STUDIES ON THE EARLY ESTABLISHMENT OF DIPTEROCARP SEEDLINGS IN A MALAYSIAN LOGGED HILL FOREST

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Raja Barizan Raja Sulaiman
B.Sc., M.Sc. (Botany) UKM, Malaysia

Department of Biological and Molecular Sciences

University of Stirling

Scotland

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ABSTRACT

A 5.6 ha research plot in logged hill forest in central Peninsular Malaysia at Berkelah F.R., Pahang was set up to study the early establishment of dipterocarp species in the field. The site of the logged forest could be broadly grouped into three classes based on the degree of canopy opening and soil compaction: (1) categories B & A: open (25-55 % relative light intensity (RLI) as a high light level) and compacted or less compacted soil, respectively (2) category C: partial shade (8-9 % RLI as a medium) and less compacted soil, and (3) categories D & E: closed canopy (2-3 % RLI as a low light level) with high and low dipterocarp abundances, respectively. Planting trials in the field were conducted with two dipterocarp species, *Hopea odorata* and *Dryobalanops oblongifolia*.

Application of Triple superphosphate (TSP), a fast-release fertiliser, (0.33 - 0.40 g per pot) in the nursery increased the P concentrations of the two dipterocarp species, *Hopea odorata* and *Dryobalanops oblongifolia*, and improved the performance of their seedlings when out-planted in the field plot. The growth of the species under high light level was greatly increased, but the concentration of foliar nutrients of the seedlings was correspondingly reduced. The order of performance in the field subplot categories was A & B > C > D & E and the order of foliar concentrations was D & E > C > A & B.

The study of the effect of P fertiliser, light and types of soil on the growth was supplemented by nursery experiments using two dipterocarp species, *Hopea odorata* and *Shorea acuminata*. Soils from the plot and nursery soil as a control were used for potting the seedlings under two light levels, open (high) and shade (low). Adding P increased the infection of ectomycorrhizas (ECM) on the root tips and also increased the foliar P concentrations of *Hopea odorata*. Light appeared to reduce the infection of ECM.

Experiments using sand cultures showed that P and Mg play an important role in influencing the growth of dipterocarp species. The growth of *Hopea odorata* significantly reduced when

the concentrations of P was less than 2.07 mg l^{-1} and when Mg was less than 3.63 mg l^{-1} . The growth and the concentrations of foliar P and Mg of *Hopea odorata* were increased in response to an increase in external P and/or Mg supply. These results are interpreted as support for the hypothesis that P and maybe Mg availabilities would limit the establishment of the dipterocarp species.

Based on these results, *Hopea odorata* is grouped as a light demanding species, *Shorea acuminata* is shade tolerant and *Dryobalanops oblongifolia* is intermediate species. Reforestation of the logged areas by means of enrichment planting with mixed species of different ecological requirements is one possible way of reclaiming the disturbed areas. Boosting P levels prior to planting may be an effective silvicultural approach in enrichment planting.

Declaration

I declare that the thesis has been composed by myself and that it embodies the results of my own research. Where appropriate I have acknowledge the work carried out by others included in the thesis.


..... Raja Barizan R.S.

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CHAPTER 1: GENERAL INTRODUCTION

1.1 Tropical rain forests of Malaysia

The Malaysian tropical rain forest was first divided by Foxworthy (1927) into three broad types - littoral, lowland and hill or mountain forests. Later the forest types were further classified based on ecological characters with special reference to their dipterocarp composition (Symington 1943). Then, based on information available at the Forest Research Institute Malaysia on vegetation types and different silviculture treatments given, Wyatt-Smith (1961) broadly divided the commercially important inland forests into the following main categories: fresh-water swamp forest, peat swamp forests, lowland dipterocarp forests, and hill dipterocarp forests. The dipterocarp forests extend over large areas in the inland and hill regions and are of vital ecological and economic important to the country. These forests supply a variety of forest products besides timber.

The forest is one of the most complex ecosystems in the world. It is a unique natural heritage which is rich and varied in plants and animals. There are estimated to be over 14,500 species of flowering plants, of which 2,500 are tree species, in Malaysia. It is also plays a significant protective role in the maintenance of a stable local climatic and physical environment, safeguarding water supplies and minimising damage to agricultural land.

1.2 The dipterocarp forests of Peninsular Malaysia

The total land under natural forest in Malaysia is estimated to be 20.1 million ha (61.1 % of the total land area) with 6.2 million ha in Peninsular Malaysia, 4.5 million ha in Sabah and 9.4 million ha in Sarawak. Of the forested land, 17.4 million ha are dipterocarp forests while the remaining 2.1 million and 0.6 million ha are freshwater swamp and mangrove forests, respectively (Ministry of Primary Industries Malaysia 1995).

The dipterocarp forests are among the most diverse in its species composition. In Peninsular Malaysia, the lowland and hill dipterocarp forests are the areas of greatest potential for sustained commercial timber production. The forests, which represent 86.6 % of the total forested land (primary and secondary forests), are characterised by the predominance of the family Dipterocarpaceae with many species of the genera *Anisoptera* ("mersawa"), *Dipterocarpus* ("keruing"), *Dryobalanops* ("kapur"), *Hopea* ("merawan") and *Shorea* ("meranti"). Dipterocarpaceae is the dominant timber family in the dipterocarp forests and it is a medium-sized family of trees consisting of three sub-families: Dipterocarpoideae, Monotoideae and Pakaraimoideae. The sub-family of Dipterocarpoideae consists of 13 genera, 495 species has its major representation in the Indo-Malesia region, extending to New Guinea, Sri Lanka, Seychelles and mainland Tropical Asia including Peninsular Malaysia from India to South China.

Dipterocarpaceae produces the largest volume of timber in Peninsular Malaysia ranging from the dense durable hardwoods "chengal" (*Neobalanocarpus hemii*), "balau" (*Shorea* spp) and "resak" (*Vatica* spp) through medium hardwoods of "keruing" (*Dipterocarpus* spp) and "kapur" (*Dryobalanops aromatica*) to the light hardwoods, mainly of "meranti" (*Shorea* spp). The breakdown of the subfamily Dipterocarpoideae according to its genera and species as found in Peninsular Malaysia is shown in Table 1.

Table 1: The breakdown by genera of the subfamily Dipterocarpoideae in Peninsular Malaysia.

Genus	No. of species
1. *Shorea*	59
2. *Dipterocarpus*	31
3. *Hopea*	30
4. *Vatica*	21
5. *Anisoptera*	6
6. *Parashorea*	3
7. *Dryobalanops*	2
8. *Neobalanocarpus*	1
9. *Pentacme*	1

1.2.1 The hill dipterocarp forest

The hill dipterocarp forests occur on the inland ranges between the approximate altitudinal limits of 300 and 750 m. The main difference between the hill and lowland dipterocarp forest is a shift in floristic composition of the dominant species in the upper and the main tree storeys although there is no sharp difference in vegetation at the 300 m contour. The most common large tree species of this type of forest is *Shorea curtisii* which tends to be gregarious and shows a distinct preference for ridge tops. Hill forests are in fact known to be poorly stocked in regeneration of economic species (mainly dipterocarps) compared with lowland dipterocarp forests (Wyatt-Smith 1960, 1963; Burgess 1968, Manokaran & Swaine 1994). The ground flora is usually very poor, due partly to the common occurrence of the palm *Eugeissona tristis*.

1.2.2 The silviculture and management of the hill dipterocarp forest

In 1994, a total of 12.50 million ha of the country's forest had been gazetted as the Permanent Forest Estate (PFE) in accordance with the National Forestry Policy. In Peninsular Malaysia the PFE covers 4.69 million ha, in Sabah 3.35 million ha and in Sarawak 4.46 million ha (Ministry of Primary Industries Malaysia 1995). About 3.44 million ha of the Estate of Permanent Forest is maintained as Protective Forest. The Protective Forest covers 1.90 million ha in Peninsular Malaysia, 0.61 million ha in Sarawak and 0.93 million ha in Sabah. It is preserved in its natural state where no logging is permitted in order to protect the hilly areas, watersheds and genetic diversity; it constitute national parks, wildlife sanctuaries and nature reserves. The other 9.06 million ha of the Estate is allocated as Production Forest. Areas within the Production Forest are commercially logged on a rotational cycle, under a sustained-yield management system. Each round of harvesting leaves behind of the stand's younger trees which enable the logged-forest to regain its floristic composition. Under selective logging, it is believed that the tropical forests have the ability to regenerate on their own or with the help of silvicultural treatments and return to their former state of ecological balance.

As presently practised, scientifically-based techniques to assist regeneration are undertaken as a follow-up to logging operations. These involve silvicultural treatment and enrichment planting. The process of selective logging allows a better biological functioning of the Production Forest in a sense that by taking away the fully matured trees, the younger trees and saplings have more space for growth, and this hastens the process of forest regeneration.

The objective of silvicultural treatments is to enhance and sustain the potential productivity of the Permanent Forest Estate in order to yield a commercial crop of prime quality logs. A post-felling inventory is carried out to assess the residual stocking and distribution in the harvested area. Silvicultural treatment prescription is then carried out based on the analysis of the inventory data. Undesirable moribund and defective trees, incapable of producing clear boles of $\geq$ 5 m in length are poison-girdled and climbers are cut. Forest rehabilitation and development operations in Peninsular Malaysia were implemented on a substantial scale by the Forestry Department.

Until the early 1950's little attention was paid to hill forests. After World War II, pressures on the lowland areas intensified, and the introduction of mechanised methods of extraction considerably eased the problems of forestry operations in the hills. Thus, the hilly terrain became increasingly important for timber production particularly as more and more lowland forest areas were being converted into agricultural plantations. The traditional Malayan Uniform System (MUS) of forest management successfully applied to the lowland dipterocarp forests was found to be unsuitable for hill dipterocarp forests because of the more difficult terrain, uneven stocking and the sparse natural regeneration. Finally the 'best' silvicultural and management alternative for the hill dipterocarp forests, the Selective Management System (SMS) has been accepted to be adopted from the end of the 1970's. The SMS involves the use of trees of intermediate size classes to form the next rotation and it presupposes that these trees will be able to respond vigorously to the release provided by logging operations. Such a system would theoretically undoubtedly offer several advantages, namely, a reduced cutting-cycle and reduced total silvicultural costs. However, it can only be effectively applied if the residual stand contains an adequate number of

undamaged trees of "regeneration" species which are capable of responding vigorously to the release created by the logging operation.

1.2.3 Dipterocarp seedling regeneration - natural and artificial regenerations

Members of the family Dipterocarpaceae dominate many of the species-rich lowland and hill tropical rain forests of aseasonal western Malesia, a region that lacks a regular dry season, which is includes Peninsular Malaysia (Ashton 1964, 1982; Whitmore 1984, Ashton *et al.* 1988). A striking feature of dipterocarp forests in aseasonal Malesia is the phenomenon of mass flowering, followed by mast fruiting (Ridley 1901, Foxworthy 1932, Wood 1956, McClure 1966, Medway 1972, Janzen 1974, Cockburn 1975, Chan 1977, Chan & Appanah 1980). Enormous numbers of seeds and fruits ripen after a mass flowering and these are released onto the forest floor; individual dipterocarps can present up to four million flowers, from which up to 120,000 fruits may be set (Ashton *et al.* 1988). As a result, the forest floor becomes densely or clumply covered by the seedlings and saplings of dipterocarps.

The regeneration practice in dipterocarp forests depends largely on the presence of seedlings on the forest floor before and after logging. The behaviour of dipterocarp regeneration has been studied by few foresters (Nicholson 1958, 1965; Liew & Wong 1973, Brown 1990). The density of dipterocarp seedlings fluctuates within both virgin and logged forests. Although a heavy seed fall will produce a large number of seedlings on a forest floor, it could be that only a small percentage survive to contribute to the tree regeneration. Nicholson (1965) reported that the abundance of seedlings in virgin forests in Sandakan, Sabah, varied greatly with forest type: it was lowest in a low-lying forest subject to floods and highest in a sandstone ridge forest and in a volcanic-soil forest. Liew & Wong (1973) reported that *c.* 13.7 % of the original number of dipterocarp seedlings present on the forest floor before logging survived after logging.

It is a well known fact that seedlings of various species belonging to the family Dipterocarpaceae almost approach a state of dormancy in undisturbed virgin forest (Baur 1964). Liew & Wong

(1973) also reported that the height growth of dipterocarp seedlings is very much greater under extensive opening of the canopy due to the logging operations than in virgin forest treated with a light liberation only. Nicholson (1960) observed, however, that the mortality of dipterocarp seedlings under an exposed environment may be high as they require shade for growth and development at the early stage. Once the seedlings have established in open areas they can tolerate these exposed conditions. Liew & Wong (1973) suggested that, in order to maintain forest production, it is preferable to manage the regenerating forest than planting dipterocarp trees in open areas. Regenerating forest will not grow into stands of commercially sized trees by the next cutting cycle unless silvicultural treatments can release the understorey.

Since 1960's, it has become increasingly clear that natural regeneration could no longer be relied upon for the renewal of the majority of permanent production forest after logging. Artificial regeneration has therefore assumed an important alternative role in reforestation operations. The awareness of the need for artificial regeneration by means of enrichment planting has been due to the new understanding of dipterocarp regeneration process. Limited experiments on artificial regeneration were carried out as early as the 1930's (Walton 1932, Watson 1935) and were followed by others (Ismail 1964, Chai 1975, Tang & Wadley 1976, Tang & Chew 1980, P. Moura-Costa unpubl. report). Enrichment planting is a technique for promotion of artificial regeneration in which seedlings of the preferred timber trees are planted in the understorey of logged forest and then given preferential treatments to encourage their growth (Lamprecht 1989).

Plantations in Kepong (FRIM) represent the largest testing ground for timber trees and reforestation work in Malaysia. There are about 115 species of dipterocarps and 260 species of non-dipterocarps (Kochummen 1960). The areas for planting consisted of abandoned mining land which were cultivated in patches as vegetable gardens during the Japanese occupation and then abandoned.

1.2.4 Forest plantation

Forest plantations capable of yielding a high volume of wood per unit area in shorter periods of time are becoming increasingly important in meeting the future timber requirements of the country. In the early 1950's a number of forest plantation trials were established in Peninsular Malaysia, mainly with fast growing exotic species. Commercial establishment of forest plantation was started in 1957 with the planting of teak in the northern states of Perlis and Kedah. In the late 1960's and 1970's plantation efforts in Peninsular Malaysia were directed at establishing fast growing tropical pines to produce long fibre pulp with a view to setting up a local pulp and paper mill. Approximately 6,754 ha were planted mainly with *Pinus caribaea, Pinus merkusii* and *Araucaria* spp. in the states of Johore, Negri Sembilan, Pahang Darulmakmur and Selangor Darulehsan.

With the increase in domestic demand for timber and timber products owing to population growth and rising standards of living, Peninsular Malaysia was projected to experience shortage in timber supply by mid 1990's (Chong 1979). Among other strategies to encounter this was to reduce the hectare of harvested areas. In the case of Peninsular Malaysia, for example, the National Forestry Council has agreed that for the Seventh Malaysian Plan (1996-2000), the harvested areas will be reduced to 47,450 ha (Forestry Departments Peninsular Malaysia, Sabah & Sarawak 1993). The other strategy was to implement a programme of fast growing forest plantation species, under the Compensatory Forest Plantation Project which was launched in 1982. The establishment of forest plantations can be considered as a reclamation approach even though the main objective of establishing forest plantations is to meet the future demands of timber. The fast-growing species chosen were *Acacia mangium* ("akasia"), *Gmelina arborea* ("yemane") and *Paraserianthes falcataria* ("batai"). An estimated 500,000 ha of forest plantations will be established in the country by the year 2000 (Ministry of Primary Industries 1989). Peninsular Malaysia would have 188,000 ha of forest plantations under the Compensatory Forest Plantation Project. The plantations were planned to produce general utility timber of small saw-log dimensions for the domestic market in 15-y rotations. As of December 1994, a total of 54,189 ha were planted with

fast-growing timber species, mainly *Acacia mangium* and 5,682 ha of *Pinus caribaea* (Forest Department Peninsular Malaysia 1995). In addition a 2,020 ha of teak (*Tectona grandis*) were planted.

1.3 Plant nutrients and fertilisation in forestry

The chemical analysis of plants measures the following essential elements: carbon (C), hydrogen (H), oxygen (O), which constitute the organic matter and represent about 90-95 % of the dry plant weight (Marschner 1995). C and O, required for photosynthesis and respiration are rarely limiting factors, while the supply of H depends on the availability of water. The other elements constitute on average 5-10 % of the dried plant material and are vital for the growth of the plants: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S), which are considered as macronutrients; manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), boron (B), chlorine (Cl) and molybdenum (Mo), are called micronutrients because of their lower concentrations in plant tissues compared with macronutrients.

Several studies on tropical conifers and broad-leaved species show that the highest concentrations of N, P, K and Mg are found in the foliage and decline in the bark, branch and stem (Nwoboshi 1980; Drechsel & Zech 1991, 1993). Trees accumulate nutrients as their biomass increases. Based on the dry weight of plant, the highest accumulation of nutrients will be in the foliage in early stages of the growth. The proportion of total tree nutrients in the roots is reportedly greater in poor than in high fertility soils, due to higher root production (Jordan 1985).

Besides nutrient retrieval from senescing leaves, litterfall constitutes the major pathway in the biogeochemical cycle of nutrients. The nutrient loss due to removal of one year's litterfall (or foliage) is equal to or greater than the amount which would be removed in stemwood by harvesting (Attiwill 1981, Turner 1981). According to Miller (1984), in the early stages of stand development in plantation forests prior to canopy closure, the annual rate of nutrient accumulation increases rapidly and tree growth is very dependent on current nutrient uptake. Mineral

deficiencies are frequently observed and responses to the application of fertilisers are common during this stage. However, once the canopy has closed, the reduction in rate of nutrient accumulation is associated with attaining maximum foliage biomass, high internal retranslocation of mobile nutrients as well as increasing amounts of nutrients in litterfall and by capture from the atmosphere. Therefore, fertiliser response will be unlikely during this second stage. The magnitude of nutrient requirement met by retranslocation may be the dominant influence on the longevity of response to early fertilisation (Switzer & Nelson 1972).

Fertiliser trials would seem necessary in tropical plantations since most of the soils for plantation forestry are low to moderate in fertility and have a low cation exchange capacity. Common practice in forestry plantation work in Malaysia is to fertilise at the time of planting into a planting hole. This is apparently helps the development of a vigorous root system and has little effect on whole-site fertility (Herbert & Schonau 1991).

1.3.1 Foliar and soil analyses

The identification of tree growth-related nutrients (foliar and soil data) by correlation analyses has been widely used in the tropics and subtropics. These analyses are common tools for diagnosing plant nutritional status both in agriculture (Chapman 1941, Pusparajah & Tan 1972) and in forestry (Kaul & Sharma 1963, Leaf 1968, Everard 1973, van den Driessche 1974). Nutritional problems are in many cases only symptoms of unfavourable soil conditions such as acidity, salinity, shallowness, stagnating water, low organic matter, low nutrient adsorption or high nutrient fixation, low available water capacity, etc. The nutrient status of a tree is often thought to be reflected best by the chemical composition of its foliage. Thus, the foliar analysis is highly favoured because the tree itself is the best integrator of all the factors affecting its nutritional status (Amir 1991).

Soil analysis has been used to evaluate site fertility (Ballard 1977, Shrivastava 1980, Sippola *et al.* 1985). However, the accuracy of using soil analytical results in diagnosing site fertility

or mineral deficiencies, depends on proper calibration of soil parameters against tree growth (Ballard 1977). Growth of plants is a function of soil and above-ground environment (Mead 1984), therefore, soil testing alone is insufficient to predict plant performance and should be supplement by biomass ideally involving the plants under direct study.

1.3.2 Living and dead organic matter and mycorrhizal infection

After cutting, nutrients are immediately released and solubilised if the forest biomass is burned. If not, they are released more gradually, as the wood and leaves decompose. In either case, the nutrients are incorporated into microbes living in soil. The micro-organisms hold the nutrients and they are released through the excretion or through the death of organisms into the soil organic matter and directly uptake by the plants. The Dipterocarpaceae are one of the few tropical tree taxa which form ectomycorrhizas. Ectomycorrhizas are also found in certain legumes (subfamily Caesalpinoideae), Fagaceae, Pinaceae, Myrtaceae (subfamily Leptospermoideae), (Alexander 1987) and some other genera in South America (Janos 1983). The role of mycorrhizas in increasing the absorptive efficiency of roots in laboratory and in nursery experiments is well known (Harley & Smith 1983).

1.4 Objectives of the study

The causes of destruction of tropical forests are different not only from country to country but also due to economic, political and social factors. The most obvious activities which contribute to the destruction of the forests are: shifting cultivation, agro-industrial land use (e.g. for production of cash crops), extensive livestock farming, mining of mineral resources, fuelwood utilisation and timber harvesting. One of the major ecological consequences of improper utilisation of the forests (extensive logging, burning, etc.) is the loss of the surface organic matter from the top soil. With the current interest in conservation of tropical rain forests and biodiversity, increased efforts in rehabilitation and reforestation of logged areas with either exotic or indigenous tree species,

dipterocarp species in particular are required. Empirical studies on ecological and environmental requirements or tolerances of these species need to be carried out.

The objectives of the work were:

1. To study the environmental factors and soil conditions in influencing seedling growth in the field.
2. To investigate the effect of P fertiliser on growth and nutrients uptake.
3. To examine the status of nutrients of seedlings under different field conditions.
4. To study the role of P and Mg in dipterocarps seedling growth and to investigate whether the species were P and/or Mg limited at early establishment.
5. To determine the potential of the species for forest plantation: to enrich the degraded and open areas within logged forest.

1.5 Abbreviations

Throughout this thesis y refers to year(s), mo to month(s), wk to week(s) and d refers to day(s).

CHAPTER 2 : SPECIES USED

2.1 INTRODUCTION

Flowering and fruiting in dipterocarps are generally considered to be unpredictable. It has been often reported that the gregarious flowering and fruiting, referred to as 'mast fruiting' (Janzen, 1974) or 'general flowering' (Ashton 1969, Wood 1956, Medway 1972), occurs in the family Dipterocarpaceae. Such a flowering phenomenon is apparently restricted to the West Malesian region of South-east Asia. In Malaysia such occasions were observed in Pasoh Forest Reserve, Peninsular Malaysia in 1976 and 1981 by Appanah (1985). And the next general flowering was observed in 1989 (Aisha pers. comm.). However, dipterocarps do flower and fruit outside the general flowering periods in what is referred to as 'isolated' or 'sporadic' flowering, but at low intensities and they often fruit poorly and the fruits are usually destroyed by predators (Wood 1956, Ashton 1969).

Most of the dipterocarps' seeds are recalcitrant, i.e. they do not retain their germinating capacity for a long time (Jensen 1971, Tang 1971, Tang & Tamari 1973, Tamari 1976, Sasaki 1980, Mauri-Lechon *et al.* 1981, Yap 1981). Many studies on storage of dipterocarps seeds under laboratory conditions have been tried and some improvements to the life span have been shown in media such as peat, sawdust, sand and perlite (King & Roberts 1979, Song *et al.* 1984, Tompsett 1989). The best temperature to store dipterocarp seeds is believed to be 15 °C (Tang & Tamari 1973) but 21°C is reported preferable for practical purposes (Sasaki 1980, Tompsett 1985).

Due to the problems in obtaining high quality dipterocarp seed at the times required, the choice of species for use in experiments was very much dependent on the availability of the seeds of a particular species in sufficient quantity. As a result, studies in the nursery were conducted with *Hopea odorata* Roxb. and *Shorea acuminata* Dyer and field planting had to be conducted with *Hopea odorata* and *Dryobalanops oblongifolia* Dyer, because these were the species available in 1991.

2.2 *Hopea odorata* Roxb.

The genus *Hopea*, commonly known as "merawan", is found naturally grown in India, Ceylon, Burma and South China and extends throughout the Malayan region to the Philippines, Celebes and New Guinea. In the Malay Peninsula *c.* 30 species have been described (Symington 1974). *Hopea* occurs throughout the Peninsula's dipterocarp forests from the lower coastal peat swamps up to 1,219 m altitude. *Hopea odorata* is found growing well in the northern part of the Peninsular Malaysia, in Langkawi, Perlis, Kedah and north of Perak, Kelantan and Trengganu. The vernacular name of the species is "merawan siput jantan". It is essentially a riparian species and it was reported that the species rarely occurs far from streams. In early times it was planted as a shade tree in villages in Kelantan and Trengganu. The trees form a tall clear bole, with a scaly brown and thick bark and the crown is dense and dark-green in colour. *Hopea odorata* has been reported to reach heights of 37 m (Burkill 1966). Small resinous exudations, called "dammar" (resin) may be present.

The species is said to be "light demanding". It has been recommended for plantations among other timber species (Anonymous 1991) because it is one of a few dipterocarps that can be open-planted (Ang *et al.* 1992, Wan Razali & Ang 1991, Aminah & Lokmal 1995). Under the classification of timber trees in Peninsular Malaysia, the species was classified in the "medium hardwoods group" which possessed both a medium natural durability and a medium growth rate.

In Malaysia this species is cut for general purposes, although, in Burma, Thailand and Indo-China it is of considerable importance as a source of construction timber. Recently the species has become a popular shade tree in urban areas. To provide planting stock, it can be raised by seeds and it can easily be propagated by cuttings (Aminah 1991, 1996).

2.2 *Dryobalanops oblongifolia* Dyer

Dryobalanops is a small but important genus of nine species. All species occur in Borneo but only *D. aromatica* and *D. oblongifolia* occur in Peninsular Malaysia and Sumatra (Symington 1974). It is a genus of tall trees of the family Dipterocarpaceae, producing camphoraceous oleo-

resin and the more interesting of them producing camphor (Burkill 1966). The species is locally known as "keladan" in Peninsular Malaysia, whilst in Borneo it is called "kapur paya" and on the eastern coast of Sumatra, "kuras". Considerable areas of plantations were established at Kepong and elsewhere in the vicinity of Kuala Lumpur (Walton 1937).

Foxworthy (1932), described this species as a large tree, 46 to 55 m in height, with a clear bole of 15-21 m, and a girth of from 2-5 m. It is very distinct in appearance from *D. aromatica* ("kapur"), because of its shorter and stouter trunk, larger fruit and larger and oblong leaves. The fruits have a less pronounced odour of camphor. It is found growing on low, flat land and usually near streams on poorly drained soil and sometimes in shallow swamps. In Kelantan, however, it is found growing on hill sides at 183 m. It occurs gregariously, but never makes up so large a proportion of the volume of the forest as does "kapur".

The species fruits frequently but is not strictly annual. When it does flower annually, it is not always the same individual each year or at the same location e.g. remarkable fruitings in Kanching F.R., have not always coincided with those in Kepong, 20 km away (Appanah & Weinland 1993). Its fruit germinates at once and sometimes this occurs while still on the tree (Foxworthy 1932, Barnard 1954). Thus, it is important to sow the seeds as soon as possible.

Early studies on transplanting and on survival of *D. oblongifolia* were carried out by a few foresters. A planting trial of the species by Walton (1938) in a "resam young belukar" (open area) showed that seedlings planted in a deep planting hole (root collar 10 cm below surface) had higher survival (72 %) compared with those planted in less deeply (root collar 2.5 cm above surface) with 62 % survival. A study by Barnard (1949) on the survival of "keladan" planted in a clear felled and burned plot, was quite high (80 %). The wildings of "keladan" with the range of age between 2 to 12 mo planted under the shade of "belukar" (dense bush) at Kepong plantation had a survival of 63-79 % (Barnard 1954). "Keladan" planted in 1928 at the Kepong plantation showed that in 5 y the species grew to a height of 7.6 m with a diameter of 14.5 cm. The species is said to be tolerant of dense shade. However, its shape is poor and with a tendency to a heavy branching (Watson 1935). The timber of the species has been classified in the same group of "merawan siput jantan" - the medium hardwoods. The timber of *D. oblongifolia* is essentially

similar to that of *D. aromatica* and its trade name is known as "kapor" too, and its timber is valued for the construction of domestic boats.

2.3 *Shorea acuminata* Dyer

Shorea is the largest genus of trees of the family Dipterocarpaceae and economically it has the most important species. It is found from India to the Philippines Islands. Nearly one third of the species occurs in Peninsular Malaysia. Several different kinds of timber are produced by species of this genus, which may be considered in four groups (Symington 1974), viz: "balau", "meranti pa'ang", "meranti damar hitam" and "red meranti". The "red meranti" provided the commonest Malaysian timbers and this group includes *Shorea acuminata*. The vernacular name of the species is "meranti rambai daun". It is a large tree from 30-46 m in height, with a 18-27 m straight bole and reached 2-3 m in girth. It is found in the Malay Peninsula from Perak to Johore. It is also found growing in Temerloh and Kuantan in the State of Pahang and it grows plentifully in Negri Sembilan and Melaka states. It is normally occurs on low-lying, well-drained land of mixed dipterocarp forest but it is more abundant in hilly country up to 400 m.

Shorea acuminata is reported as a fast-growing species, and the average annual girth increment is recorded as 4 cm; from this it can be calculated that a girth of 2 m is attained in *c.* 50 y (Symington 1974). The species is well represented in the Kepong plantations where it has been cultivated since 1929. The timber is classified under the "light hardwoods". The species has fast growth rates, and posseses a timber which is lighter and softer, and thus easy to handle.

The form of the stem of the species is varied. Individuals can have kinked and bent stems or can grow with straight stems. The trees will grow with large branches in the open when there is no competition. The crowns have a dense foliage allowing little light penetration. The stems have distinctly swollen knots and waterholes are formed when the branch axis is broken which makes the stems susceptible to rot. Based on these difficulties, the species is not to be recommended in planting programmes, especially in open areas (Appanah & Weinland 1993).

CHAPTER 3: THE STUDY AREA AND ESTABLISHMENT OF THE RESEARCH PLOT

3.1 Malaysia in general

Malaysia is located within the latitudes 1° to 6° 45` N and longitudes 99° 40` to 119° E. Malaysia receives abundant radiation and rainfall, and has large stretches of evergreen tropical rain forest. The total land area is estimated to be 33 million ha with 13.2 million ha (54.8 %) in Peninsular Malaysia and 19.9 million ha in Sabah and Sarawak. About 72 % are under forest and tree plantations. Forests account for 19.4 million ha and tree plantations 4.2 million ha. The population of Malaysia in 1992 was recorded at 18.6 million with 15.3 million in Peninsular Malaysia, 1.6 million in Sabah and 1.7 million in Sarawak (Ministry of Primary Industries Malaysia 1995).

3.2 Peninsular Malaysia

Peninsular Malaysia, which is separated from Sabah and Sarawak (both being on the northern parts of the Island of Borneo) by 720 km of South China Sea, occupies a central position within South East Asia. Its length is approximately 740 km, and it lies entirely within the tropics between latitudes 1° 20` to 6° 45` N and latitudes 99° 40` to 104° 20` E.

The climate of Peninsular Malaysia is typical of the wet tropical rainforest type which is generally characterised by high and uniform temperatures, high humidity and copious year round rainfall. The mean temperatures during the day and night times are 32 °C and 28 °C respectively with an average monthly temperature variation of *c.* 2 °C. The average rainfall of Peninsular is *c.* 2,540 mm which is spread over the greater part of the year with the highest of rainfall is 5893 mm recorded in Bukit Larut, Taiping, and the minimum is 1651 mm in Jelebu, Negri Sembilan (Malaysian Meteoroligical Service 1985). The humidity is constantly high ranging from 70 % to 98 % .

3.3 Berkelah Forest Reserve

Berkelah Forest Reserve is situated in Jengka of central of state of Pahang lies roughly between latitudes 3° 40` and 3° 55` N and longitudes 102° 39` and 102° 45` E and it is about 234 km to the north-east of Kuala Lumpur (Figure 3.1) and 218 km to the north-east of Forest Research Institute Malaysia (FRIM). It is a selectively logged mixed hill dipterocarp forest stand. The Berkelah F.R. has been identified as a red meranti forest (Wyatt-Smith 1961) and it was characterised by a high percentage of species of the "red meranti" group of *Shorea* (Table 3.4). The area was tractor-logged once in 1986-1987 (Kamaruzaman 1992, Temerloh District Forest Office pers. comm..).

3.3.1 Location of the study plot

The study plot was located in a compartment 37 (TT 04/86 KP) and the compartment was within the C72 logging block (Figure 3.2). The plot (5.6 ha) was established in a compartment of an area of 298 ha. A pre-felling inventory in the area was carried out by the staff of Pahang Forest Department on 2-24 July 1986. During the pre-felling exercise the number of trees of dipterocarp and non-dipterocarp per hectare that could be cut were marked and counted. The direction of tree felling was also determined and marked. A licence for the logging operation in the area was issued by the Forest Department of State of Pahang to a logger from 1 September 1986 - 31 August 1987. No information is available for the name of the logger. After the logging operation was completed, a post-felling inventory was carried out in 1988 to assess the residual stocking and its distribution in the harvested area.

(a) Establishment of the permanent plot

In March 1991 approximately 4 y after logging was completed, a 4 ha plot (100 m x 400 m) was demarcated. A group of four persons was involved in the plot establishment, two persons for clearing and two for demarcating the lines. The base and grid lines were marked with 1 m PVC pipes at 20 m intervals. To allow enough subplots for the planting trial, the plot was extended by another 1.6 ha in November 1991, making it 5.6 ha (120 m x 400 m). The plot was divided into

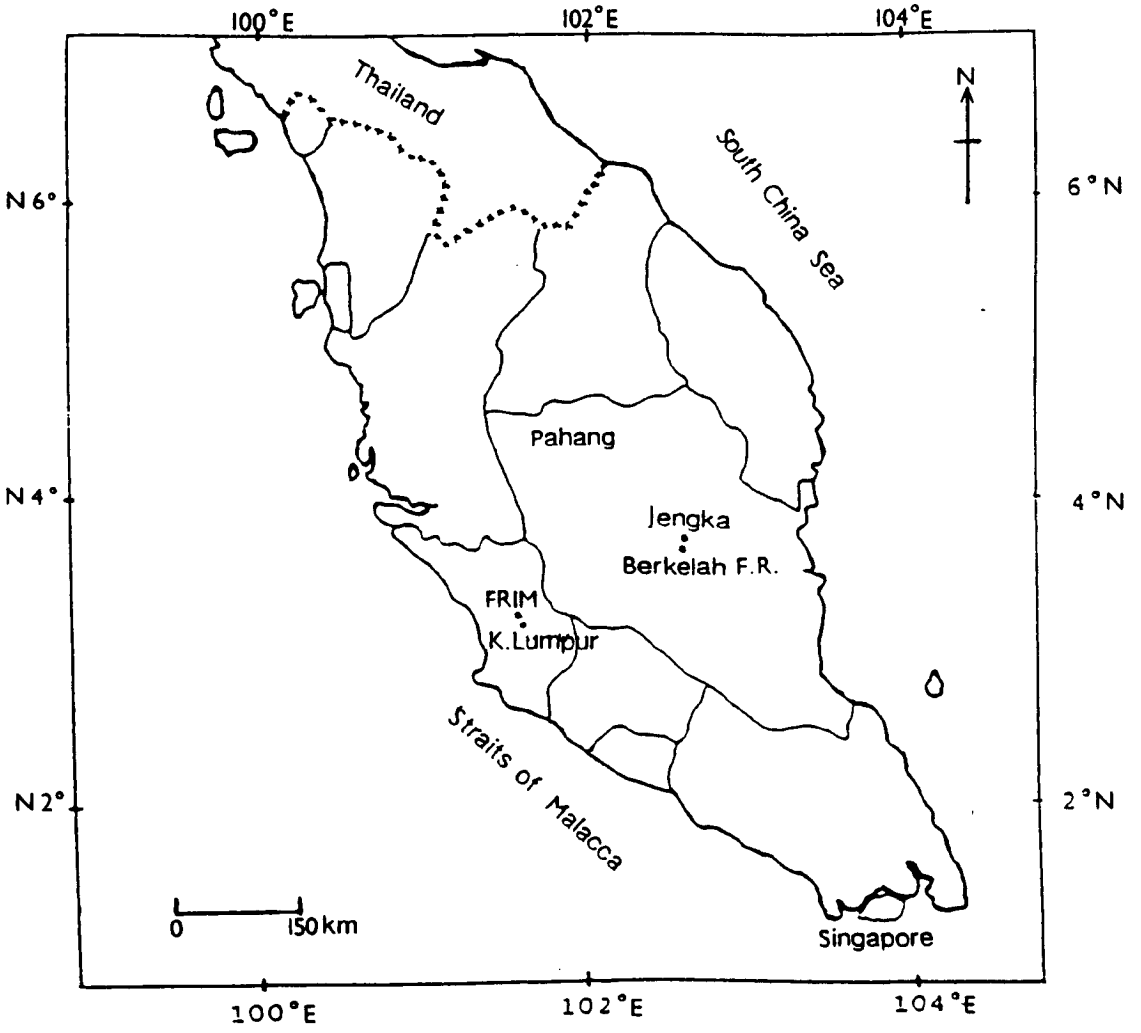


Figure 3.1: Location of study site (Berkelah F.R.) in the State of Pahang in Peninsular of Malaysia.

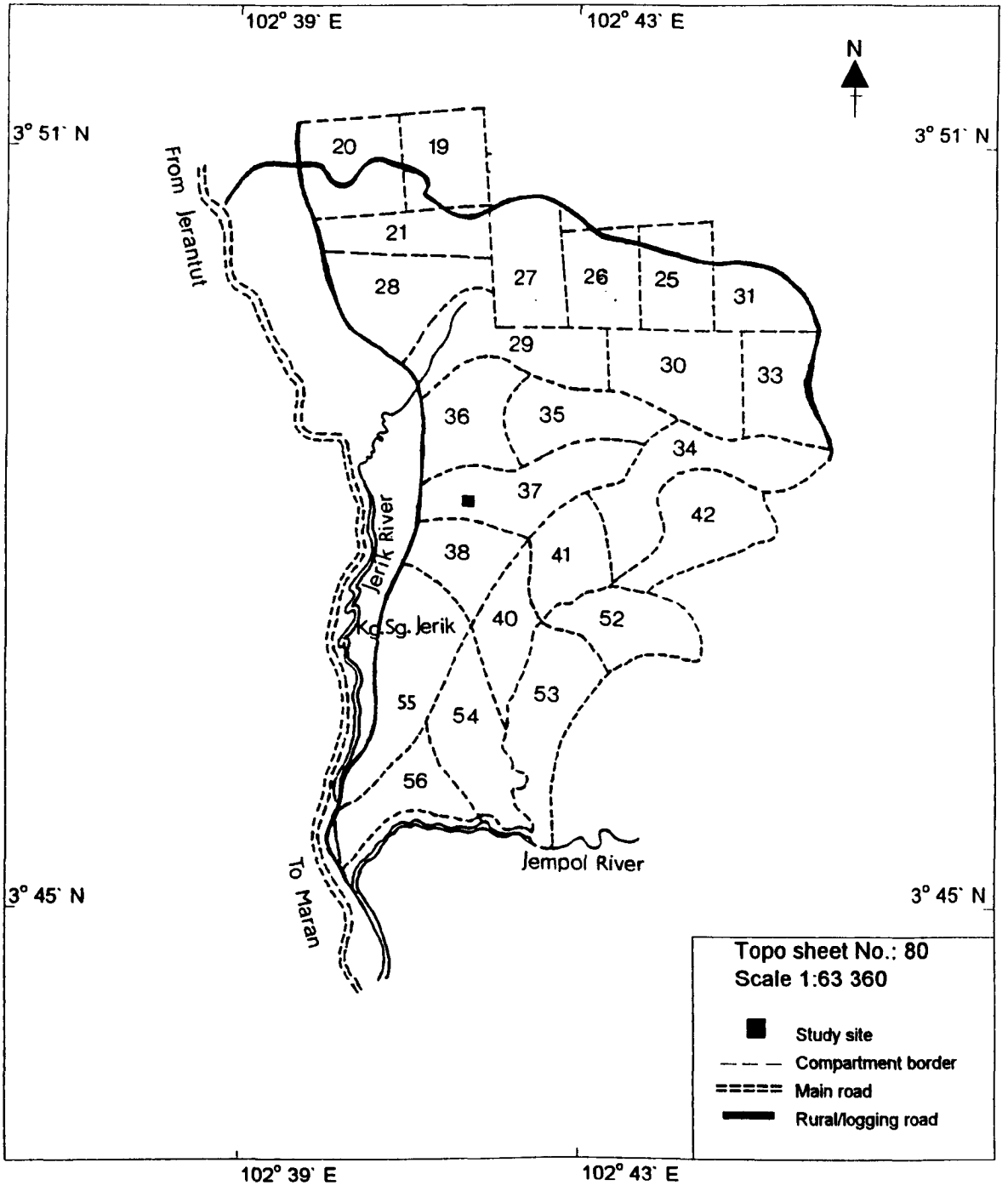


Figure 3.2: Compartment of study site (compartment 37) at Berkelah Forest Reserve, Pahang. (Source: Forest Department of Pahang, Kuantan, unpubl. report).

