting program should take into account other important PSF tree species. Source plants must be established in the nursery for *Shorea teysmanniana* (Meranti bunga) and *Shorea uliginosa* (Meranti bakau) where the natural population of seedlings in the wild is very low.

5. Sufficient seed production area in the PSF should be allocated, especially in Selangor. It has been a tough experience in getting planting materials from PSF in Selangor because most of the areas have been logged.

6. More regular phenological monitoring of commercial PSF species should be conducted to understand flowering and fruiting behaviours. The information will help to determine the appropriate timing to collect seeds and wildings.

7. Specific studies need to be conducted to determine appropriate methods of preventing and controlling forest fire in PSF particularly in highly degraded areas. The study is very crucial as many of the highly degraded PSF are susceptible to forest fire especially during a prolonged dry period.

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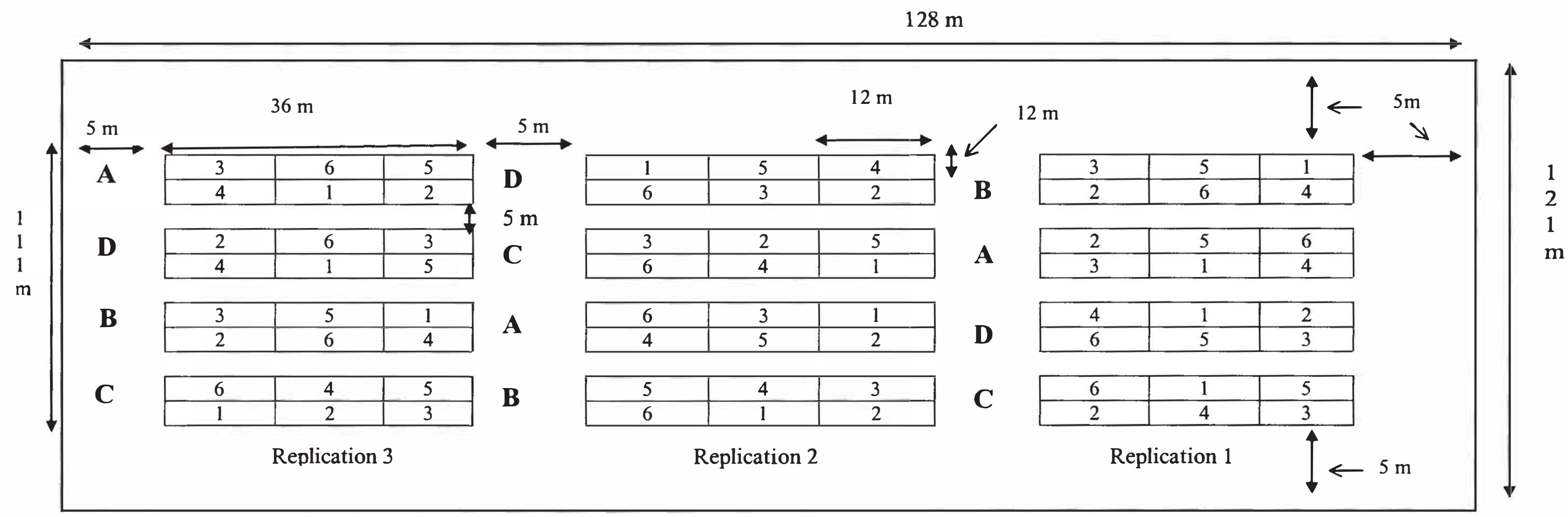
Appendix A

Planting design of the experiment *



* not based on scale

N

Legend

Spesies:
1: *Anisoptera marginata*
2: *Calophyllum ferrugenium*
3: *Durio carinatus*
4: *Ganua motleyana*
5: *Gonystylus bancanus*
6: *Shorea platycarpa*

Planting technique:
A: Open planting
B: Open planting + mulching
C: Open planting + topsoil
D: Open planting + nurse tree