140 subplots, each of which is 20 m x 20 m. All trees ≥ 30 cm girth at breast height (gbh), were tagged and measured in July 1991. Tree sizes were converted to diameter at breast height, dbh (≥ 9.6 cm dbh). Enumeration of plots involved taxonomic identification to species whenever this was possible. Each trees was identified using vegetative field characteristics and most of the trees were not in flower. Leaves, both fallen and detached from trees, were compared against herbarium specimens in the Forest Research Institute (FRIM), Kepong. The identification of the species was made with the assistance of the staff of the Ecology Unit at FRIM. Within the 5.6 ha plot all subplots were classified and 30 were selected as six random replicates of each of five types of subplot categories for field planting trials (Figure 3.3). The five categories of the subplots were:

A= Large gap (>80 % ground exposed) with less compacted soil;

B= Large gap with compacted soil;

C= Partially shaded area (30-70 % ground exposed) with less compacted soil;

D= Closed canopy area with many dipterocarps (seedlings, saplings and poles);

E= Closed canopy area with few dipterocarps.

Category B was formed from log landings and secondary decking sites within the logged forest, where all vegetation, litter and top soil had been removed during the logging operations. The soil of these areas was heavily compacted by heavy machinery used during logging activities. After 4 y the areas were still barren with no vegetation although a few *Macaranga* spp were found growing at the edges of the subplots. Categories A & C were skid trails where all vegetation, litter and top soil had been removed but some canopy cover from the surrounding trees remained. Four years after logging, the subplots were covered mainly by the trees of light demanding species (secondary species), such as *Macaranga* spp. The areas were also heavily colonised by the rhizomatous fern, *Dichranopteris linearis* (Gleicheniaceae). For the purpose of planting trials, subplots A, B and C were given silvicultural treatments. Categories A and B were opened up to 80-100 % for open planting. Subplot C was opened up to 30-70 % by felling all trees < 9.6 cm dbh to create partially shaded categories. All brush (stumps and logs left behind at the planting points) was cut and removed to the edges of subplots and left to rot. Categories D and E were left intact for closed canopy planting. Both subplot categories of these two closed canopy types were

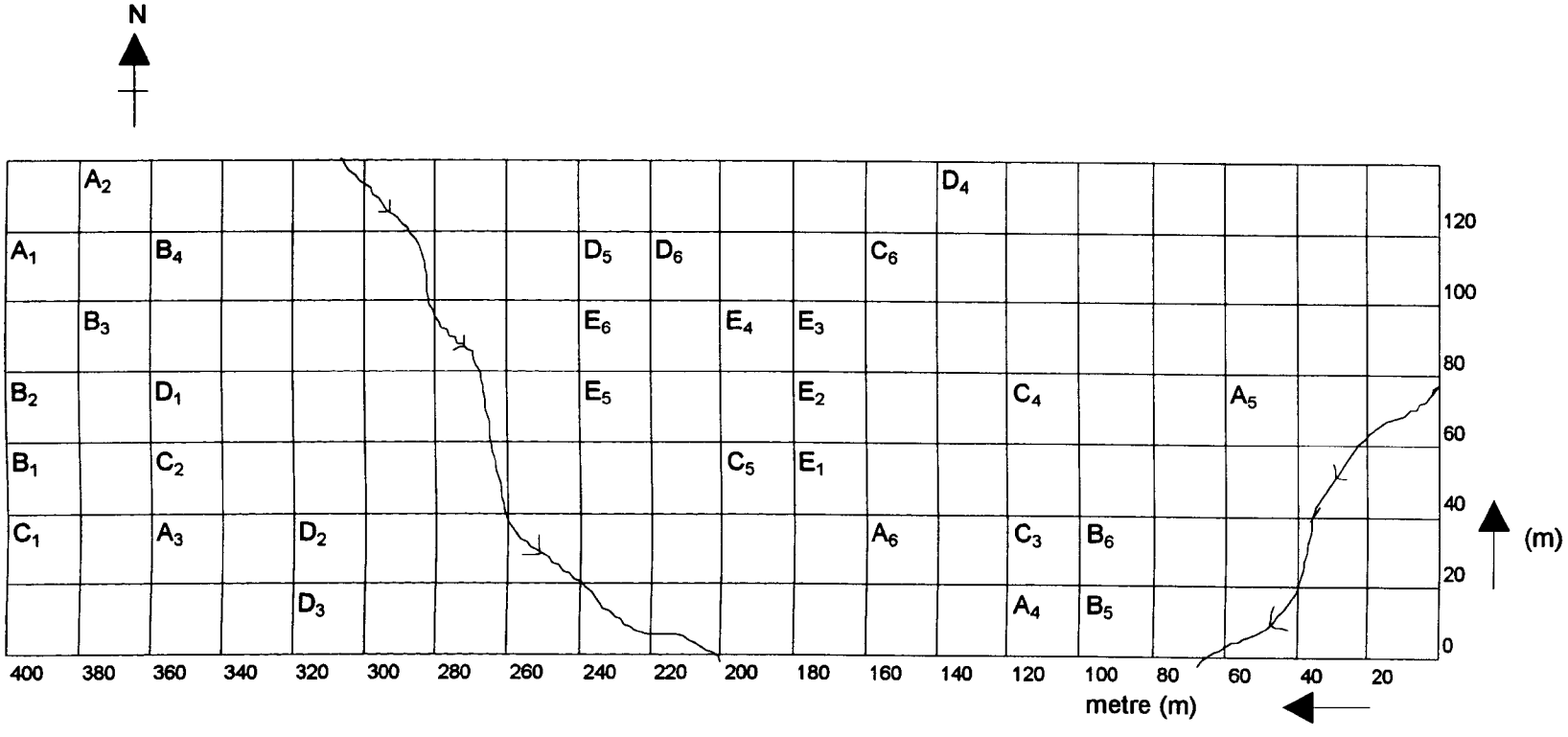


Figure 3.3: The 5.6 ha plot in a logged forest at Berkelah Forest Reserve, Pahang. Subplot categories, A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded and less compacted soil; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. (streams) The subscripted numbers indicate the subplot replicates.

mainly covered with the residual trees after logging and secondary species which were mainly *Macaranga* spp (*Euphorbiaceae*).

(b) Topographical ground survey

The topographical survey of the initial 4 ha (100 m x 400 m) of the plot was carried out in July 1991. It showed that the plot had a gentle slope and lay at an altitude of 204 m to 236 m asl (Figure 3.4). It was located at the lower part of the hill forest area.

3.3.2 Climate of the area

The nearest climatological station is at the Forest Research Institute Malaysia (FRIM) substation in Jengka, Pahang. The station is approximately 30 km away from the research plot and was assumed to be representative of the area. The total monthly rainfall and the maximum and minimum monthly temperature periods 1993-1995 are presented in Figure 3.5 (FRIM Hydrology Unit, unpubl. data). The wetter periods in the year are usually from September to December and the drier periods are from April to July. The highest total monthly rainfall recorded during the study period was 523 mm in November and the minimum monthly temperature was 19 °C and maximum temperature was 34 °C.

3.3.3 Soils

The soil profiles in Berkelah F.R. can be categorised as belonging to the Durian Series in the ultisols order (Kamaruzaman 1988). The texture of the soil was reported as a sandy loam soil (Kamaruzaman 1992). Physical properties and mineral nutrients of the soil in the plot are reported in Chapter 5.

3.3.4 Vegetation

The vegetation of Berkelah F.R. can be classified as a mixed hill dipterocarp forest (Wyatt-Smith 1961). A forest formation in Peninsular Malaysia is characterised by the dominance of the timber-

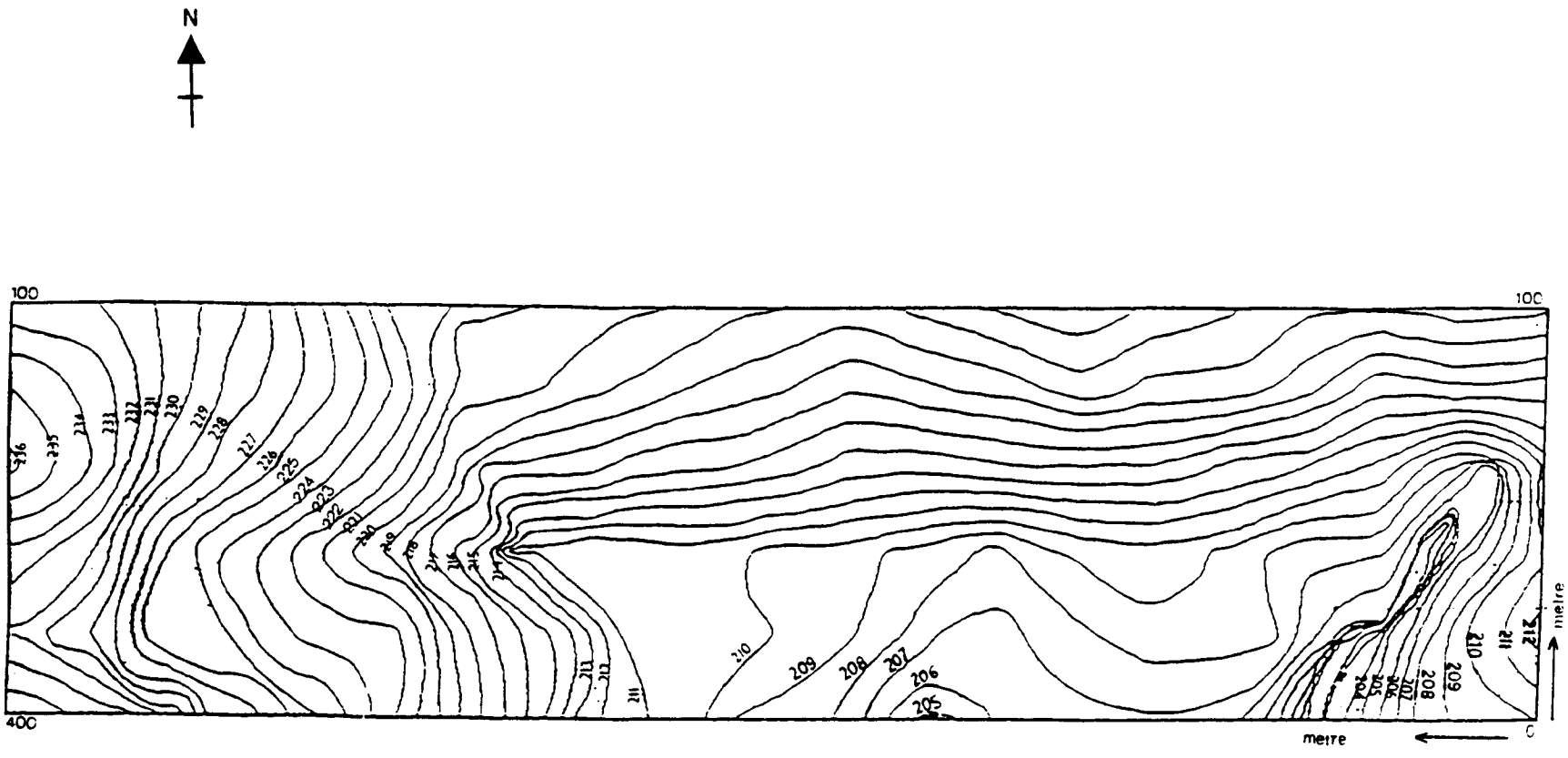


Figure 3.4: The 4 ha topography map in a logged forest at Berkelah F.R., Pahang.

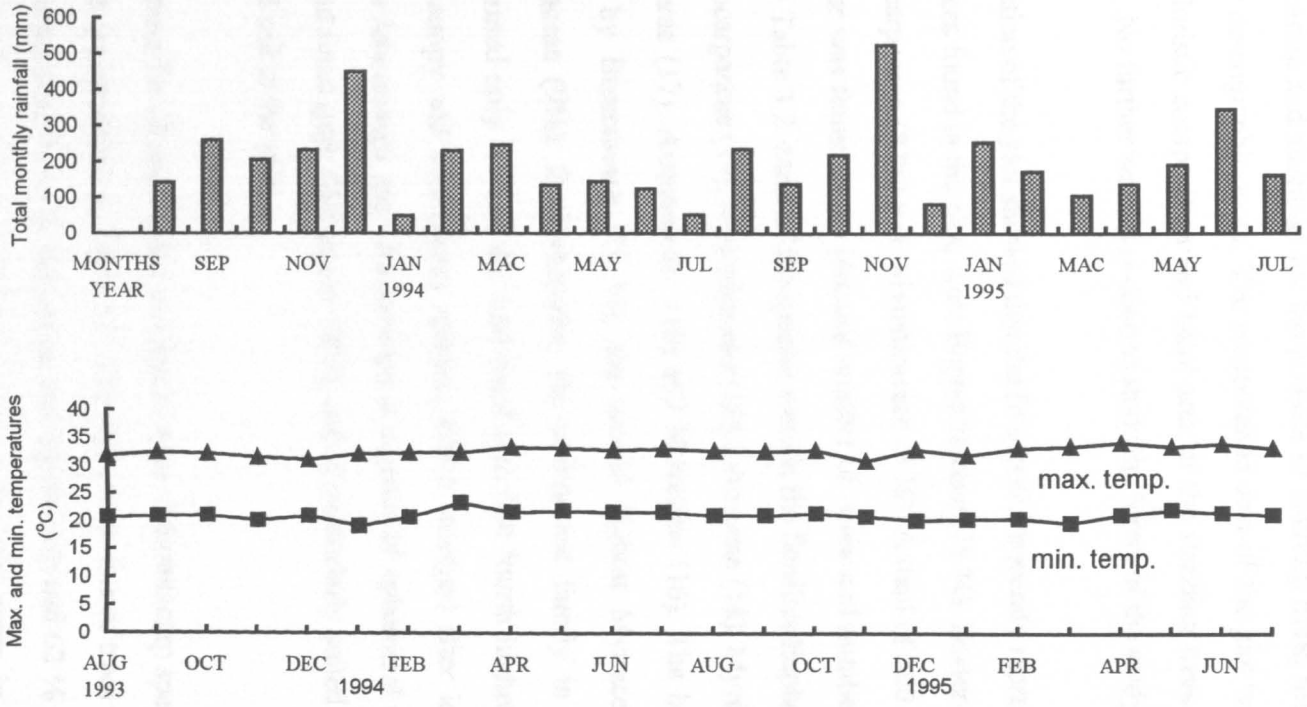


Figure 3.5: Total monthly rainfall and monthly maximum and minimum temperatures for the periods 1993-1995 at the plot Berkelah F.R., Pahang.

producing tree family Dipterocarpaceae. A joint project by FRIM and GTZ made a study of the floristic composition in 20 ha of the forest in the same compartment (No. 37). The project was started in September 1990 , however to date no results have been published. The 5.6 ha plot was set up and enumerated for demographic study and to be also used as planting site. Due to the changes to the objectives of the studies, 12 % of the total areas was given silvicultural treatments (thinning, clearing and slashing) for the purpose of planting trials, therefore, it is not suitable to carry out the demographic work. The enumeration data of the plot was reported in Table 3.1 to present the floristic composition and basal area of the standing trees of the families in the plot after logging. No further work was done to study the forest of the study site.

The enumeration of the plot showed that the five most frequently represented families, in terms of number of trees found in the plot, were Euphorbiaceae (18 %), Burseraceae (11 %), Myrtaceae (8 %), Dipterocarpaceae (8 %) and Myristicaceae (5 %). A total of 360 identified species in a total of 54 families was found in the plot and number of trees and number of species in each family are shown in Table 3.2. Most of the species were in the families Euphorbiaceae (47), Burseraceae (21), Dipterocarpaceae (19), Myristicaceae (18), Lauraceae (18), Myrtaceae (17), Annacardiaceae (17), Guttiferae (17), Annonaceae (16) and Meliaceae (16). The highest total basal area was represented by Burseraceae (19 %), the second highest Myrtaceae (11 %) and the third Dipterocarpaceae (9%). Euphorbiaceae, the commonest family in the plot in terms of tree numbers, formed only 9 % of the total basal area (the fourth highest); trees of this family are mostly subcanopy and understorey species, which emerged after logging. The most frequent species were *Macaranga* spp. *Macaranga* is a genus of ephemeral rain forest habitats, such as land-slips and wind gaps (Whitmore 1973), and is particularly suited to the colonisation of areas of disturbed soil in the plot.

Number of trees for all species and number of trees of dipterocarp species found in the plot for the range of dbh are presented in Table 3.2. The highest number of trees was in the range 9-19.9 cm; 5 % of the total trees found in this range was dipterocarp and 62 % of the total trees was other species. The maximum sizes of dipterocarps in the plot were in the dbh class 60-69.9 cm. Nineteen species of dipterocarp species were identified in the plot and the most abundant species were *Shorea leprosula, Shorea macroptera* and *Hopea mengerawan* (Table 3.3).

Table 3.1: Floristic composition and basal area of the standing trees of the families (after logging), in the 5.6 ha at plot Berkelah F.R., Pahang, recorded in July 1991. Values in parentheses indicate the descending rank order of the ten most frequent and abundant families.

Families	Number of trees	Number of species	Basal area (m^2 ha^{-1})
Euphorbiaceae	361 (1)	47 (1)	1.49
Burseraceae	221 (2)	21 (2)	3.18
Myrtaceae	167 (3)	17 (6)	1.95
Dipterocarpaceae	159 (4)	19 (3)	1.50
Myristicaceae	109 (5)	18 (4)	0.39
Anacardiaceae	76 (6)	17 (7)	1.26
Leguminosae	73 (7)	12	1.16
Guttiferae	70 (8)	17 (8)	0.35
Annonaceae	60 (9)	16 (9)	0.35
Ixonanthaceae	54 (10)	1	0.52
Olacaceae	53	2	0.47
Lauraceae	52	18 (5)	0.25
Lecythidaceae	47	4	0.21
Sterculiaceae	44	6	0.43
Moraceae	40	10	0.27
Meliaceae	34	16 (10)	0.10
Rubiaceae	34	10	0.18
Sapindaceae	33	8	0.19
Melastomataceae	27	5	0.14
Fagaceae	26	7	0.14
Sapotaceae	25	6	0.36
Ulmaceae	25	4	0.06
Flacourtiaceae	24	7	0.09
Polygalaceae	21	8	0.11
Oxalidaceae	20	2	0.54

Table 3.1 (cont.)

Families	Number of trees	Number of species	Basal area (m^2 ha^{-1})
Rhizophoraceae	14	3	0.07
Rosaceae	13	6	0.09
Ebenaceae	12	6	0.06
Bombacaceae	11	3	0.04
Verbenaceae	10	4	0.07
Tiliaceae	10	3	0.02
Hypericaceae	10	2	0.12
Elaeocarpaceae	8	5	0.14
Alangiaceae	8	3	0.02
Dilleniaceae	8	2	0.11
Linaceae	7	1	0.10
Ochnaceae	7	1	0.05
Apocynaceae	4	2	0.08
Celastraceae	4	2	0.01
Trigoniaceae	4	1	0.01
Icacinaceae	3	3	0.01
Theaceae	3	2	0.01
Irvingiaceae	3	1	0.21
Loganaceae	3	1	0.22
Rutaceae	3	1	0.01
Simarubiaceae	3	1	0.01
Symplocaceae	3	1	0.01
Myrsinaceae	2	2	0.00
Cornaceae	2	1	0.01
Styracaceae	2	1	0.01
Compositae	1	1	0.00
Erythroxylaceae	1	1	0.00
Proteaceae	1	1	0.00
Saxifragaceae	1	1	0.01
Total	2014	360	17.20

Table 3.2: Number of trees of all species in the plot and number of trees of dipterocarp species in increasing classes from the enumeration of the 5.6 ha plot at Berkelah F.R., Pahang.

dbh range (cm)	All species	Dipterocarp species
(9.6 - 19.9)	1356	101
(20 - 29.9)	328	23
(30 - 39.9)	144	12
(40 - 49.9)	85	11
(50 - 59.9)	53	6
(60 - 69.9)	22	5
(70 - 79.9)	14	-
(80 - 89.9)	5	-
(90 - 99.9)	1	-
(100 - 109.9)	2	-
(110 - 119.9)	2	-
(120 - 129.9)	2	-
Total	2014	159

Table 3.3: Number of trees of the dipterocarp species ($\geq$ 9.6 cm dbh) found in the plot at Berkelah F.R., Pahang.

Species	Number of trees
Shorea leprosula	34
Shorea macroptera	25
Hopea mengerawan	24
Shorea parvifolia	18
Hopea sp.	8
Dipterocarpus crinitus	8
Vatica pauciflora	7
Shorea ovalis	6
Shorea pauciflora	5
Anisoptera laevis	4
Hopea dryobalanoides	4
Hopea pubescens	4
Shorea maxima	4
Shorea sp.	2
Vatica bella	2
Anisoptera costata	1
Shorea lepidota	1
Vatica maingayi	1
Vatica sp.	1
Total	159

Under the selective management system (SMS) for hill dipterocarp forests, minimum cutting limits of at least 45 cm dbh for non-dipterocarps and 50 cm dbh for dipterocarp species are advocated, when the next cutting is expected to be 25-30 y after logging. The residual stocking should have at least 32 sound commercial trees per ha in the diameter class 30-45 cm or its equivalent (Forestry Department of Malaysia, unpubl. report). In this study, the total number of trees above 9.6 cm dbh in 5.6 ha plot was 2,014 (dipterocarps and non-dipterocarps), and therefore, *c.* 360 trees per ha of the residual stands would potentially be the next harvest crop. The figure (360 trees per ha), however, was comprised of commercial and non-commercial tree species. The total number of trees extracted from 4 ha of the plot was 129, therefore, *c.* 32 trees per ha of timber were cut during the logging. However, no information is available about the numbers of dipterocarp and non-dipterocarp trees removed from the plot. According to the State of Forest Department of Pahang, the total cubic metre volume of trees that were removed from the C72 logging block, of which compartment of 37 is part, was 64.7 m^3 ha^{-1}.

3.4 Nursery of the Forest Research Institute Malaysia (FRIM)

The experiments to be described in Chapters 6 & 7 were made in the FRIM nursery. The nursery is located in the FRIM ground *c.* 16 km north-west of Kuala Lumpur at 3° 14` N and 101° 38` E. The monthly total rainfall recorded for periods 1992-1994 ranged between 42 and 449 mm (Malaysian Meteorological Service unpubl. data). The mean relative humidity in the morning (08.00 h) ranged between 97 and 100 % and in the afternoon (14.00 h) ranged between 55 and 70 %. The mean minimum temperature was 21-23 °C and the mean maximum temperature was 31-34 °C.

CHAPTER 4: GENERAL METHODS

4.1 Soil sampling

Soil for potting

Soil from depths 0-10 cm was randomly collected within each of the subplot categories (A, B, C, D & E) at Berkelah F.R., to provide five soils S1, S2, S3, S4 and S5, respectively. These soils were used to pot the seedlings in the nursery. Two collections were made for potting the different species. The first collection was made on 1 February 1992 for *Hopea odorata* seedlings. The seedlings were potted in polythene bags (12.5 cm x 20 cm), each needing *c.* 1.5 kg of soil. Therefore, *c.* 100 kg of each type of soil was collected for potting 64 seedlings. Prior to potting, large aggregations of soil, especially soils from categories A and B, were manually crushed to accommodate the soil into the polythene bag. The second collection was made in a similar way on 15 March 1992, for the potting *Shorea acuminata* wildings. Approximately 80 kg of each type of soil was needed to pot 48 seedlings with the same size of bag.

Soil for analysis

Chemical and physical properties of the soils were determined at the Laboratory of Soil Science, FRIM. For each plot categories, three subplots out of six subplots were randomly chosen for collection. One bulked sample was collected within each selected subplot for each of the depths of 0-15 cm and 15-30 cm. The bulk sample was taken from 15 sampling points along a line from corner to corner in 20 m x 20 m using a screw-auger. The samples, by depth, were thoroughly mixed to ensure uniformity and packed in plastic bags for transportation to the laboratory for analyses. The same method was used for the other subplots.

The soil pH was measured using a Corning-155 pH meter. The water-based pH value was determined using the ratio of 1:2.5 for soil to water and a similar ratio was used for pH in KCL. Organic carbon (C %) was determined using the Walkley and Black method (Nelson & Sommers 1982). The carbon present as organic matter in the soil (1 g) was determined by oxidising it with a

known excess of potassium dichromate with ferrous ammonium sulphate using diphenylamine as the indicator. Total N was determined by the Kjeldahl digestion method and the total N was determined colorimetrically by measuring the ammonium concentration in the filtrate on the Technicon autoanalyser. Available P was determined by Bray & Kurtz (1945) method No. 2 using 2 g of air-dried soil. Exchangeable potassium (K) was determined by a Corning-410 flame photometer and exchangeable of Ca and Mg by a Hitachi 170-30 atomic absorption spectrophotometer. Total free Fe including the Fe oxides and other forms of Fe found in soil, was determined according to the method developed by Mehra & Jackson (1960) using sodium dithionate and buffered citrate solution as the extractant. Air dried soil samples of 10 g were used for filtration and for determining the concentration of Fe using the same atomic absorption spectrophotometer. Soil texture (sand, clay and silt) was measured by a hydrometric method. Cation exchange capacity (CEC) was determined according to Norhayati & Singh (1980). The soils were leached continuously for six hours with excess ammonium acetate (pH 7). The excess ammonium ions were then washed with ammonia free alcohol and then leached with potassium sulphate solution for six hours. The CEC was determined by measuring the ammonium ion concentration in the leachate using autoanalyser.

Bulk density

The same approach as for soil analysis samples was made in selecting the subplots. Three subplots out of six subplots were chosen for each subplot categories. Measurements of soil bulk density were taken for only the top 10 cm of soil. This was because the seedlings were planted in holes within 0-15 cm from the surface and the soils used for potting the seedlings were collected from depths 0-10 cm. The compactness of soil for each categories was determined by coring. The soil cores used were 5.52 cm in diameter and 4.25 cm deep. The soils were taken by driving a metal core into the ground to the depth required and removing the core with full of soil intact. The samples were taken to the laboratory and the fresh weight of soil with the core was determined. The samples were then dried in an oven at 38-42 °C for 24 h. Soil bulk density was calculated as the weight of the dry soil (minus the weight of core) divided by the sample volume (100 cm^3) and expressed in g cm^{-3} of dry soil.

4.2 Relative light intensity (RLI)

The light in a forest consists of diffused light and sunflecks. The diffused light is composed of light reflected and deflected by the leaves as well as light transmitted through leaves (Evans *et al.* 1960, Evans 1966, Sasaki & Mori 1981). However, sunflecks consist of direct sunlight penetrating through canopy gaps. The light transmitted through the canopy layers is altered in quality as the leaves absorb the red portion of the light spectrum. However, in the case of this study the determination of light was only on the quantity of light received by the seedlings either in the nursery or in the field.

The mean relative light intensity (RLI), received by the seedlings planted in the plot under full sunlight with a clear sky, was determined in April 1994 using a LI-COR quantum sensor radiophotometer. The RLI in the nursery was determined in May 1992 for Experiment I and in October 1993 for Experiment II. Only one meter was used for the measurements, therefore, the photosynthetic active radiation (PAR) of the seedlings in the subplot categories and in the shade house in the nursery were determined immediately with the PAR ($\mu E\ m^{-2}\ s^{-1}$) in the open after completing the reading in each subplot and in the shade house. The calculation is shown below:

$$RLI(\%) = \frac{\text{PAR (in the subplot or in the shade house)}}{\text{PAR (in the open)}} .100\ \%$$

4.3 Destructive measurements of growth

Destructive measurements of growth for seedlings in the Berkelah plot, were made at 12 mo intervals (1 and 2 y after planting). Seedlings in the nursery, for the soils and fertiliser study, were harvested at 9 mo intervals (9 and 18 mo), whilst, for the sand culture experiments, the seedlings were harvested at 6 mo intervals (6 and 12 mo). Height (cm) and stem diameter (mm) were measured and total number of nodes and total number of green leaves were counted. Each harvested seedling, was divided into leaves, stems and roots. The plant parts were stored in paper bags labelled by species, treatment and harvesting date and dried in an oven at 75 °C for 24 h. Before measuring the dry weights, samples were placed in a desiccator for 1 h to prevent in gain in weight from air humidity.

4.4 Root sampling - mycorrhizal inspection

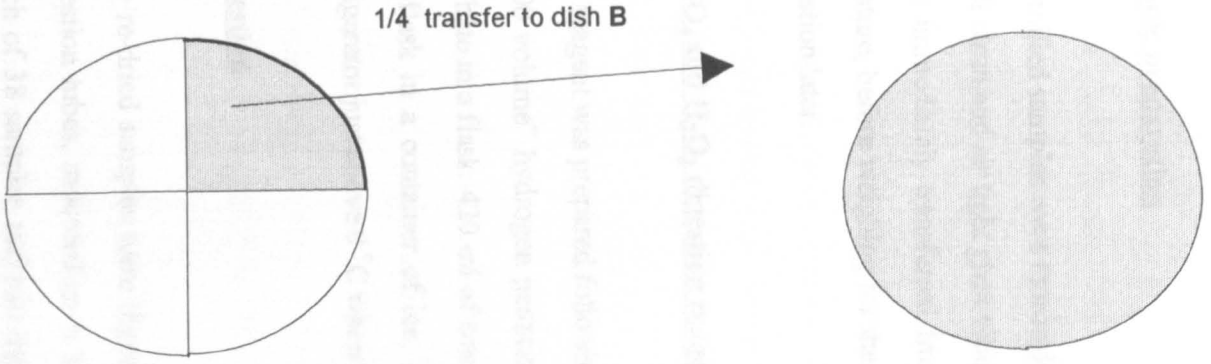
The study of mycorrhizas was only carried out on *Hopea odorata* seedlings in the nursery for the soils and fertiliser experiment (Chapter 6.2a). Root preparation for ectomycorrhizal quantification was followed according to Grand & Harvey (1984). Fresh small roots of seedlings, 18 mo after potting, were cut and fixed in 10 ml of gluteraldehyde in 28-ml vials. In the laboratory, the roots were cleaned of soil and other organic matter with water before inspection. The cleaned roots were cut into 1 cm lengths and evenly distributed in water, in a 14 cm diameter petri-dish. The roots were divided into four parts and one part was selected and transferred into a new dish of the same size with water. The dish was placed over a paper grid which was marked with 20 squares of 1 cm^2 (Figure 4.1). The roots were spread out evenly in the dish to remove clumping and to enhance light transmission. Under a stereo microscope, tips of roots in each square were scored and counted for (A) ectomycorrhizas (ECM), (B) non-ectomycorrhizas, and (C) dead ectomycorrhizas. ECM infection was indicated by the presence of a complete fungal mantle on the short root tips. The estimation of ECM was expressed as a percentage of the total number of ectomycorrhizal root tips over the total number of root tips per plant.

4.5 Foliar sampling

Ten mature leaves from the middle branches of each harvested seedling were randomly selected and oven-dried separately at 70 °C for 24 h, and then were milled with a microhammer mill. The milled samples were kept in small zip-top plastic bags labelled by species, treatment and date of harvesting. These samples were sent to the University of Stirling for chemical analysis. The remainder of the leaves were oven-dried in a separate paper bag at the same temperature for 24 h. Eventually, both dry weights were summed to give the final dry weight of leaves.

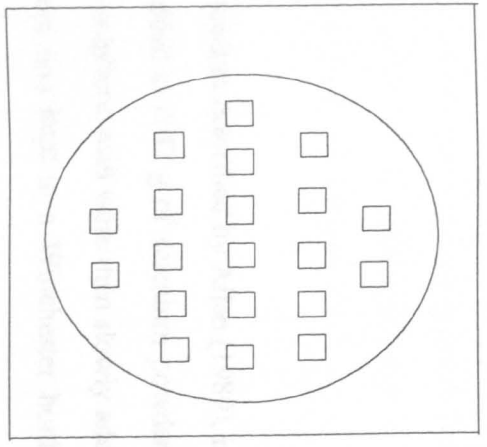
4.6 Foliar chemical analyses

Most of the analyses (80 %) were under taken by Mr. M. White and later the analyses were completed by Mr. S. Gardiner and by the candidate at the Laboratory of Department of



Petri-dish **A** - whole roots per sample

Petri-dish **B** with a quarter of roots per sample



Grid paper with 20 squares of 1 cm^2

Figure 4.1: Root sampling for scoring the ECM root tips.

Biological and Molecular Sciences, University of Stirling. The analyses were started in 1993 and completed in 1996.

4.6.1 Preparation and digestion of samples

Preparation of sample solution for the analysis of the macro-elements: nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca) was by acid digestion (wet ashing) as described below:

Sample preparation

The milled samples were thoroughly mixed and subsamples of approximately 0.15 g were kept in small clean and air tight glass tubes (of known weight) and oven-dried at 70 °C for 4 h. The tubes were immediately transferred from oven to a desiccator for 2 h, to avoid any reabsorption of moisture, before weighing for the new dry weight. The samples were then capped and stored for digestion later.

H_2SO_4 and H_2O_2 digestion reagent

The reagent was prepared following the procedure described by Allen (1989), in which 350 ml of "100 volume" hydrogen peroxide were added to 0.42 g of selenium powder and 14 g lithium sulphate in a flask. 420 ml of concentrated sulphuric acid were then slowly added, whilst cooling the flask in a container of ice. The reagent was kept in a Winchester bottle and stored in a refrigerator just above 0 °C when not in use.

Digestion

The re-dried samples were digested in 4.4 ml of the prepared reagent in "acid-washed" 75 ml digestion tubes, mounted on a Tecam DG-1 block digestor. Each digestion run consisted of a batch of 38 samples and two treatment blanks which were made up of 4.4 ml of the digestion

mixture only. The blanks served as a the "zero standard" for correcting the readings recorded for each run.

Three reference materials of known chemical concentration were also included among the digestion batches. These were: (i) a standard foliar material supplied by Dr. E. V. J. Tanner (Cambridge University) which was treated in the same manner as the other samples, (ii) 64 mg of phenacetin as the nitrogen standard (50 mg g^{-1} N), and (iii) 25 mg of potassium orthophosphate as the phosphate standard (5.7 mg g^{-1} P). The N and P compounds were used to assess digestion recovery and instrument performance.

For each run, the digestion block was initially raised to 80 °C for 30 min to allow a full wetting of the organic material and thereby reduce frothing. Later, the temperature was gradually increased by 30 °C every 30 min to 300-330 °C. This temperature was maintained until the digest cleared, usually after 6 h. The sample solutions were allowed to cool and then filtered through Whatman filter paper no. 44 into a 100 ml volumetric flask. The tubes were washed out well with deionised water to ensure that all of the digest solution was through the filter paper and eventually the filter papers were rinsed. The solution was make up to 100 ml, well mixed with deionised water and transferred to a labelled plastic bottle ready for elemental analysis.

4.6.2 Elemental analyses

The sample solutions were analysed for elemental concentrations in the same order as the batches were digested. Each sample solution was analysed for nitrogen, phosphorus, potassium, magnesium and calcium. Nitrogen was determined by flow injection analysis and gas diffusion technique using a Tecator 5020 auto-analyser and following the procedure given in Tecator's application notes ASN 50-03/84 (Tecator 1984). The detection range used for N was 10 - 100 mg l^{-1}.

Phosphorus was also determined by flow injection analysis following the procedure given in Tecator's application notes ASN 60-02/83 (Tecator 1983). The colour of the reduced heteropoly acid was measured at 650 nm by a Tecator 5030 spectrophotometer and the range of detection

was 0.25-5.0 mg l^{-1}. For nitrogen and phosphorus, the first sample in each batch was re-measured at the end of each batch run to estimate the magnitude of the drift in that run and this enable any correction for drift.

The concentrations of calcium, potassium and magnesium in each sample were determined by flame spectroscopy using a Varian AA-575 atomic absorption spectrophotometer. Potassium was measured by flame emission using air-acetylene flame, while calcium and magnesium were measured by atomic absorption using a hotter nitrous oxide-acetylene flame (Grimshaw *et al.* 1989).

All standard and reagent blanks used in calibrating the two instruments were prepared in 0.5 M sulphuric acid to maintain the same levels of acidity as those in the sample solutions. Samples with concentrations above the detection limit of calibration were diluted with deionised water in 0.5 M sulphuric acid (ten-fold) and rerun. The readings for each batch of samples and standards (foliar and chemical, respectively) were corrected by subtracting the mean value recorded for the treatment blanks in that batch. For each batch of nitrogen and phosphorus with a drift of more than 5 %, corrections were also made by subtracting the drift factor from each reading which was related to the sample's rank order in the batch. The drift was estimated for each sample by using the expression:

$$\frac{\text{Drift} \cdot \text{rank order of sample}}{40}$$

4.6.3 Data calculation

After corrections with values recorded for blanks and for drift, the elemental concentrations were expressed on a dry weight of material basis (mg g^{-1}) are calculated as follow:

a) Calculation for N, P & Mg

$$\text{Concentration (mg g}^{-1}) = \frac{S \cdot V}{W \cdot 1000}$$

(b) Calculation for K & Ca (1 in 10 dilution)

$$\text{Concentration (mg g}^{-1}) = \frac{S \cdot V \cdot 10}{W \cdot 1000}$$

where,

S = concentration ~~in sa~~mple solution (μg ml^{-1})

V= solution volume of diluted digest (100 ml)

W = dry weight of sample used (g)

CHAPTER 5: FIELD PLANTING TRIALS

5.1 INTRODUCTION

Deforestation in Peninsular Malaysia has mainly been due to the expansion of tree-crop plantations (rubber and oil palm) and land settlement. Commercial logging and harvesting may cause forest degradation and ultimately result in deforestation. Ahmad Zainal (1992) reported that deforestation in Peninsular Malaysia increased from *c.* 0.25 million ha annually between 1981-85 to 0.48 million ha in 1989. It was estimated that a total of 4.9 million ha were harvested within the Permanent Forest Estate (PFE) between 1971-1990 in Peninsular Malaysia and *c.* 80,940 ha per annum for the stateland forest (The Ministry Industries Malaysia 1989).

The logging process in a selectively-logged mixed hill dipterocarp forest in Peninsular Malaysia is a crawler-tractor logging system. It usually involves tree felling with power chainsaws, ground skid of felled trees to a roadside or temporary landing by a Caterpillar or Komatsu crawler. From the temporary landing the logs are winched directly to the roadside by a six-wheel drive vehicle known as a winch-lorry. Further transportation of logs between the forest areas and the processing mills has resulted in soil disturbance (Kamaruzaman 1992). The activities are becoming a major problem in threatening the sustainability of forest and agricultural productivity and causing the deterioration of both land and water resources (Kamaruzaman *et al.* 1986, Kamaruzaman & Nik Muhamad 1987). The logging operations result in opening up of the forest canopy, displacing the soil surface and compacting the soil at the decking site or log landing and along the skid trails. The extent of damage in the forest due to logging operations has been reported in other studies. A study in logged forest in Sabah showed that 40 % of the logged area was covered with skid trails and log landings (Fox 1968). The extraction of timber prior to clear-felling to convert to plantation in eastern Sabah resulted in 24 % coverage by tractor tracks (Malmer & Grip 1990), and a survey in logged forest in the Ulu Segama Forest Reserve, Sabah showed that 25 to 30 % of the survey areas were covered by the log landings and skid trails (Nussbaum 1995). Study in Peninsular Malaysia reported that *c.* 45-50 % of the logged areas were severely disturbed and *c.* 20 % of the areas undisturbed (Kamaruzaman 1991b).

This study is similar to enrichment planting, in particular to enriching the disturbed areas in the logged forest with timber quality species. Wyatt-Smith (1963) outlined the categories when the enrichment planting should be considered and also the problems which may encountered in the effort. Among the indigenous species recommended for enrichment planting were *Dryobalanops aromatica* ("kapur"), *Shorea* spp. ("meranti") and *Dipterocarpus* ("keruing") (Wyatt-Smith 1963, Ismail 1964). Recently, dipterocarp species were among other timber species recommended for plantation in Peninsular Malaysia, viz: *Shorea parvifolia*, *Hopea odorata* and *Dryobalanops aromatica* (Anonymous 1991).

The aims of the study were to test the responses of the species to open planting, under partial shade and planting under closed categories, and to study the growth of the seedlings in the degraded categories. Differences in the growth of seedlings need not only be because of light effects but it could also be attributed to other factors viz: fertilising in the nursery and the fertility of soil at the site could be either enhancing or inhibiting the growth. For these reasons, foliar chemical analysis was needed to interpret the growth data. Two species of dipterocarp were used for planting trials, *Hopea odorata* and *Dryobalanops oblongifolia*. The chosen species were not found in the plot. Since the study had to begin in 1991, which was outside of a "general flowering" period, very few dipterocarps species were flowering and fruiting, and therefore little choice of species was possible.

5.2 MATERIALS AND METHODS

5.2.1 The plot

Field experiments were conducted in the 5.6 ha plot at Berkelah Forest Reserve, Pahang. The location of the study site, the categories of the plot before clearing and the preparation of the plot for planting were described and discussed in the Study Area and Establishment of the Research Plot (Chapter 3.3.1; Figure 3.3). Five types of planting categories were defined within the 5.6 ha plot. The categories were named A, B, C, D & E. The subplots were categorised into three groups based on soil compaction: B, compacted soil; A and C, less compacted; and D and E, undisturbed. The details of compaction of the subplot were described in Chapter 3.3.1(a). Based on the light

levels, the categories of the subplot were categorised: A & B as open categories, C as partial shade and D & E as closed categories. Each category was randomly replicated at six locations within the plot. The light category of the subplot was defined according to the percentage of the exposure of the ground and means percentage of relative light intensity (RLI) received by the seedlings within the subplot. The light measurements (PAR) were determined from a wide sampling within the subplot categories. The mean PAR value for each subplot was found by averaging 16 readings from the centre and from the edge. The determination of RLI in the plot was described in the General Methods (Chapter 4.2). The percentages of RLI in each subplot category were: A, 20-25 %; B, 50-55 %; C, 8-9 %; and D & E, 2-3 %.

The categories of the subplots, interms of the percentage of the exposure of the ground, were maintained through out the study periods by weeding in categories A and B and the shade of the subplots in category C, was manipulated by thinning. Closed canopy categories, D and E, were defined according to the total number of poles, saplings and seedlings of dipterocarp species present in the each of subplot (20 m x 20 m). Category D was defined as many dipterocarps and the number of dipterocarps (dbh < 9.6 cm) found naturally grown in the subplots was between 67-146. Whilst, category E was named as few dipterocarps with 13-33 of dipterocarps found in the subplots.

5.2.2 Soil of the plot

The soil collection for the chemical and physical analyses were described in the General Methods (Chapter 4.1). The analyses of composite samples of cores of the top 0-15 cm and 15-30 cm of soils for each subplot categories in the plot research are shown in Tables 5.2a & 5.2b for the chemical characteristics and physical properties, respectively. The soils of surrounding areas were not studied but there is no reason to believe that the plot's soils were in any way atypical.

5.2.3 Experiment I - *Hopea odorata*

Seeds of *H. odorata* were collected from trees growing in the FRIM compounds on the 18 November 1991 and were sown on the 20 November 1991 in the FRIM nursery. The size of the

Table 5.2a: Soil chemical characteristics of the subplots at different depths prior to planting. Plot categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps (Mean ± SE, n=3).

Plot category	Depth (cm)	(%)			(ppm)	Exchangeable (meq.100 g^{-1})		
		N	Organic carbon	Fe	P available	Mg	Ca	K
A	10	0.17 ± 0.02	1.89 ± 0.27	0.94 ± 0.03	4.21 ± 0.94	0.40 ± 0.10	0.18 ± 0.07	0.18 ± 0.03
	30	0.13 ± 0.02	1.26 ± 0.30	1.04 ± 0.01	2.22 ± 0.75	0.23 ± 0.03	0.10 ± 0.03	0.16 ± 0.03
B	10	0.10 ± 0.01	1.13 ± 0.17	1.00 ± 0.08	1.75 ± 0.50	0.14 ± 0.02	0.15 ± 0.04	0.11 ± 0.01
	30	0.09 ± 0.01	0.88 ± 0.13	0.99 ± 0.08	0.97 ± 0.31	0.09 ± 0.02	0.10 ± 0.03	0.10 ± 0.03
C	10	0.13 ± 0.01	1.49 ± 0.21	0.81 ± 0.05	3.17 ± 0.38	0.25 ± 0.08	0.16 ± 0.09	0.10 ± 0.01
	30	0.12 ± 0.01	1.34 ± 0.22	0.92 ± 0.06	2.19 ± 0.57	0.20 ± 0.10	0.10 ± 0.05	0.08 ± 0.007
D	10	0.14 ± 0.01	1.54 ± 0.13	0.99 ± 0.06	2.20 ± 0.12	0.48 ± 0.05	0.09 ± 0.01	0.17 ± 0.01
	30	0.10 ± 0.001	1.00 ± 0.10	1.10 ± 0.06	1.13 ± 0.23	0.33 ± 0.05	0.06 ± 0.01	0.13 ± 0.01
E	10	0.14 ± 0.003	1.85 ± 0.17	0.88 ± 0.05	4.48 ± 1.11	0.30 ± 0.07	0.18 ± 0.12	0.14 ± 0.01
	30	0.12 ± 0.01	1.48 ± 0.06	0.99 ± 0.07	3.01 ± 0.38	0.36 ± 0.21	0.07 ± 0.03	0.09 ± 0.003

Table 5.2b: Soil physical properties in the subplots at different depths prior to planting. Plot categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps (Mean ± SE, n=3).

Plot category	Depth (cm)	%					Bulk density ($g\ cm^{-3}$)	pH
		CEC	Fine sand	Coarse sand	Silt	Clay		
A	10	5.89 ± 0.46	40.67 ± 1.76	17.00 ± 10.54	12.67 ± 4.10	29.33 ± 4.70	1.06	4.31 ± 0.04
	30	6.81 ± 0.86	44.67 ± 0.88	15.33 ± 10.48	11.67 ± 3.84	32.33 ± 5.70	-	4.34 ± 0.12
B	10	6.50 ± 2.62	36.67 ± 7.13	27.00 ± 11.37	9.00 ± 7.00	29.33 ± 11.39	1.13	4.41 ± 0.07
	30	6.58 ± 3.11	36.67 ± 8.45	26.33 ± 12.73	10.33 ± 6.36	30.67 ± 12.72	-	4.43 ± 0.08
C	10	4.21 ± 0.09	38.33 ± 2.60	43.33 ± 2.96	2.67 ± 0.67	17.33 ± 0.67	0.94	4.40 ± 0.13
	30	3.66 ± 0.04	39.33 ± 1.76	43.33 ± 2.33	2.67 ± 0.67	17.33 ± 0.67	-	4.48 ± 0.07
D	10	6.81 ± 0.90	45.00 ± 4.73	7.67 ± 1.76	15.00 ± 2.65	32.33 ± 1.33	0.91	4.44 ± 0.04
	30	5.64 ± 0.49	43.67 ± 5.24	8.00 ± 1.52	16.00 ± 3.21	35.00 ± 1.15	-	4.52 ± 0.07
E	10	6.36 ± 1.20	39.67 ± 1.45	39.67 ± 0.67	2.67 ± 0.67	19.00 ± 1.53	0.89	4.28 ± 0.13
	30	5.42 ± 0.37	50.00 ±8.50	29.33 ± 8.41	3.00 ± 1.00	19.33 ± 1.33	-	4.34 ± 0.04

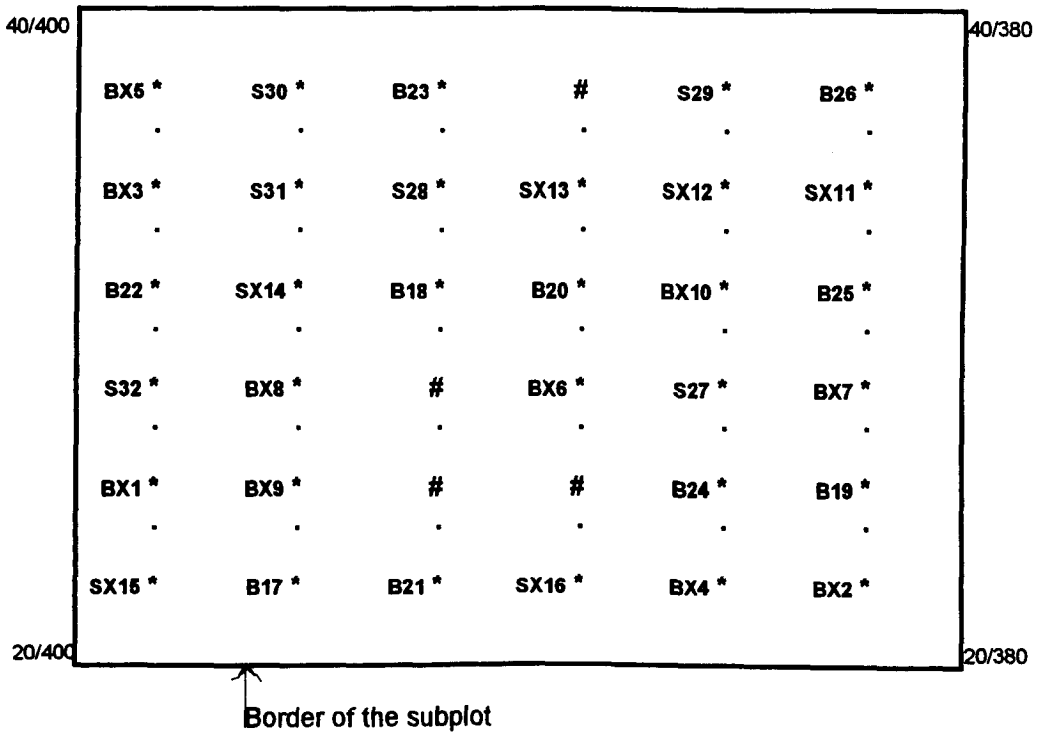
seeds was varied and therefore this resulted a range of sizes in term of seedling height. A sowing trial on the three different sizes of *H. odorata* seeds (small, medium and large) was done on the 23 December 1992 in the FRIM nursery showed that different sizes of seeds produced different sizes of seedlings, viz: small, medium and large seedlings, respectively (Raja Barizan unpub. data). A total of 1,200 seedlings with the range of size, 6-10 cm were potted for out-planting in the 5.6 ha plot at Berkelah F.R. The seedlings were potted in a 12.5 cm x 20 cm black polythene bags with a standard nursery soil mixture of three parts of soil and one part of sand. Triple superphosphate (TSP), a fast-release fertiliser, was used for the experiments. The amount of TSP to be applied to the seedlings was based on the study of phosphate adsorption by some Malaysian soils (Zaharah 1979). Half of the total seedlings was applied with triple superphosphate (TSP) fertiliser, 0.33 g (144 mg P) per pot. The fertiliser was applied at monthly intervals over 5 mo. Due to the different initial sizes of the seedlings used for potting, this resulted in two distinct ranges of sizes 6 mo after potting. Thus, the seedlings were grouped into two size classes, small seedlings with range of height 10-15 cm and large seedlings 20-30 cm of height.

The seedlings were transported from FRIM to the plot in a lorry with no cover. Due to the transporting shock (exposed to the sunlight and wind), 50 % of the total seedlings was severely affected; the leaves were wilted and dropped. However after 3 wk of hardening, *c.* 40 % of the seedlings recovered with new flush of leaves. It is a standard practise to harden the seedlings before planting, however, precautions need to be undertaken to protect the seedlings from pests (e.g. wild boars and elephants). During the hardening periods the seedlings were relieved from transporting shock and also to enable the seedlings to acclimatise to the new environment. The dates of transferring and planting the seedlings in the Berkelah F.R. plot are reported in Table 5.1. After 3 wk of hardening, 32 seedlings at the age of 8 mo: 16 fertilised and 16 non-fertilised, were randomly planted in each subplot. For each fertiliser level, out of 16 seedlings, six were small and ten were large seedlings. The lay-out of the planting in one of the subplots is shown in Figure 5.1. Plate 5.1a shows the seedlings of *H. odorata* on the day of planting in category B.

Hopea odorata was planted at a spacing of 3.4 m x 3.4 m. Such spacing, is actually not suitable for enrichment planting which requires a wider spacing between rows. However, in this study, all seedlings were harvested after 2 y in the field, therefore, the exact spacing and alignment used

Plate 5.1: *Hopea odorata* seedlings planted in the open and compacted soil, category B: (a) on the day of planting (b) small fertilised seedlings 2 y after planting.

Figure 5.1: Lay-out of the planting in subplot C_1 in a 5.6 ha plot at Berkelah F.R. Pahang.



Abbreviations:

Bx = Large size and fertilised seedlings of *Hopea odorata*
SX = Small and fertilised seedlings of *Hopea odorata*
B = Large non-fertilised seedlings of *Hopea odorata*
S = Small and non-fertilised seedlings of *Hopea odorata*
# = No plant
. = Planting position for *Dryobalanops oblongifolia*
1-32 = Tag number of *Hopea odorata* seedlings in plot C_1

was not imperative. The size of the planting hole was 20 cm x 20 cm x 30 cm. One seedling with a ball of nursery soil was placed in a hole. The root collar of the seedling was levelled with the ground or slightly below it. The hole was re-filled with the soil from the planting hole. The soil around the roots was pressed in by hand and then tamped down with feet to ensure the seedling was steadily placed in the planting hole. In all planting categories, the only disturbance to the soil was due to the planting holes, and no addition of fertiliser to the planted seedlings was made in the field. Total number of seedlings planted in the plot was: 5 categories x 6 subplots x 2 harvests x 2 P levels x (3 replicates for small size + 5 replicates for large size) = 960.

Survival of the seedlings was determined after each year of planting as a percentage of the number of seedlings remaining alive in each subplot category. The measurements of growth and the dry weight of the seedlings were determined at 12 and 24 mo after planting as described in the General Methods (Chapter 4.3). Sample sizes varied within and between the subplot categories as the harvest was conducted in the laboratory of Department of Biological & Molecular Sciences, University of Stirling as described in the General Methods (Chapter 4.6). Under the split-plot design as applied here, categories were replicated at the forest subplot level and the fertiliser, size and harvest factors were all nested within these subplots.

Table 5.1: Chronological details for out-planting *Hopea odorata* and *Dryobalanops oblongifolia* in the 5.6 ha plot at Berkelah F.R. Pahang.

Activities	*H. odorata*	*D. oblongifolia*
Sowing	20/11/1991	24/07/1992
Potting	22/01/1992	04/09/1992
Fertilising (5 applications)	22/03/1992	02/12/1992
Hardening in the forest	10/07 - 03/08/1992	17/04 - 16/05/1993
Planting	04/08 - 14/08/1992	17/05 - 22/05/1993
First Harvest	24/08/1993	10/05/1994
Second Harvest	16/08/1994	15/05/1995

5.2.4 Experiment II - *Dryobalanops oblongifolia*

A total of 1,200 seedlings of *D. oblongifolia* or locally known as "keladan", were raised and potted in the same size of polythene bag and with the same type of soil as used for Experiment I. The seedlings were treated in a similar manner as Experiment I, but the seedlings were raised, potted, fertilised, transferred to the field, planted and harvested at the different of dates (refer to Table 5.1). The seedlings were applied with 0.40 g of TSP (175 mg P) per pot at monthly intervals. The size of the seedlings prior to planting, was quite uniform (number of leaves was 4-5; height was 17-22 cm). Only one size class of seedlings was considered. After hardening, 30 seedlings at age of 8.5 mo: 15 fertilised and 15 non-fertilised seedlings, were randomly planted in the subplots. The total number of seedlings planted in the plot was: 5 categories x 6 subplots x 2 P levels x (8 replicates for first harvest + 7 replicates for second harvest) = 900.

The seedlings were planted in between the *H. odorata* ones with a spacing 1.7 m x 3.4 m, but the spacing in between "keladan" was 3.4 m x 3.4 m. The planting lay-out in one of the subplot is shown in Figure 5.1. The survival of the seedlings was determined in a similar way as Experiment 1. The measurements of growth and dry weight were carried out at 12 mo intervals, 12 and 24 mo after the planting in a similar manner as Experiment I. As for *H. odorata*, the sample size of *D. oblongifolia* within and between the subplot categories, also varied due to the death of the seedlings as the experiment progressed. Foliar sampling and foliar chemical analyses of the harvested seedlings were done as described in the General Methods (Chapters 4.5 & 4.6, respectively).

5.2.5 Data analysis

Analysis of variance for a split-plot unbalanced design has two strata (a and b) and here it involved the five different categories (CAT) in the plot as levels of the main factor (stratum a). Each category was replicated as six subplots (SPLOT) and was located completely at random within the plot. The two levels of fertiliser, fertilised (P1) and non-fertilised (P0) seedlings, were randomly assigned within each subplot (stratum b). The analysis of the growth and the nutrient data were divided into four parts to ease analysis and interpretation. Each harvest (at 1 y and 2 y)

and each size class (small and large) combination was analysed separately. A combined analysis would have led to main interactions within the subplot stratum. Analysis was only carried out on the surviving seedlings. Thus, for growth and nutrient data some treatment combinations were naturally "missing" and the replication was unequal. As a result, the unbalanced split-plot model Type III was used for the analysis using SAS GLM procedure (SAS System for Linear Model 1993). The least significant difference (LSD) test was used to test the significant differences between levels of factors (Appendix 5.1). Thus for each ANOVA, the error term for stratum a, at subplot unit was used to test the category factor and a second error term for stratum b, at the planting location (within subplot unit), used to test the fertiliser effect and the fertiliser and category interaction.

The survivorship of each species under the different plot categories was examined. The means of percentage seedlings data were derived after calculating the percentage values for each subplot category. The survival data for both experiments was arcsine transformed prior to analysis (Zar 1984). Correlation coefficient's Pearson was carried out to measure the degree of association between variables; total dry weight and foliar nutrients concentrations (mg g^{-1}) of N, P, Mg, Ca and K, using MINITAB Release 10 for Windows (Minitab Reference Manual 1994). The data were analysed by summing up the six replicates of surviving fertilised seedlings, separately for different planting categories at different harvests (1 y & 2 y after planting). For comparison of the growths, dry weights and the nutrient concentrations of the seedlings at different harvests and at two different size classes (only for *H. odorata*), the percentage changes in the means were calculated as described by Evans (1972).

5.3 RESULTS

5.3.1 Soil of the plot

Results of an analysis of soils in the different subplot categories showed that the soil mineral nutrients in subplot B at depth 30 cm, in general, had lower concentrations compared with other subplot categories but a higher cation exchange capacity (CEC) (Table 5.2a). Organic carbon, N, available P and exchangeable Mg were found the lowest in category B at 30 cm depth. These could have been due to the removal of the top soil together with the existing vegetation during logging operations. The bulk density (soil compaction) in subplot B was relatively higher (1.13 g cm^{-3}) than in the other categories as a result of ground skidded of felled trees using heavy machinery. The soils in the plot were considered as strongly acidic with pH values between 4.31 and 4.48. Soil in subplot C had high percentages of fine and coarse sand but low percentages of CEC due to the low content of soil colloids. The soil in subplot C had also a relatively low with silt and clay contents than in the other subplot categories (Table 5.2b).

5.3.2 Experiment I - *Hopea odorata*

Survival of seedlings

The survival of the seedlings was significantly affected by the subplot categories, 1 y after planting in either size class (Table 5.3: $p<0.01$, small size; $p<0.05$, large size). However, there was no significant effect of fertiliser nor interaction between category and fertiliser on the survival of the seedlings. The survival of small seedlings in the open categories (A & B) and in the partially shaded (C) was significantly higher than that in the closed canopy categories (D & E). The survival of the large seedlings was also found to be significantly higher in categories A, B and C (Table 5.4). In the other categories, the survival of large seedlings was higher than the small seedlings: in closed areas (D & E) it increased by 7 and 22 %, respectively.

After 2 y in the plot, the category and the level of fertiliser significantly affected the survival of seedlings in both size classes (Table 5.5). No interaction effect of fertiliser and category was

Table 5.3: Summary of the ANOVA results of the effect of plot category (CAT) and phosphorus fertiliser (FERT) on the survival, as arcsine transformed percentage data, of *Hopea odorata* in two size classes, 1 y after planting in the plot at Berkelah F.R., Pahang.

Source of variance	df	Small F-value[1]	Large F-value[1]
CAT	4	5.60 **	3.08 *
FERT	1	0.23 ns	3.69 ns
CAT*FERT	4	2.71 ns	1.21 ns

* P < 0.05; ** P < 0.01; ns = not significant

[1] Error (a) df = 25, error (b) df = 25

Table 5.4: The effect of plot category and fertiliser levels on the mean percentage of survival (calculated from the detransformed arcsine data used in the ANOVA) of *H. odorata* in two size classes, 1y after planting. Categories and fertiliser levels within size classes were compared with LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. Fertiliser levels: P1, +TSP; P0, control.

	Size of seedlings		% effect of initial size[2]
	Small	Large	
Category			
A	100 *a*	100 *a*	0
B	100 *a*	100 *a*	0
C	100 *a*	100 *a*	0
D	90 *b*	96 *b*	7
E	79 *b*	96 *b*	22
Fertiliser			
P1	98 *a*	100 *a*	2
P0	97 *a*	99 *a*	2

[1] Means not sharing the same small letter are significantly different at p < 0.05

[2] % increase of large size over small seedlings; i.e. [(large-small)/small].100

shown. For small seedlings, the survival of seedlings was significantly higher in category B (93 %) but significantly lower in category E (22 %), as shown in Table 5.6. There were no significant differences in survival of large seedlings between categories A, B and C, although, survival in these three categories was significantly different from those in categories D and E. There was no significant differences of survival found between categories D and E after 2 y in the field. The survival of fertilised seedlings in either size class was significantly higher than for non-fertilised ones. Larger seedlings led to increased survival in categories: A by 11 %, C by 43 % and E by 105 %, but in categories B and D, the survival of small seedlings was higher than the large one by 16 and by 45%, respectively.

Growth of seedlings

At 1 y after planting, categories of the plot highly significantly affected all the non-destructive variables of growth and the dry weights of small seedlings (Table 5.7, $p<0.001$). Fertiliser also significantly affected all of the growth variables and the dry weights of the seedlings but to different levels of significance. There was no significant effect observed for the interaction between category and fertiliser. Table 5.8 shows that all growth parameters and dry weight of stem and roots for small and large seedlings were not significantly different between the two open categories (A & B), except that dry weight of leaves in category B was significantly higher than that in category A. All growth parameters and dry weights of the seedlings in the closed categories (D & E) were also not significantly different from each other, for both size classes. All growth variables and dry weight of small seedlings in partial shade (C) showed no significance differences from those in closed categories but their growth was significantly different from that in the open categories.

All the growth variables and the dry weights of seedlings in either size class, were significantly higher in the open categories (A, Plate 5.2a & B, Plate 5.1b) than in the partial shade (C) and closed categories (D, Plate 5.2b & E). Large seedlings had a better growth compared to small seedlings, regardless of planting category. Fertilising the seedlings also significantly improved the growth of seedlings in either size class (Table 5.9), although, the percent effect of size showed

Plate 5.2: *Hopea odorata* seedlings (a) of the large and fertilised treatment in the open and less compacted soil (category B) 1 y after planting, and (b) of the large and non-fertilised treatment in closed canopy category with many dipterocarps (D) 2 y after planting.

Table 5.5: Summary of the ANOVA results of the effect of plot catogory (CAT) and phosphorus fertiliser (FERT) on the percentage survival, as arcsine transformed percentage data, of *Hopea odorata* in two size classes, 2 y after planting in the plot at Berkelah F.R., Pahang.

Source of variance	df	Small	Large
		F-value[1]	
CAT	4	4.49 **	5.14 **
FERT	1	5.76 *	11.37 **
CAT*FERT	4	1.26 ns	2.42 ns

* P < 0.05; ** P < 0.01; ns = not significant

[1] Error (a) df = 25, error (b) df = 25

Table 5.6: The effect of plot category and fertiliser levels on the mean percentage of survival (calculated from the detransformed arcsine data used in the ANOVA) of *H. odorata* in two size classes, 2 y after planting. Categories and fertiliser levels within size classes were compared with LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. Fertiliser levels: P1, +TSP; P0, control.

	Size of seedlings		% effect of initial size[2]	% change of harvest[3]
	Small	Large		
Category				
A	70 *ab*	78 *a*	11	-22
B	93 *a*	78 *a*	-16	-22
C	60 *bc*	86 *a*	43	-14
D	64 *ab*	35 *b*	-45	-64
E	22 *c*	45 *b*	105	-53
Fertiliser				
P0	52 *b*	57 *b*	10	-43
P1	73 *a*	73 *a*	0	-26

[1] Means not sharing the same small letter are significantly different at p< 0.05

[2] % increase of large size over small seedlings; i.e. [(large-small)/small].100

[3] % change from 1 y to 2 y for large seedlings; i.e. [(2y - 1y)/1y].100

Table 5.7: Summary of the ANOVA results of the effect of plot category (CAT) and phosphorus fertiliser (FERT) on the growth of *H. odorata* , 1 y after planting, in the plot at Berkelah Forest Reserve, Pahang.

	Source of variance	df	F-value[1] No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
Small									
	CAT	4	15.09 ***	15.21 ***	26.84 ***	35.53 ***	8.21 ***	11.15 ***	10.78 ***
	FERT	1	9.23 **	5.04 *	7.36 **	12.91 ***	6.73 *	5.38 *	7.14 **
	CAT*FERT	4	2.34 ns	0.95 ns	0.98 ns	1.92 ns	2.32 ns	1.45 ns	2.36 ns
Large									
	CAT	4	39.44 ***	18.01 ***	35.58 ***	73.43 ***	13.01 ***	14.06 ***	29.68 ***
	FERT	1	18.13 ***	12.94 ***	31.67 ***	57.47 ***	15.34 ***	22.52 ***	35.78 ***
	CAT*FERT	4	5.08 ***	4.11 **	4.51 **	13.00 ***	5.07 ***	7.55 ***	12.84 ***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error (a) df = 25; error (b) df = 125, 127, 128 & 130 (Small); 249 to 251 (Large)

Table 5.8: The effect of plot category on the mean growth and dry weight of *H. odorata* in two size classes, 1 y after planting. Categories within size classes for each variable, were compared with LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps.

	Plot category	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
Small								
	A	50 *a*	67 *a*	38.8 *a*	6.00 *a*	4.25 *b*	4.08 *a*	4.05 *a*
	B	60 *a*	83 *a*	43.7 *a*	7.00 *a*	7.12 *a*	6.12 *a*	6.02 *a*
	C	23 *ab*	36 *b*	21.3 *b*	3.24 *b*	1.67 *bc*	1.39 *b*	1.28 *b*
	D	6 *c*	17 *b*	14.5 *bc*	2.29 *bc*	0.19 *c*	0.20 *b*	0.29 *b*
	E	5 *c*	15 *b*	12.9 *c*	1.98 *c*	0.16 *c*	0.13 *b*	0.22 *b*
	Mean	**29**	**44**	**26.2**	**4.10**	**3.53**	**2.38**	**2.37**
Large								
	A	89 *a*	124 *a*	60.5 *a*	8.97 *a*	12.93 *a*	14.07 *a*	11.01 *a*
	B	104 *a*	137 *a*	64.7 *a*	9.65 *a*	13.99 *a*	16.46 *a*	13.79 *a*
	C	40 *b*	55 *b*	37.8 *b*	5.48 *b*	3.29 *b*	3.15 *b*	3.40 *b*
	D	8 *c*	20 *b*	21.5 *c*	2.91 *c*	0.50 *b*	0.42 *b*	0.48 *b*
	E	8 *c*	18 *b*	19.8 *c*	2.78 *c*	0.36 *b*	0.34 *b*	0.32 *b*
	Mean	**50**	**71**	**40.9**	**5.96**	**6.21**	**6.89**	**5.80**
% effect of size[2]		**72**	**61**	**56**	**45**	**76**	**189**	**145**

[1] Means not sharing the small letter are significantly different at $p < 0.05$.

[2] % increase of large size over small seedlings; i.e. [(large-small)/small].100

Table 5.9: The effect of fertilisation on the mean growth and dry weight of *H. odorata* seedlings 1 y, after planting. Treatments were compared by LSD[1] test using (P1, +TSP; P0, control).

	Fertiliser level	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
Small								
	P0	25 *b*	41 *b*	24.6 *b*	3.82 *b*	1.87 *b*	1.80 *b*	1.74 *b*
	P1	40 *a*	54 *a*	31.1 *a*	4.90 *a*	4.21 *a*	3.52 *a*	3.61 *a*
	Mean	**33**	**48**	**28**	**4.36**	**3.04**	**2.66**	**2.68**
Large								
	P0	39 *b*	60 *b*	35.6 *b*	5.23 *b*	3.79 *b*	3.91 *b*	3.53 *b*
	P1	62 *a*	83 *a*	46.6 *a*	6.77 *a*	8.75 *a*	9.88 *a*	8.14 *a*
	Mean	**51**	**72**	**41.1**	**6.00**	**6.27**	**6.90**	**5.84**
% effect of size[2]		**55**	**50**	**47**	**38**	**106**	**159**	**118**

[1] Means not sharing the small letter are significantly different at $p < 0.05$.

[2] % increase of large size over small seedlings; i.e. [(large-small)/small].100

that the larger the seedling the better the growth of seedling regardless of fertiliser level (Table 5.10).

After 2 y in the field, the categories highly significantly affected the diameter of small seedlings ($p<0.001$), number of nodes and height growth at $p<0.01$, and the number of leaves and the dry weights of stem and roots at $p<0.05$ (Table 5.11). The effect of fertiliser only significantly affected the diameter of the seedlings. However, there was no interaction effect of category and fertiliser on all the growth variables and the dry weights of small seedlings. The categories highly significantly affected the growth and the dry weight of large seedlings ($p<0.001$ & $p<0.01$). Fertiliser highly significantly affected the diameter of the large seedlings ($p<0.001$), height growth and the dry weight of roots ($p<0.01$), number of leaves, number of nodes and the dry weight of stem ($p<0.05$) but no significant effect of fertiliser was shown on the dry weight of leaves. The interaction of category and fertiliser significantly affected the diameter ($p<0.01$) and the dry weight of stem and roots ($p<0.05$) of large seedlings.

Regardless of size of the seedlings and of the subplot categories, fertiliser increased the growth and the dry weight of seedlings, 2 y after planting (Table 5.13). The mean growth and the mean dry weight of seedlings in either size class showed that seedlings in the open categories (A & B) were significantly higher than those seedlings in the partial category (C) and in the closed categories (D & E) (Table 5.12). The diameter of small seedlings in category C was significantly lower than those in categories A & B but higher than those in categories D & E. As for small seedlings, the height and the diameter growths of large seedlings in category C were significantly lower than in categories A & B but significantly higher than in categories D & E. However, the percent size effect showed that the growth and the dry weight of large seedlings were higher than of small seedlings, irrespective of planting category. Fertiliser significantly improved the growth of the seedlings for both sizes but larger seedlings had higher mean percentages of growth (Table 5.13).

Table 5.10: The effect of plot categories and phosphorus fertiliser on the mean growth and dry weight of large seedlings of *H. odorata*, 1 y and 2 y after planting. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. Fertiliser (P1, +TSP; P0, control).

	Plot Category	Fertiliser levels	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
1 y	A	P0	67	102	50.3	7.32	6.96	6.52	5.95
	B		71	102	42.8	7.78	7.47	8.98	7.23
	C		39	56	37.8	5.56	3.23	2.93	3.35
	D		5	17	17.5	2.58	0.19	0.23	0.35
	E		5	15	16.7	2.45	0.22	0.21	0.20
		Mean	**37**	**58**	**33.0**	**5.14**	**3.61**	**3.77**	**3.42**
	A	P1	112	146	70.7	10.62	18.89	21.61	16.07
	B		136	171	76.7	11.51	20.50	24.20	20.35
	C		41	54	37.7	5.41	3.34	3.35	3.46
	D		11	22	25.3	3.23	0.79	0.61	0.61
	E		9	21	22.7	3.09	0.49	0.46	0.43
		Mean	**62**	**83**	**46.6**	**6.77**	**8.80**	**10.05**	**8.18**
	% effect of size[1]		**68**	**43**	**41**	**32**	**144**	**167**	**139**
2 y	A	P0	71	125	65.2	9.50	12.85	28.10	19.02
	B		96	135	72.4	9.72	14.86	27.87	21.04
	C		42	56	40.6	6.05	2.80	5.49	4.58
	D		8	18	18.7	2.54	0.27	0.40	0.26
	E		6	14	17.1	2.28	0.19	0.24	0.18
		Mean	**45**	**70**	**42.8**	**6.02**	**6.19**	**12.42**	**9.02**
	A	P1	128	164	90.1	12.19	23.06	49.75	47.01
	B		156	215	102.2	15.00	24.33	66.04	45.54
	C		63	74	47.8	6.58	5.53	7.13	6.10
	D		13	24	22.5	3.50	0.74	0.80	0.59
	E		14	23	22.6	3.04	0.60	0.67	0.54
		Mean	**75**	**100**	**57.0**	**8.06**	**10.85**	**24.88**	**19.96**
	% effect of size[1]		**67**	**43**	**33**	**34**	**75**	**100**	**121**

[1] % increase of fertilised over non-fertilised seedlings; i.e. [(P1-P0)/P0].100

Table 5.11: Summary of the ANOVA results of the effect plot categories (CAT) and phosphorus fertiliser (FERT) on the growth of *H. odorata*, 2 y after planting, in the plot at Berkelah Forest Reserve, Pahang.

	Source of variance	df	F-value[1] No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
Small									
	CAT	4	2.83 *	5.47 **	5.18 **	9.37 ***	2.14 ns	3.53 *	3.70 *
	FERT	1	2.93 ns	3.72 ns	3.90 ns	7.93 **	1.43 ns	3.62 ns	2.31 ns
	CAT*FERT	4	0.38 ns	0.45 ns	0.49 ns	1.43 ns	0.34 ns	0.68 ns	1.24 ns
Large									
	CAT	4	4.75 **	9.24 ***	18.73 ***	41.04 ***	5.14 **	12.11 ***	13.50 ***
	FERT	1	6.64 *	5.18 *	10.87 **	16.84 ***	3.80 ns	5.82 *	7.98 **
	CAT*FERT	4	1.29 ns	1.48 ns	1.92 ns	4.21 **	0.96 ns	2.67 *	2.99 *

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error (a) df = 25; error (b) df = 63 & 64 (Small); 152, 154 & 155 (Large)

Table 5.12: The effect of plot categories on the mean growth and dry weight of *H. odorata* in two size classes, 2 y after planting. Categories within size classes for each variable were compared with LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps.

	Plot category	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
Small								
	A	55 *ab*	81 *ab*	54.6 *ab*	8.23 *a*	6.79 *ab*	6.79 *ab*	16.67 *a*
	B	80 *a*	120 *a*	63.6 *a*	9.42 *a*	9.96 *a*	9.96 *a*	20.51 *a*
	C	39 *b*	51 *bc*	34.0 *bc*	5.46 *b*	2.70 *bc*	2.70 *b*	3.50 *b*
	D	7 *c*	14 *c*	15.5 *c*	2.10 *c*	0.22 *c*	0.22 *b*	0.19 *b*
	E	7 *c*	13 *c*	15.4 *c*	1.96 *c*	0.17 *c*	0.17 *b*	0.15 *b*
	Mean	**38**	**56**	**36.6**	**5.43**	**3.97**	**3.97**	**8.20**
Large								
	A	103 *a*	147 *a*	79.3 *a*	11.03 *b*	18.65 *a*	40.40 *a*	35.30 *a*
	B	129 *a*	180 *a*	89.0 *a*	12.67 *a*	20.15 *a*	49.17 *a*	34.71 *a*
	C	52 *b*	65 *b*	44.1 *b*	6.31 *c*	4.11 *bc*	6.29 *bc*	5.34 *bc*
	D	11 *b*	22 *b*	21.1 *c*	3.16 *d*	0.57 *c*	0.66 *c*	0.47 *c*
	E	10 *b*	18 *b*	19.7 *c*	2.64 *d*	0.38 *c*	0.44 *c*	0.35 *c*
	Mean	**61**	**86**	**50.6**	**7.16**	**8.77**	**19.39**	**15.23**
% effect of size[2]		**61**	**54**	**38**	**32**	**121**	**388**	**86**

[1] Means not sharing the small letter are significantly different at $p < 0.05$.

[2] % increase of large size over small seedlings; i.e. [(large-small)/small].100

Table 5.13: The effect of fertilisation on the mean growth and dry weight of *H. odorata* seedlings, 2 y after planting. Within each size class, for each variable, the treatments were compared by the LSD[1] test. Fertiliser (P1, +TSP; P0, control).

	Fertiliser levels	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
Small								
	P0	26 *b*	46 *b*	31.1 *b*	4.90 *b*	2.67 *b*	4.84 *b*	5.38 *b*
	P1	65 *a*	90 *a*	53.2 *a*	7.78 *a*	7.23 *a*	17.62 *a*	15.45 *a*
	Mean	**46**	**68**	**42.2**	**6.34**	**4.95**	**11.23**	**10.42**
Large								
	P0	50 *b*	77 *b*	46.6 *b*	6.60 *b*	6.87 *b*	13.88 *b*	10.08 *b*
	P1	87 *a*	115 *a*	63.8 *a*	9.00 *a*	12.87*a*	29.62 *a*	23.84 *a*
	Mean	**69**	**96**	**55**	**7.80**	**9.87**	**21.75**	**16.96**
% effect of size[2]		**50**	**41**	**30**	**23**	**99**	**94**	**63**

[1] Means not sharing the small letter are significantly different at $p < 0.05$.

[2] % increase of large size over small seedlings; i.e. [(large-small)/small].100

Foliar nutrients of seedlings

Categories of the subplot significantly affected the concentrations of foliar nutrients of the seedlings for both sizes ($P<0.001$), 1 y after planting. However, the concentrations of N in either size class were not significantly affected by the categories (Table 5.14). There was no effect of fertiliser on nutrient concentrations. The concentrations of N of small seedlings were significantly the highest in E (closed category) and significantly the lowest in B (open category) (Table 5.15). The concentrations of P and Mg were significantly higher in closed categories (D & E) and significantly lower in open categories (A & B) in both sizes of seedlings. The concentrations of Ca were significantly higher in the closed categories and in the partial shade but significantly lower in the open categories for small seedlings. For large seedlings, the concentration of Ca was highest in category E followed by category D and then category C but it concentration was lowest in open categories (A & B). The mean percentages of nutrients concentrations were slightly reduced in the large seedlings by 2 % (P), 4 % (Mg), 3 % (Ca) and 8 % (K). Table 5.16 shows that the addition of fertiliser reduced the concentrations of N (4 %), Mg (6 %) and K (7 %) but increased the concentrations of P by only 1 % and Ca by 4 %. The interaction of category and fertiliser did not significantly affect the concentrations of nutrients of small seedlings but it significantly affected the concentrations of N, P and K ($p<0.05$), and Mg ($p<0.01$) of large seedlings. The interaction effect, however, did not significantly affect the concentration of Ca of large seedlings (Table 5.14).

After 2 y in the field, the concentrations of P, Mg and Ca of small seedlings were still highly significantly affected by the categories ($p<0.001$) but less affected the concentrations of N and K ($p<0.05$; Table 5.17). Neither fertiliser nor the interaction of category and fertiliser significantly affected the concentrations of nutrients of small seedlings. As for small seedlings, categories also highly significantly affected the concentrations of P, Mg and Ca ($p<0.001$), but less affected the concentration of K ($p<0.05$) in large seedlings. However, no significant effect was shown for N. Fertiliser only significantly affected the concentrations of Ca ($p<0.01$), and P and K ($p<0.05$) but no interaction effect was shown in the large seedlings. The concentrations of Mg in large seedlings were higher than in small seedlings by 6 %, N higher by 5 %, Ca and K higher only by 1 % but no concentration differences of P were shown in either size class (Table 5.18).

Table 5.14: Summary of the ANOVA results on the effect of plot category (CAT) and phosphorus fertiliser (FERT) on the foliar mineral nutrient concentrations (mg g^{-1}) of *H. odorata* in two size classes, 1 y after planting.

	Source of variance	df	F- value[1] N	P	Mg	Ca	K
Small							
	CAT	4	2.57 ns	29.70 ***	29.19 ***	8.79 ***	10.86 ***
	FERT	1	2.60 ns	0.66 ns	0.00 ns	3.10 ns	1.34 ns
	CAT*FERT	4	2.16 ns	2.08 ns	0.81 ns	0.73 ns	0.38 ns
Large							
	CAT	4	2.29 ns	34.18 ***	50.58 ***	25.41 ***	3.85 *
	FERT	1	1.22 ns	0.06 ns	2.39 ns	0.57 ns	1.81 ns
	CAT*FERT	4	2.53 *	3.18 *	3.79 **	1.32 ns	2.74 *

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error (a) df = 25; error (b) df = 114 (Small); 230 to 233 (Large)

Table 5.15: The effect of plot category on the mean mineral nutrient concentrations of *H. odorata* in two size classes, 1 y after planting. Categories within size classes for each variable, were compared with LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps.

	Plot category	(mg g^{-1} oven dry weight)				
		N	P	Mg	Ca	K
Small						
	A	17.20 *bc*	0.59 *c*	0.73 *c*	4.97 *c*	7.11 *c*
	B	15.76 *c*	0.58 *c*	0.75 *c*	5.17 *c*	7.06 *c*
	C	17.65 *bc*	0.84 *b*	1.57 *b*	8.44 *b*	8.42 *b*
	D	18.00 *b*	1.30 *a*	2.01 *a*	10.29 *a*	9.97 *a*
	E	20.66 *a*	1.38 *a*	1.74 *ab*	10.33 *a*	9.98 *a*
	Mean	**17.85**	**0.94**	**1.36**	**7.84**	**8.51**
Large						
	A	16.72 *b*	0.60 *c*	0.73 *c*	5.07 *d*	7.18 *bc*
	B	18.05 *b*	0.57 *c*	0.70 *c*	4.39 *d*	6.21 *c*
	C	18.02 *b*	0.83 *b*	1.28 *b*	7.21 *c*	7.54 *bc*
	D	18.65 *ab*	1.28 *a*	1.95 *a*	9.80 *b*	8.48 *ab*
	E	20.61 *a*	1.34 *a*	1.90 *a*	11.50 *a*	9.64 *a*
	Mean	**18.41**	**0.92**	**1.31**	**7.59**	**7.81**
% effect of size[2]		**3**	**-2**	**-4**	**-3**	**-8**

[1] Means not sharing the small letter are significantly different at $p < 0.05$.