Appendix B

Average of survival in different planting techniques

Species	Planting Technique	Aug-99 (%)	Sep-99 (%)	Oct-99 (%)	Nov-99 (%)	Dec-99 (%)	Jan-00 (%)	Feb-00 (%)	Mar-00 (%)
A. marginata	A	100	92	92	92	88	85	81	81
	B	100	79	69	67	67	67	63	63
	C	100	96	96	96	96	96	94	94
	D	100	94	88	83	83	83	81	81
C. ferrugenium	A	100	88	85	85	79	67	63	63
	B	100	69	63	58	50	46	44	44
	C	100	92	90	83	73	67	63	56
	D	100	92	85	85	77	73	69	63
D. carinatus	A	100	94	94	94	85	81	75	75
	B	100	48	46	44	42	42	38	31
	C	100	100	92	92	90	88	88	81
	D	100	90	90	90	88	85	81	75
G. motleyana	A	100	100	100	100	100	100	100	100
	B	100	88	77	77	77	77	75	75
	C	100	100	100	100	100	100	100	100
	D	100	96	96	96	96	96	94	94
G. bancanus	A	100	100	100	96	96	94	94	94
	B	100	67	50	48	48	48	38	31
	C	100	100	100	100	96	94	88	88
	D	100	94	90	90	90	88	81	81
S. platycarpa	A	100	96	96	96	96	96	94	94
	B	100	63	60	58	58	58	56	50
	C	100	100	92	90	88	81	81	81
	D	100	94	94	94	94	94	94	94

Note:

A = Open planting B = Open planting + mulching C = Open planting + topsoil D = Open planting + nurse tree

Appendix C

Average cumulative of basal diameter increment (in mm) in different planting techniques

Species	Planting Technique	Aug-99	Sep-99	Oct-99	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00
A. marginata	A	0.00	1.08	1.61	1.93	2.13	2.41	2.92	3.37
	B	0.00	0.47	1.20	1.65	2.07	2.42	2.94	3.32
	C	0.00	1.45	2.30	2.77	3.01	3.49	4.00	4.31
	D	0.00	1.06	1.39	1.97	2.41	2.82	3.42	4.39
C. ferrugenium	A	0.00	0.85	1.43	1.76	2.40	3.01	3.58	4.13
	B	0.00	0.88	1.60	2.19	2.70	3.14	3.20	3.23
	C	0.00	1.33	2.08	2.63	3.03	3.76	4.05	4.36
	D	0.00	0.84	1.18	1.75	2.26	2.76	3.79	4.30
D. carinatus	A	0.00	0.97	1.54	2.01	2.38	2.78	3.38	4.14
	B	0.00	0.49	0.82	1.17	1.51	1.68	2.17	3.24
	C	0.00	1.35	2.34	2.57	2.90	3.30	4.09	4.54
	D	0.00	1.62	2.04	2.48	2.77	3.13	3.84	4.10
G. motleyana	A	0.00	1.11	1.61	1.97	2.33	2.60	3.10	3.67
	B	0.00	0.71	1.48	2.09	2.47	2.90	3.86	4.40
	C	0.00	1.61	2.42	2.63	3.18	3.78	4.81	5.34
	D	0.00	1.15	1.56	1.87	2.36	2.77	3.40	3.83
G. bancanus	A	0.00	1.10	1.61	2.11	2.39	2.75	3.20	3.95
	B	0.00	0.28	1.30	1.50	1.83	1.99	2.53	3.13
	C	0.00	1.45	2.28	2.71	2.96	3.28	4.10	4.46
	D	0.00	1.52	1.93	2.48	2.73	3.15	3.92	4.31
S. platycarpa	A	0.00	1.40	2.23	2.68	3.33	4.08	5.01	5.76
	B	0.00	0.74	1.91	2.91	3.25	4.01	4.70	5.05
	C	0.00	1.34	2.48	2.90	3.22	4.08	4.73	5.05
	D	0.00	1.93	2.39	2.78	3.26	4.16	5.04	5.51

Note:

A: Open planting B: Open planting + mulching C: Open planting + top soil D: Open planting + nurse tree

Appendix D

Average cumulative of total height increment (in cm) in different planting techniques