[2] % increase of large size over small seedlings; i.e. [(large-small)/small].100

Table 5.16: The effect of plot category and phosphorus fertiliser on the mean of foliar mineral nutrient concentrations of large seedlings of *H. odorata*, 1 y after planting. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. Fertiliser levels: P1, +TSP; P0, control.

Plot category	Fertiliser	(mg g^{-1} oven dry weight)				
		N	P	Mg	Ca	K
A	P0	17.72	0.51	0.72	4.98	6.52
B		19.58	0.54	0.66	4.45	6.15
C		17.68	0.73	1.19	6.66	7.23
D		17.64	1.33	2.15	9.03	9.28
E		21.32	1.51	2.09	12.05	11.70
	Mean	**18.79**	**0.92**	**1.36**	**7.43**	**8.18**
A	P1	15.79	0.69	0.75	5.15	7.78
B		16.52	0.60	0.74	4.32	6.26
C		18.31	0.91	1.36	7.69	7.82
D		19.41	1.24	1.81	10.41	7.89
E		20.08	1.22	1.76	11.08	8.10
	Mean	**18.02**	**0.93**	**1.28**	**7.73**	**7.57**
% effect of fertiliser[1]		**-4**	**1**	**-6**	**4**	**-7**

[1] % increase of fertilised over non-fertilised seedlings; i.e. [(P1-P0)/P0].100

Table 5.17: Summary of the ANOVA results on the effect of plot category (CAT) and phosphorus fertiliser (FERT) on the foliar mineral nutrient concentrations (mg g^{-1}) of *H. odorata* in two size classes, 2 y after planting.

	Source of variance	df	F- value[1]				
			N	P	Mg	Ca	K
Small							
	CAT	4	4.08 *	13.61 ***	32.71 ***	12.52 ***	3.71 *
	FERT	1	0.90 ns	0.34 ns	0.00 ns	0.01 ns	0.46 ns
	CAT*FERT	4	0.44 ns	0.42 ns	0.51 ns	0.12 ns	0.42 ns
Large							
	CAT	4	1.01 ns	19.86 ***	42.73 ***	10.43 ***	3.69 *
	FERT	1	2.77 ns	5.40 *	3.69 ns	7.21 **	4.33 *
	CAT*FERT	4	0.99 ns	1.25 ns	0.89 ns	1.85 ns	2.40 ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error (a) df = 25; error (b) df = 61 (Small); 149, 150 (Large)

Table 5.18: The effect of plot category on the mean of foliar mineral nutrient concentrations of *H. odorata* in two size classes, 2 y after planting. For each variable, within each size class. Categories were compared with the LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps.

	Plot category	(mg g^{-1} oven dry weight)				
		N	P	Mg	Ca	K
Small						
	A	19.66 *a*	0.66 *b*	0.94 *c*	4.76 *c*	6.94 *c*
	B	17.06 *b*	0.63 *b*	0.87 *c*	4.09 *c*	7.26 *bc*
	C	18.97*ab*	0.75 *b*	1.38 *b*	6.14 *b*	7.75 *bc*
	D	20.89 *a*	1.22 *a*	2.22 *a*	7.81 *a*	9.17 *a*
	E	20.65 *a*	1.14 *a*	2.12 *a*	8.99 *a*	8.36 *ab*
	Mean	**19.45**	**0.88**	**1.51**	**6.36**	**7.90**
Large						
	A	18.63 *b*	0.61 *b*	0.97 *c*	4.37 *c*	6.79 *c*
	B	17.56 *b*	0.68 *b*	0.82 *c*	4.11 *c*	8.50 *ab*
	C	19.91 *b*	0.71 *b*	1.44 *b*	6.50 *b*	7.44 *bc*
	D	19.57 *b*	1.21 *a*	2.50 *a*	8.49 *a*	8.76 *a*
	E	26.47 *a*	1.20 *a*	2.29 *a*	8.70 *a*	8.39 *ab*
	Mean	**20.43**	**0.88**	**1.60**	**6.43**	**7.96**
% effect of size[2]		**5**	**0**	**6**	**1**	**0.8**

[1] Means not sharing the small letter are significantly different at $p < 0.05$.

[2] % icrease of large size over small seedlings; i.e. [(large-small)/small].100

As for 1 y, the concentrations of P after 2 y planting were significantly higher in the closed categories (D & E) but significantly lower in the open and in the partial shade categories (A, B & C) in either size class. The concentrations of Mg and Ca in partial shade (C) were significantly higher than in open categories (A & B) but significantly lower than in closed categories (D & E). Fertilising the seedlings significantly reduced the concentrations of Mg but it significantly increased the concentrations of Ca (Table 5.19). However, it did not significantly affected the foliar concentrations of N, P and K regardless of size classes. Although there was no significant effect of fertiliser addition on the concentrations of N, P and K, fertilising the seedlings reduced the mean percentages of nutrients by 8 % (N), by 7 % (P & Mg) and by 6 % (K) (Table 5.20) irrespective of size classes.

Correlations between total dry weight and foliar nutrient concentrations of the seedlings

The mineral elements showed some specific associations in their concentrations with total dry weight of the seedlings. They varied, however, with the different mineral elements for both harvests (Table 5.21). At both harvests (1 y & 2 y), there were strong and positive significant correlations between P and Mg ($p<0.001$) in the open category (B), P and N ($p<0.01$), and Mg and Ca ($p<0.01$) in the partial shade category (C). In most cases the total dry weight of seedlings was negatively correlated with the foliar nutrients concentrations at 1 y after planting. However, these relationships were only found to be significant for P in category C ($p<0.01$), for N in category D ($p<0.05$) and for P in category E ($p<0.05$). The total dry weight of seedlings was positively correlated with N ($p<0.05$) in category A and with Ca ($p<0.05$) in category D.

5.3.3 Experiment II - *Dryobalanops oblongifolia*

Survival of seedlings

The survival of seedlings was highly significantly affected by the categories of subplot in both years of harvesting (Table 5.22). However, fertilising the seedlings only significantly affected the survival at the first year of planting ($p<0.05$). No effect of interaction between category and fertiliser was shown on the survival of seedlings. Table 5.23 shows that the survival of seedlings

Table 5.19: The effect of phosphorus fertiliser on the mean of foliar mineral nutrient concentrations of large seedlings of *H. odorata*, 2 y after planting. Treatments were compared by LSD[1] test. Fertiliser levels: P1, +TSP; P0, control.

Fertiliser	(mg g^{-1} oven dry weight)				
	N	P	Mg	Ca	K
P0	20.89 *a*	0.84 *a*	1.51 *a*	5.63 *b*	7.98 *a*
P1	19.15 *a*	0.80 *a*	1.40 *b*	6.31 *a*	7.70 *a*

[1] Means not sharing the small letter are significantly different at $p<0.05$.

Table 5.20: The effect of plot category and phosphorus fertiliser on the mean of foliar mineral nutrient concentrations of large seedlings of *H. odorata*, 2 y after planting. Ccategories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. Fertiliser levels: P1, +TSP; P0, control.

Plot category	Fertiliser	(mg g^{-1} oven dry weight)				
		N	P	Mg	Ca	K
A	P0	19.19	0.65	1.02	3.73	7.26
B		17.81	0.67	0.83	4.09	8.76
C		19.60	0.70	1.46	6.01	7.05
D		20.75	1.32	2.72	6.86	9.84
E		29.43	1.25	2.33	9.00	8.38
	Mean	**21.36**	**0.92**	**1.67**	**5.94**	**8.26**
A	P1	18.21	0.58	0.93	4.86	6.43
B		17.38	0.68	0.82	4.13	8.31
C		20.25	0.73	1.41	7.00	7.85
D		18.90	1.16	2.37	9.40	8.15
E		23.02	1.15	2.24	8.38	8.21
	Mean	**19.55**	**0.86**	**1.55**	**6.75**	**7.79**
% effect of fertiliser[1]		**-8**	**-7**	**-7**	**14**	**-6**

[1] % increase of fertilised over non-fertilised seedlings; i.e. [(P1-P0)/P0].100

Table 5.21: Correlation coefficient's Pearson between mean total dry weight (TDRY) and the mean foliar nutrients CATcentrations (mgg^{-1}) of the different mineral elements of large and fertilised seedlings of *H. odorata* for 1 y and 2 y after planting under different categories (CAT) in the 5.6 ha plot at Berkelah F.R., Pahang. Categories A - E as given in Table 5.8.

CAT		1 y					CAT	2y				
		TDRY	N	P	Mg	Ca		TDRY	N	P	Mg	Ca
A	N	0.37 *					A	-0.21				
(n=29)	P	-0.16	0.29				(n=24)	0.11	0.62 ***			
	Mg	-0.18	-0.10	0.44 *				-0.31	-0.14	-0.03		
	Ca	-0.21	-0.31	0.30	0.68 ***			-0.60**	0.09	-0.33	0.25	
	K	-0.19	0.20	0.55 **	0.42 *	0.05		-0.13	0.21	0.42 *	0.41 *	-0.08
B	N	0.00					B	-0.31				
(n=29)	P	-0.12	0.20				(n=24)	-0.10	0.41 *			
	Mg	-0.13	-0.01	0.65 ***				0.01	0.23	0.73 ***		
	Ca	-0.03	-0.11	0.34	0.64 ***			0.48 *	-0.18	-0.37	-0.12	
	K	-0.05	0.06	0.37 *	0.52 **	0.39 *		-0.13	0.12	-0.09	-0.38	-0.50**
C	N	-0.34					C	0.06				
(n=30)	P	-0.53**	0.51 **				(n=23)	-0.42*	0.51 **			
	Mg	-0.04	0.24	-0.09				-0.47*	-0.42	0.05		
	Ca	-0.10	0.22	-0.06	0.88 **			-0.20	-0.63	-0.35	0.56 **	
	K	0.11	0.45 **	0.16	0.39 *F1	0.25		-0.40*	0.13	0.18	0.17	0.01
D	N	-0.48*					D	0.30				
(n=27)	P	-0.16	0.22				(n=16)	-0.18	0.32			
	Mg	-0.06	-0.40	0.00				0.14	0.25	0.05		
	Ca	0.35 *	-0.46	-0.22	0.49 **			0.27	0.27	-0.11	0.57 *	
	K	-0.01	0.03	0.33	-0.28	-0.14		0.02	0.14	0.04	0.46	0.06
E	N	-0.35					E	-0.14				
(n=24)	P	-0.47*	0.36				(n=12)	-0.53	0.70 *			
	Mg	-0.10	0.35	-0.07				-0.38	0.20	0.20		
	Ca	-0.21	-0.08	-0.26	-0.10			-0.18	-0.68*	-0.66*	0.05	
	K	0.02	-0.30	0.03	-0.07	-0.19		0.11	0.42	0.48	0.15	-0.55

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

in the open (A & B) and in the partial shade (C) were significantly higher than the survival in closed categories at both harvests. However, in all categories, the mean percentage survival of the seedlings was reduced at the second year's harvest by 24 % in category A, 14 % in B, 2 % in C, 68 % in D and 42 % in category E. At first year, no significant survival was found between categories D and E but at second year, the survival of seedlings in category D was significantly lower than in category E. The fertilised seedlings had a significantly lower survival after the first year in the field, but there was no significant difference in survival between fertiliser levels after the second year. Although no significant differences were shown for the application of fertiliser after 2 y in the field, non-fertilised seedlings had shown lower percentages of mean survival.

Growth of seedlings

As for *H. odorata*, subplot category also highly significantly affected the growth parameters and the dry weights of *D. oblongifolia* seedlings in either year of harvests (Table 5.24). After the first year, fertilising the seedlings highly significantly affected the number of nodes, height growth and the dry weight of leaves ($p<0.001$), number of leaves and dry weight of stem ($p<0.01$) but no significance differences were shown for diameter growth and for dry weight of roots. The interaction between category and fertiliser significantly affected the number of leaves and the dry weight of leaves and stem ($p<0.001$), but it was only significant at $p<0.05$ on the height growth, number of nodes and the dry weight of roots. No significance differences were shown for diameter growth. At 2 y, only categories of the subplot highly significantly affected the growth parameters and the dry weight of the seedlings.

Table 5.25 shows that the growth of the seedlings was significantly better in the open and in the partial shade categories than in the closed categories (D & E) in either year of harvest (Plates 5.3a & 5.3b). Despite this, the means percentage of the growth variables and the dry weight of seedlings increased at second harvest, regardless of planting categories and fertiliser levels (Table 5.26). Fertilising the seedlings increased the growth and the dry weight of seedlings at 1 y and 2 y after planting. However, the increment of fertiliser effect of fertilised seedlings over non-fertilised seedlings were only slightly increased the number of leaves, number of nodes, and the dry weights of leaves and stem after 2 y. The effect of fertiliser substantially increased the height

Plate 5.3: *Dryobalanops oblongifolia* seedlings of fertilised seedlings in (a) open and compacted soil, B, 1 y after planting, and (b) partial shade, C, 1 y after planting.

Table 5.22: Summary of the ANOVA results of the effect of plot category (CAT) and phosphorus fertiliser (FERT) on the survival as arcsine transformed percentage data, of *D. oblongifolia* at two harvests in the plot at Berkelah F.R., Pahang.

Source of variance	df	1 y	2 y
		F-value[1]	
CAT	4	10 .43 ***	28.84 ***
FERT	1	6.49 *	0.78 ns
CAT*FERT	4	0.62 ns	1.52 ns

* $p < 0.05$; *** $p < 0.001$; ns = not significant

[1] Error (a) df = 25; error (b) df = 25

Table 5.23: The effect of plot category and phosphorus fertiliser on the mean survival (calculated from the detransformed arcsine data used in AVOVA) of *D. oblongifolia* at two harvests. Categories of the plot and fertiliser within harvest periods were compared with LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. Fertiliser levels: P1, +TSP; P0, control.

Harvest periods	1 y	2 y	% change of harvest[2]
Category			
A	91 *a*	69 *a*	-24
B	91 *a*	78 *a*	-14
C	81 *a*	79 *a*	-2
D	40 *b*	13 *c*	-68
E	48 *b*	28 *b*	-42
Fertiliser			
P0	81 *a*	55 *a*	-32
P1	64 *b*	50 *a*	-22

[1] Means not sharing the same small letter are significantly different at $p < 0.05$.

[2] % change from 1y to 2y; i.e. [(2y-1y)/1y].100

Table 5.24: Summary the ANOVA results of the effect of plot category (CAT) and phosphorus fertiliser (FERT) on the growth of *D. oblongifolia* at 1 y and 2 y after planting in the plot at Berkelah Forest Reserve, Pahang.

Source of variance	df	F-value[1]						
		No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
1 y								
CAT	4	30.33 ***	27.80 ***	6.62 ***	18.60 ***	27.49 ***	23.43 ***	22.67 ***
FERT	1	8.19 **	10.98 ***	12.62 ***	0.18 ns	12.32 ***	10.33 **	1.45 ns
CAT*FERT	4	6.13 ***	2.68 *	2.50 *	0.80 ns	6.57 ***	6.79 ***	2.61 *
2 y								
CAT	4	6.94 ***	8.99 ***	21.88 ***	7.34 ***	2.82 *	8.35 ***	10.53 ***
FERT	1	2.28 ns	2.41 ns	5.32 *	0.04 ns	2.44 ns	2.71 ns	3.50 ns
CAT*FERT	4	1.09 ns	0.90 ns	1.25 ns	0.67 ns	1.43 ns	1.75 ns	2.93 *

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns = not significant

[1] Error (a) df = 25; error (b) df = 286 to 288 (1 y); 197 (2 y)

Table 5.25: The effect of plot category on the mean growth and dry weight of *D. oblongifolia* at 1 y and 2 y after planting irrespective of fertiliser level. Categories within harvest, for each variable were compared with the LSD[1] test.

	Plot category	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
1 y								
	A	46 *a*	63 *a*	67.6 *ab*	8.25 *a*	8.30 *a*	10.18 *a*	4.12 *a*
	B	50 *a*	74 *b*	72.4 *a*	7.90 *a*	9.47 *a*	11.84 *a*	5.04 *a*
	C	31 *b*	43 *c*	56.8 *b*	5.96 *b*	3.97 *b*	4.60 *b*	2.11 *b*
	D	12 *c*	24 *d*	43.7 *bc*	4.93 *bc*	1.06 *c*	2.10 *b*	1.39 *bc*
	E	13 *c*	21 *d*	43.6 *bc*	4.94 *bc*	1.16 *c*	2.15 *b*	0.97 *c*
2 y								
	A	117 *a*	164 *a*	113.2 *a*	14.51 *a*	30.79 *ab*	36.45 *b*	13.94 *a*
	B	106 *a*	165 *a*	111.1 *a*	12.40 *a*	36.71 *a*	66.13 *a*	16.82 *a*
	C	48 *b*	92 *b*	70.1 *b*	7.57 *b*	13.40 *bc*	16.20 *bc*	5.95 *b*
	D	18 *b*	28 *b*	42.6 *c*	5.02 *b*	1.90 *bc*	3.22 *c*	2.53 *b*
	E	21 *b*	32 *b*	43.1 *c*	5.28 *b*	1.94 *c*	2.30 *c*	1.25 *b*

[1] Means not sharing the same small letters are significantly different at $p<0.05$

Table 5.26: The effect of phophorus fertiliser on the mean growth and dry weight of *D. oblongifolia* at 1y and 2 y after planting. Fertiliser levels within year of harvest, for each variable were compared with the LSD[1] test. (P1, +TSP; P0, control).

	Fertiliser level	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
1 y								
	P0	29 *b*	44 *b*	56.2 *b*	6.64 *a*	4.38 *b*	5.77 *b*	2.85 *a*
	P1	41 *a*	58 *a*	64.6 *a*	6.91 *a*	7.30 *a*	8.87 *a*	3.41 *a*
	Mean	**35**	**51**	**60.4**	**6.78**	**5.84**	**7.32**	**3.13**
2 y								
	P0	60 *b*	92 *a*	74.7 *b*	9.6 *a*	15.5 *a*	22.7 *a*	7.3 *a*
	P1	93 *a*	133 *a*	100.0 *a*	10.8 *a*	28.8 *a*	42.8 *a*	13.1 *a*
	Mean	**77**	**113**	**87.4**	**10.2**	**22.2**	**32.8**	**10.2**
% change of harvest[2]		**120**	**122**	**45**	**50**	**280**	**348**	**226**

[1] Means not sharing the same small letters are significantly different at $p<0.05$.

[2] % change from 1y to 2y; i.e. [(2y-1y)/1y].100

growth and the dry weight of roots by 2-fold and 5-fold, respectively, after 2 y in the field. No effect on diameter growth increment was shown (Table 5.27).

Foliar nutrients of seedlings

At the first year's harvest the concentrations of P, Mg and K were significantly affected by the categories ($p<0.001$) but no significance differences were shown for the concentrations of N and Ca (Table 5.28). Fertilising the seedlings highly significantly affected the concentrations of P and K ($p<0.001$) but it had no significant effect on the concentrations of N, Mg and Ca. The interaction of category and fertiliser was significant only for P ($p<0.001$). At the second harvest the concentrations of P, Mg and Ca ($p<0.001$) and N ($p<0.01$) were significantly affected by the categories but no significant difference was shown for K. Fertilising the seedlings highly significantly affected the concentrations of P ($p<0.001$) but not of the other elements. The interaction between category and fertiliser was only significantly affected the concentrations of P ($p<0.001$) and K ($p<0.01$).

As for *H. odorata*, concentrations of foliar P, Mg and K were significantly lower in the open categories and significantly higher in the closed categories (Table 5.29). The concentrations of P, Mg, Ca and K were lower by 32, 8, 9 and 21 %, respectively, after 2 y regardless of planting category and fertiliser level. Fertiliser significantly increased the concentrations of P and K but no significance differences were seen on the concentrations of N, Mg and Ca for 1 y after planting, regardless of planting categories. After 2 y, only concentrations of foliar P significantly increased by fertilising the seedlings but it significantly reduced the concentrations of N (Table 5.30). Fertilising *D. oblongifolia* increased the P concentration by 114 % after 1 y but it only increased the P concentration by 43 % after 2 y (Table 5.31).

Correlation between total dry weight and foliar nutrients concentrations of the seedlings

After 1 y, total dry weight and foliar P concentrations of the seedlings were negatively and highly significantly correlated in the open and in the partial shade categories (Table 5.32). Total dry weight was also found negatively and significantly correlated with Ca and K ($p<0.05$) in

Table 5.27: The effect of plot category and phosphorus fertiliser on the mean growth and dry weight of *D. oblongifolia* at 1 y and 2 y after planting. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. (P1, +TSP; P0, control).

	Plot category	Fertiliser level	No. of leaves	No. of nodes	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
1 y	A	P0	41	57	63.5	8.59	6.60	8.62	3.77
	B		37	63	64.9	7.30	6.32	8.25	4.26
	C		29	39	55.1	5.87	3.77	4.17	2.13
	D		14	23	43.8	4.99	1.20	2.28	1.70
	E		13	20	41.6	4.79	1.08	2.25	1.00
		Mean	**27**	**40**	**53.8**	**6.31**	**3.79**	**5.11**	**2.57**
	A	P1	51	71	72.2	7.85	10.27	11.94	4.53
	B		67	88	81.8	8.66	13.42	16.34	6.03
	C		33	47	58.6	6.05	4.17	5.02	2.10
	D		10	25	43.4	4.84	0.81	1.78	0.84
	E		13	22	46.1	5.13	1.26	2.02	0.94
		Mean	**35**	**51**	**60.4**	**6.51**	**5.99**	**7.42**	**2.89**
		% fertiliser effect[1]	**30**	**28**	**12**	**3**	**58**	**45**	**12**
2 y	A	P0	91	133	99.4	15.70	18.68	23.14	10.76
	B		89	145	93.8	10.58	28.79	49.24	11.35
	C		43	62	65.4	7.60	12.51	15.45	5.96
	D		19	28	42.8	5.18	1.60	2.66	1.77
	E		19	29	39.9	5.03	1.49	1.55	0.85
		Mean	**52**	**79**	**68.3**	**8.82**	**12.61**	**18.41**	**6.14**
	A	P1	140	191	125.2	13.48	41.34	48.04	16.70
	B		122	182	126.3	14.00	43.69	81.04	21.65
	C		54	77	75.6	7.54	14.40	17.04	5.94
	D		17	28	42.2	4.78	2.37	4.11	3.74
	E		24	35	48.2	5.68	2.67	3.52	1.90
		Mean	**71**	**103**	**83.5**	**9.1**	**20.89**	**30.75**	**9.99**
		% fertiliser effect[1]	**37**	**30**	**22**	**3**	**66**	**67**	**63**

[1] % increase of fertilised over non-fertilised seedlings; i.e. [(P1-P0)/P0].100

Table 5.28: Summary of the ANOVA results on the effect of plot category (CAT) and phosphorus fertiliser (FERT) on the mineral nutrient concentrations (mg g^{-1}) of *D. oblongifolia* 1 y and 2 y after planting.

	Source of variance	df	F- value[1] N	P	Mg	Ca	K
1 y							
	CAT	4	1.44 ns	31.44 ***	53.08 ***	1.64 ns	8.52 ***
	FERT	1	2.89 ns	237.94 ***	1.14 ns	1.46 ns	26.62 ***
	CAT*FERT	4	1.46 ns	21.84 ***	1.22 ns	1.56 ns	0.59 ns
2 y							
	CAT	4	5.37 **	26.10 ***	18.37 ***	8.33 ***	2.59 ns
	FERT	1	0.01 ns	19.47 ***	0.29 ns	1.66 ns	0.16 ns
	CAT*FERT	4	0.69 ns	9.28 ***	0.34 ns	0.15 ns	4.33 **

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error (a) df = 25; error (b) df = 285 (1 y); 192,193 (2 y)

Table 5.29: The effect of plot category on the mean mineral nutrient concentrations of *D. oblongifolia* at 1 y and 2 y, after planting. Categories within year of harvest for each variable, were compared with the LSD[1] test. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps.

Plot category	(mg g^{-1} oven dry weight)				
	N	P	Mg	Ca	K
1 y					
A	12.84 *ab*	0.85 *c*	0.84 *d*	3.63 *a*	7.32 *bc*
B	12.30 *b*	0.74 *c*	0.76 *d*	3.51 *a*	7.12 *c*
C	14.13 *a*	1.19 *b*	1.08 *c*	3.50 *a*	8.00 *b*
D	12.71 *ab*	1.56 *a*	1.47 *b*	4.39 *a*	9.03 *a*
E	13.99 *ab*	1.70 *a*	1.74 *a*	4.31 *a*	9.46 *a*
Mean	**13.19**	**1.21**	**1.18**	**3.87**	**8.19**
2 y					
A	14.47 *bc*	0.62 *c*	0.91 *bc*	2.67 *b*	6.51 *ab*
B	12.78 *c*	0.61 *c*	0.87 *c*	2.80 *b*	6.15 *b*
C	15.57 *ab*	0.85 *b*	1.00 *b*	3.08 *b*	6.83 *a*
D	15.88 *ab*	0.95 *ab*	1.26 *a*	4.54 *a*	6.43 *ab*
E	17.78 *a*	1.06 *a*	1.42 *a*	4.66 *a*	6.34 *ab*
Mean	**15.30**	**0.82**	**1.09**	**3.55**	**6.45**
% change of harvest[2]	**16**	**-32**	**-8**	**-9**	**-21**

[1] Means in each column not sharing small letter significantly different at $p<0.05$

[2] % change from 1y to 2y; i.e. [(2y-1y)/1y].100

Table 5.30: The effect of phosphorus fertiliser on the mean mineral nutrient concentrations of *D. oblongifolia* at 1 y and 2 y, after planting. Fertiliser levels within year of harvest for each variable, were compared with the LSD[1] test. (P1, +TSP; P0, control).

	Fertiliser level	(mg g^{-1} oven dry wt)				
		N	P	Mg	Ca	K
1 y						
	P0	12.94 *a*	0.78 *b*	1.11 *a*	3.74 *a*	7.57 *b*
	P1	13.40 *a*	1.52 *a*	1.05 *a*	3.79 *a*	8.40 *a*
2 y						
	P0	15.04 *a*	0.69 *b*	1.02 *a*	3.15 *a*	6.44 *a*
	P1	14.51 *b*	0.82 *a*	0.99 *a*	3.23 *a*	6.51 *a*

[1] Means in each column not sharing small letter significantly different at $p<0.05$.

Table 5.31: The effect of plot category and phosphorus fertiliser on the mean foliar mineral nutrient concentrations of *D. oblongifolia*, at 1 y and 2 y after planting. Categories: A, large gap and less compacted soil; B, large gap and compacted soil; C, partially shaded; D, closed canopy with many dipterocarps; and E, closed canopy with few dipterocarps. Fertiliser levels: P1, +TSP; P0, control.

	Plot category	Fertiliser level	(mg g^{-1} oven dry weight) N	P	Mg	Ca	K
1 y	A	P0	13.14	0.71	0.91	3.54	6.97
	B		12.44	0.63	0.76	3.64	6.81
	C		13.62	0.75	1.11	3.29	7.39
	D		12.28	0.93	1.40	4.15	8.63
	E		13.12	1.04	1.78	4.50	9.21
		Mean	**12.92**	**0.81**	**1.19**	**3.82**	**7.80**
	A	P1	12.49	1.02	0.76	3.73	7.74
	B		12.12	0.88	0.76	3.34	7.51
	C		14.65	1.65	1.05	3.72	8.64
	D		13.45	2.63	1.59	4.80	9.70
	E		14.97	2.46	1.70	4.10	9.74
		Mean	**13.54**	**1.73**	**1.17**	**3.94**	**8.67**
	% fertiliser effect[1]		**5**	**114**	**-2**	**3**	**11**
2 y	A	P0	14.52	0.63	0.94	2.54	6.91
	B		12.96	0.62	0.86	2.66	6.11
	C		15.79	0.77	1.00	2.99	6.83
	D		16.28	0.70	1.27	4.58	6.09
	E		17.57	0.77	1.38	4.51	5.73
		Mean	**15.42**	**0.70**	**1.09**	**3.46**	**6.33**
	A	P1	14.43	0.61	0.89	2.78	6.19
	B		12.61	0.60	0.87	2.94	6.20
	C		15.32	0.94	1.01	3.17	6.84
	D		15.25	1.34	1.27	4.48	6.96
	E		18.10	1.50	1.47	4.87	7.25
		Mean	**15.14**	**1.00**	**1.10**	**3.65**	**6.69**
	% fertiliser effect[1]		**-2**	**43**	**1**	**6**	**6**

[1] % increase of fertilised over non-fertilised seedlings; ie. [(P1-P0)/P0].100

Table 5.32: Correlation coefficient's Pearson between mean total dry weight (TDRY) and mean foliar nutrients concentrations (mgg^{-1}) of the different mineral elements of fertilised seedlings of *D. oblongifolia* for 1 y and 2 y after planting under different categories (CAT) in the 5.6 ha plot at Berkelah F.R., Pahang. Categories A - E as given in Table 5.8.

CAT		1 y					CAT	2y				
		TDRY	N	P	Mg	Ca		TDRY	N	P	Mg	Ca
A	N	-0.03					A	0.60 ***				
(n=37)	P	-0.44**	0.12				(n=31)	0.09	-0.05			
	Mg	-0.15	-0.12	-0.01				0.15	0.15	0.25		
	Ca	-0.38*	0.21	0.48 **	-0.03			-0.29	0.1	-0.45**	-0.17	
	K	-0.41*	-0.02	0.58 ***	0.02	0.27		0.19	0.29	0.61 ***	0.09	-0.37*
B	N	-0.07					B	0.15				
(n=36)	P	-0.55**	0.16				(n=33)	0.19	0.22			
	Mg	-0.27	0	0.25				-0.11	-0.05	0.03		
	Ca	-0.2	0.01	0.27	0.1			-0.25	-0.24	-0.18	0.21	
	K	-0.49**	0.49 **	0.53 ***	0.08	-0.16		-0.19	0.16	0.25	0.17	-0.18
C	N	-0.24					C	-0.06				
(n=36)	P	-0.7***	0.3				(n=29)	-0.38*	-0.31			
	Mg	-0.49**	0.04	0.35 *				-0.2	-0.17	0.28		
	Ca	-0.46**	-0.17	0.46 **	0.26			-0.13	-0.13	0.57 ***	0.34	
	K	-0.29	0.63 ***	0.52 ***	-0.07	-0.02		0.19	0.01	0.19	-0.14	-0.07
D	N	-0.11					D	-0.7				
(n=12)	P	-0.33	0.70 **				(n=7)	0.05	0.35			
	Mg	-0.1	-0.37	0.16				0.72	-0.7	-0.03		
	Ca	-0.3	0.15	0.53 *	0.38			-0.54	0.47	0.45	-0.65	
	K	0.01	0.33	0.43	-0.29	-0.02		0.61	-0.03	0.63	0.19	-0.14
E	N	-0.23					E	-0.78**				
(n=21)	P	-0.26	0.2				(n=10)	-0.59	0.27			
	Mg	-0.11	-0.2	0.15				-0.31	-0.17	0.42		
	Ca	-0.35	0.16	-0.01	-0.07			-0.68*	0.80 **	0.29	0.03	
	K	-0.38	0.21	0.47 *	0.09	-0.24		0.61	-0.74*	-0.01	0.15	-0.73*

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

category A and with K ($p<0.01$) in category B. In the partial shade category (C), the total dry weight of seedlings was negatively and highly significantly correlated with concentrations of Mg and Ca ($p<0.01$). Strong and significant correlations were found between P and Ca ($p<0.01$), and P and K ($p<0.001$) in category A, and P and K ($p<0.001$) in category B. There were also significant correlations between N and K ($p<0.001$), N and Ca ($p<0.01$) in category C, N and K ($p<0.01$) in category B, and N and P ($p<0.01$) in category D.

After 2 y, the associations between total dry weight and foliar nutrients concentrations varied with the different mineral elements. The total dry weight of the seedlings was highly and positively correlated with the foliar N concentrations ($p<0.001$) in category A but negatively and significantly correlated with N ($p<0.01$) and with Ca ($p<0.05$) in closed category (E). Strong and significant positive correlations were found between P and K in category A, P and Ca in the partial shade category (C), and N and Ca in the closed category (E).

5.3.4 Comparison studies of *H. odorata* and *D. oblongifolia*

Total dry weight

The total dry weight of both species in the field was significantly greater in the open categories (A & B) than in the closed categories (D & E) (Figure 5.2). The growth of seedlings in category C (partial shade) was in between these two main light regimes. In the first year, fertilised *H. odorata* in the open grew faster than *D. oblongifolia*, however, in the second year both species showed a similar growth in the open categories. Although both species showed a need for radiation which enhanced the growth at low radiation, *D. oblongifolia* performed relatively better than *H. odorata* (Figure 5.2). In closed categories (D & E), total dry weight of the fertilised seedlings of *D. oblongifolia* was higher than those of *H. odorata* by 4.8-fold and 4.5-fold, respectively, 2 y after planting.

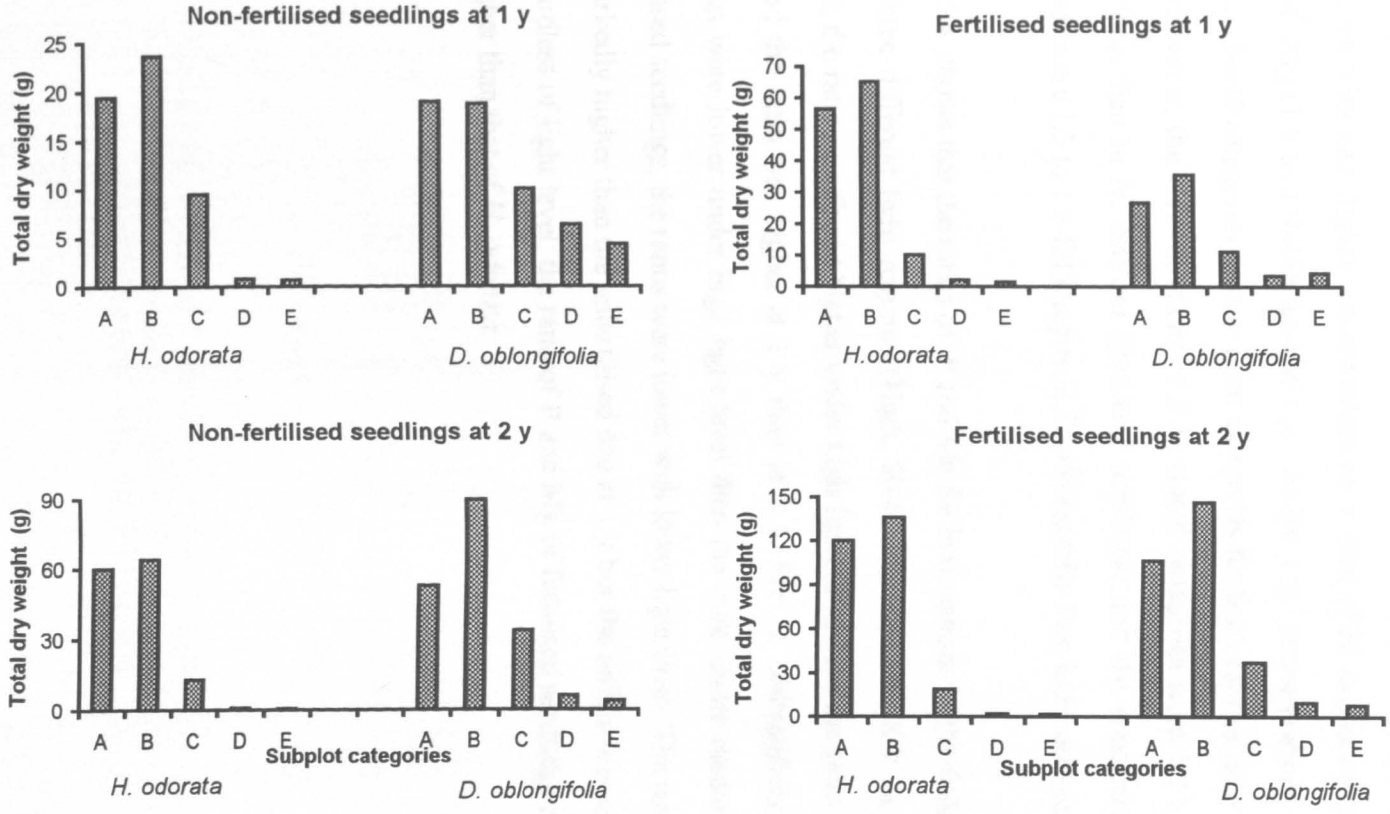


Figure 5.2: Comparison of total dry weights *H. odorata* and *D. oblongifolia* at two different fertiliser levels and at two different harvests (1 y and 2 y after planting) in the five different planting categories. Categories A - E as given in Table 5.8.

Phosphorus and magnesium

The concentrations of P and Mg for both species were highest in closed categories and lowest in open categories at either fertiliser level (Figure 5.3a). Fertilised seedlings of *D. oblongifolia* in closed categories had higher concentrations of P than of *H. odorata* (1.2 to 1.3-fold more) but lower of Mg (1.5 to 1.9-fold less) at 1 y. As for 1 y, concentrations of P and Mg were also higher in closed categories than in open categories for both species after 2 y in the field (Figure 5.3b). However, the concentrations of P in closed categories were 1.2 to 1.3-fold higher in *D. oblongifolia* than in *H. odorata* (fertilised seedlings) and the concentrations of Mg in closed categories were 1.5 to 1.9-fold higher in *D. oblongifolia* than in *H. odorata* (fertilised seedlings).

Figure 5.4 shows that the ratios of P and Mg for both species in the field were found differently under three different light regimes (High, 20-55 %; Medium, 8-9 %; Low, 2-3 %). For *H. odorata*, the ratio was found higher under high light level than the ratio under medium and low light and the ratio was higher at 1 y than at 2 y. For *D. oblongifolia*, the ratios of fertilised seedlings were lower under high light level than the ratio under medium and low one but for unfertilised seedlings, the ratios were lower with lower light level. The ratio of fertilised seedlings was markedly higher than the unfertilised one at 1 y but the differences of ratio were weaker at 2 y. Regardless of light level, the ratio of P and Mg of fertilised seedlings of *D. oblongifolia* at 1 y was higher than that of *H. odorata*.

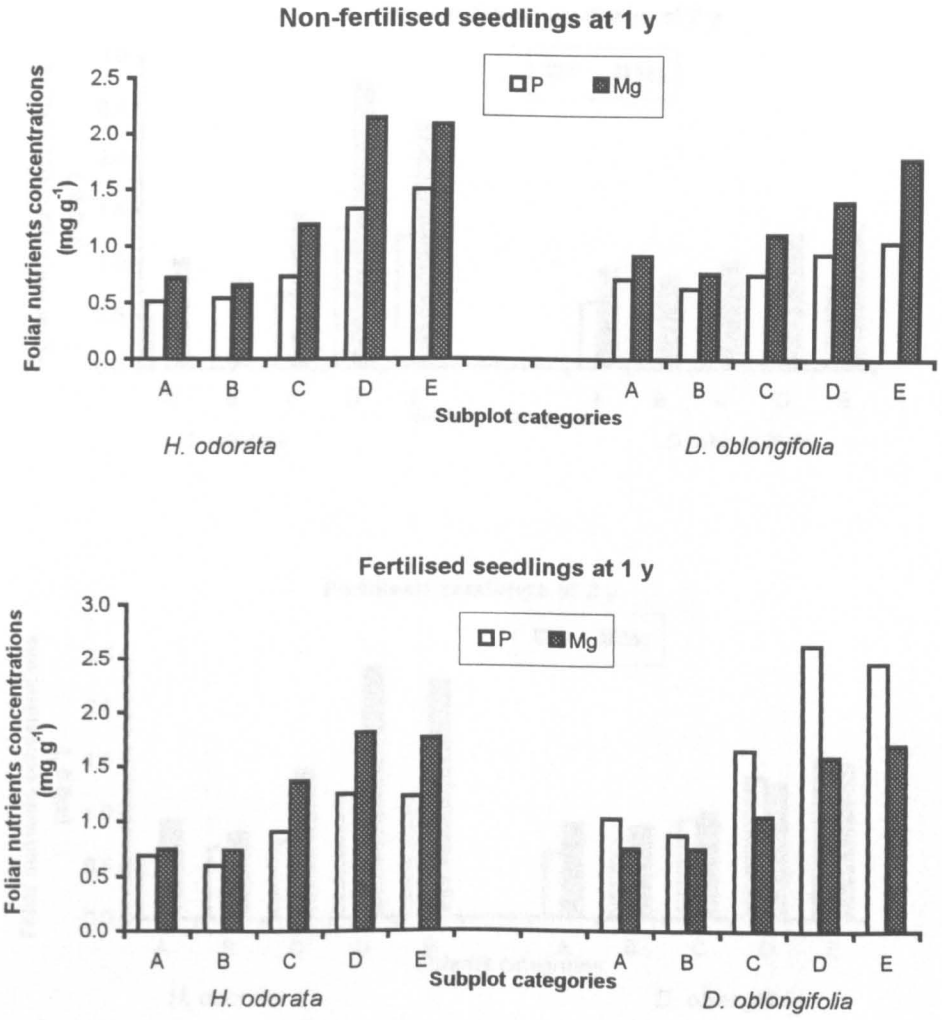


Figure 5.3a: Comparison of foliar nutrients of *H. odorata* and *D. oblongifolia* seedling concentrations at two different fertiliser levels after 1 y planted in the five different planting categories. Categories A - E as given in Table 5.8.

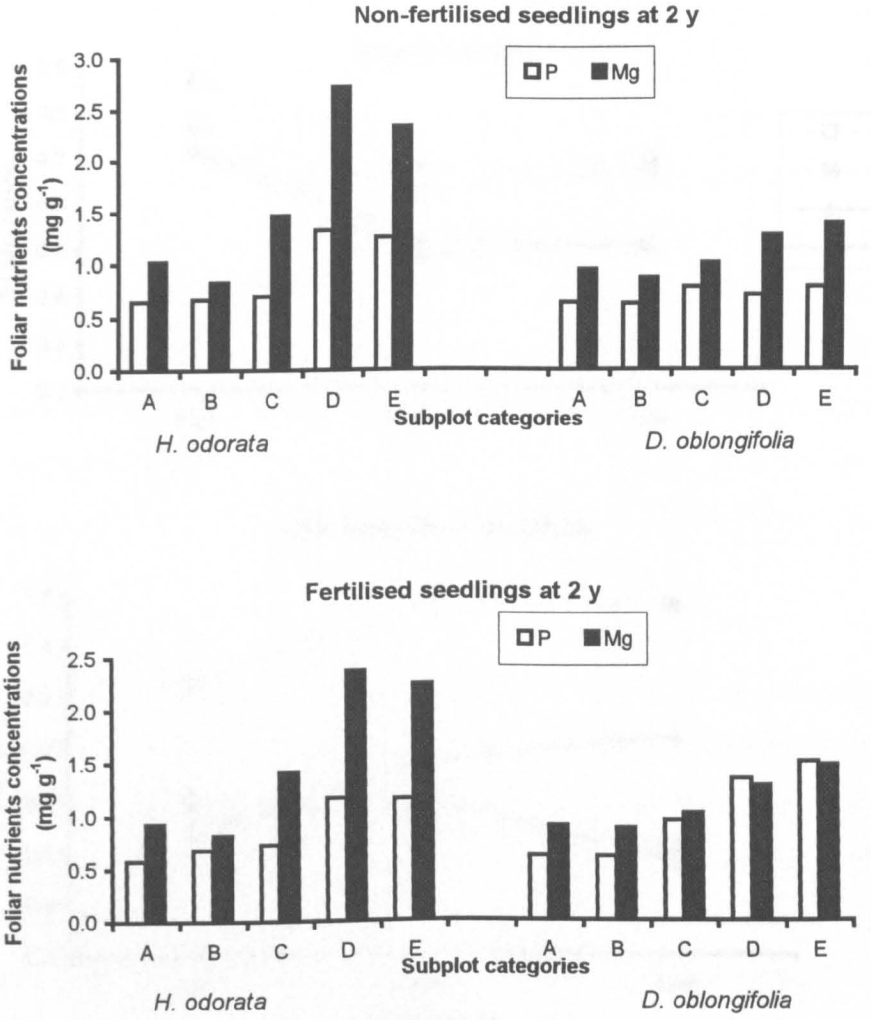


Figure 5.3b: Comparison of foliar nutrients of *H. odorata* and *D. oblongifolia* seedling concentrations at two different fertiliser levels after 2 y planted in the five different planting categories. Categories A - E as given in Table 5.8.

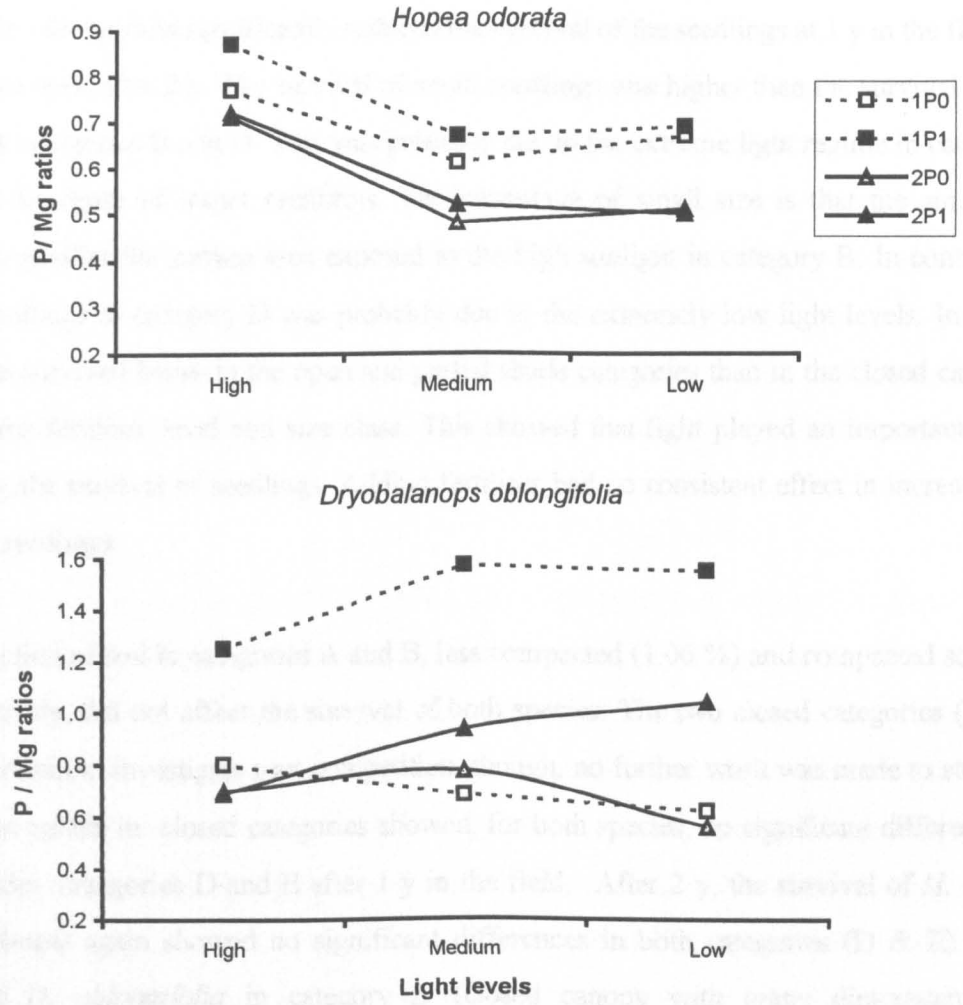


Figure 5.4: Phosphorus and magnesium ratios of *H.odorata and D. oblongifolia* leaves
1 y after planting: non-fertilised (1P0); fertilised seedlings (1P1).
2 y after planting: non-fertilised (2P0); fertilised seedlings (2P1).

5.4 DISCUSSION

5.4.1 Survival of the seedlings

Addition of fertiliser did not affect the survival of *H. odorata* at 1 y in the field, however, fertilising significantly increased the survival of the seedlings after 2 y in the field. Whereas fertilising *D. oblongifolia* significantly reduced the survival of the seedlings at 1 y in the field, and no effect was seen after 2 y. The survival of small seedlings was higher than the survival of large seedlings in categories B and D. This was probably due to the extreme light regime in category B had led to the death of larger seedlings. The advantage of small size is that the smaller the seedling the smaller the surface area exposed to the high sunlight in category B. In contrast, the death of seedlings in category D was probably due to the extremely low light levels. In general both species survived better in the open and partial shade categories than in the closed categories regardless the fertiliser level and size class. This showed that light played an important role in determining the survival of seedlings. Adding fertiliser had no consistent effect in increasing the survival of seedlings.

The compaction of soil in categories A and B, less compacted (1.06 %) and compacted soil (1.13 %), respectively, did not affect the survival of both species. The two closed categories (D & E) were first chosen to investigate root competition, though, no further work was made to study this process. The results in closed categories showed, for both species, no significant differences in survival under categories D and E after 1 y in the field. After 2 y, the survival of *H. odorata* (large seedlings) again showed no significant differences in both categories (D & E) but the survival of *D. oblongifolia* in category D (closed canopy with many dipterocarps) was significantly lower than that in category E. Although no root interference or root competition study was done in categories D and E, probably the significantly lower of survival in category D was due to a root competition between the planted *D. oblongifolia* and the existing seedlings and saplings of dipterocarps in the subplots.

5.4.2 Response of seedling growth on light and soil factors

Categories of the subplot strongly affected the growth variables and the dry weight of seedlings for both species 1 y after planting. Open (A & B) and partial shade (C) categories had significantly improved the growth of small seedlings for both species than those in closed categories (D & E). Seedlings grown in the open categories had better growth and with more leaves compared to those in the partial shade and closed categories but the leaves were yellowish in colour. The seedlings grew in open category developed better root systems, for the first year of planting the roots were grown within the planting hole but after 1 y the roots started penetrating beyond the planting hole for water and mineral nutrients. Whilst seedlings grown in closed categories were relatively smaller in size, with a few small dark green leaves, and they also developed poor root systems. The seedlings were also unhardened, therefore, they were prone to pest attack e.g. wild boars, squirrels and termites. The size of seedlings had greater impact on the growth of the seedlings, thus, larger seedlings had better growth in all subplot categories than the smaller ones.

Differences in soil compaction had little effect on the growth of seedlings of either species. Soils in categories B, A and C were relatively compacted and with higher bulk density and this reduced the number of larger pores of soils. However this inhibition is not necessarily correlated with inhibited uptake of mineral nutrients and their uptake might even be increased (Talha *et al.* 1979, Marschner 1995) and the increment partly due to the increase in the buffer power for nutrients at higher bulk densities (Silberbush *et al.* 1983). This was probably explained despite of high bulk density and also poor in fertility in categories A, B and C (Table 5.2a), it did not appear to be a significant factor limiting the early growth of the seedlings up to 2 y. The other reason was probably because of the roots of the seedling were largely confined to the looser soil in the planting hole and the mineral nutrients were mainly supplied by the nursery (potting) soil.

Although both species, *H. odorata* and *D. oblongifolia* were not naturally grown in the plot, results from the studies showed that both species established well in the open categories regardless of soil fertility and soil compaction. No further analysis was done to test the effect of soil compaction in the different categories: open (A & B), partial shade (C), and closed canopy (D

& E). The reason for this was because the light factor was a primary limiting factor, therefore, it might be confounded the effect of soil compaction on the growth of seedlings.

5.4.3 Effect of phosphorus fertiliser on total dry weight and foliar nutrients

Fertilising *H. odorata* (144 mg P per plant) and *D. oblongifolia* (175 mg P per plant) at the nursery stage improved the growth of seedlings in all planting categories. Fertiliser studies on dipterocarp species in the logged forest were also been carried out by others (Wan Razali & Ang 1991, Ang *et al.* 1992 , Turner *et al.* 1993, Nussbaum 1995, Nussbaum *et al.* 1995). In these studies, fertiliser was applied in the field and produced different results. Application of fertiliser on *Shorea curtisii* in small canopy openings (10 g N and 5 g P) and on *Hopea beccariana* under a closed canopy (10 g of NPK) showed no significant improvement in height and stem diameter growth (Turner *et al.* 1993). The absence of a clear response here was probably due to low light level rather than the nutrients: the seedlings were unable to respond to the added nutrients. It is thus thought that fertilising seedlings under closed canopy will not be of significant benefit to the growth of dipterocarp seedlings. However, results from this study (this chapter) showed that application TSP in closed categories (D & E) significantly increased 2 to 2.6-fold the dry weight of stem and roots of *H. odorata* after 1 y, and 2 to 3-fold after 2 y. Although fertilising *D. oblongifolia* reduced the dry weight of stem and roots 1 to 2-fold at 1 y, it did significantly increase 1.5 to 2-fold the dry weight of stem and roots at 2 y (Table 5.25). It was also suggested that the absence of a clear response to fertiliser by Ang *et al.* (1992) and by Turner *et al.* (1993) was probably because the low rates fertiliser addition, did not exceed losses due to leaching, denitrification and immobilisation, i.e. the available nutrients did not meet plant requirements (Nussbaum 1995, Nussbaum *et al.* 1995). In other studies, application of rock phosphate (100 g per plant) and 40 g of granular fertiliser with the rates of 4.8 g (N), 2.1 g (P) and 4.7 g (K), significantly improved the growth of two dipterocarp species, *Dryobalanops lanceolata* and *Shorea leprosula* after 6 mo (Nussbaum 1995, Nussbaum *et al.* 1995).

Earlier studies have indicated relationships between the productivity of moist tropical forests and the availability of P, that moist tropical forest productivity is limited by the availability of P (Vitousek 1984, Burslem *et al.* 1994). This was tested in this study by applying phosphorus

fertiliser (TSP, a fast-release fertiliser) at the nursery stage with the aim of boosting the concentration of P in plant tissue before planting out in the field. Foliar analyses showed that TSP slightly increased the concentration of P of *H. odorata* at 2 y but it caused a significantly greater concentration of P in *D. oblongifolia*.

5.4.4 Relationships between nutrients and total dry weight of seedlings

Results from this study showed that the total dry weight of both species negatively correlated with the nutrient concentrations in leaves (Tables 5.21 & 5.32). However, the concentrations of nutrients in the leaves had differing effects on the growth of seedlings for both species under different planting categories (Figures 5.2 & 5.3a, 5.3b). Fertilising the seedlings substantially increased the total dry weight of the seedlings receiving higher light levels but markedly reduced the concentrations of nutrients in the leaf tissues. The decreasing of the nutrients was due to a "dilution effect", the relative rate of dry matter of the seedlings accumulated more rapidly than the rate of nutrient accumulation. This phenomenon has been observed by Steenberg (1951), Steenberg & Jakobsen (1963), and Jarrell & Beverly (1981). The total dry weight of large seedlings of *H. odorata* was higher than the smaller ones but these smaller seedlings had higher concentrations of nutrients (P, Mg, Ca and K) than the larger ones at 1 y (Table 5.14). This same phenomena was also observed for *D. oblongifolia*. Application of fertiliser significantly increased the biomass of the seedlings over time (1 y to 2 y) but concentrations of P, Mg, Ca and K were diluted with the age of the seedlings. It has often been found that the young plants contain higher concentrations of N, P and K than do older plants (Loehwing 1953, Jarrell & Beverly 1981).

5.4.5 Phosphorus and magnesium relationships

Although the ratio of P and Mg was higher for *H. odorata* and lower for *D. oblongifolia* at high light level, the ratio value of fertilised seedlings at 1 y was higher for *D. oblongifolia* than for *H. odorata*. Therefore, the concentration of foliar P was higher than the concentration of foliar Mg of *D. oblongifolia*.

CHAPTER 6: EFFECTS OF PHOSPHORUS FERTILISER, LIGHT AND TYPES OF SOIL ON THE GROWTH OF DIPTEROCARP SEEDLINGS IN THE NURSERY

6.1 INTRODUCTION

The aim of the experiments was to study the effect of light (open versus shade), phosphorus fertiliser (triple superphosphate) and types of soil on the growth and total biomass of dipterocarp seedlings and also to study the effect of treatments on the concentrations of mineral nutrients contents in the plants. The experiments were carried out in the nursery at FRIM. Two species of dipterocarps were chosen, *Hopea odorata* and *Shorea acuminata.* The experiments were started in 1991, and since it was outside a general flowering year, only *Hopea odorata* seeds were available in sufficient quantities for the experiment. For the purposes of comparison, wildings of *Shorea acuminata* were used.

6.2 MATERIALS AND METHODS

6.2.1 Experiment I - *Hopea odorata*

Seeds of *Hopea odorata* were collected from a tree growing in the FRIM compound on the 18 November 1991 and were sown on the 20 November 1991 in the FRIM nursery. The location of the nursery and the climate of the nursery were described in the Study Area and Establishment of the Research Plot (Chapter 3.4). After 2 mo and 10 d in the sowing bed, 384 uniform seedlings were chosen for potting. The seedlings were potted on the 1 February 1992 with six types of soil: S1 to S5 were collected from subplots A (large gap and less compacted soil), B (large gap and compacted soil), C (partially shaded), D (closed canopy with many dipterocarps), and E (closed canopy with few dipterocarps), respectively; and S6 which was a standard nursery soil mixture used at FRIM. Soil S6 was a mixture of three parts of soil and one part of sand (3:1). The soil used in S6 was collected from a forest top soil nearby FRIM from up to 30-60 cm depth from the surface. Prior to potting, soils S1 to S5 were collected from the 5.6 ha plot at Berkelah F.R. from a depth of 0-10 cm. Collection

of soil from the subplots was explained in the General Methods (Chapter 4.1). The soils were immediately prepared for potting a week after the collection.

At the start (1 February 1992), all seedlings was kept under green shade netting and received *c.* 16 % of full daylight. Two months later (1 April 1992), half of the total seedlings was transferred to the open, and the remainder grew on in the shade. Triple superphosphate (TSP) was used to fertilise the seedlings. The application of fertiliser was made five times at monthly intervals. The first application was on the 28 March 1992 with 0.33 g per pot (144 mg P). Within each light level, half of the pots selected at random, received the fertiliser and the other half did not.

The measurements of growth were carried out at 9 mo intervals, 9 and 18 mo after potting (October 1992 and July 1993). Height, number of leaves, number of nodes, leaf area and basal stem diameter were recorded and dry weights of seedlings were determined. Foliar analysis was conducted as described in the General Methods (Chapter 4.6). At the end of the experiment (after 18 mo), the soils (S1,....., S6) used for potting the seedlings were analysed at the Laboratory of Soil Science in FRIM. The chemical and physical properties were determined as described in the General Methods (Chapter 4.1). The roots of the seedlings were inspected for the ectomycorrhizas (ECM), non-ectomycorrhizas and dead ectomycorrhizas. The method used for scoring ectomycorhizas was conducted as described in the General Methods (Chapter 4.4).

The experiment had a randomised block design with two factors, i.e. fertiliser (two levels) and soil type (six levels). The treatments were repeated in four blocks and the total number of seedlings required was: 6 soils x 2 P levels x 2 harvests x 2 light levels x 4 blocks x 2 replicates = 384.

6.2.2 Experiment II - *Shorea acuminata*

The wildings of *Shorea acuminata* were collected on the 21 October 1991 from the Sg. Lalang F.R., Selangor and the ages were estimated to be *c.* 2.5 y old based on the

observation that the wildings were produced after the fruiting season of 1989. The heights were in the range 20-30 cm. The wildings were dug up with soil attached to their roots, and immediately wrapped in damp newspaper or wet tissue. The seedlings were then brought back to the FRIM nursery and they were immediately potted into the six types of soil in a similar manner as experiment I. However, only 50 % of the wildings survived the shock of transplanting and the survivors were used for the experiment. The mortality of wildings was not the result of selection of a component of the population at the site but it was sue to the transporting shock.

This experiment had the same treatments and the same design as experiment I but the treatments were repeated only three times as blocks. Total number of seedlings required was: 6 soils x 2 P levels x 2 light levels x 2 harvests x 3 blocks x 2 replicates = 288.

The first fertilisation was made on the 2 June 1992 and subsequently five times at monthly applications. The wildings were harvested at 9 and 18 mo (11 February 1993 and 1 November 1993). The measurements of growth and the dry weight determinations of the seedlings and the foliar chemical analysis were done in a similar manner as experiment I.

6.2.3 Data analysis

The growth and the nutrients data of the seedlings for both species were analysed separately for the two light levels (open and shade) and at different times of harvesting (9 and 18 mo). The reason why the analysis was done separately for light levels was because in this study the treatments were only randomised within each of the light levels and the whole unit of the experiments was not repeated independently under these two different light categories. Therefore, the growth data and the nutrient data of the seedlings could not be compared for two different light levels. Analysis of variance (ANOVA) for a two-way factorial experiment was only carried out on the surviving seedlings (due to deaths during the experiments), using the SAS GLM procedure (SAS System for Linear Models 1993). The least significant difference (LSD) test was used to test for significant differences between treatments (Appendix 6.1). Correlation coefficient's Pearson analysis was carried out between the

infection of ECM, total dry weight and five different mineral nutrients concentrations of *H. odorata* leaves using MINITAB Release 10 for Windows (Minitab Reference Manual 1994). As for *H. odorata*, correlations was also carried out for *S. acuminata* except that no root infection of ECM were analysed. The analysis was done by summing up the four blocks for *H. odorata* and three blocks for *S. acuminata*, separately under two different light levels. For comparison of the growths, the dry weights and the nutrient concentrations of the seedlings at different harvests and at different light levels, the percentage changes in the means were calculated (Evans 1972).

6.3 RESULTS

6.3.1 Effect of phosphorus, light and soil

6.3.1.1 Experiment I - *Hopea odorata*

Growths

After 9 mo, the addition of TSP significantly increased the mean growth of variables and the dry weights of the seedlings in either light level, except for the number of nodes in the open (Tables 6.1 & 6.2). However, there were no significant differences between type of soil on the growth and on the dry weight of seedlings, under either light level, except that type of soil significantly affected the dry weight of roots under both light levels (open & shade). No significant interaction of fertiliser and soil were shown. Table 6.2 shows that the dry weight of leaves increased by 9 %, stems increased by 25 % and the dry weight of roots increased by 75% after 9 mo in the open. However, the light did not increase the number of leaves and it reduced the number of nodes and the leaf area by 13 and 9 %, respectively. There was a significant interaction between fertiliser and type of soil on growth parameters and on dry weights of seedlings in the shade category, 9 mo after the treatments ($p<0.05$). Table 6.3 shows that the unfertilised seedlings in soil S6 (nursery soil) only led to greater growth and greater dry weight. However, the percent fertiliser effect showed that application of fertiliser increased the growth of seedlings.

After 18 mo in the open category, fertilisation significantly increased the height growth (Table 6.4; $p<0.001$) and the number of nodes, stem diameter and the dry weight of stem ($p<0.01$). TSP also significantly increased the height growth and the stem diameter of seedlings ($p<0.001$) and the number of leaves, leaf area and the dry weight of leaves, stem and roots ($p<0.01$), in the shade category. However, neither the effect of soil type nor the interaction of soil type and fertiliser were significant on growth, either in the open or in the shade. Table 6.5 shows that, the light increased the dry weight of roots by 79 %, the dry weight of stem by 26 % and the dry weight of leaves by 25 %. But the number of nodes fell by 21 % and leaf area fell by 26 %.

Table 6.1: Summary of the ANOVA results of the effect of fertiliser (FERT) and soils on the mean growth and dry weight of *Hopea odorata* seedlings, separately under two light levels, 9 mo after the treatments were applied.

	Source of variance	df	F-value[1] No. of leaves	Height (cm)	No. of nodes	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) of leaves	stem	roots
Open										
	BLOCK	3	1.89 ns	1.8 n s	0.1 ns	0.4 ns	2.4 ns	1.2 ns	0.8 ns	1.0 ns
	FERT	1	8.25 **	18.6 ***	1.6 ns	18.3 ***	13.9 ***	11.0 **	7.8 **	12.0 ***
	SOIL	5	0.29 ns	0.66 ns	0.5 ns	0.8 ns	0.3 ns	0.3 ns	0.2 ns	2.4 *
	FERT*SOIL	5	0.90 ns	1.55 ns	2.6 ns	1.2 ns	1.5 ns	1.2 ns	0.6 ns	0.4 ns
Shade										
	BLOCK	3	0.2 ns	1.8 ns	10.4 ***	0.4 ns	0.1 ns	0.1 ns	0.1 ns	0.6 ns
	FERT	1	6.4 *	12.0 ***	9.7 **	10.2 **	5.5 *	5.8 *	5.8 *	7.8 **
	SOIL	5	1.2 ns	2.0 ns	1.8 ns	2.2 ns	2.1 ns	2.1 ns	2.1 ns	3.0 *
	FERT*SOIL	5	2.9 *	2.5 *	2.2 ns	1.9 ns	2.5 *	2.7 *	2.7 *	3.0 *

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns = not significant

Table 6.2: Effect of phosphorus fertiliser (TSP) on mean growth and mean dry weight of *Hopea odorata* seedlings under two different light conditions, 9 mo after the treatments were applied (P1, +TSP ; P0, control). Treatments within each light level (open and shade) for each variables were compared by LSD[1] test.

		No. of leaves	Height (cm)	No. of nodes	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) of leaves	stem	roots
Open									
	P0	20 *b*	22.1 *b*	13 *a*	3.8 *b*	127 *b*	1.0 *b*	0.8 *b*	1.1 *b*
	P1	24 *a*	27.4 *a*	14 *a*	4.6 *a*	185 *a*	1.4 *a*	1.1 *a*	1.7 *a*
	Mean	**22**	**24.8**	**14**	**4.2**	**156**	**1.2**	**1.0**	**1.4**
Shade									
	P0	20 *b*	21.2 *b*	15 *b*	3.3 *b*	150 *b*	0.9 *b*	0.7 *b*	0.7 *b*
	P1	24 *a*	26.1 *a*	16 *a*	4.0 *a*	193 *a*	1.2 *a*	0.9 *a*	0.9 *a*
	Mean	**22**	**23.7**	**16**	**3.7**	**172**	**1.1**	**0.8**	**0.8**
% light effect[2]		**0**	**5**	**-13**	**14**	**-9**	**9**	**25**	**75**

[1] Means in each column with the same small letter are not significantly different at $p<0.05$

[2] % increase in the open over the shaded condition; i.e. [(Open-Shaded)/shaded].100

Table 6.3: Interaction between fertiliser and soils under the shade category on the mean growth and dry weight of *Hopea odorata* seedlings, 9 mo after the treatments.Fertiliser levels: P1,+TSP; P0, control.

Fertiliser level	Soil type	No. of leaves	Height (cm)	No. of nodes	Diameter (cm)	Leaf area (cm^2)	Dry weight (g) o		
							leaves	stem	roots
P0	S1	17	19.2	15	2.8	136	0.9	0.5	0.5
	S2	21	22.7	15	3.6	169	1.0	0.7	0.6
	S3	15	16.1	15	2.5	96	0.5	0.4	0.4
	S4	19	20.7	15	3.3	109	0.7	0.6	0.6
	S5	17	19.8	14	2.9	132	0.8	0.6	0.6
	S6	29	28.7	17	4.5	256	1.7	1.3	1.3
	Mean	**20**	**19.5**	**15**	**3.3**	**150**	**0.9**	**0.7**	**0.7**
P1	S1	28	27.8	16	4.3	249	1.5	1.1	1.4
	S2	21	22.1	15	3.7	156	1.0	0.8	0.7
	S3	25	27.5	17	4.0	209	1.3	0.8	1.0
	S4	21	22.4	16	3.9	148	1.0	0.8	0.7
	S5	24	29.3	18	3.7	207	1.3	1.0	0.9
	S6	22	27.6	17	4.1	190	1.2	0.9	1.0
	Mean	**24**	**26.1**	**16.5**	**4.0**	**177**	**1.2**	**0.9**	**1.0**
% fertiliser effect[1]		**20**	**34**	**10**	**21**	**18**	**33**	**29**	**43**

[1] % increase of fertilised over non-fertilised seedlings; i.e. [(P1-P0)/P0].100

Table 6.4: Summary of the ANOVA results of the effect of fertiliser (FERT) and soils on the mean growth and dry weight of *Hopea odorata* seedlings, separately under different two light levels, 18 mo after the treatments were applied.

	Source of variance	df	F - value[1]							
			No. of leaves	Height (cm)	No. of nodes	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) of leaves	stem	roots
Open										
	BLOCK	3	0.1 ns	0.3 ns	1.5 ns	1.7 ns	2.0 ns	0.2 ns	0.1 ns	0.1 ns
	FERT	1	3.0 ns	24.8 ***	7.4 **	7.3 **	2.0 ns	3.2 ns	7.6 **	2.0 ns
	SOIL	5	1.5 ns	1.4 ns	3.2 *	0.7 ns	0.4 ns	1.3 ns	1.0 ns	0.5 ns
	FERT*SOIL	5	0.5 ns	0.6 ns	0.1 ns	1.4 ns	1.5 ns	0.8 ns	0.5 ns	0.7 ns
Shade										
	BLOCK	3	0.7 ns	1.1 ns	1.8 ns	2.3 ns	4.0 *	0.9 ns	0.8 ns	0.6 ns
	FERT	1	7.6 **	19.0 ***	0.2 ns	14.1 ***	8.3 **	9.3 **	11.7 **	10.4 **
	SOIL	5	0.7 ns	0.6 ns	1.6 ns	1.6 ns	1.2 ns	0.7 ns	0.5 ns	1.7 ns
	FERT*SOIL	5	0.8 ns	0.9 ns	0.8 ns	1.5 ns	0.7 ns	1.2 ns	1.6 ns	1.0 ns

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns = not significant

[1] Error df = range 77 to 79 (Open); 74 to 76 (Shade)

Table 6.5: Effect of phosphorus fertiliser (TSP) on the mean growth and on the mean dry weight of *Hopea odorata* seedlings under different light categories, 18 mo after the treatments were applied (P1, +TSP ; P0, control). Treatments within light level (Open and Shade) for each variables were compared by LSD[1] test.

	Fertiliser level	No. of leaves	Height (cm)	No. of nodes	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) of leaves	stem	roots
Open									
	P0	39 *b*	36.9 *b*	46 *b*	6.6 *b*	244 *b*	3.2 *a*	4.7 *b*	7.1 *a*
	P1	44 *a*	43.0 *a*	52 *a*	7.3 *a*	277 *a*	3.7 *a*	5.9 *a*	8.3 *a*
	Mean	**42**	**40**	**49**	**7**	**261**	**3.5**	**5.3**	**7.7**
Shade									
	P0	32 *b*	35.1 *b*	59 *a*	6.0 *b*	291 *b*	2.3 *b*	3.3 *b*	3.3 *b*
	P1	40 *a*	43.7 *a*	64 *a*	7.4 *a*	414 *a*	3.3 *a*	5.0 *a*	5.2 *a*
	Mean	**36**	**39.4**	**62**	**6.7**	**353**	**2.8**	**4.2**	**4.3**
% light effect[2]		**17**	**2**	**-21**	**4**	**-26**	**25**	**26**	**79**

[1] Means in each column with the same small letter are not significantly different at $p<0.05$

[2] % increase in the open over the shaded condition; i.e. [(Open-Shaded)/shaded].100

Nutrients

Application of TSP highly significantly affected the concentrations of foliar P, Mg and Ca (Table 6.6; $p<0.001$) of seedlings in the open category but only the concentrations of P and Ca were significantly different in the shade ($p<0.001$) after 9 mo. However, there were no significant differences in the foliar N and K concentrations of fertilised and non-fertilised seedlings under either light level. Types of soil significantly affected the concentrations of Mg and K under both light levels ($p<0.001$) after 9 mo. There was no significant effect of an interaction of fertiliser and soil on the mineral nutrients concentrations under either light category (Table 6.6). Tables 6.7 and 6.8 show that the concentrations of Ca in the open increased by 10 % but there were decreases in the concentrations of N (6 %), Mg (11%) and K (15 %). Light did not contribute to the changes in concentration of P.

The application of fertiliser after 18 mo highly significantly affected the concentrations of P and Ca ($p<0.001$) under both light levels but the concentration of Mg was significantly affected to different extents, in the open ($p<0.01$) and in the shade ($p<0.001$) (Table 6.9). Type of soil highly significantly affected the concentration of Mg ($p<0.001$) in either light level but it only significantly affected the concentration of K ($p<0.01$) in the shade. No significant interactions were found for fertiliser and soils. Table 6.10 shows that the concentration of N in the leaves of seedlings, regardless of fertiliser levels, in the open fell by 23 % but the light did not affect the concentrations of Mg. However, it did increase the concentrations of K (6 %), P (9 %) and Ca (32 %) , 18 mo after the treatments were given. A similar trend was found on the effect of light on the seedlings potted in the different type of soils (Table 6.11).

Soil nutrients and physical properties

The six types of soil used for potting *H. odorata* seedlings were analysed for their mineral nutrients concentrations and for physical properties, after the treatments were completed (at 18 mo). Table 6.12 shows that no significant differences in concentrations were recorded for soil N, K, Mg and organic carbon (C) which was applied with TSP at either light level. But

Table 6.6: Summary of the ANOVA results on the effect of fertiliser (FERT) and soils on the leaf nutrient concentrations of *Hopea odorata*, separately under two light levels 9 mo after the treatments were applied.

	Source of variance	df	F-value[1] N	P	Mg	Ca	K
Open							
	BLOCK	3	0.22 ns	1.15 ns	8.93 ***	2.31 ns	1.43 ns
	FERT	1	1.18 ns	146.72 ***	22.47 ***	88.93 ***	2.54 ns
	SOIL	5	1.19 ns	0.12 ns	10.00 ***	0.95 ns	9.04 ***
	FERT*SOIL	5	0.58 ns	1.40 ns	1.96 ns	1.92 ns	0.72 ns
Shade							
	BLOCK	3	3.09 *	1.62 ns	5.22 **	6.71 ***	4.37 **
	FERT	1	0.23 ns	62.66 ***	0.30 ns	40.46 ***	0.01 ns
	SOIL	5	2.08 ns	2.26 ns	8.95 ***	3.25 *	8.13 ***
	FERT*SOIL	5	1.11 ns	0.69 ns	0.50 ns	1.67 ns	0.40 ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 80

Table 6.7: Effect of phosphorus fertiliser on the leaf mineral nutrient concentrations (mg g^{-1} oven dry wt) of *Hopea odorata* seedlings under two light levels, 9 mo after the treatments were applied (P1, +TSP; P0, control). Treatments within each light level for each variables were compared by LSD[1] test.

	Fertiliser level	N	P	Mg	Ca	K
Open						
	P0	13.3 *a*	0.9 *b*	0.7 *b*	7.9 *b*	7.6 *a*
	P1	13.8 *a*	1.5 *a*	0.9 *a*	11.6 *a*	7.1 *a*
	Mean	**13.6**	**1.2**	**0.8**	**9.8**	**7.4**
Shade						
	P0	14.6 *a*	0.9 *b*	0.9 *a*	7.7 *b*	8.7 *a*
	P1	14.3 *a*	1.4 *a*	0.9 *a*	10.1 *a*	8.6 *a*
	Mean	**14.5**	**1.2**	**0.9**	**8.9**	**8.7**
% light effect[2]		-6	0	-11	10	-15

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over shaded condition; i.e. [(Open-Shaded)/Shaded].100

Table 6.8: Effect of types of soil on the mean of foliar mineral nutrient concentrations (mg g^{-1} oven dry weight) of *Hopea odorata* seedlings, separately under two light levels, 9 mo after the treatments were applied. Treatments within each light level for each variables were compared by LSD[1] test.

	Soil	N	P	Mg	Ca	K
Open						
	S1	13.4 *ab*	1.2 *a*	0.9 *b*	10.1 *a*	6.3 *b*
	S2	14.5 *a*	1.2 *a*	0.6 *d*	10.0 *a*	9.1 *a*
	S3	13.5 *ab*	1.2 *a*	0.8 *c*	10.0 *a*	8.5 *a*
	S4	13.6 *ab*	1.2 *a*	0.8 *bc*	8.9 *a*	7.1 *b*
	S5	13.8 *ab*	1.2 *a*	0.8 *b*	9.8 *a*	6.5 *b*
	S6	12.4 *b*	1.2 *a*	1.0 *a*	10.1 *a*	6.5 *b*
	Mean	**13.5**	**1.2**	**0.8**	**9.8**	**7.3**
Shade						
	S1	15.0 *a*	1.2 *a*	1.0 *a*	8.9 *ab*	8.2 *b*
	S2	13.9 *ab*	1.1 *ab*	0.7 *b*	8.4 *bc*	8.8 *ab*
	S3	15.7 *a*	1.2 *a*	1.0 *a*	9.0 *ab*	9.9 *a*
	S4	12.6 *b*	1.0 *a*	0.7 *b*	7.5 *c*	6.6 *c*
	S5	14.7 *a*	1.2 *a*	1.0 *a*	9.4 *ab*	9.1 *ab*
	S6	14.7 *a*	1.2 *a*	1.1 *a*	9.9 *a*	9.4 *ab*
	Mean	**14.4**	**1.2**	**0.9**	**8.9**	**8.7**
% light effect[2]		-6	0	-11	10	-16

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded condition; i.e. [(Open-Shaded)/Shaded].100

Table 6.9: Summary of the ANOVA results of the effect of fertiliser (FERT) and soils on the leaf nutrient concentrations of *Hopea odorata*, separately under two light levels 18 mo after the treatments were applied.

	Source of variance	df	F-value[1]				
			N	P	Mg	Ca	K
Open							
	BLOCK	3	2.52 ns	0.27 ns	0.72 ns	1.24 ns	2.76 *
	FERT	1	1.86 ns	74.91 ***	11.39 **	76.76 ***	0.15 ns
	SOIL	5	2.18 ns	1.82 ns	6.99 ***	1.06 ns	2.14 ns
	FERT*SOIL	5	0.68 ns	0.52 ns	1.70 ns	0.37 ns	0.95 ns
Shade							
	BLOCK	3	1.21 ns	0.29 ns	5.09 **	1.66 ns	7.95 ***
	FERT	1	2.98 ns	75.28 ***	12.73 ***	83.55 ***	0.61 ns
	SOIL	5	1.23 ns	1.07 ns	12.93 ***	0.77 ns	3.83 **
	FERT*SOIL	5	0.32 ns	1.52 ns	0.47 ns	1.62 ns	1.47 ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 76 to 77 (Open); 76 (Shade)

Table 6.10: Effect of phosphorus fertiliser on the leaf mineral nutrient concentrations (mg g^{-1} oven dry weight) of *Hopea odorata* seedlings under two light levels, 18 mo after the treatments were applied (P1, +TSP; P0, control). Treatments within each light level for each variable were compared by LSD[1] test.

	Fertiliser level	N	P	Mg	Ca	K
Open						
	P0	10.7 *a*	0.8 *b*	0.9 *b*	15.0 *b*	8.9 *a*
	P1	10.3 *a*	1.5 *a*	1.1 *a*	20.0 *a*	8.7 *a*
	Mean	**10.5**	**1.2**	**1.0**	**17.5**	**8.8**
Shade						
	P0	13.3 *a*	0.8 *b*	0.9 *b*	11.3 *b*	8.1 *a*
	P1	14.1 *a*	1.4 *a*	1.1 *a*	15.2 *a*	8.4 *a*
	Mean	**13.7**	**1.1**	**1.0**	**13.3**	**8.3**
% light effect[2]		**-23**	**9**	**0**	**32**	**6**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over shaded condition; i.e. [(Open-Shaded)/Shaded].100

Table 6.11: Effect of types of soil on the mean of foliar mineral nutrient concentrations (mg g^{-1} oven dry wt) of *Hopea odorata* seedlings, separately under two light levels, 18 mo after the treatments were applied.Treatments within each light level for each variables were compared by LSD[1] test.

	Soil	N	P	Mg	Ca	K
a) Open						
	S1	10.6 *ab*	1.2 *ab*	1.0 *bc*	16.6 *a*	8.0 *b*
	S2	10.0 *b*	1.0 *b*	0.9 *c*	17.2 *a*	9.3 *ab*
	S3	9.8 *b*	1.0 *b*	1.1 *ab*	16.8 *a*	9.4 *a*
	S4	11.5 *a*	1.3 *ab*	1.0 *bc*	17.0 *a*	8.4 *ab*
	S5	10.4 *ab*	1.3 *ab*	1.1 *a*	18.1 *a*	9.4 *a*
	S6	10.7 *ab*	1.4 *a*	1.2 *a*	17.9 *a*	8.6 *ab*
	Mean	**10.5**	**1.2**	**1.1**	**17.3**	**8.9**
b) Shade						
	S1	14.2 *a*	1.1 *ab*	1.2 *b*	13.3 *ab*	7.9 *bc*
	S2	12.5 *b*	1.0 *b*	0.8 *d*	12.4 *b*	9.1 *a*
	S3	13.4 *ab*	1.1 *ab*	1.1 *b*	13.3 *ab*	8.8 *ab*
	S4	14.2 *a*	1.2 *ab*	0.9 *cd*	13.2 *ab*	8.3 *ab*
	S5	14.0 *ab*	1.2 *ab*	1.0 *bc*	13.1 *ab*	8.2 *ab*
	S6	13.7 *ab*	1.3 *a*	1.4 *a*	14.0 *a*	7.1 *c*
	Mean	**13.7**	**1.2**	**1.1**	**13.2**	**8.2**
% light effect[2]		**-23**	**0**	**0**	**31**	**9**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded condition; i.e. [(Open-Shaded)/Shaded].100

Table 6.12: Summary of the ANOVA results of mineral nutrients concentrations of soil used for potting *Hopea odorata* seedlings with fertiliser (FERT) treatment of different soils (SOIL), separately under two light levels, 18 mo after the treatments were applied.