Species	Planting Technique	Aug-99	Sep-99	Oct-99	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00
A. marginata	A	0.00	3.92	4.52	6.08	6.89	9.94	11.18	12.76
	B	0.00	1.76	3.32	5.38	5.96	7.85	9.82	11.73
	C	0.00	2.80	3.79	4.79	6.67	9.95	10.92	11.52
	D	0.00	1.15	3.17	5.66	5.69	9.79	11.00	11.53
C. ferrugenium	A	0.00	1.82	2.68	5.14	6.48	7.16	8.08	8.54
	B	0.00	3.22	5.97	8.88	10.45	11.84	13.22	14.83
	C	0.00	2.07	2.85	5.07	6.82	7.33	8.00	8.77
	D	0.00	2.92	5.08	7.91	9.28	11.12	13.14	14.99
D. carinatus	A	0.00	2.55	4.75	6.53	9.17	11.08	13.98	17.05
	B	0.00	1.43	2.06	2.83	4.62	6.84	8.40	9.11
	C	0.00	2.77	4.59	5.75	9.09	12.00	17.10	20.59
	D	0.00	1.06	1.71	2.59	3.56	6.44	7.59	9.06
G. motleyana	A	0.00	3.72	4.33	5.17	10.28	13.44	16.50	18.83
	B	0.00	2.43	3.30	5.15	6.96	7.80	8.88	13.29
	C	0.00	2.65	4.50	4.99	7.61	10.40	12.92	14.26
	D	0.00	2.61	3.15	4.10	5.28	6.69	7.55	9.90
G. bancanus	A	0.00	2.06	4.17	6.75	7.22	8.14	8.58	12.58
	B	0.00	3.09	5.65	10.87	12.28	14.72	16.65	18.43
	C	0.00	2.79	4.37	5.41	6.21	6.72	7.29	8.47
	D	0.00	1.96	4.60	6.71	8.07	11.40	14.01	16.03
S. platycarpa	A	0.00	3.23	4.12	4.84	5.89	11.64	12.12	13.28
	B	0.00	2.63	3.33	5.44	6.15	6.96	7.58	13.70
	C	0.00	1.96	2.98	3.85	5.85	9.10	9.60	11.03
	D	0.00	2.80	3.96	4.98	6.63	9.59	11.02	12.89

Note:

A: Open planting
B: Open planting + mulching
C: Open planting + top soil
D: Open planting + nurse tree

Appendix E

Average cumulative of basal diameter increment (in mm) in different relative light intensity (RLI)

Species	RLI	Week 1	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12
A. marginata	100%	0.00	0.19	0.37	0.64	0.79	1.18	1.52
	70%	0.00	0.01	0.17	0.39	0.55	1.20	1.20
	30%	0.00	0.07	0.21	0.56	0.63	1.03	1.03
C. ferrugenium	100%	0.00	0.22	0.43	0.57	1.07	1.07	1.64
	70%	0.00	0.23	0.40	0.48	0.48	0.75	1.36
	30%	0.00	0.24	0.33	0.37	0.79	0.79	1.09
D. carinatus	100%	0.00	0.16	0.43	0.49	0.63	0.63	0.94
	70%	0.00	0.26	0.61	0.68	0.68	0.92	1.21
	30%	0.00	0.19	0.31	0.42	0.69	0.69	0.80
G. motleyana	100%	0.00	0.07	0.26	0.28	0.84	0.84	0.85
	70%	0.00	0.23	0.43	0.45	0.45	0.64	1.30
	30%	0.00	0.26	0.42	0.50	0.90	0.90	1.27
G. bancanus	100%	0.00	0.20	0.51	0.55	0.99	0.99	1.22
	70%	0.00	0.12	0.47	0.52	0.52	0.79	0.94
	30%	0.00	0.16	0.38	0.54	0.72	0.72	0.87
S. platycarpa	100%	0.00	0.32	0.64	0.65	1.64	1.64	2.13
	70%	0.00	0.17	0.46	0.56	0.56	1.08	1.74
	30%	0.00	0.14	0.30	0.44	1.09	1.09	1.36

Appendix F

Average cumulative of total height increment (in cm) in different relative light intensity (RLI)