	Source of variance	df	F-value[1] N	P	K	Ca	Mg	C
Open								
	BLOCK	2	0.02 ns	2.76 ns	0.40 ns	0.34 ns	5.07 *	5.54 *
	FERT	1	1.09 ns	184.86 ***	2.52 ns	8.98 **	0.03 ns	0.10 ns
	SOIL	5	2.12 ns	0.70 ns	1.04 ns	0.73 ns	2.28 ns	5.76 **
	FERT*SOIL	5	0.2 ns	0.51 ns	0.75 ns	1.09 ns	0.22 ns	0.30 ns
Shade								
	BLOCK	2	0.30 ns	0.79 ns	2.33 ns	1.79 ns	0.07 ns	0.48 ns
	FERT	1	2.31 ns	134.05 ***	0.31 ns	29.14 ***	0.27 ns	1.70 ns
	SOIL	5	1.22 ns	0.51 ns	6.42 ***	5.41 **	12.24 ***	2.30 ns
	FERT*SOIL	5	1.37 ns	0.65 ns	1.64 ns	0.42 ns	1.09 ns	0.28 ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 22

the concentrations of P and Ca were found to be highly significantly different in the effect of fertiliser application ($p<0.001$) for both light levels. Type of soil only significantly affected the concentration of organic carbon ($p<0.01$) in the open and it also highly significantly affected the concentrations of K and Mg ($p<0.001$), and Ca ($p<0.01$) in the shade. However, no significant differences were seen in the interactions of fertiliser and soils.

Table 6.13 shows that addition of TSP in the open category substantially increased the concentrations of P in the soil by 11-fold compared to the unfertilised one and increased the concentrations of Ca and N by 88 and 22 %, respectively. The addition of TSP, however, reduced the concentrations of K by 56 % and organic carbon by 4 %, but it did not affect the concentration of Mg in the soil. As in the open category, adding TSP to the soil in the shade was also substantially increased the concentration of P by 23-fold and as well as to the concentration of Ca. In contrast with the response in the open, TSP reduced N by 18 % but increased K by 2-fold in the shade category. However addition of TSP did not change the concentration of Mg in the soil in the shade category. The type of soils used for potting the seedlings highly and significantly affected the concentrations of K, Mg and Ca in the shade categories (Table 6.12). In general, soil S3 (collected from partial shade subplots) gave low concentrations of soil N, K, Ca and Mg but soil S2 gave low concentration of P, 18 mo after the treatments were completed (Table 6.13).

Only the types of soil showed strongly significantly different on the physical properties of the soil used for potting (Table 6.14). The analysis of the soils showed that the percentage of fine sand was high in soil S4 and coarse sand was found higher in soils S1, S3, S4 and S6 (Table 6.15). Whilst, silt and clay were found higher in soil S2. Basically soil with heavy clay has more positions to hold cations, thus the soil (S2) had higher CEC.

Root infection - mycorrhizas

Application of TSP did not significantly affect the percentages of infection of ectomycorrhizas (ECM) on the root tips of *H. odorata* in the open category, but it highly

Table 6.13: Mean of mineral nutrients concentrations of soil used for potting *Hopea odorata* seedlings, separately under two light levels, 18 mo after the treatments were applied (P1,+TSP; P0, control). Mean ± SE, n=3.

	Fertiliser level	Soil	Total N (%)	P (ppm)	Exchangeable (meq.100 g^{-1}) K	Ca	Mg	(%) Organic carbon
Open	P0	S1	0.11 ± 0.01	38.7 ± 19.1	0.41 ± 0.33	0.60 ± 0.40	0.14 ± 0.05	1.54 ± 0.11
		S2	0.11 ± 0.02	11.7 ± 2.7	0.14 ± 0.12	0.33 ± 0.03	0.13 ± 0.03	0.70 ± 0.03
		S3	0.07 ± 0.01	17.9 ± 3.2	0.06 ± 0.01	0.27 ± 0.07	0.09 ± 0.02	0.82 ± 0.06
		S4	0.08 ± 0.01	17.1 ± 2.6	0.26 ± 0.10	0.30 ± 0.06	0.13 ± 0.02	0.80 ± 0.01
		S5	0.09 ± 0.01	19.5 ± 3.3	0.13 ± 0.08	0.23 ± 0.03	0.08 ± 0.02	0.95 ± 0.14
		S6	0.10 ± 0.01	21.5 ± 2.7	0.06 ± 0.01	0.67 ± 0.03	0.15 ± 0.02	1.31 ± 0.02
		Mean	**0.09 ± 0.01**	**21.1 ± 5.7**	**0.18 ± 0.10**	**0.40 ± 0.10**	**0.12 ± 0.03**	**1.02 ± 0.06**
	P1	S1	0.14 ± 0.05	212.1 ± 20.7	0.08 ± 0.01	0.39 ± 0.17	0.12 ± 0.01	1.78 ± 0.06
		S2	0.14 ± 0.03	184.5 ± 32.5	0.13 ± 0.02	0.83 ± 0.07	0.14 ± 0.03	0.72 ± 0.09
		S3	0.08 ± 0.01	213.4 ± 30.8	0.05 ± 0.01	0.73 ± 0.03	0.09 ± 0.03	0.71 ± 0.05
		S4	0.07 ± 0.01	190.5 ± 39.0	0.11 ± 0.03	0.93 ± 0.35	0.15 ± 0.03	0.80 ± 0.43
		S5	0.10 ± 0.01	251.8 ± 37.6	0.06 ± 0.01	0.70 ± 0.10	0.09 ± 0.003	0.82 ± 0.43
		S6	0.11 ± 0.01	234.2 ± 50.8	0.06 ± 0.01	0.93 ± 0.37	0.13 ± 0.03	1.06 ± 0.58
		Mean	**0.11 ± 0.02**	**249.8 ± 33.5**	**0.08 ± 0.02**	**0.75 ± 0.18**	**0.12 ± 0.02**	**0.98 ± 0.27**
	fertiliser effect[1]		**0.22**	**10.83**	**-0.56**	**0.88**	**0**	**-0.04**
Shade	P0	S1	0.11 ± 0.02	9.6 ± 1.9	0.05 ± 0.003	0.16 ± 0.04	0.05 ± 0.00	1.57 ± 0.05
		S2	0.10 ± 0.01	5.7 ± 1.7	0.19 ± 0.07	0.20 ± 0.06	0.06 ± 0.003	1.11 ± 0.26
		S3	0.09 ± 0.01	3.4 ± 0.4	0.05 ± 0.01	0.40 ± 0.00	0.07 ± 0.02	0.87 ± 0.01
		S4	0.12 ± 0.003	7.4 ± 1.1	0.09 ± 0.02	0.60 ± 0.40	0.09 ± 0.01	0.91 ± 0.02
		S5	0.12 ± 0.003	4.6 ± 0.5	0.05 ± 0.00	0.23 ± 0.03	0.05 ± 0.00	1.29 ± 0.03
		S6	0.09 ± 0.01	8.6 ± 1.0	0.04 ± 0.003	0.67 ± 0.03	0.13 ± 0.01	1.46 ± 0.07
		Mean	**0.11 ± 0.01**	**6.6 ± 1.0**	**0.08 ± 0.02**	**0.31 ± 0.04**	**0.08 ± 0.01**	**1.20 ± 0.07**
	P1	S1	0.06 ± 0.03	110.9 ± 58.0	0.04 ± 0.003	0.43 ± 0.23	0.04 ± 0.02	1.09 ± 0.55
		S2	0.12 ± 0.01	164.7 ± 18.1	0.10 ± 0.01	0.73 ± 0.03	0.08 ± 0.01	1.04 ± 0.37
		S3	0.10 ± 0.02	176.4 ± 22.7	0.06 ± 0.02	1.00 ± 0.00	0.06 ± 0.01	0.77 ± 0.08
		S4	0.11 ± 0.01	161.3 ± 39.4	0.11 ± 0.03	1.33 ± 0.35	0.14 ± 0.01	0.86 ± 0.02
		S5	0.09 ± 0.003	165.1 ± 5.1	0.06 ± 0.01	0.70 ± 0.11	0.04 ± 0.01	1.19 ± 0.06
		S6	0.07 ± 0.003	176.5 ± 18.6	0.05 ± 0.01	1.30 ± 0.15	0.13 ± 0.04	1.28 ± 0.05
		Mean	**0.09 ± 0.01**	**159.2 ± 27.0**	**0.23 ± 0.01**	**0.92 ± 0.15**	**0.08 ± 0.02**	**1.04 ±0.19**
	fertiliser effect[1]		**-0.18**	**23.3**	**1.88**	**1.97**	**0**	**-0.13**

[1] Fertiliser effect of fertilised over non-fertilised seedlings; i.e. [(P1-P0)/P0].100

Table 6.14: Summary of the ANOVA results of physical properties of soil used for potting seedlings of *Hopea odorata* seedlings with fertiliser (FERT) treatment of different soils (SOIL), separately under two light levels, 18 mo after the treatments were applied.

	Source of variance	df	F-value[1]					
			[2] CEC	FS	CS	SLT	CLY	pH
Open								
	BLOCK	2	10.94 ***	0.33 ns	0.86 ns	0.89 ns	0.34 ns	3.77 *
	FERT	1	8.05 *	1.91 ns	6.04 *	0.29 ns	3.43 ns	0.77 ns
	SOIL	5	1.14 ns	11.27 ***	86.02 ***	15.65 ***	5.95 **	1.50 ns
	FERT*SOIL	5	1.08 ns	0.53 ns	1.24 ns	0.56 ns	0.58 ns	0.37 ns
Shade								
	BLOCK	2	56.28 ***	7.01 **	0.42 ns	0.24 ns	0.90 ns	9.82 ***
	FERT	1	0.04 ns	0.40 ns	0.46 ns	0.02 ns	2.79 ns	10.18 **
	SOIL	5	0.38 ns	19.32 ***	52.43 ***	33.49 ***	46.09 ***	9.70 ***
	FERT*SOIL	5	0.31 ns	2.38 ns	1.51 ns	1.72 ns	0.43 ns	2.84 *

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 17 (Open); 21 (Shade)

[2] CEC=Cation exchange capacity, FS=Fine sand, CS=Coarse sand, SLT=Silt, CLY=Clay.

Table 6.15: Mean of physical properties of soil used for potting *Hopea odorata* seedlings, separately under two light levels, 18 mo after the treatments were applied (P1, +TSP; P0, control). Mean ± SE, n=3.

	Fertiliser level	Soil	CEC	Fine sand (%)	Coarse sand (%)	Silt (%)	Clay (%)	pH
Open	P0	S1	5.0 ± 1.54	28.7 ± 1.54	48.0 ± 1.53	2.7 ± 0.67	21.0 ± 6.03	4.3 ± 0.15
		S2	5.8 ± 0.60	36.7 ± 1.67	8.0 ± 1.15	17.7 ± 2.91	34.7 ± 1.45	4.1 ± 0.11
		S3	5.2 ± 1.29	32.3 ± 2.19	49.0 ± 2.52	3.3 ± 0.67	15.3 ± 0.67	4.3 ± 0.03
		S4	6.6 ± 0.47	53.7 ± 0.88	4.7 ± 0.33	9.7 ± 2.40	30.3 ± 0.67	4.1 ± 0.12
		S5	5.5 ± 1.20	32.7 ± 1.67	49.7 ± 2.33	3.3 ± 0.67	16.0 ± 0.00	4.5 ± 0.26
		S6	3.8 ± 1.13	17.7 ± 5.17	50.0 ± 3.51	2.7 ± 0.67	30.7 ± 0.33	4.4 ± 0.16
		Mean	**5.3 ± 1.0**	**33.6 ± 2.2**	**34.9 ± 1.9**	**6.6 ± 1.7**	**24.7 ± 1.5**	**4.3 ± 0.10**
	P1	S1	3.2 ± 0.75	26.5 ± 4.50	56.0 ± 4.00	3.5 ± 1.50	14.0 ± 0.00	4.2 ± 0.04
		S2	4.4 ± 1.36	35.0 ± 0.00	9.5 ± 2.50	14.0 ± 0.00	27.0 ± 12.00	4.3 ± 0.36
		S3	2.8 ± 0.39	30.5 ± 5.50	49.5 ± 8.50	3.0 ± 1.00	17.5 ± 0.50	4.2 ± 0.23
		S4	4.0 ± 1.05	41.0 ± 4.00	19.0 ± 4.00	11.5 ± 4.50	27.0 ± 4.00	4.2 ± 0.15
		S5	3.4 ± 0.66	26.5 ± 6.50	52.5 ± 6.50	3.0 ± 1.00	16.0 ± 0.00	4.4 ± 0.11
		S6	4.5 ± 0.89	17.0 ± 5.03	55.3 ± 1.20	5.0± 2.08	22.7 ± 4.33	4.4 ± 0.18
		Mean	**3.7 ± 0.90**	**29.4 ± 4.30**	**40.3 ± 4.5**	**6.7 ± 1.7**	**20.7 ± 3.50**	**4.3 ± 0.20**
	% fertiliser effect[1]		**-30**	**-14**	**15**	**2**	**-16**	**0**
Shade	P0	S1	5.8 ± 1.70	14.7 ± 0.33	60.3 ± 1.67	2.0 ± 0.00	15.7 ± 0.88	4.3 ± 0.14
		S2	6.8 ± 2.19	25.0 ± 5.13	12.3 ± 1.33	13.0 ± 1.00	39.0 ± 1.53	4.2 ± 0.08
		S3	6.2 ± 1.14	27.3 ± 3.71	40.7± 12.86	4.3 ± 2.33	21.0 ± 5.00	4.4 ± 0.06
		S4	6.3 ± 1.19	36.7 ± 1.20	8.3 ± 1.76	5.3 ± 1.76	30.3 ± 1.20	4.3 ± 0.04
		S5	5.9 ± 0.94	19.7 ± 4.10	56.3 ± 1.86	2.7 ± 0.67	16.3 ± 0.33	4.3 ± 0.14
		S6	6.0 ± 0.61	16.0 ± 4.51	50.3 ± 1.20	2.0 ± 0.00	29.0 ± 2.52	4.4 ± 0.06
		Mean	**6.2 ± 1.30**	**23.2 ± 3.20**	**40.3 ± 4.50**	**6.7 ± 1.70**	**20.7 ± 3.50**	**4.3 ± 0.09**
	P1	S1	4.6 ± 0.04	22.0 ± 4.00	54.5 ± 4.50	3.0 ± 1.00	13.0 ± 1.00	4.4 ± 0.04
		S2	6.1 ± 1.00	32.3 ± 4.06	9.7 ± 1.45	12.3 ± 0.67	37.7 ± 1.76	4.1 ± 0.11
		S3	5.7 ± 0.87	22.3 ± 4.84	57.0 ± 2.89	2.0 ± 0.00	16.0 ± 0.00	4.7 ± 0.05
		S4	6.5 ± 1.30	38.3 ± 1.33	9.7 ± 0.67	8.7 ± 0.67	30.3 ± 0.67	4.3 ± 0.15
		S5	5.8 ± 1.57	16.3 ± 1.20	56.7 ± 3.00	2.0 ± 0.00	15.3 ± 0.67	4.5 ± 0.11
		S6	6.6 ± 2.47	12.0 ± 1.53	52.0 ± 1.73	2.0 ± 0.00	28.0 ± 1.73	4.7 ± 0.04
		Mean	**5.9 ± 1.2**	**23.9 ± 2.8**	**39.9 ± 2.4**	**5.0 ± 0.40**	**23.4 ± 1.00**	**4.5 ± 0.08**
	% fertiliser effect[1]		**-5**	**3**	**-1**	**-25**	**13**	**5**

[1] % change of fertilised over non-fertilised seedlings; i.e. [(P1-P0)/P0].100

significantly affected the percentages of ECM of the root tips in the shade category (Table 6.16; $p<0.001$). Table 6.17 shows that adding P significantly increased the percentage of ECM infection on the root tips of the seedlings in the shaded category but no significant differences were seen in the open. The results also showed that type of soil and interactions of fertiliser and soils highly significantly affected the percentage of ECM on the root tips ($p<0.001$) in either light level. Fertilised *H. odorata* seedlings, under the shade, potted in soils collected from the closed categories (S4 & S5) and potted in the nursery soil (S6) had higher infection compared to those potted in soils collected from the open categories (S1 & S2) and from partial shade category (S3), (Figures 6.1 & 6.2). From overall means of infection, seedlings in the open had *c.* 55 % less infection of ECM than those in the shaded category. Light appeared to reduce the percentages of ECM infection on the root tips by 20 % but it appeared to increase the dead of ECM by 36 % (Table 6.17).

Correlations between ECM, total dry weight and foliar nutrient concentrations

No significant relationships were shown between ECM of the root tips and total dry weight, and between ECM and different nutrient concentrations in the leaves of the seedlings at either light and fertiliser levels (Table 6.18). The total dry weight of the seedlings and the different nutrients concentrations showed some specific associations which varied with the different elements. Total dry weight of the non-fertilised seedlings in the open was negatively and significantly correlated with Ca ($p<0.01$) and with Mg ($p<0.05$). Mg and Ca, and Mg and P were significantly correlated at $p<0.01$ and $p<0.05$, respectively. Foliar P of fertilised seedlings in the open showed strong and significant relationship with Mg ($p<0.001$). The concentrations of both P and Mg of non-fertilised seedlings in the shade category showed significant and strong positive relationships with Ca. Total dry weight of the seedlings however was significantly and negatively correlated with Mg and K ($p<0.01$), and also with Ca ($p<0.05$).

Figures 6.1 and 6.2 show the relationships between the concentration of P in the leaves and the dry weight of leaves with the percentage of infections on the root tips of *H. odorata* seedlings. Among the non-fertilised seedlings, in the open and shaded categories, the

Table 6.16: Summary of the ANOVA results on the effect of fertiliser and types of soil on the mycorrhizal infection of *Hopea odorata* roots with fertiliser (FERT) treatment of different soils (SOIL), separately under two light levels 18 mo after the treatments were applied. A=ectomycorrhizal root tips, B=non-ectomycorrhizal root tips, and C=dead ectomycorrhizal root tips.

	Source of variance	df	F-value[1] A	B	C
Open					
	BLOCK	2	40.30 ***	62.55 ***	176.16 ***
	FERT	1	0.00 ns	55.62 ***	79.66 ***
	SOIL	5	15.63 ***	13.63 ***	9.28 ***
	FERT*SOIL	5	10.74 ***	3.34 **	8.95 ***
Shade					
	BLOCK	2	160.56 ***	181.77 ***	16.32 ***
	FERT	1	161.82 ***	103.04 ***	0.01 ns
	SOIL	5	7.54 ***	4.85 ***	5.87 ***
	FERT*SOIL	5	15.85 ***	11.27 ***	7.50 ***

** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 705 (Open); 704 (Shade)

Table 6.17: Overall mean percentage of root tips with ectomycorrhizas (ECM) of *H. odorata* at different levels of fertiliser within each light level for each variable, separately under two light categories. A=ectomycorrhizal root tips, B=non-ectomycorrhizal root tips, C=dead ectomycorrhizal root tips; P1 =fertilised seedlings, P0 =non-fertilised seedlings. The treatments were compared by LSD[1] test.

Light level	Fertiliser level	A	B	C
Open	P0	24 *a*	43 *b*	26 *b*
	P1	24 *a*	50 *a*	34 *a*
	Mean	**24**	**47**	**30**
Shade	P0	23 *b*	42 *b*	22 *a*
	P1	36 *a*	55 *a*	22 *a*
	Mean	**30**	**49**	**22**
% light effect[2]		**-20**	**-40**	**36**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] increase in the open over the shaded condition; i.e. [(Open-Shaded)/Shaded].100

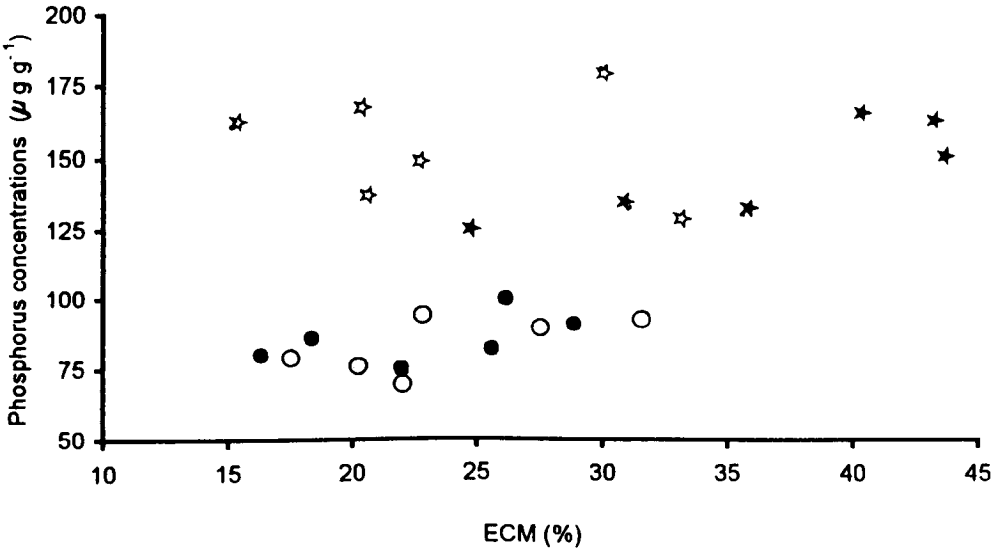


Figure 6.1: Relationship between the percentage of root tips with ECM and foliar phosphorus of *H. odorata* seedlings. Non-fertilised seedlings: open circles = seedlings in the open, closed circles = seedlings in the shade. Fertilised seedlings: open stars = seedlings in the open, closed stars = seedlings in the shade. The six points of each symbol are means for each of the six soil types (S1,...,S6).

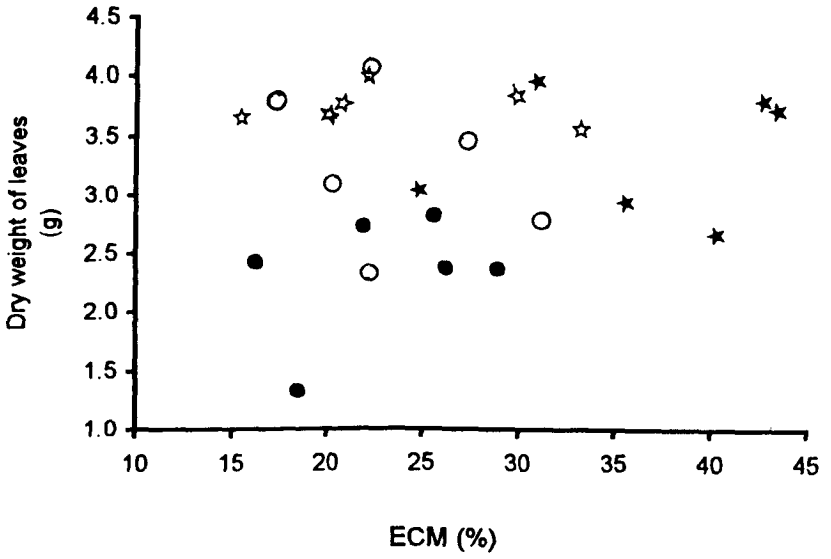


Figure 6.2: Relationship between the percentage of root tips with ECM and dry weight of leaves of *H. odorata* seedlings. Non-fertilised seedlings: open circles=seedlings in the open, closed circles=seedlings in the shade. Fertilised seedlings: open stars=seedlings in the open, closed stars=seedlings in the shade. The six points of each symbol are means for each of the six soil types (S1,...,S6).

Table 6.18: Correlation coefficient's Pearson between ectomycorrhizal roots (ECM), total dry weight (TDRY) and foliar mineral nutrients concentrations (mg g^{-1}) of *Hopea odorata* seedlings of fertilised and non-fertilised under two different light levels, 18 mo after the treatments were applied.

Open condition

(a) Non-fertilised seedlings

(n=18)	%ECM	TDRY	N	P	Mg	Ca
TDRY	0.08					
N	0.33	0.15				
P	-0.04	-0.33	0.28			
Mg	-0.13	-0.48*	-0.38	0.30		
Ca	-0.09	-0.60**	-0.15	0.57 *	0.69 **	
K	-0.22	-0.44	-0.09	-0.23	0.01	0.17

(b) Fertilised seedlings

(n=18)	%ECM	TDRY	N	P	Mg	Ca
TDRY	-0.41					
N	-0.11	-0.14				
P	-0.10	-0.11	-0.06			
Mg	0.13	-0.29	-0.31	0.72 ***		
Ca	-0.19	-0.26	0.02	0.44	0.53 *	
K	0.37	-0.31	0.40	-0.21	-0.20	-0.28

Shade condition

(a) Non-fertilised seedlings

(n=18)	%ECM	TDRY	N	P	Mg	Ca
TDRY	0.27					
N	-0.07	-0.17				
P	-0.14	-0.07	0.50 *			
Mg	0.05	-0.21	0.12	0.36		
Ca	-0.02	-0.16	0.07	0.60 **	0.75 ***	
K	-0.22	-0.39	0.51 *	0.50 *	-0.07	0.33

(b) Fertilised seedlings

(n=18)	%ECM	TDRY	N	P	Mg	Ca
TDRY	-0.24					
N	-0.16	0.45				
P	0.31	-0.17	0.08			
Mg	-0.07	0.12	0.03	0.11		
Ca	-0.31	-0.49*	-0.07	0.35	0.19	
K	-0.29	-0.26	-0.07	-0.39	-0.67**	-0.09

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

seedlings were not distinguished by their ECM infections but in the fertilised seedlings they were. Fertilised seedlings had higher foliar P than non-fertilised ones, however, seedlings in the shaded category had higher infections of ECM than in the open categories. Figure 6.2 shows that although fertilised seedlings in the open and in the shaded categories, and non-fertilised seedlings in the open category had higher dry weight of leaves, only root tips of the fertilised seedlings in the shaded category had higher with ECM infection. In both relationships (Figures 6.1 & 6.2) fertilised seedlings in the shaded category, potted in soils S4 and S5 (soil collected in closed canopy categories) and S6 (nursery soil) had higher infection of ECM (40 - 45 %) on the root tips of *H. odorata* seedlings.

6.3.1.2 Experiment II - *Shorea acuminata*

Growths

Addition of fertiliser to *S. acuminata* in the open category did not significantly increase the growth of seedlings after 9 mo, except that it slightly increased the height growth of seedlings (Table 6.19; $p<0.05$). Types of soil significantly affected height growth and dry weight of stems ($p<0.01$), but stem diameter and leaf area were only affected at $p<0.05$. Interactions of fertiliser and soil only significantly affected the number of leaves of *S. acuminata* seedlings ($p<0.01$) in the open but no significant differences in other growth parameters and in dry weights of the seedlings were observed 9 mo after the treatments were given. After 9 mo in the shade, fertilising the seedlings only significantly affected the leaf area and the dry weight of leaves ($p<0.05$). Types of soil only significantly affected the number of leaves ($p<0.05$). No interactions of fertiliser and soil were observed after 9 mo in the shade. As shown in Table 6.20, the effect of light on *S. acuminata* reduced the growth increment except that it slightly increased the dry weight of roots by 8 % after 9 mo. Soil S3, regardless of fertiliser level, gave the lowest mean of the growth and the dry weights of seedlings.

After 18 mo, fertilisation contributed highly significantly to the dry weight of roots (Table 6.21). Type of soil highly significantly affected the stem diameter and the dry weight of stem

Table 6.19: Summary of the ANOVA results of the effect of fertiliser (FERT) and soils (SOIL) on the mean growth and dry weight of *Shorea acuminata* seedlings, separately under two different light levels 9 mo after the treatments were applied.

	Source of variance	df	F-value[1] No. of leaves	Height (cm)	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) leaves	stem	roots
Open									
	BLOCK	2	1.7 ns	2.3 ns	1.0 ns	4.4 *	3.6 *	1.8 ns	0.3 ns
	FERT	1	3.4 ns	6.2 *	0.1 ns	1.6 ns	0.8 ns	0.01 ns	1.7 ns
	SOIL	5	1.4 ns	4.1 **	2.9 *	0.8 *	0.4 ns	4.1 **	1.9 ns
	FERT*SOIL	5	3.7 **	0.7 ns	0.1 ns	2.0 ns	1.3 ns	1.04 ns	1.2 ns
Shade									
	BLOCK	2	0.8 ns	2.4 ns	0.6 ns	2.1 ns	2.0 ns	0.6 ns	1.0 ns
	FERT	1	3.3 ns	0.01 ns	3.2 ns	5.6 *	5.2 *	0.2 ns	0.5 ns
	SOIL	5	3.09 *	1.0 ns	1.6 ns	1.2 ns	1.8 ns	1.8 ns	1.5 ns
	FERT*SOIL	5	1.1 ns	0.5 ns	0.6 ns	1.1 ns	0.7 ns	0.7 ns	0.8 ns

* $p < 0.05$; ** $p < 0.01$; ns = not significant

[1] Error df = 56

Table 6.20: Effect of phosphorus fertiliser (TSP) and types of soil on the mean growth and mean dry weight of *Shorea acuminata* seedlings, 9 mo after the treatments were applied (P1, +TSP; P0, control). Treatments within each light level for each variables were compared by LSD[1] test.

	Fertiliser level	No. of leaves	Height (cm)	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) of leaves	stem	roots
Open								
	P0	11.0 *a*	37.7 *b*	6.1 *a*	188 *a*	1.56 *a*	2.60 *a*	2.46 *a*
	P1	13.0 *a*	41.9 *a*	6.1 *a*	220 *a*	1.73 *a*	2.61 *a*	2.08 *a*
	Mean	**12**	**39.8**	**6.1**	**204**	**1.65**	**2.61**	**2.27**
Shade								
	P0	14.5 *a*	48.1 *a*	5.9 *a*	313 *b*	2.03 *b*	2.78 *a*	1.93 *a*
	P1	17.1 *a*	48.2 *a*	6.5 *a*	407 *a*	2.60 *a*	2.94 *a*	2.18 *a*
	Mean	**15.8**	**48.2**	**6.2**	**360**	**2.32**	**2.86**	**2.1**
% light effect[2]		**-24**	**-17**	**-2**	**-43**	**-29**	**-9**	**8**
Types of soil in the open								
	S1	13 *a*	41.3 *ab*	6.2 *ab*	202 *ab*	1.67 *a*	2.37 *b*	2.51 *ab*
	S2	12 *ab*	37.9 *bc*	5.5 *c*	218 *ab*	1.59 *a*	2.26 *b*	1.91 *b*
	S3	8 *b*	34.6 *c*	5.4 *c*	169 *c*	1.42 *a*	1.78 *b*	1.53 *b*
	S4	12 *ab*	45.5 *a*	6.6 *ab*	242 *a*	1.92 *a*	3.49 *a*	2.39 *ab*
	S5	13 *a*	41.6 *ab*	6.9 *a*	199 *b*	1.65 *a*	3.46 *a*	3.05 *a*
	S6	10 *ab*	36.6 *bc*	5.8 *bc*	185 *b*	1.55 *a*	2.15 *b*	2.13 *ab*
	Mean	**11**	**39.6**	**6.1**	**202**	**1.63**	**2.59**	**2.25**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded condition; i.e. [(Open-Shaded)/Shaded].100

Table 6.21: Summary of the ANOVA results of the effect of fertiliser (FERT) and soils (SOIL) on the mean growth and dry weight of *Shorea acuminata* seedlings, separately under two different light levels 18 mo after the treatments were applied.

	Source of variance	df	F-value[1] No. of leaves	Height (cm)	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) of leaves	stem	roots
Open									
	BLOCK	2	9.23 ***	6.21 **	4.35 *	4.48 *	3.72 ns	6.14 **	2.26 ns
	FERT	1	1.74 ns	0.10 ns	3.60 ns	0.07 ns	0.74 ns	1.99 ns	12.71 ***
	SOIL	5	2.14 ns	4.85 **	8.48 ***	1.38 ns	1.37 ns	8.25 ***	4.39 **
	FERT*SOIL	5	0.42 ns	2.20 ns	0.36 ns	0.21 ns	0.26 ns	1.24 ns	0.91 ns
Shade									
	BLOCK	2	6.11 **	4.83 *	0.56 ns	7.02 **	5.57 **	2.59 ns	1.87 ns
	FERT	1	0.02 ns	0.35 ns	1.12 ns	0.29 ns	0.30 ns	0.71 ns	2.71 ns
	SOIL	5	0.65 ns	0.37 ns	0.53 ns	0.96 ns	0.92 ns	0.16 ns	0.65 ns
	FERT*SOIL	5	0.91 ns	0.39 ns	0.48 ns	0.29 ns	0.72 ns	0.56 ns	1.20 ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 44,50 (Open); 54,55 (Shade)

in open category ($p<0.001$) and it also significantly affected the height growth and the dry weight of roots at $p<0.01$. However, there was no significant interaction between fertiliser and type of soil for all growth parameters and for dry weights of the seedlings in the shaded category. Table 6.22 shows that light substantially reduced the number of leaves (58 %), leaf area and the dry weight of leaves (72 %). As for 9 mo, soil S3 used for potting the seedlings in open category gave the lowest mean of growth variables and of dry weights after 18 mo.

Nutrients

The addition of phosphorus fertiliser in the open category significantly increased the concentrations of N, P, Mg, Ca and K in the leaves of *S. acuminata* seedlings, 9 mo after the treatments were applied (Table 6.23; $p<0.001$) but for K significant at $p<0.01$. Results of seedlings in the shade showed that the applications of TSP only significantly affected the concentrations of P, Mg and Ca ($p<0.001$). Type of soil highly significantly affected the concentrations of Mg and K in either light level ($p<0.001$). However, the interaction of fertiliser and soil only significantly affected the concentration of Mg ($p<0.01$) in the open. Tables 6.24 and 6.25 show that, light reduced the concentrations of N by 2 %, Mg by 10-11 % and Ca by 1-3 % but it increased the concentrations of P by 27-31 % and K by 8 %.

The concentration of foliar Mg was significantly higher in the seedlings potted in S6 and significantly lower in S1 under both light levels (Table 6.25). Whilst, the concentration of foliar K was also significantly higher in seedlings potted in S2 under both light levels. The foliar K was found to be lower in seedlings potted in S5 in the open, whereas its concentration was lower in S5 and S6 in the shade. Table 6.26 shows that, even though the application of fertiliser increased the concentration of foliar Mg under both light levels, light reduced the concentrations of Mg of fertilised seedlings by 19 % and of non-fertilised seedlings by 18 %.

After 18 mo in the open category, addition of fertiliser significantly affected the concentrations of P and Ca ($p<0.001$), Mg ($p<0.01$) and K ($p<0.05$) but no significant differences were shown for the concentrations of N (Table 6.27). However, the application

Table 6.22: Effect of phosphorus fertiliser (TSP) and types of soil on the mean growth and mean dry weight of *Shorea acuminata* seedlings, 18 mo after the treatments were applied (P1, +TSP; P0, control). Treatments within each light level for each variables were compared by LSD[1] test.

	Fertiliser level	No. of leaves	Height (cm)	Diameter (mm)	Leaf area (cm^2)	Dry weight (g) of leaves	stem	roots
Open								
	P0	6.9 *a*	47.3 *a*	6.45 *a*	100 *a*	0.72 *a*	3.47 *a*	2.77 *b*
	P1	8.1 *a*	47.6 *a*	6.88 *a*	103 *a*	0.83 *a*	3.90 *a*	4.19 *a*
	Mean	**8**	**47.5**	**6.67**	**102**	**0.78**	**3.69**	**3.48**
Shade								
	P0	19.6 a	63.5 a	7.37 a	513 a	2.97 a	5.48 a	4.03 a
	P1	18.7 a	61.0 a	7.05 a	470 a	2.63 a	4.87 a	3.18 a
	Mean	**19.2**	**62.3**	**7.21**	**492**	**2.8**	**5.18**	**3.61**
% light effect[2]		**-58**	**-24**	**-7**	**-72**	**-72**	**-29**	**-4**
Types of soil in the open								
	S1	9.5 *a*	45.3 *b*	6.3 *bc*	110 *ab*	0.91 *ab*	3.71 *b*	3.96 *abc*
	S2	7.7 *abc*	44.2 *b*	6.2 *bc*	115 *ab*	0.89 *ab*	2.90 *bc*	2.64 *cd*
	S3	5.4 *c*	43.2 *b*	5.7 *c*	66 *b*	0.49 *b*	2.41 *c*	2.17 *d*
	S4	9.1 *ab*	57.3 *a*	7.5 *a*	121 *a*	0.96 *a*	5.40 *a*	4.60 *ab*
	S5	8.1 *abc*	53.1 *a*	8.0 *a*	108 *ab*	0.77 *ab*	4.99 *a*	4.79 *a*
	S6	5.6 *bc*	42.7 *b*	6.6 *b*	89 *ab*	0.68 *ab*	3.07 *bc*	3.19 *bcd*
	Mean	**8**	**47.6**	**6.7**	**102**	**0.78**	**3.75**	**3.56**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded condition; i.e. [(Open-Shaded)/Shaded].100

Table 6.23: Summary of the ANOVA results of the effect of fertiliser (FERT) and types of soil (SOIL) on the leaf nutrient contents of *Shorea acuminata,* separately under two light levels, 9 mo after the treatments were applied.

	Source of variance	df	F-value[1] N	P	Mg	Ca	K
Open							
	BLOCK	2	1.40 ns	0.54 ns	3.20 *	2.16 ns	0.28 ns
	FERT	1	20.46 ***	241.33 ***	55.59 ***	54.36 ***	7.41 **
	SOIL	5	1.52 ns	2.15 ns	20.01 ***	1.32 ns	9.69 ***
	FERT*SOIL	5	0.21 ns	1.68 ns	4.04 **	2.36 ns	1.40 ns
Shade							
	BLOCK	2	1.22 ns	0.99 ns	0.01 ns	4.54 *	8.79 ***
	FERT	1	1.13 ns	139.89 ***	13.20 ***	42.73 ***	2.85 ns
	SOIL	5	0.30 ns	1.93 ns	14.96 ***	1.35 ns	11.58 ***
	FERT*SOIL	5	0.81 ns	2.00 ns	1.57 ns	0.56 ns	0.73 ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 56

Table 6.24: Effect of phosphorus fertiliser on the mean of foliar mineral nutrients concentrations (mg g^{-1} oven dry wt) of *Shorea acuminata* seedlings, separately under two light levels, 9 mo after the treatments were applied (P1, +TSP; P0, control). Treatments within each light level for each variable were compared by LSD[1] test.

	Fertiliser level	N	P	Mg	Ca	K
Open						
	P0	13.11 *b*	0.94 *b*	1.42 *b*	8.31 *b*	7.61 *b*
	P1	15.85 *a*	4.10 *a*	1.93 *a*	12.87 *a*	8.51 *a*
	Mean	**14.48**	**2.52**	**1.68**	**10.59**	**8.06**
Shade						
	P0	14.46 *a*	0.93 *b*	1.72 *b*	8.63 *b*	7.30 *a*
	P1	14.97 *a*	2.90 *a*	2.02 *a*	12.85 *a*	7.64 *a*
	Mean	**14.72**	**1.92**	**1.87**	**10.74**	**7.47**
% light effect[2]		**-2**	**31**	**-10**	**-1**	**8**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded condition; i.e. [(Open-Shaded)/Shaded].100

Table 6.25: Effect of types of soil on the mean of leaf mineral nutrient concentrations (mg g^{-1} oven dry wt) of *Shorea acuminata* seedlings, separately under two light levels, 9 mo after the treatments were applied. Treatments within each light level for each variable were compared by LSD[1] test.

	Soil	N	P	Mg	Ca	K
Open						
	S1	14.21 *ab*	2.19 *b*	1.21 *c*	10.17 *ab*	7.62 *bc*
	S2	14.14 *ab*	2.38 *b*	1.48 *b*	9.94 *ab*	10.29 *a*
	S3	12.66 *b*	2.08 *b*	1.75 *b*	9.34 *b*	7.51 *bc*
	S4	15.42 *a*	2.76 *ab*	1.62 *b*	11.47 *ab*	8.34 *b*
	S5	14.70 *ab*	2.25 *b*	1.63 *b*	10.26 *ab*	6.90 *c*
	S6	15.22 *a*	3.12 *a*	2.33 *a*	11.79 *a*	7.55 *bc*
	Mean	**14.39**	**2.46**	**1.67**	**10.50**	**8.04**
Shade						
	S1	14.84 *a*	2.23 *a*	1.51 *c*	9.73 *a*	7.59 *b*
	S2	15.11 *a*	1.59 *b*	1.62 *c*	10.70 *a*	9.20 *a*
	S3	14.67 *a*	1.79 *ab*	1.90 *b*	9.67 *a*	7.21 *bc*
	S4	14.85 *a*	1.84 *ab*	18.9 *b*	11.95 *a*	7.40 *bc*
	S5	14.73 *a*	1.93 *ab*	1.77 *bc*	11.22 *a*	6.72 *c*
	S6	14.14 *a*	2.26 *a*	2.57 *a*	11.56 *a*	6.72 *c*
	Mean	**14.72**	**1.94**	**1.88**	**10.81**	**7.47**
% light effect[2]		**-2**	**27**	**-11**	**-3**	**8**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded category; i.e. [(Open-Shaded)/Shaded].100

Table 6.26: Effect of fertiliser and types of soil on the mean of Mg concentrations of *Shorea acuminata* leaves, separately under two light levels, 9 mo after the treatments were applied (P1, +TSP; P0, control). Means with standard deviation in parentheses; (n = 6 unless indicated; $n_a = 4$, $n_b = 5$).

Fertiliser level	Soil	Mg (mg g^{-1} oven dry wt)		% light effect[1]
		Open	Shade	
P0	S1	0.095 (0.016)	0.138 (0.015)	
	S2	0.142 (0.037)	0.152 (0.038)	
	S3	0.145 (0.031)	0.188 $(0.049)_b$	
	S4	0.153 (0.027)	0.172 $(0.172)_b$	
	S5	0.133 (0.027)	0.163 (0.036)	
	S6	0.182 (0.037)	0.222 (0.026)	
	Mean	**0.17**	**0.207**	**-18**
P1	S1	0.147 (0.032)	0.162 (0.023)	
	S2	0.157 (0.032)	0.172 (0.021)	
	S3	0.218 $(0.022)_a$	0.190 (0.020)	
	S4	0.170 (0.032)	0.203 (0.037)	
	S5	0.192 (0.034)	0.188 (0.033)	
	S6	0.283 (0.031)	0.295 (0.048)	
	Mean	**0.195**	**0.242**	**-19**
% fertiliser effect[2]		**15**	**17**	

[1] % increase in the open over the shaded category; i.e. [(Open-Shaded)/Shaded].100

[2] % change of P1 over P0; i.e. [(P1-P0)/P0].100

Table 6.27: Summary of the ANOVA results of the effect of fertiliser (FERT) and types of soil (SOIL) on leaf nutrient contents of *Shorea acuminata*, separately under two light levels, 18 mo after the treatments were applied.

	Source of variance	df	F-value[1] N	P	Mg	Ca	K
Open							
	BLOCK	2	6.90 **	0.41 ns	0.64 ns	2.57 ns	0.42 ns
	FERT	1	0.01 ns	157.87 ***	9.59 **	37.06 ***	6.45 *
	SOIL	5	6.60 ***	0.87 ns	2.89 *	1.21 ns	4.28 **
	FERT*SOIL	5	1.12 ns	0.58 ns	0.80 ns	1.42 ns	1.37 ns
Shade							
	BLOCK	2	17.76 ***	1.72 ns	3.34 ns	0.39 ns	0.02 ns
	FERT	1	1.99 ns	136.45 ***	1.22 ns	2.47 ns	11.24 **
	SOIL	5	0.79 ns	5.47 ***	7.68 ***	1.48 ns	2.51 *
	FERT*SOIL	5	0.88 ns	4.59 **	2.93 *	0.94 ns	1.02 ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant

[1] Error df = 44 (Open); 54 (Shade)

of fertiliser only significantly affected the concentrations of P ($p<0.001$) and K ($p<0.01$) in the shade category. Types of soil were significantly affected the concentrations of N ($p<0.001$), K ($p<0.01$) and Mg ($p<0.05$) in the open, but in the shade, the soils highly significantly affected the concentrations of P and Mg ($p<0.001$) and K ($p<0.05$). There was no significant interaction between fertiliser and soil type on the nutrient concentration in the open, but there was on P ($p<0.01$) and on Mg ($p<0.05$) in the shade.

Regardless of fertiliser level, light effectively increased the foliar concentrations of P, Mg, Ca and K but reduced the concentration of N by 13 % (Table 6.28). The concentrations of N were lower in the seedlings potted in S3, of P lower in S5, of Mg lower in S2 and K was found significantly higher in seedlings potted in S2, left in the open category (Table 6.29). In the shaded category, the concentrations of P and Mg were found significantly higher in seedlings potted in soil S6 (nursery soil).

Correlations between total dry weight and foliar nutrient concentrations

As for *H. odorata*, total dry weight of *S. acuminata* seedlings was also negatively correlated with the foliar nutrient concentrations but varied with the different mineral elements for fertiliser and light levels (Table 6.30). In the open category, total dry weight of the non-fertilised seedlings was significantly and negatively correlated with K concentration ($p<0.01$) but the total dry weight of fertilised seedlings was significantly negatively correlated with the concentration of P ($p<0.05$). Significant correlations were found between P and N ($p<0.01$), and P and Mg ($p<0.05$) of non-fertilised seedlings in the open categories. However, negative correlations were found between Mg and N ($p<0.05$), and Mg and K ($p<0.05$) of fertilised seedlings. In the shade category, total dry weight of the fertilised seedlings was significantly negatively correlated with N ($p<0.05$) and with K ($p<0.05$) but positively correlated with Ca ($p<0.01$). However, weak correlation was shown between the total dry weight and foliar Ca ($p<0.05$) of non-fertilised in the shaded category. Positive correlations were shown between Mg and N ($p<0.05$) of non-fertilised seedlings and between Mg and N ($p<0.05$) and Mg and P ($p<0.01$) of fertilised seedlings in the shaded category.

Table 6.28: Effect of phosphorus fertiliser on the mean of foliar mineral nutrients concentrations (mg g^{-1} oven dry wt) of *Shore acuminata* seedlings, separately under two light levels, 18 mo after the treatments were applied (P1, +TSP; P0, control). Treatments within each light level for each variable were compared by LSD[1] test.

	Fertiliser level	N	P	Mg	Ca	K
Open						
	P0	12.55 *a*	1.07 *b*	1.74 *b*	8.78 *b*	8.49 *b*
	P1	13.06 *a*	5.13 *a*	2.18 *a*	15.59 *a*	10.12 *a*
	Mean	**12.81**	**3.1**	**1.96**	**12.19**	**9.46**
Shade						
	P0	14.40 *a*	1.20 *b*	1.76 *a*	9.81 *a*	7.22 *b*
	P1	15.18 *a*	2.70 *a*	1.87 *a*	11.43 *a*	8.28 *a*
	Mean	**14.79**	**1.95**	**1.82**	**10.62**	**7.75**
% light effect[2]		**-13**	**60**	**8**	**15**	**22**

[1] Means in each column with the *same small* letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded category; i.e. [(Open-Shaded)/Shaded].100

Table 6.29: Effect of types of soil on the mean of foliar mineral nutrient concentrations (mg g^{-1} oven dry wt) of *Shorea acuminata* seedlings, separately under two light levels, 18 mo after the treatments were applied. Treatments within each light level for each variable were compared by LSD[1] test.

	Soil	N	P	Mg	Ca	K
Open						
	S1	12.67 *bc*	2.96 *ab*	1.81 *ab*	13.28 *a*	8.23 *b*
	S2	15.16 *a*	3.24 *ab*	1.60 *b*	12.07 *a*	11.42 *a*
	S3	10.5 *d*	2.61 *ab*	2.17 *a*	11.49 *a*	8.91 *b*
	S4	14.03 *ab*	2.54 *ab*	1.78 *ab*	12.22 *a*	8.71 *b*
	S5	11.90 *cd*	2.36 *b*	2.12 *a*	11.47 *a*	9.50 *b*
	S6	11.60 *cd*	3.60 *a*	2.25 *a*	10.05 *a*	9.09 *b*
	Mean	**12.69**	**2.89**	**1.96**	**11.8**	**9.31**
Shade						
	S1	15.13 *a*	1.90 *b*	1.74 *b*	9.54 *b*	7.30 *b*
	S2	14.31 *a*	2.00 *b*	1.59 *b*	12.55 *a*	8.82 *a*
	S3	14.20 *a*	1.79 *b*	1.77 *b*	9.13 *b*	7.38 *b*
	S4	14.90 *a*	1.71 *b*	1.76 *b*	10.49 *ab*	7.81 *ab*
	S5	15.25 *a*	1.76 *b*	1.69 *b*	11.59 *ab*	7.92 *ab*
	S6	15.08 *a*	2.62 *a*	2.33 *a*	10.37 *ab*	7.36 *b*
	Mean	**14.81**	**1.96**	**1.81**	**10.61**	**7.77**
% light effect[2]		**-14**	**47**	**8**	**11**	**20**

[1] Means in each column with the same small letter are not significantly different at $p < 0.05$

[2] % increase in the open over the shaded category; i.e. [(Open-Shaded)/Shaded].100

Table 6.30: Correlation coefficient's Pearson between total dry weight (TDRY) and foliar mineral nutrient concentrations (mg g^{-1}) of *Shorea acuminata* seedlings of fertilised and non-fertilised under light levels, 18 mo after the treatments were applied.

Open condition

(a) Non-fertilised seedlings

(n=32)	TDRY	N	P	Mg	Ca
N	-0.10				
P	0.06	0.47 **			
Mg	0.02	0.10	0.42 *		
Ca	0.11	0.31	0.21	0.30	
K	-0.46**	0.10	0.14	0.00	-0.24

(b) Fertilised seedlings

(n=26)	TDRY	N	P	Mg	Ca
N	-0.14				
P	-0.39*	0.27			
Mg	-0.07	-0.38*	0.13		
Ca	0.17	0.00	0.19	0.33	
K	-0.30	0.48 *	0.46 *	-0.46*	-0.06

Shade condition

(a) Non-fertilised seedlings

(n=33)	TDRY	N	P	Mg	Ca
N	0.10				
P	0.20	-0.04			
Mg	-0.32	0.36 *	-0.18		
Ca	0.36 *	0.13	0.22	0.05	
K	-0.15	0.33	0.21	-0.23	0.02

(b) Fertilised seedlings

(n=35)	TDRY	N	P	Mg	Ca
N	-0.45*				
P	-0.30	0.06			
Mg	-0.22	0.35 *	0.50 **		
Ca	0.51 **	-0.25	0.14	0.17	
K	-0.45*	0.26	0.23	0.06	-0.21

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6.3.2 Comparison studies of *H.odorata* and *S. acuminata*

Total dry weight

Figure 6.3 shows that the total dry weight of *H.odorata* in the nursery greatly increased from 9 mo to 18 mo under high light level. Although there was an increment in growth under low light but the total dry weight of the seedlings was lower than under high light. A contrast response was shown in *S. acuminata*. There was little increment in the total dry weight of the seedlings between 9 mo to 18 mo under high light but better increment was found under low light level. The total dry weight of non-fertilised seedlings of *S. acuminata* was higher than the fertilised one.

Phosphorus and magnesium

The ratios of P and Mg of *H.odorata* were higher at high light level than at low ones for fertilised seedlings at 9 and 18 mo and non-fertilised seedlings at 9 mo, except that there was no clear response of unfertilised seedlings at 18 mo (Figure 6.4). The ratios of fertilised seedlings of *S. acuminata* were greatly reduced at low light level in either month of harvests but there was weak response to the light level for unfertilised seedlings. The concentrations of foliar P and Mg of fertilised seedlings of *S. acuminata* were found higher than the concentration in *H.odorata* under high light level.

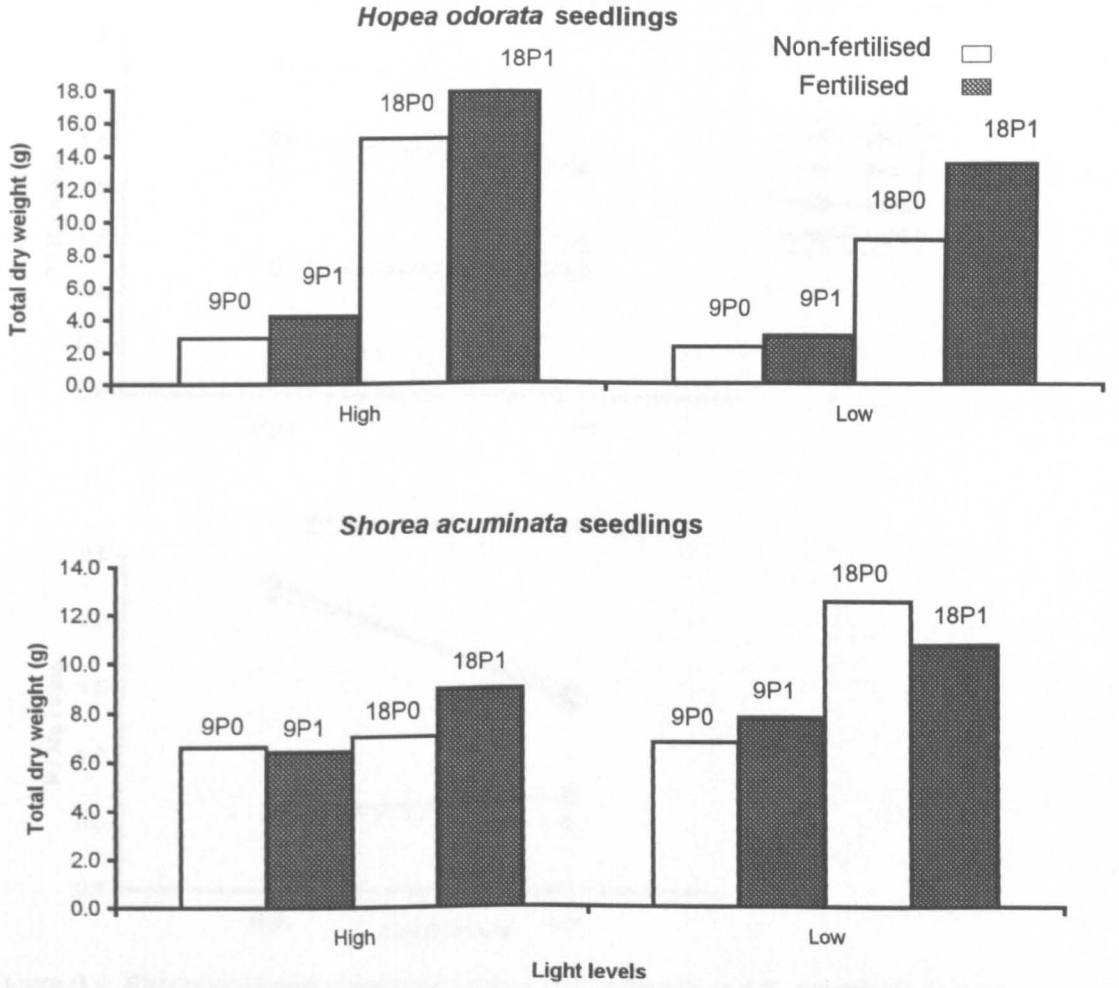


Figure 6.3: Comparison of total dry weights of *H. odorata* and *S. acuminata* seedlings at two different harvests (9 and 18 mo) and at two different fertiliser levels (P1, +TSP; P0, control) under two different light levels (High, open; Low, shade).

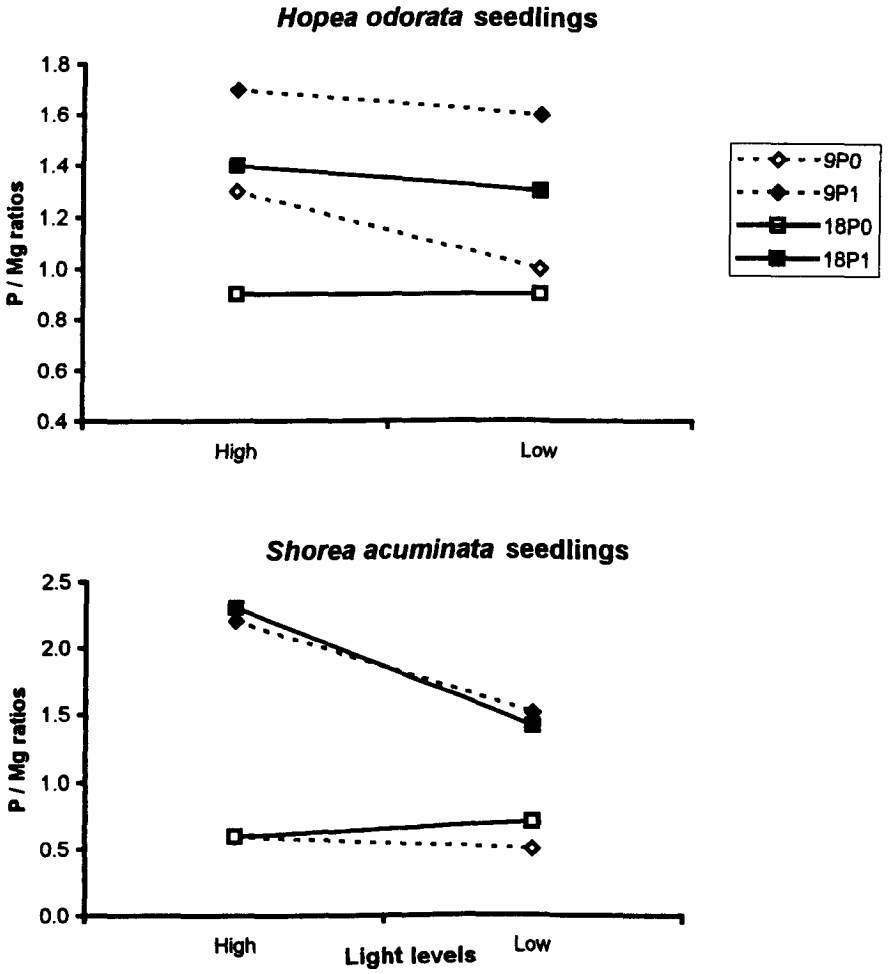


Figure 6.4: Phosphorus and magnesium ratios of *H. odorata* and *S. acuminata* leaves 9 mo after the treatments: non-fertilised (9P0); fertilised seedlings (9P1) 18 mo after the treatments: non-fertilised (18P0); fertilised seedlings (18P1).

6.4 DISCUSSION

6.4.1 Effect of fertiliser, light and soil on growth

Fertilising *H. odorata* seedlings significantly increased the growth under both light categories at 9 and 18 mo after the treatments were given. Of the growth parameters, TSP substantially increased the growth rate of roots when the seedlings were under higher light level but the light either reduced the number of nodes (13 %) and leaf area (9 %) or had no effects on the number of leaves. Although light improved the growth of *H. odorata* seedlings, the leaf area of the seedlings was larger in the shade than in the open. Fertilising *S. acuminata* had no marked effect on its growth except that the height growth at 9 mo was slightly improved and a similar effect was shown on the dry weight of roots at 18 mo in the open. As shown in Table 6.20, seedlings of *S. acuminata* grew in the open category had poor growth when compared to those in the shaded category except that light slightly increased the dry weight of roots.

Results from this study also support the observations on *H. odorata* in the field. This species can be grown in the open categories from an early age without any problem and this is also observed by others (Wan Razali & Ang 1991, Ang & Yusof Muda 1989, Aminah & Lokmal 1995). Studies on most of the *Shorea* species showed a tendency for shade to be needed in the early stages of growth i.e. *S. parvifolia* (Azman *et al.* 1991, Abd. Rahman Kassim *et al.* 1992), *S. trapezifolia* (Ashton & De Zoysa 1989), and *S. leptocladus* (Nicholson 1960). Study (this chapter) on the effect of light showed that *S. acuminata* needs partial shade (*c.* 16 % RLI) in early growth. Fertiliser studies on other pot-grown dipterocarp species showed that an application of NPK at a rate of 10 g per plant had no significant effect on the growth of *Shorea macroptera* Dyer seedlings 6 mo after the treatments were given (Turner *et al.* 1993). Sundralingam (1983), reported that application of NP (0.3 g N + 0.05 g P_2O_5) on pot-grown *D. oblongifolia* and *D. aromatica* showed greater improvements in seedling growth after 6 mo. Differences in response to fertilisers by the different dipterocarp species were not simply due to the amount and types of fertiliser added but probably a result of the appropriate level of light required by those different species.

Although types of soil did not significantly affect the growth of *H. odorata*, in general, the growth of seedlings potted in soils S2 and S3 was lower than those potted in other types of soil. The reduction of growth was probably due to the relatively poor inherent fertility and texture in these two soils (S2 & S3), as shown in Tables 6.13 & 6.15. Addition of TSP to the pot-grown seedlings significantly increased the concentration of P in all types of soil. The concentration of soil P increased 12-fold in the open category and 23-fold in the shaded category. Soil S2 (collected from subplot category B) had high percentages of silt and clay and relatively high fine sand contents, and perhaps because of high clay and high fine sand, the growth of the seedlings was much affected by the high water holding capacity (waterlogged). Type of soil had the greatest impact on the growth of *S. acuminata* in the open category. Soil S3 contained relatively little N, K, Mg and organic carbon compared with the other types of soil, and in general it gave the lowest mean of growth of *S. acuminata* seedlings.

6.4.2 Relationships between nutrients and growth of the seedlings

As observed in the field, pot-grown of *H. odorata* seedlings in open category in the nursery showed greater growth than the seedlings in the shade category. However, the concentration of leaf N in the open category was lower than that in the shade at both harvests. The total dry weight of seedlings in the open was more clearly negatively correlated with the concentrations of nutrients in the leaves than it was as in corresponding relationships in the shade. These results were likely to have been due to the "dilution effect", i.e. when seedlings receive enough light they grew faster and due to the accumulation of dry matter being faster than the rate of accumulation of nutrients, this results in lower leaf concentrations in the seedlings. This "effect" has also been observed by Steenbjerg (1951), Steenberg & Jakobsen (1963) and Jarrell & Beverly (1981).

The growth of *S. acuminata* seedlings exposed to the higher light category was greatly reduced compared with seedlings in the shaded category. In the open category, only N was lower in seedlings for both harvests but P, Mg, Ca and K were all higher at 18 mo. For *S. acuminata*, the dilution effect was shown for seedlings in the shade because of the relatively

faster growth in the shade than in the open. The total dry weight of fertilised seedlings was clearly negatively correlated with nutrient concentrations in the shaded category.

Addition of P consistently increased the foliar P concentrations of *H. odorata* and *S. acuminata* at 9 and 18 mo. Application of the TSP fertiliser also showed the same trend in increasing the foliar concentrations of Mg and Ca for both species in the open categories at both harvests but no consistent trend was shown for K. Addition of P did not affect the concentrations of N and K in leaves of *H. odorata* at either harvest. For *S. acuminata*, the addition of fertiliser only increased the concentrations of foliar N and K in the open at 9 mo. However, at 18 mo the seedlings responded to the P application by increasing the concentrations of K at both light levels but there was no response in the concentration of N. There is no clear explanation could be made on how P affect the changes in Mg, Ca and K concentrations. Further studies are needed to enable to answer these associations.

The study in this chapter showed that light either reduced or had no effect on the concentrations of Mg in the leaves of either species at both harvests. P, N and Mg are known for their importance in plant growth (Marschner 1995). With limited amounts of N and Mg in the potting media and with high growth rates in the open category, probably these two elements had begun to be exhausted by the seedlings. Further physiological studies are needed to test this idea. Although P is also important for growth, in this study there appears to have been no limitation of P of fertilised seedlings of *H. odorata* since it was provided by fertilising the seedlings with TSP. When P was added all the growth parameters and the concentration of P in leaves of fertilised seedlings significantly increased above that in the non-fertilised ones. However for the non-fertilised ones, the growth and the foliar P concentrations of *H. odorata* seedlings were significantly reduced (Tables 6.2, 6.5 & 6.7). This suggests that P was limiting the growth of this species. *S. acuminata*, a shade tolerant and ectomycorrhizal species, had different responses on P addition. Addition of P did not significantly affect all growth parameters of *S. acuminata*, except for dry weight of roots, although the concentration of P was significantly higher in the leaves. The growth of this species under these experimental categories, was apparently not limited by P availability

(Table 6.22). This was probably because ECM effectively relieved the seedlings of P limitation and/or the seedlings had a low demand of nutrients for growth.

6.4.3 Effect of the treatments on mycorrhizal infection

Studies by other workers had shown that fertilisation increases ectomycorrhizal infection but the infection was only correlated for unfertilised seedlings (Becker 1983, Lee & Lim 1989, Lee & Alexander 1994). Under this experimental category (this chapter), the infection of ectomycorrhizal in *H. odorata* was not significantly correlated with the total dry weight of the seedlings in either fertiliser level (Table 6.18). In other studies, ectomycorrhizal infection is reported to be often reduced by application of fertiliser (e.g. Richards & Wilson 1963, Dumbroff 1968, Lee & Lim 1989). The added of fertiliser in these studies was probably more than enough to enhance the growth of seedlings, and therefore the influence of ECM in facilitating the uptake of nutrients was less effective or the addition of P tended to reduce ECM infection (Lee Su See pers. comm.).

In this study, however, optimum amount of phosphorus fertiliser was added to the seedlings therefore it has not just significantly increased the P foliar (Tables 6.7 & 6.10) and increased the total dry weight of *H. odorata* seedlings at 9 and 18 mo in either light level (Figure 6.3) but it was also increased the ECM infection on the root tips of the seedlings. The root tips of fertilised seedlings in the shaded category had higher infections of ECM and the seedlings were also higher with the dry weight of leaves and the foliar P concentrations. This suggested that ECM improved the uptake of P and increased the dry weight of leaves in *H. odorata*. Similar findings have also been reported for *H. odorata* and *H. helferi* (Lee 1992, Lee & Alexander 1994). Assessment of ECM infection on *H. odorata* showed that light affected the existence of ECM by reducing the infection on the root tips and increasing the percentage of dead ECM. The growth of the seedlings under high light levels was increased due to high photosynthetic activity but this probably also increased the soil temperature and consequently caused the death of mycorrhizal fungus.

Seedling growth has been reported to respond more to mycorrhizal inoculation than to P addition (Harley & Smith 1983, Lee & Lim 1989, Alexander *et al.* 1992, Lee & Alexander 1994) but in this study there was no significant correlation between the percentage of ECM infection and the total dry weight of *H. odorata* seedlings. This was probably because the mean total dry weight was pooled from six types of soil (Table 6.18): thus it reduced the significant of the relationships. However, seedlings potted in soils S4 and S5 (from closed canopy categories) and S6 (nursery soil) had higher infection of ECM, and this was probably because these soils had higher indigenous ECM fungus populations compared to those soils from open and partial shade categories with no or less roots of trees due to the logging activities (Figures 6.1 & 6.2).

Although no assessment of ectomycorrhizas on *S. acuminata* was made in this study, studies on dipterocarps by other workers confirmed that *S. acuminata* is ectomycorrhizal (Lee & Lim 1989; Lee 1990a, b, 1992; Alexander *et al.* 1992).

CHAPTER 7: EFFECTS OF PHOSPHORUS AND MAGNESIUM USING SAND CULTURE EXPERIMENTS

7.1 INTRODUCTION

Two experiments were carried out in a shade house at the FRIM nursery. The species used was *Hopea odorata* for both experiments. Seeds were collected from trees growing in the FRIM compound in different fruiting seasons. The sand culture method was employed to study the effect of phosphorus and magnesium concentrations on the growth of seedlings and to study whether there was any effect of a combination of these nutrients on seedling growth. Mg was chosen as a treatment in view of the work of Baillie *et al.* (1987) who suggested that it was an important element in dipterocarp distribution. Based on the results, the optimum concentration of nutrients required by this dipterocarp species and whether P and Mg availabilities limit the dipterocarp seedling growth, will be discussed.

7.2 MATERIALS AND METHODS

7.2.1 Experiment I - The effect of phosphorus on growth of *Hopea odorata*

Fifty plastic pots of 20 cm height and 18 cm diameter were used. Each had three 1 cm diameter holes at the bottom. A piece of green-netting with 1 mm mesh was placed at the base of each pot to prevent sand from being lost during watering. A plastic saucer was placed under each pot for collecting the excess of nutrient solution. River sand was used as the potting medium. The sand was treated to remove debris, clay and organic matter by thoroughly washing it with tap water until the supernatant was clear. The sand was then rinsed with distilled water.

The experiment was carried out in the shade house with benches. The shade material was a thick clear plastic and the light under it was determined at the beginning of the experiment, 1

May 1992. The relative light intensity (RLI; see General Methods, Chapter 4.2) in the middle of the shade house was 5.3 % and at the side was 9.3 %. Therefore, the pots were rearranged within the block every fortnight to ensure that the seedlings received overall an equal illumination throughout the period of experiment.

The experiment was conducted in a randomised block design with the P (5 concentrations) as a factor. The treatments were repeated in the five blocks. The seedlings were allocated at random to the treatments within each block. The total number of seedlings used was: 5 P concentrations x 5 blocks x 2 harvests = 50 .

The nutrient solutions were prepared based on the complete nutrient solution of Long Ashton formula used by Hewitt (Hewitt & Smith 1975), as shown in Appendix 7.1. The five different concentrations of P were: 1P (41.37 mg l^{-1}), 0.5P (20.68 mg l^{-1}), 0.2P (8.27 mg l^{-1}), 0.1P (4.14 mg l^{-1}) and 0.05P (2.07 mg l^{-1}).

Seeds of *Hopea odorata* were collected from the FRIM grounds on 18 November 1991, and were sown in the nursery on 20 November 1991. On 19 April 1992, at age 5 mo, 50 seedlings of similar size (6-9 cm in height and with 4-5 leaves), were selected and transplanted into pots of washed sand. To avoid the shock of chemical solutions, the seedlings were given 200 ml of distilled water per pot for the first week. The seedlings were then watered twice a week with the five nutrient solutions which had different concentrations of P (200 ml per pot). When there was any remaining liquid in the plastic saucers, it was discarded before applying a fresh solution to the seedlings. The seedlings were flushed out with distilled water (200 ml per pot) at the end of each week. This was to ensure that the seedlings were accurately supplied with only the fresh solutions every week.

The measurements of growths, (height, stem diameter, total number of leaves and total number of nodes were recorded for each plant), were recorded at 6 mo intervals, 6 and 12 mo after potting (November 1992 and May 1993). The dry weights of the seedlings were

determined by oven-drying the leaves, stem and roots separately as described in the General Methods (Chapter 4.3). Foliar analysis was also conducted as described in the General Methods (Chapter 4.6).

7.2.2 Experiment II - The effect of different concentrations of phosphorus and magnesium on growth of *Hopea odorata*

The second experiment on nutrient uptake using the sand culture method was started on 15 October 1993, in the same shade house which was used for Experiment I. The relative light intensity was also determined at the beginning of the experiment, 20 October 1993 as in Experiment I. However, the RLI in the middle of the shade house was slightly lower than from the reading in Experiment I, 4-5 % and at the side of the house was 8-9 %. This was due to the changes in colour of the plastic roofing (becoming slightly darker) after 1 y. Experiment II was also conducted as a randomised block design with P (3 concentrations) and Mg (3 concentrations) as the two factors. The treatments were repeated in five blocks. The seedlings were allocated at random to treatments within the block. The total number of seedlings used in the experiment was: 3 P concentrations x 3 Mg concentrations x 5 blocks x 2 replicates x 2 harvests =180.

180 seedlings of *H. odorata*, similar in size (10-12 cm in height and with 5-6 leaves), were chosen for the experiment. Age of the seedlings at potting was 8 mo. The materials used were the same as Experiment I and the sand and nutrient solution preparation was done in a similar manner. Based on the results of experiment I, three concentrations of P were chosen; 0.01P, 0.1P and 1P and three concentrations of Mg were used; 0.01Mg, 0.1Mg and 1Mg. The seedlings were treated with nine solutions of different combinations of the concentrations of P and Mg:

T1=(0.01P +1Mg),	T4=(0.1P+1Mg),	T7=(1P+1Mg)
T2=(0.01P+0.1Mg),	T5=(0.1P+0.1Mg),	T8=(1P+0.1Mg)
T3=(0.01P+0.01Mg),	T6=(0.1P+0.01Mg),	T9=(1P+0.01Mg)

The concentrations of the elements used for each level of the nutrients are shown in Table 7.1. The volume of nutrient solutions and the way of watering employed were the same as in Experiment I. The same growth parameters were recorded too. The seedlings were harvested at 6 mo intervals, on 30 March and on 30 September 1994. Foliar analyses were carried out as similar as in Experiment I.

Table 7.1: Concentrations of P and Mg used in the Experiment II.

Concentrations	P ($Na_2HPO_4.7H_2O$)		Mg ($MgSO_4.7H_2O$)	
	$g\ l^{-1}$	$mg\ l^{-1}$	$g\ l^{-1}$	$mg\ l^{-1}$
0.01	0.0036	0.414	0.0037	0.363
0.1	0.036	4.137	0.037	3.63
1	0.358	41.365	0.368	36.300

7.2.3 Data analysis

For Experiment I, one-way analysis of variance (ANOVA) was carried out to determine whether the growth and the nutrient concentrations of the seedlings were affected by the application of different concentrations of P (Appendix 7.2). A two-way analysis of variance was carried out for Experiment II to determine whether the effect of P and Mg concentrations affected the growth and the concentrations of nutrients (Appendix 7.3). When factors were significant ($p<0.05$) the least significant difference (LSD) multiple comparison, based on the t-test, was carried out. The analyses of the data (growth parameters and nutrients) were made on the surviving seedlings (some seedlings died because of the treatments effects), thus, the analysis of variance using SAS GLM procedure was carried out (SAS System for Linear Models 1993). For comparison of growths, dry weights and nutrient concentrations between the two harvests, the percentage changes in the means were calculated (Evans 1972).

7.3 RESULTS

7.3.1 Experiment I - Effect of phosphorus

Growth and nutrient

Although *H. odorata* is an ectomycorrhizal species but in this sand culture experiment there was no ECM infection observed on the root tips of the seedlings at 6 and 12 mo. This was probably of no mycorrhizal fungus was existed in the washed sand. The effect of P was not significant on the non-destructive measurements of growth and on the dry weights of *H. odorata* seedlings after 6 and 12 mo (Tables 7.2 & 7.4) nor on the foliar macronutrients concentrations. Although no significant differences were seen on the effect of the treatments, the percentage change in growth showed that the seedlings grew substantially between 6 and 12 mo (Table 7.3). The changes in nutrient concentrations in the leaves varied with the elements. N and K concentrations increased by 13 % and 25 %, respectively, between 6 and 12 mo. Though the concentrations of P fell by 24 %, Mg by 9 % and Ca fell by 10 % in that period (Table 7.5).

7.3.2 Experiment II - Effect of phosphorus and magnesium

Growth

As in Experiment I, none of the root tips exhibited infection by ECM after 6 and 12 mo. The effect of P was not significant on any of the growth parameters of *Hopea odorata* seedlings after 6 and 12 mo but Mg significantly affected the number of leaves after 6 mo, though not at 12 mo. The interaction between P and Mg significantly affected the stem diameter ($p<0.01$) after 6 mo but the interaction only significantly affected the dry weight of roots after 12 mo (Table 7.6, $p<0.001$). Due to the fixed block positions under the shading, the block effect highly significantly affected on the growth of the seedlings at the first harvest (6 mo).

The trends in the growth of *H. odorata* seedlings due to the effects of P and Mg concentrations at 6 mo was not clearly seen (Table 7.7). However, there was a marked trend in the growth at 12

Table 7.2: Summary of the ANOVA results on the effect of phosphorus level (PHOS) in sand culture on the mean growths and dry weight of *Hopea odorata* seedlings after 6 mo and 12 mo.

	Source of variance	df	F-value[1] No. of leaves	Leaf area (cm^2)	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
6 mo									
	BLOCK	4	0.87 ns	4.73 *	2.32 ns	4.19 *	2.25 ns	3.83 ns	2.63 ns
	PHOS	4	0.13 ns	1.20 ns	1.30 ns	2.54 ns	0.69 ns	1.73 ns	1.14 ns
12 mo									
	BLOCK	4	0.49 ns	0.47 ns	0.52 ns	0.47 ns	0.47 ns	0.39 ns	1.73 ns
	PHOS	4	0.07 ns	0.40 ns	1.35 ns	1.57 ns	0.49 ns	2.09 ns	0.62 ns

* $p<0.05$; ns = not significant

[1] Error df = 14 (6 mo); 14,15 (12 mo)

Table 7.3: Effect of phosphorus level in sand culture on the mean growths and dry weights of *Hopea odorata* seedlings after 6 mo and 12 mo.

	Phosphorus level	No. of leaves	Leaf area (cm^2)	Height (cm)	Diameter (mm)	Dry weight (g) of leaves	stem	roots
6 mo								
	0.05 P	19	127	21.4	2.31	0.95	0.29	0.27
	0.1 P	20	98	17.9	2.29	0.75	0.23	0.22
	0.2 P	20	138	21.3	2.79	0.84	0.32	0.27
	0.5 P	18	145	20.3	2.66	0.92	0.37	0.33
	1P	21	177	23.8	2.60	1.07	0.41	0.29
	Mean	**20**	**137**	**20.9**	**2.53**	**0.91**	**0.32**	**0.28**
12 mo								
	0.05 P	47	680	28.9	4.61	3.10	1.92	1.91
	0.1 P	47	740	34.3	5.23	3.90	3.07	1.97
	0.2 P	49	735	37.7	4.81	3.87	2.75	1.48
	0.5 P	51	682	36.4	5.71	3.94	3.84	2.27
	1P	52	893	35.3	5.45	4.59	3.16	2.07
	Mean	**49**	**746**	**34.5**	**5.16**	**3.88**	**2.95**	**1.94**
% harvest effect[1]		**145**	**445**	**65**	**104**	**326**	**822**	**593**

[1] % change between harvests; [(12 mo - 6 mo)/6 mo].100

Table 7.4: Summary of the ANOVA results on the effect of phosphorus concentrations (PHOS) in sand culture on the foliar nutrient concentrations of *Hopea odorata* seedlings after 6 mo and 12 mo.

	Source of variance	df	F-value[1] N	P	Mg	Ca	K
6 mo							
	BLOCK	4	0.22 ns	0.62 ns	1.06 ns	1.88 ns	0.92 ns
	PHOS	4	0.45 ns	0.69 ns	0.77 ns	2.40 ns	1.24 ns
12 mo							
	BLOCK	4	1.57 ns	29.49 ***	3.25 ns	0.44 ns	0.37 ns
	PHOS	4	1.95 ns	0.42 ns	0.88 ns	2.64 ns	1.02 ns

*** $p < 0.001$; ns = not significant

[1] Error df = 14 (6 mo); 14,15 (12 mo)

Table 7.5: Effect of phosphorus level in sand culture on the mineral nutrient concentrations of *Hopea odorata* seedlings after 6 mo and 12 mo. Treatments within month of harvest for each variable were compared by LSD[1] test.

Phosphorus level	(mg g^{-1} oven dry weight) N	P	Mg	Ca	K
6 mo					
0.05 P	24.14 *a*	1.55 *a*	1.55 *a*	4.75 *ab*	11.04 *a*
0.1 P	23.73 *a*	1.61 *a*	1.54 *a*	4.36 *b*	12.50 *a*
0.2 P	24.51 *a*	1.72 *a*	1.63 *a*	5.49 *a*	11.94 *a*
0.5 P	24.92 *a*	1.74 *a*	1.52 *a*	4.71 *ab*	14.11 *a*
1P	24.36 *a*	1.71 *a*	1.44 *a*	4.85 *ab*	12.00 *a*
Mean	**24.33**	**1.67**	**1.54**	**4.83**	**12.32**
12 mo					
0.05 P	27.88 *ab*	1.24 *a*	1.28 *a*	3.86 *b*	15.38 *a*
0.1 P	26.67 *ab*	1.27 *a*	1.45 *a*	4.10 *b*	14.49 *a*
0.2 P	27.18 *ab*	1.29 *a*	1.43 *a*	4.69 *ab*	16.05 *a*
0.5 P	29.33 *a*	1.31 *a*	1.35 *a*	5.09 *a*	16.64 a
1P	25.86 *b*	1.22 *a*	1.50 *a*	4.13 *b*	14.45 *a*
Mean	**27.39**	**1.27**	**1.40**	**4.37**	**15.40**
% harvest change[2]	**13**	**-24**	**-9**	**-10**	**25**

[1] means in each column with the same small letters are not significantly different at $p < 0.05$

[2] change from 6 mo to 12 mo; [(12 mo - 6 mo)/6 mo].100

Table 7.6: Summary of the ANOVA results of the effect of phosphorus (PHOS) and magnesium (MAGN) on the growth and the dry weight of *Hopea odorata* seedlings after 6 mo and 12 mo.

	Source of variance	df	F-value[1] No. of leaves	Leaf area (cm^2)	Height (cm)	Diameter (mm)	Oven dry weight (g) of leaves	stem	roots	Root:Shoot ratio
6 mo										
	BLOCK	4	5.23 ***	1.77 ns	15.08 ***	6.06 ***	4.94 **	12.17 ***	3.03 *	5.05 **
	PHOS	2	2.44 ns	2.71 ns	0.39 ns	0.69 ns	0.70 ns	1.42 ns	0.13 ns	1.81 ns
	MAGN	2	5.08 **	0.25 ns	0.39 ns	0.32 ns	0.29 ns	0.41 ns	2.65 ns	3.30 *
	PHOS*MAGN	4	0.93 ns	1.11 ns	1.43 ns	3.96 **	1.87 ns	1.70 ns	1.78 ns	0.12 ns
12 mo										
	BLOCK	4	1.27 ns	0.30 ns	0.79 ns	4.71 **	1.07 ns	3.73 **	1.71 ns	0.70 ns
	PHOS	2	0.89 ns	0.19 ns	1.37 ns	0.68 ns	0.02 ns	0.08 ns	0.94 ns	1.05 ns
	MAGN	2	2.34 ns	1.58 ns	0.36 ns	0.35 ns	0.91 ns	0.23 ns	3.05 ns	0.16 ns
	PHOS*MAGN	4	0.97 ns	1.36 ns	1.05 ns	1.18 ns	1.14 ns	2.01 ns	6.07 ***	2.00 ns

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns = not significant

[1] Error df = 77 (6 mo); 66 (12 mo)

Table 7.7: Effect of phosphorus and magnesium on the growth and dry weight of *Hopea odorata* seedlings after 6 and 12 mo.