Species	RLI	Week 1	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12
A. marginata	100%	0.00	0.69	3.19	4.25	5.81	6.94	6.94
	70%	0.00	0.40	3.00	3.45	4.65	6.65	6.65
	30%	0.00	0.00	0.45	0.50	1.60	3.25	3.25
C. ferrugenium	100%	0.00	0.20	4.70	7.60	8.35	8.35	8.90
	70%	0.00	0.20	4.00	6.45	6.45	7.10	7.10
	30%	0.00	0.40	4.00	6.90	6.90	8.15	9.80
D. carinatus	100%	0.00	1.30	1.45	4.10	4.35	4.35	4.65
	70%	0.00	0.60	2.65	5.75	5.75	6.95	6.95
	30%	0.00	2.15	4.40	11.00	11.00	13.70	14.15
G. motleyana	100%	0.00	2.00	2.54	2.54	3.08	3.08	4.08
	70%	0.00	0.88	2.26	4.70	4.70	7.45	7.89
	30%	0.00	0.60	2.80	7.60	7.60	9.87	10.47
G. bancanus	100%	0.00	0.00	0.30	1.05	3.85	3.85	4.80
	70%	0.00	0.25	0.60	0.95	0.95	2.70	2.70
	30%	0.00	0.65	1.05	1.85	1.85	4.50	4.90
S. platycarpa	100%	0.00	0.15	0.85	2.00	2.75	2.75	3.45
	70%	0.00	2.45	4.75	5.00	5.00	5.40	5.80
	30%	0.00	0.45	3.00	3.90	3.90	4.85	5.75

Appendix G

Macronutrient status (in percent) in the nursery

Species	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)
A. marginata	1.45	0.09	0.58	0.39	0.07
C. ferrugineum	0.75	0.04	0.28	0.83	0.08
D. carinatus	1.08	0.14	1.09	0.92	0.28
G. motleyana	1.15	0.08	0.82	0.45	0.15
G. bancanus	1.04	0.10	0.92	1.04	0.36
S. platycarpa	0.75	0.04	0.28	0.83	0.08

Appendix H

Micronutrient status (in ppm) in the nursery

Species	Natrium (Na)	Ferum (Fe)	Aluminium (Al)	Copper (Cu)	Manganese (Mn)	Zinc (Zn)	Boron (B)
A. marginata	0.10	0.10	0.10	0.10	102.50	10.90	0.80
C. ferrugineum	0.07	0.10	0.10	0.10	2.40	0.10	0.20
D. carinatus	0.09	0.10	0.10	0.10	9.50	0.10	7.80
G. motleyana	0.20	0.10	0.10	0.10	2.30	0.10	1.50
G. bancanus	0.07	0.10	0.10	0.10	74.60	1.00	12.60
S. platycarpa	0.07	146.00	334.00	2.19	4.20	17.80	7.40

Appendix I

Macronutrient status (in percent) of *Anisoptera marginata* three and six months after planting

	Planting	Technique		
Nitrogen (N)	Open planting	Open planting + mulching	Open planting + topsoil	Open planting + nurse tree
Month-3	1.60	1.54	1.58	1.53
Month-6	1.50	1.27	1.46	1.44
Phosphorus (P)				
Month-3	0.08	0.07	0.06	0.07
Month-6	0.08	0.08	0.08	0.08
Potassium (K)				
Month-3	0.22	0.18	0.16	0.14
Month-6	0.83	0.73	0.63	0.71
Calcium (Ca)				
Month-3	1.60	0.46	0.53	0.56
Month-6	1.50	0.82	1.41	1.05
Magnesium (Mg)				
Month-3	0.06	0.04	0.04	0.06
Month-6	0.08	0.07	0.07	0.07

Appendix J

Macronutrient status (in percent) of *Calophyllum ferrugineum* three and six months after planting

	Planting Technique			
Nitrogen (N)	Open planting	Open planting + mulching	Open planting + topsoil	Open planting + nurse tree
Month-3	0.68	0.76	0.75	0.65
Month-6	0.78	0.78	0.74	0.71
Phosphorus (P)				
Month-3	0.03	0.03	0.03	0.03
Month-6	0.04	0.05	0.04	0.05
Potassium (K)				
Month-3	0.38	0.39	0.21	0.20
Month-6	0.76	0.76	0.77	0.58
Calcium (Ca)				
Month-3	0.60	0.62	0.71	0.61
Month-6	0.39	1.13	1.42	1.19
Magnesium (Mg)				
Month-3	0.06	0.07	0.07	0.06
Month-6	0.07	0.08	0.09	0.07