	Treatment	P level	Mg level	No. of leaves	Leaf area (cm^2)	Height (cm)	Diameter (mm)	Dry weight (g) per plant			Root:Shoot ratio
								leaves	stem	roots	
6 mo	T1	0.01P	1Mg	10	341	12.3	1.99	0.20	0.09	0.15	0.63
	T2	0.01P	0.1Mg	9	310	13.0	1.93	0.17	0.11	0.18	0.66
	T3	0.01P	0.01Mg	9	260	11.8	1.71	0.13	0.08	0.15	0.80
	T4	0.1P	1Mg	10	352	12.5	1.70	0.16	0.09	0.11	0.49
	T5	0.1P	0.1Mg	9	382	12.1	1.88	0.19	0.10	0.17	0.60
	T6	0.1P	0.01Mg	9	443	13.1	1.92	0.23	0.10	0.20	0.69
	T7	1P	1Mg	10	390	13.2	2.02	0.21	0.10	0.15	0.54
	T8	1P	0.1Mg	9	312	11.9	1.76	0.16	0.10	0.13	0.56
	T9	1P	0.01Mg	7	351	13.5	1.96	0.17	0.12	0.19	0.66
12 mo	T1	0.01P	1Mg	26	241	20.3	2.92	1.00	0.47	0.45	0.34
	T2	0.01P	0.1Mg	19	176	18.9	2.55	0.70	0.33	0.27	0.27
	T3	0.01P	0.01Mg	18	119	18.0	2.75	0.64	0.29	0.22	0.29
	T4	0.1P	1Mg	18	167	19.1	2.46	0.66	0.29	0.20	0.23
	T5	0.1P	0.1Mg	16	179	20.8	2.48	0.78	0.39	0.29	0.28
	T6	0.1P	0.01Mg	20	199	21.2	2.81	0.81	0.43	0.32	0.31
	T7	1P	1Mg	22	224	21.6	2.70	0.90	0.40	0.34	0.29
	T8	1P	0.1Mg	17	207	21.2	2.80	0.77	0.40	0.32	0.29
	T9	1P	0.01Mg	19	160	19.5	2.69	0.67	0.35	0.21	0.21

Arrows show the gradient of increasing response in dry weights, and root and shoot ratio.

mo. The interactions of 1P and 1Mg, and 0.01P and 1Mg, had the highest means of all growth variables and also the highest means of the dry weights of seedlings, whilst the combination of 0.1P and 1Mg, had the lowest mean of seedling growth.

Nutrients

After 6 mo, P concentrations highly significantly affected the concentrations of foliar P, Mg and Ca ($p<0.001$) and the concentration of K at $p<0.05$ of *H. odorata* (Table 7.8). The higher the concentration of P in solution, the higher the concentration of P in leaves was detected (Table 7.9). However, the response of foliar Mg and Ca concentrations to P addition was in contrast to that for P. When full strength of P was applied, the concentrations of Mg and Ca were significantly reduced in the leaves. However, no significant differences were shown in the concentrations of N with different concentrations of P in solution. The concentrations of Mg significantly affected the concentrations of Mg and Ca in leaves. The higher the concentration of Mg in the solution, the higher the concentration of Mg in leaves but it significantly reduced the concentration of Ca. No significant differences were shown for N, P and K due to the effect of Mg level in solution. The P and Mg interaction was not significant for any of the leaf nutrient concentrations at 6 mo (Table 7.8).

After 12 mo, the higher the P in the culture solution, the higher the concentration of P that was detected in the leaves ($p<0.001$), but the concentration of Ca in the leaves was again reduced (Table 7.9, $p<0.05$). No significant differences were shown for N, Mg and K by the effect of P level in the solution. When full strength Mg solution was applied, it significantly increased the concentration of Mg in the leaves ($p<0.001$). A similar trend was seen for the effect of Mg on Ca concentration as shown at 6 mo: the higher the Mg in solution, the lower the concentration of Ca in the leaves. There were no significant interactions between P and Mg at 12 mo either (Table 7.8). Seedlings of *H. odorata* received full strength of Mg did not respond in increasing the total dry weight of seedlings to the increment of concentrations of P (Figure 7.1). Seedlings received full strength of P, however, responded to the increment of Mg by increasing the total

Table 7.8: Summary of the ANOVA results of the effect of phosphorus (PHOS) and magnesium (MAGN) on the leaf nutrient concentrations of *Hopea odorata* seedlings, after 6 mo and 12 mo.

	Source of variance	df	F-value[1] N	P	Mg	Ca	K
6 mo							
	BLOCK	4	10.83 ***	1.22 ns	1.22 ns	1.54 ns	4.46 **
	PHOS	2	2.38 ns	89.54 ***	12.25 ***	12.13 ***	5.08 **
	MAGN	2	0.45 ns	0.74 ns	97.71 ***	15.48 ***	0.83 ns
	PHOS*MAGN	4	0.72 ns	0.25 ns	1.48 ns	0.34 ns	1.53 ns
12 mo							
	BLOCK	4	3.15 *	1.02 ns	0.94 ns	0.79 ns	0.74 ns
	PHOS	2	0.96 ns	8.12 ***	2.28 ns	3.54 *	0.66 ns
	MAGN	2	0.67 ns	0.80 ns	31.00 ***	7.41 **	2.36 ns
	PHOS*MAGN	4	0.55 ns	1.09 ns	1.31 ns	0.52 ns	0.79 ns

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns = not significant

[1] Error df = 77 (6 mo); 65,66 (12 mo)

Table 7.9: Effect of phosphorus and magnesium levels in sand culture on the leaf nutrient concentrations of *Hopea odorata* seedlings, after 6 mo and 12 mo. Treatments within month of harvest for each variable were compared by LSD[1] test.

	Nutrient solution	(mg g^{-1} oven dry weight)				
		N	P	Mg	Ca	K
6 mo						
	0.01P	25.74 *b*	1.20 *c*	1.85 *a*	10.61 *a*	9.79 *b*
	0.1P	27.81 *a*	1.51 *b*	1.94 *a*	9.15 *b*	10.77 *a*
	1P	27.06 *ab*	2.04 *a*	1.50 *b*	8.09 *c*	10.82 *a*
	0.01Mg	27.31 *a*	1.57 *a*	1.29 *b*	10.55 *a*	10.71 *a*
	0.1Mg	26.41 *a*	1.55 *a*	1.48 *b*	9.57 *a*	10.44 *a*
	1Mg	26.89 *a*	1.63 *a*	2.52 *a*	7.74 *b*	10.24 *a*
12 mo						
	0.01P	26.84 *a*	1.43 *c*	1.44 *ab*	6.93 *a*	12.90 *a*
	0.1P	28.29 *a*	1.56 *b*	1.46 *a*	6.25 *ab*	12.61 *a*
	1P	27.91 *a*	1.68 *a*	1.29 *b*	5.86 *b*	13.23 *a*
	0.01Mg	27.92 *a*	1.58 *a*	1.00 *b*	7.35 *a*	13.64 *a*
	0.1Mg	28.11 *a*	1.57 *a*	1.60 *a*	6.07 *b*	12.51 *a*
	1Mg	27.06 *a*	1.51 *a*	1.55 *a*	5.81 *b*	12.63 *a*

[1]Means in each column with the same small letters are not significantly different at $p < 0.05$

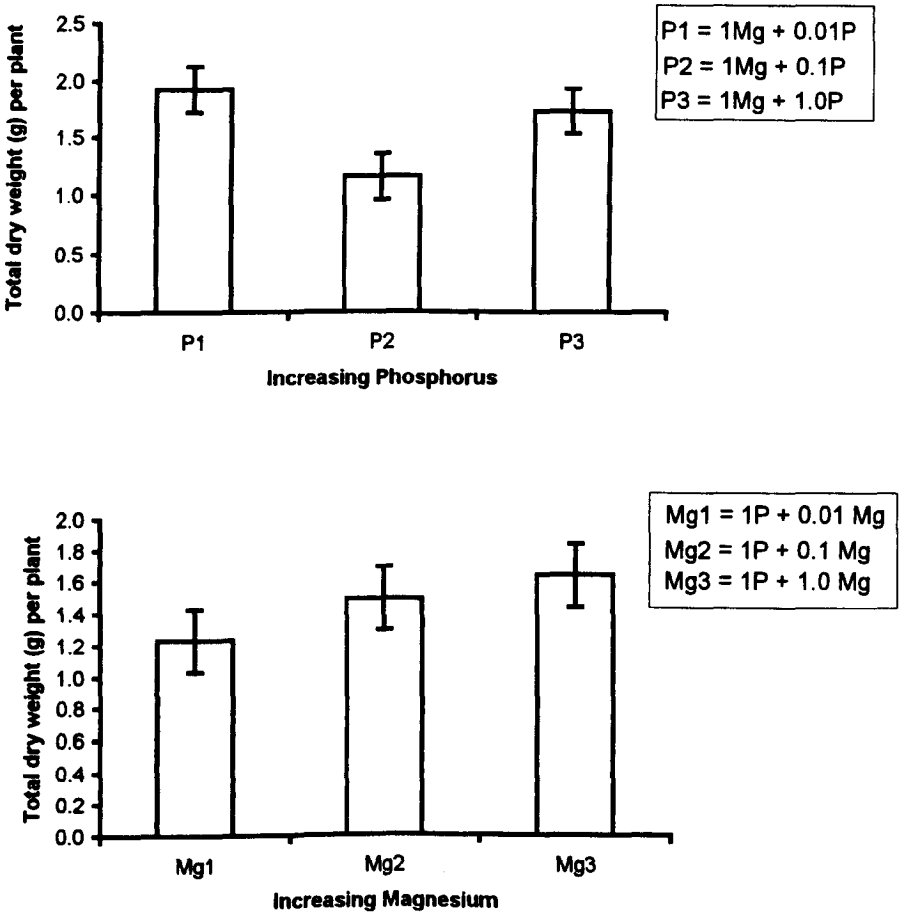


Figure 7.1: The effect of P and Mg addition in the culture solutions on the total dry weight of *Hopea odorata* seedlings 12 mo after the treatments were given. Bars represent standard errors of the mean (n=10).

dry weight of the seedlings. When the culture solution had lowest P (0.01P), the gradients of seedling growth was followed with increasing of Mg concentrations. However, when the concentration of P was 0.1P, the gradients of the growths of seedlings were contradicted to the above: the lower the Mg in the culture the higher the growths of the seedlings. Increasing the concentrations of P in the culture solution led to increasing the concentrations of P and K but decreasing the concentrations of Mg and Ca in leaves. Increased the concentrations of Mg in the culture solution was also resulted with higher Mg in leaf tissues and reduced the concentrations of Ca but had no effect on foliar P.

7.3.3 Comparison studies between Experiments I and II

The comparison of the dry weights of seedlings between experiments I and II was shown in Figure 7.2. The seedlings compared from these experiments were treated with the same level of P. However, the dry weights of leaves, stem and roots for both harvests (6 and 12 mo) in Experiment I were substantially higher than the dry weights of those in Experiment II, regardless the level of P in the culture solution. Figure 7.3 shows that the concentration of foliar P recorded from seedlings in the solution with 1P level for Experiment II was higher than in Experiment I after 6 and 12 mo. No clear pattern was shown for Mg concentrations in leaves at the two P concentrations in either experiment. Examining combinations of two elements, P and Mg, showed that the total dry weight of seedlings was better in solution with higher Mg (1Mg) and lower P (0.01P) but was lower in higher P (1P) and lower Mg (0.01Mg), 12 mo after the treatments were began (Figure 7.3).

7.3.4 Nutrient deficiency symptoms

The descriptions on visual symptoms of leaf of Experiment were done prior to harvest (5 mo and 11.5 mo). Young and old leaves of the seedlings exhibited symptoms of some nutrient deficiency or imbalance to a different extent dependence on the type of treatments. The details

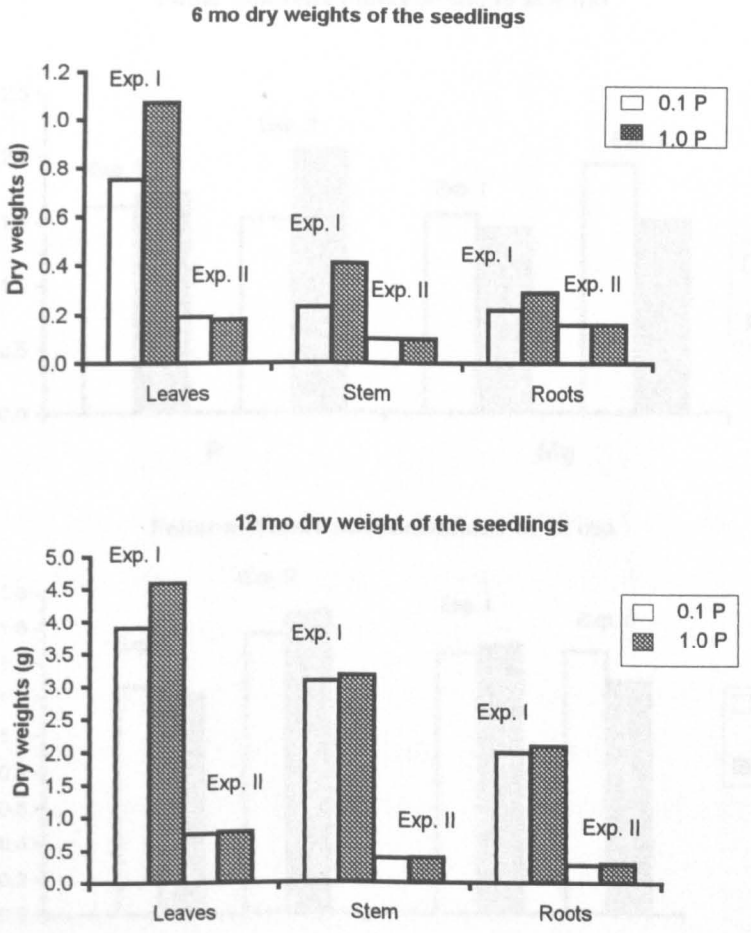


Figure 7.2: Comparison of dry weights of the seedlings at 6 mo and 12 mo between Experiments I and II at two levels of phosphorus.

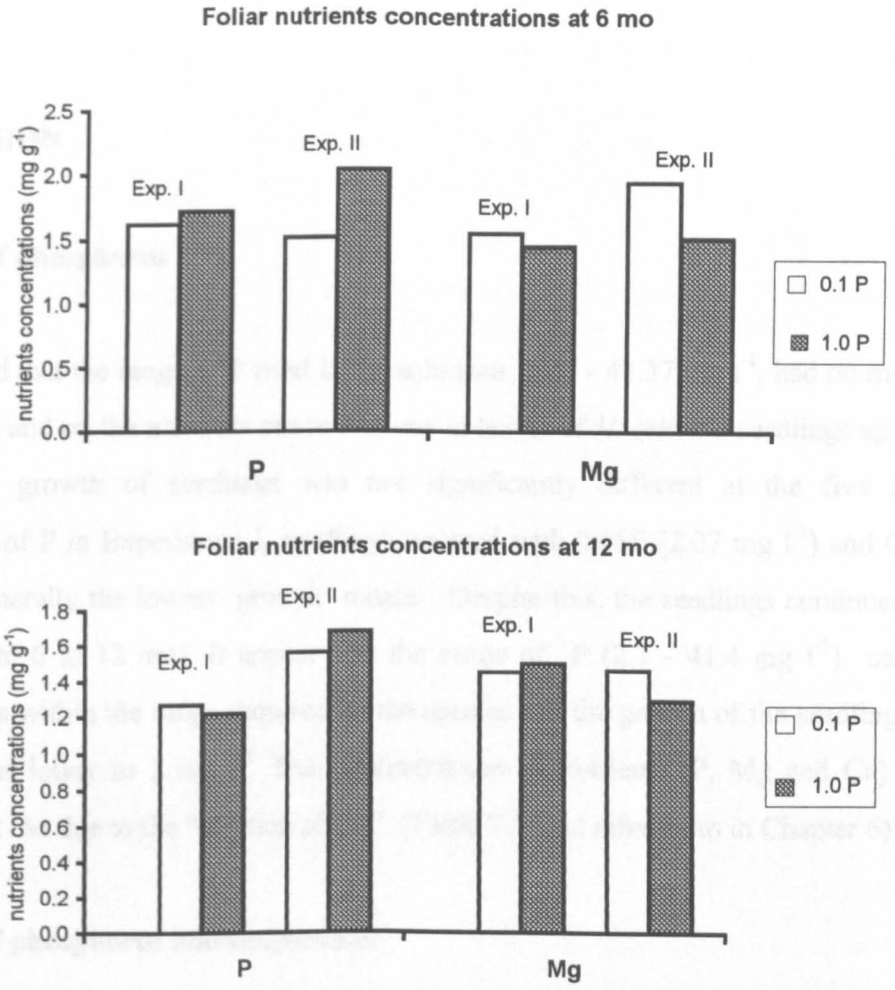


Figure 7.3: Comparison of foliar nutrients concentrations of the seedlings at 6 mo and 12 mo between Experiments I and II at two levels of phosphorus.

of the symptoms due to the treatments were described in Table 7.10. In all treatments, the symptoms of old leaves were more severe than of young ones. Treatment T3 (0.01P + 0.01Mg) showed a very severe symptoms and greatly reduced the growth of the seedlings. P and Mg deficiency (T3 = 0.01P + 0.01Mg) had led to an increase in the ratio of roots to shoots (Table 7.7) at 6 mo, however, the ratio was not so strong at 12 mo.

7.4 DISCUSSION

7.4.1 Effect of phosphorus

Results showed that the range of P used in the solutions, 2.07 - 41.37 mg l^{-1}, had no major effect on the growths and on the nutrients concentrations in leaves of *H. odorata* seedlings up to 12 mo. Although, the growth of seedlings was not significantly different at the five different concentrations of P in Experiment I, seedlings watered with 0.05P (2.07 mg l^{-1}) and 0.1P (4.14 mg l^{-1}) had generally the lowest growth means. Despite this, the seedlings continued to grow over time (from 6 to 12 mo). It appear that the range of P (2.1 - 41.4 mg l^{-1}) used in this experiment was within the range required by the species and the growth of the seedlings was not limited by P as lower as 2 mg l^{-1} The concentrations of nutrients (P, Mg and Ca) in leaves decreased at 12 mo due to the "dilution effect" (Table 7.5; and referred to in Chapter 6).

7.4.2 Effect of phosphorus and magnesium

Since no consistent trends were seen at 6 mo on the growth and the dry weight of the seedlings, no conclusion can be made on the effect of P and Mg combinations. Results at 12 mo showed that the higher the combination of P and Mg the higher the growth and the dry weight of seedlings. Results in Experiment II showed that when the seedlings received full strength of P, it increased the total dry weight of seedlings but reduced the concentrations of foliar Mg and

Table 7.10: Symptoms of phosphorus and magnesium levels in sand culture on the growth of *H. odorata* seedlings at 5 mo and 11.5 mo after the treatments were given.

Month	Treatments	Visual symptoms
5	T1 = 0.01P + 1Mg	Young leaves green and broad but old leaves with blotches and chlorotic spots scattered on the surface.
	T2 = 0.01P + 0.1Mg	Young leaves green and with broader leaves. Old leaves with serious blotches and chlorotic areas on the surface.
	T3 = 0.01P + 0.01Mg	Young leaves green but old leaves with chlorotic areas on the surface and a mass of minute orange spots.
	T4 = 0.1P + 1Mg	Young leaves broad and green in colour but a few showed chlorosis. Old leaves with yellow spots scattered on the surface.
	T5 = 0.1P + 0.1Mg	Seedlings looked hardy with green and broad young leaves but a few were slightly yellowish. Old leaves showed chlorotic areas and developed to necrotic (dead tissues).
	T6 = 0.1P + 0.01Mg	Young leaves green but old leaves seriously chlorotic and progressively developed to necrotic.
	T7 = 1P + 1Mg	Young leaves broad and green but older leaves yellowish and some had very seriously chlorotic areas on the leaf surface.
	T8 = 1P + 0.1Mg	Young leaves green in colour but some with slightly yellowish along the main veins. Old leaves appeared as blotches on the leaf surface and tips with dieback.
	T9 = 1P + 0.01Mg	The seedlings with hardy look and with dark green young leaves but a few tips had dieback. Old leaves with yellowish and brownish spots scattered on he surface and some tips with dieback.

Table 7.10 (cont.)

Month	Treatments	Visual symptoms
11.5	T1 = 0.01P + 1Mg	Seedlings looked healthy and hardy with broad and green leaves. A few young and old leaves showing yellowish spots and brownish on the main veins.
	T2 = 0.01P + 0.1Mg	Seedlings with medium size and with medium size of leaf. Young leaves with blotches on the main vein but old leaves looked green.
	T3 = 0.01P + 0.01Mg	Seedlings size were small and with smaller size of leaves. Half of the seedlings dried and died. The symptoms were more severe and greatly reduced the growth of the seedlings which consequently died of the deficiencies.
	T4 = 0.1P + 1Mg	Seedlings looked healthy with medium height and with medium size of leaf. Bleaching was shown on a few young and middle leaves.
	T5 = 0.1P + 0.1Mg	Seedlings with a healthy look medium size with medium size of leaves. Young leaves with bleaching. Old leaves seriously blotched and brown spots scattered on the surface.
	T6 = 0.1P + 0.01Mg	Seedlings looked healthy with broad and dark green leaves. Blotches were shown on the middle leaves but not so serious.
	T7 = 1P + 1Mg	Medium size of seedlings with healthy look and with large and dark green colour. Young and middle leaves had blotches along the main vein but not so serious.
	T8 = 1P + 0.1Mg	Healthy looking seedlings with medium size of height and medium size of leaves. Young leaves with blotches but dark green old leaves.
	T9 = 1P + 0.01Mg	Seedling size moderate to small with small leaves but. Young and old leaves with chlorosis symptoms. 75 % of the total leaves showing chlorotic tissues.

Ca. This was probably because when P increased, the growth of the seedlings was stimulated and at the same time it reduced the concentrations of other elements due to the dilution effect. In other cases when the seedlings received full strength P, the total dry weight of the seedlings increased with increasing level of Mg in the solution. It appeared that the growth of seedlings was not only limited by P but also by Mg.

7.4.3 Relationships between growth and nutrient

Growth of the seedlings in Experiment I was far greater than the growth in Experiment II, and this was probably due to low light intensity recorded at the second experiment than the first one (from 9.3-5.3 % to 8-4 %). Concentrations of foliar P, however, were found slightly higher in Experiment II especially at the 1P level but concentrations of foliar Mg either had no effect or slightly reduced at this level (1P).

Remobilisation of mineral nutrients is important during the ontogenesis of a plant in the periods of insufficient supply to the roots during vegetative growth (Marschner 1995). This remobilisation from mature leaves to areas of new growth (i.e. young leaves) is thus essential for the completion of the life cycle of plants under stress conditions. The extent to which remobilisation takes place, however, differs among mineral nutrients and is reflected in the distribution of visible deficiency symptoms in the plants. In all treatments, older leaves showed marked symptoms of nutrient deficiency and this indicates that P and Mg had very high rates of remobilisation from old leaves to the young ones.

The total dry weight of seedlings with an adequate supply of P but deficient in Mg was 25 % lower than the control one (1P + 1 Mg) whilst, the total dry weight of seedlings with an adequate supply of Mg but deficient in P was 17 % higher than the control one (Table 7.7). The total dry weight of *H.* odorata seedlings in the lowest P but highest Mg (T1) was 58 % higher than the total dry weight of the seedlings in the highest P but lowest with Mg (T9). It can be concluded then that the total dry weight of seedlings was limited by Mg rather than P. Baillie *et al.* (1987) found that the occurrence of some dipterocarp species in mixed dipterocarp forest in Sarawak was correlated with soil Mg status. They also suggested that mycorrhizal dipterocarps in mixed

dipterocarp depended on Mg for efficient uptake of P from soils of low P concentrations. Results from this study support the view by Baillie and co-workers. Under an adequate P supply, addition of Mg increased the growth of seedlings but when the seedlings were deficient in Mg, it reduced the growth. When the seedlings were grown in P deficient culture solution, adding Mg increased the growth of seedlings. However, when the seedlings were applied with moderate P (0.1P) the growth of the seedlings was suppressed by increasing of Mg concentrations. The roots of seedling were severely reduced at low level of Mg (0.01Mg). The interaction between P and Mg appears to be complex and sensitive to the relative proportions of these supplied elements.

CHAPTER 8: GENERAL DISCUSSION & CONCLUSION

Up until 1970's, progress in forestry in Peninsular Malaysia was made principally in the area natural forest management. This was because Peninsular Malaysia was still endowed with vast areas of timber-rich natural forests and it was unnecessary to convert the forest to monoculture forest plantation. Although production forests are commercially logged on a rotational cycle and under a sustained-yield management system, the natural regeneration of the seedlings could no longer be relied upon for the renewal of the Permanent Forest Estate. Artificial regeneration by means of enrichment planting, is perhaps the alternative for reforestation or reclamation of the disturbed areas with preferred timber trees. It is an approach which can supplement natural regeneration. In natural regenerating forest, wildings or seedlings usually grow under a forest canopy. The control of light categories on the forest floor is therefore very important for the growth of important timber trees. The light categories can be manipulated by silvicultural operations such as weeding, pruning and thinning.

If the logging damage is too great the residuals that comprise the next crop are heavily damaged. The extent of damage due to logging activities in Malaysia resulted in 25-40 % of the logged forests in Sabah being covered with log landings and skid trails (Fox 1968, Nussbaum 1995) and 45-50 % were reported in Peninsular Malaysia (Kamaruzaman 1991a, b). These sites have potential for enrichment planting. The study in Chapter 5 showed that within the logged areas, there are mainly three categories of canopy openings (open, partially shaded and closed canopy) which only require the limited aid of silvicultural treatment for planting preparation in the open and in the partial shade categories. Since dipterocarp species vary in their ecological requirements (especially for light), it is important to determine the range tolerance to radiation by the seedlings at their early development. In order to maximise the use of sites for reclaiming the disturbed areas within the logged forest, the enrichment planting perhaps should be carried out with mixtures of tree species with differing ecological needs. Results from this study and also from other studies (Watson 1935, Barnard 1949, 1954; Symington 1974, Wan Razali & Ang 1991, Ang *et al.* 1992, Aminah & Lokmal 1995)

showed that: *H. odorata* is a light demanding species or a shade intolerant, *D. oblongifolia* is a light tolerant and also a shade tolerant to a certain degree, and *S. acuminata* is a shade tolerant species. Thus, species with the same light regime requirements i.e. *H. odorata* can be planted in the open areas, *D. oblongifolia* in the open and partial shade, and *S. acuminata* can be planted in the partial shade and closed categories, and later to be followed by light liberation to enhance its growth. This would probably reduce the cost of planting operations resulting from the high man-power costs involved in canopy opening and clearing for line planting.

It has been reported that the mortality of dipterocarp seedlings under exposed condition may be high as they generally require shade for growth (e.g. Nicholson 1960). Observations in the present studies have shown that the survival of the high light demanding species and intermediate light dipterocarp seedlings (*H. odorata* and *D. oblongifolia*) were found significantly higher in the open categories. Presumably the survival of shade tolerant species substantially reduced when planted in the open condition.

Soil compaction (1.06-1.13 g cm^{-3} in this study; 4 y after logging) did not appear to be a significant factor limiting the early growth of dipterocarp seedlings and the same results were also reported in other studies elsewhere (Wan Razali & Ang 1991, Ang *et al.* 1992, Nussbaum 1995, Nussbaum *et al.* 1995). However, the degree of compaction in this study was lower than the degree of compaction in other studies: 1.22-1.52 g cm^{-3}; 2 y after logging (Kamaruzaman 1988) and 1.00-1.34 g cm^{-3} ; 18 mo after logging (Nussbaum 1995, Nussbaum *et al.* 1995).

As reported by Watson (1935) and also observed in this study (Chapter 5), *D. oblongifolia* planted in the open had a tendency producing heavy branching. Perhaps to overcome this problem, the species should be planted with close spacing and followed by thinning at later stages of growth to allow the development of tree crown and to ease crown space competition. "Keladan" was found associated with shallow, acid and finely textured soils (Baillie *et al.* 1987) and it was also associated with low contents of organic matter and

exchangeable Ca but not affected to soil Mg status. Although *H. odorata* and *D. oblongifolia* were not found at the study site and *H. odorata* was reported rarely occurs far from streams, results from planting trials showed that these species grew well in the plot, open categories, especially *H. odorata.* In Peninsular Malaysia, "Keladan" was reported from poorly-drained and swampy sites (Lee 1967, Poore 1968) but in Borneo it is wide-spread and topographically indiscriminate (Ashton 1968).

Regardless of size and fertiliser levels of *H.* odorata and *D. oblongifolia* seedlings: the growth of the seedlings in the plot with different planting categories were in the order A & B $\geq$ C $\geq$ D & E. All growth parameters and total dry weight of the seedlings, regardless of the size classes and fertiliser levels, increased with increase of light intensity in the plot. Compared with the seedlings grown in the open categories, seedlings grown in the partial shade condition have large dark green and thin leaves but when the seedlings are grown in closed categories, with extremely low light intensities, the size of leaf becomes smaller and the leaf retains its dark green colour.

Raising and nursing seedlings in the nursery by means of applying an appropriate type of fertiliser and the optimum amount of fertiliser required by the seedlings, not only reduced the cost of fertilising the seedlings in the field but also produced seedlings with high nutrient concentrations in their plant tissues, well developed root systems and plant with bigger stem diameters. Vigorous seedlings had a high potential for growth and survival when planted in the field. Brown & Whitmore (1992) observed that in gaps the most important determinant of seedling survival and growth was seedling size, regardless of species. Sasaki and Mori (1981) showed that there is a linear correlation between stem diameter and root weight, thus, they concluded that the food reserves of the stem play an important role for root development and consequently better growth and better survival. Recent studies showed that fertilising planted dipterocarp species in the logged forest improved the growth of the seedlings (Wan Razali & Ang 1991, Ang *et al.* 1992, Nussbaum 1995, Nussbaum *et al.* 1995). However, this will increase the cost of planting operation and also amount of fertiliser applied was not fully of benefit to the seedlings due to a proportion might be lost through

adsorption and leaching. Results in this study (Chapter 5) showed that fertilising the seedlings in the nursery with 0.33 - 0.40 g per pot of TSP (144 -175 mg of P), a fast-release fertiliser, monthly up to five times gave an early promising growth in the forest 2 y in the field.

It is well known that when the soil is infertile the root-shoot dry weight ratio of plant species increases, however, in this study (Chapter 5) the root-shoot dry weight ratio for both species planted in categories A, B & C (relatively infertile and with high soil compaction) decreased. This was probably because many roots (fine roots) were cut-out and left intact in the planting hole during harvesting. Thus the root dry weights measured were lower than they should have been.

Ashton and De Zoysa (1989) suggested that height of seedlings of the same age can be used to characterise the size of seedlings. Larger individuals show better and faster growth than smaller ones. This was also observed in this study, initially larger seedlings of *H. odorata* seedlings gave far better growth than the smaller ones. Leaves of seedlings are retained longer in the partially shaded condition, and thus, the number of leaves should be higher than those in fully lighted (open condition). Number of leaves and total leaf area are suggested as a measure of photosynthetic area and the parameters can be used to measure an individual's vigour when in competition with others (Ashton & De Zoysa 1989).

The basic principle in using plant analysis is that the chemical composition of the plant reflects the nutrient supply in relation to growth as a result of the interaction between nutrient and plant growth (Martin & Matocha 1973). However, if the growth rate is faster than the uptake of nutrients, it is possible that the addition of the limiting element may result in a lower concentrations of certain elements in the tissues due to "dilution effects" as seen in this study (Chapters 5 & 6). When seedlings of *H. odorata* and *D. oblongifolia* were provided with adequate nutrients (i.e. addition of P), they responded effectively to them when only receiving adequate light. Therefore, light is a primary limiting factor for light-demanding species. The growth of *H. odorata* and *D. oblongifolia* under high light level

(open) was higher than under medium (partially shaded) and low (closed canopy) light. However, the concentrations of N, P, Mg, Ca and K were lower under high light levels (open). This reduction was due to the dilution effect as a consequences of increased photosynthesis under high light levels.

Although fertilising (adding P to the seedlings) *H. odorata* either reduced the concentrations of nutrients or had no effect on them, except that for Ca, fertilising significantly increased the growth of seedlings. Fertilising seedlings of *D. oblongifolia* significantly increased the concentrations of P and K at 1 y and only P at 2 y. It was also increased the growth of the seedlings but not the dry weights of the seedlings.

Full radiation increased the growth of *H. odorata* (a light demanding species) but it reduced the growth of *S. acuminta* (a light-intolerance species) as shown in the experiment at nursery. *H. odorata* responded efficiently in increasing the total dry weight of the seedlings in the open, in contrast, the growth of *S. acuminta* seedlings in the open was lower than in the shade and the concentrations of nutrients was also lower in the open. Although *S. acuminta* was reported as a fast growing species but in this study (Chapter 6), the growth of the species was relatively slower. Slower-growing species are reported less able to respond to fertiliser addition (Mitchell & Chandler 1939, Chapin 1980, Chapin *et al.* 1986, Thomson *et al.* 1988). This was also observed for *S. acuminata* as the species responded less to the P addition.

Burslem *et al.* (1994) report that when seedlings grown under adequate supply of P, received additions of N, K or Mg, this increased all of the measured components of seedling growth. Results from the experiment on *H. odorata* in the nursery (Chapter 7, Figure 7.1) showed that under full strength of P, its increased the total dry weight of seedlings (12 mo) with increasing Mg concentration. However, when the seedlings were given full strength of Mg, the total dry weight was not showing a clear improvement with increasing of P. Perhaps Mg was also important in influencing the growth of dipterocarp seedlings.

Field and pot-grown of *H. odorata* showed that the P and Mg ratios under high light level were higher than the ratios in medium and then slightly went up again under low light level (see Figures 5.4 & 6.4). Same response was seen for *S. acuminta,* the ratio of P and Mg was higher under high light level and lower under low ones. In contrast, the ratio was lower under high light level but increased with reduced radiation for *D. oblongifolia.* Fertilised seedlings of *H. odorata* in the field and in the pots showed a positive and strong correlation between foliar P and Mg in the open categories (high light levels). This suggested that addition of P not only increased the concentration of foliar P but might also has facilitated the uptake of Mg (see Tables 5.21 & 6.18). Correlation studies between different foliar mineral elements showed some specific associations in their concentrations as well as between different elements and the total dry weight of the seedlings. These relationships however varied with different mineral elements, different species and at different age. These results demonstrated that different species with different ecological requirements and at different physiological age may response differently to the different elements in the nutrient supply.

Studies of endomycorrhizal (VAM) infection have shown that plants persisting on, or heavily colonising logged sites had 35-75 % less infection than unlogged sites (Read 1989, Alexander *et al.* 1992). The high level of mycorrhizal infection (VAM and ECM) in undisturbed or selectively logged forest is likely to support extensive mycelial networks, which in natural vegetation are considered to be the primary source of infection. This shows the importance of contact with living roots for mycorrhizal fungus growth or for its colonisation and led to the increases of mycorrhizal infections. These explained the high percentage infection of ECM found on seedlings potted in soils S4, S5 and S6 but less on those in soils S1, S2 and S3. Studies in the nursery (Chapter 6) showed that light reduced the infection of ECM and increased the percentage of dead ECM, and this support the view by Smits (1983) that high soil temperature in the open condition led to the death of mycorrhizal fungus. However results from field grown seedlings (Chapter 5) did not support his view on the failure of growth of dipterocarps in the open condition was due to the failure of ECM colonisation. The survival of the seedlings was not primarily due to the ECM

infection but also due to other specific ecological requirements (i.e. specific light regime) for early establishment. Lee & Lim (1989) also observed that there was no lack of natural regeneration after 1.5 y of logging despite logging damage to the residual stand.

Conclusion

Selection of species with a wide adaptability to environmental categories and planting species in the compatible categories are important aspects for successful forest regeneration. As shown in these studies (Chapters 5 & 6) the survival of the dipterocarp seedlings was high and the growth of the seedlings grew well and grow faster when compared with the seedlings in natural condition. It showed that when the seedlings were given help to establish at the site, they have a high chance to survive to the mature system. Therefore, artificial regeneration by means of enrichment plantings are still needed to reclaim the logged forest.

The results from this study suggest that the species can be ecologically grouped into three in terms of their light requirements. *H. odorata* is a light demanding species which is intolerant of deep shade and grow best under 50 - 55 % RLI. *D. oblongifolia* is an intermediate, shade-tolerant species i.e. this species tolerates partial and deep shade but also grows well under high radiation. In contrast, *S. acuminata* is partial and deep-shades tolerant and the species is intolerant of high radiation in the early stages of establishment but perhaps tolerant to high radiation at subsequent stages. The optimum range of RLI for *S. acuminata* was 8-16 %.

H. odorata and *D. oblongifolia* are suitable species for open planting and for reclaiming decking sites, skid trails and log landings within the logged forests. The response of survival of the seedlings for both species in the different planting categories was in the order A & B > C > D & E. However, the survival of *H. odorata* was higher than the survival of *D. oblongifolia* in all planting categories. The growth of the seedlings for both species was also in the same order as the survival, although the growth of *D. oblongifolia* in the closed categories was far better than that of *H. odorata*. The quantitative and qualitative growth of seedlings was largely affected by the amount of light reaching the forest floor.

The concentrations of foliar nutrients in the different planting categories were in a contrast order to the growth growth of the seedlings, viz: D & E < C < A & B. The growth of the seedlings of *H. odorata* appeared to be limited by P and Mg but P appeared not a limiting factor to the growth of *S. acuminata*, a shade tolerant species.

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Appendix 5.1: SAS statements used for a split-plot unbalanced design.

```
DATA JHO;
INPUT HV SPLOT CON $ FERT $ SZ $ LNO ND HGT DIAM DL DS DR;
CARDS;
-
-     (data)
-
-
;
PROC SORT DATA=JHO;
BY HV SZ;
PROC GLM DATA=JHO;
BY HV SZ;
CLASS SPLOT CON FERT;
MODEL LNO ND HGT DIAM DL DS DR=CON SPLOT(CON) FERT CON*FERT;
TEST H=CON    E=SPLOT(CON);
MEANS CON/LSD    E=SPLOT(CON);
MEANS FERT CON*FERT/LSD;
MEANS CON;
RUN;
```

Appendix 6.1: SAS statements used for a two-way factorial analysis of variance.

```
DATA GHOH;
INPUT HV REP LL $ FERT $ SOIL $ LNO HGT ND DIAM LAREA DL DS DR;
CARDS;
-
-     (data)
-
;
PROC SORT;
BY HV LL;
PROC GLM;
BY HV LL;
CLASS REP FERT SOIL;
MODEL LNO HGT ND DIAM LAREA DL DS DR=REP FERT SOIL FERT*SOIL;
MEANS FERT SOIL FERT*SOIL/LSD;
RUN;
```

Appendix 7.1: Complete nutrient solutions used in the experiments.

Salts used		g l^{-1}	mg l^{-1}	mg l^{-1}	Stock solutions g l^{-1}	Stock solutions ml l^{-1}
$(NH_4)NO_3$		0.402	402	N(140.7)	50.50	8
K_2SO_4		0.348	348	K(156.1) S(64.02)	21.75	16
$CaCl_2.2H_2O$		0.444	444	Ca(121.0) Cl(214.1)	55.50	8
$MgSO_4.7H_2O$		0.368	368	Mg(61.4) S(47.9)	46.00	8
$Na_2HPO_4.7H_2O$	(1P)	0.358	358	Na(61.4) P(41.4)	89.50	4
"	(0.5P)	0.179	179			4
"	(0.2P)	0.072	72			4
"	(0.1P)	0.036	36			4
"	(0.05P)	0.018	18			4
$C_{10}H_{12}N_2O_8FeNa$ (FeEDTA)		0.0335	33.5	Fe(5.096)	4.5	4
NaCl		0.0058	5.8	C l(3.52)	5.8	1
H_3BO_3		0.0031	3.1	B(0.542)	3.10	1
$MnSO_4.H_2O$		0.00223	2.23	Mn(0.725)	2.23	1
$ZnSO_4.7H_2O$		0.00029	0.29	Zn(0.066)	0.29	1
$CuSO_4.5H_2O$		0.00025	0.25	Cu(0.064)	0.25	1
$Na_2MoO_4.H_2O$		0.00012	0.12	Mo(0.048)	0.12	1
$CoSO_4.7H_2O$		0.000056	0.056	Co(0.021)	0.056	1

Appendix 7.2: SAS statements used for analysing a one-way factorial analysis of variance.

```
DATA HOSC1;
INPUT HV BLOCK PL $ LNO LAREA HGT DIAM DL DS DR;
CARDS;
-
-     (data)
-
-
 ;
PROC SORT;
BY HV;
PROC GLM;
BY HV;
CLASS BLOCK PL;
MODEL LNO LAREA HGT DIAM DL DS DR=BLOCK PL;
MEANS PL/LSD;
MEANS PL;
RUN;
```

Appendix 7.3: SAS statements used for analysing a two-way factorials analysis of variance.

```
DATA HOSC2;
INPUT HV BLOCK PHOS $ MAGN $ LNO LA HGT DIAM DL DS DR RTST;
CARDS;
-
-
-     (data)
-
;
PROC SORT;
BY HV;
PROC GLM;
BY HV;
CLASS BLOCK PHOS MAGN;
LNO LA HGT DIAM DL DS DR RTST = BLOCK PHOS MAGN
PHOS*MAGN;
MEANS PHOS MAGN PHOS*MAGN/LSD;
MEANS PHOS MAGN;
RUN;
```