Appendix K

Macronutrient status (in percent) of *Durio carinatus* three and six months after planting

	Planting Technique			
Nitrogen (N)	Open planting	Open planting + mulching	Open planting + topsoil	Open planting + nurse tree
Month-3	0.96	1.07	0.90	1.01
Month-6	0.97	1.07	0.88	0.96
Phosphorus (P)				
Month-3	0.07	0.11	0.11	0.13
Month-6	0.10	0.16	0.13	0.17
Potassium (K)				
Month-3	0.73	0.80	2.38	0.71
Month-6	1.37	1.56	1.34	1.41
Calcium (Ca)				
Month-3	0.41	0.79	0.65	0.74
Month-6	1.35	1.50	1.55	1.59
Magnesium (Mg)				
Month-3	0.20	0.23	0.20	0.19
Month-6	0.38	0.39	0.42	0.40

Appendix L

Macronutrient status (in percent) of *Ganua motleyana* three and six months after planting

	Planting	Technique		
Nitrogen (N)	Open planting	Open planting + mulching	Open planting + topsoil	Open planting + nurse tree
Month-3	0.62	0.90	0.90	0.95
Month-6	0.87	0.81	1.00	0.99
Phosphorus (P)				
Month-3	0.03	0.05	0.04	0.03
Month-6	0.06	0.05	0.06	0.06
Potassium (K)				
Month-3	0.35	0.44	0.31	0.32
Month-6	1.37	1.23	1.14	1.13
Calcium (Ca)				
Month-3	1.07	0.22	0.37	0.30
Month-6	0.80	0.60	0.79	0.85
Magnesium (Mg)				
Month-3	0.08	0.05	0.14	0.06
Month-6	0.15	0.12	0.15	0.14

Appendix M

Macronutrient status (in percent) of *Gonystylus bancanus* three and six months after planting

	Planting Technique			
Nitrogen (N)	Open planting	Open planting + mulching	Open planting + topsoil	Open planting + nurse tree
Month-3	1.06	1.00	1.09	1.11
Month-6	1.12	1.04	1.10	1.06
Phosphorus (P)				
Month-3	0.06	0.05	0.06	0.06
Month-6	0.07	0.08	0.07	0.08
Potassium (K)				
Month-3	0.78	0.78	0.59	0.64
Month-6	1.37	1.53	1.34	1.46
Calcium (Ca)				
Month-3	0.81	1.07	1.06	0.99
Month-6	1.78	1.45	1.81	1.61
Magnesium (Mg)				
Month-3	0.27	0.22	0.28	0.24
Month-6	0.26	0.22	0.24	0.28

Appendix N

Macronutrient status (in percent) of *Shorea platycarpa* three and six months after planting

	Planting Technique			
Nitrogen (N)	Open planting	Open planting + mulching	Open planting + topsoil	Open planting + nurse tree
Month-3	1.29	1.25	1.53	1.44
Month-6	1.34	1.18	1.19	1.18
Phosphorus (P)				
Month-3	0.08	0.07	0.09	0.09
Month-6	0.09	0.07	0.09	0.09
Potassium (K)				
Month-3	0.34	0.36	0.18	0.31
Month-6	0.54	0.62	0.58	0.62
Calcium (Ca)				
Month-3	0.46	0.88	0.91	0.88
Month-6	1.21	1.12	1.26	1.03
Magnesium (Mg)				
Month-3	0.16	0.16	0.16	0.14
Month-6	0.15	0.16	0.13	0.12

BIODATA OF THE AUTHOR

Ismail Bin Hj. Parlan was born on November 1, 1971 in Klang, Selangor. His tertiary education started when he studied for Diploma in Science at Universiti Teknologi MARA (formerly known as Institut Teknologi MARA) from 1989 to 1991. In the following year, he continued his study at Universiti Putra Malaysia or UPM (formerly known as Universiti Pertanian Malaysia) and graduated with a degree of Bachelor Science in Forestry in 1996. He was the best graduate of UPM and received the Chancellor's Gold Medal. He started to work as a research officer at Forest Research Institute Malaysia. In the subsequent year, he continued his studies for a degree of Master Science at the Faculty of Forestry, UPM.